



Fakultät III – Wirtschaftswissenschaften, Wirtschaftsinformatik
und Wirtschaftsrecht

**The Idleness of Mobility Behaviour –
Contributions and Challenges of Subsidisation and Digitalisa-
tion to Turn the Tide in Favor of Sustainable Public Transport**

Dissertation

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Abstract

This dissertation examines how innovative mobility concepts, price mechanisms, and technological developments influence mobility behaviour, the acceptance of sustainable modes of transport, and the future design of public transport (PT) in Germany. Drawing on Vincent Kaufmann's concept of mobility as a form of social action potential, mobility is understood as the interplay of structural access, individual capabilities, and cultural processes of appropriation. The dissertation thus addresses a research gap at the intersection of behavioural economics, social sciences, and technological mobility research.

The work employs a mixed-method design combining quantitative analyses on price and subsidy mechanisms (Studies 1–3) with qualitative investigations on digitalisation and autonomous buses (Studies 4–6). User surveys, regression models, expert interviews, and scenario-based explorations provide a differentiated empirical picture of current and potential mobility dynamics.

The findings reveal that price incentives – such as climate tickets or rising fuel prices – can trigger short-term shifts in the modal split, yet do not induce a sustained shift away from private motorised transport (PMT) in the absence of structural improvements. Once subsidies run out, PMT is frequently chosen again, particularly in regions with limited PT quality. Price mechanisms thus unfold their effectiveness only in combination with reliable, spatially accessible, and user-friendly services – a core dimension of Kaufmann's mobility concept.

Furthermore, the results show that ecological motivation is constrained by economic conditions. During periods of economic volatility, financial considerations tend to dominate mobility decisions. Socially balanced fare models and targeted subsidies are therefore central prerequisites for socially viable mobility strategies.

Digitalisation offers the potential to structurally reduce deficits in PT provision. Digital bus stop concepts, real-time information and mobility platforms improve

accessibility and the user experience, while on-demand services enhance flexibility, particularly in rural areas. However, the success of digital innovations ultimately depends on societal acceptance. The studies indicate that, although autonomous buses are regarded as a response to the growing shortage of bus drivers, reservations persist, especially among younger users, driven less by technical concerns and more by social and work-related considerations.

The findings show implications for three groups of stakeholders. For policy makers, a systemic approach is required that integrates pricing, infrastructure development, and digitalisation. For mobility users, the results highlight that conscious mode choice, digital competencies, and active participation in feedback or planning processes constitute essential elements of stable modal-shift dynamics. Transport companies face the challenge of evolving from reactive service providers to strategic designers of multimodal mobility environments that integrate physical, digital, and fare-related components.

Overall, the studies demonstrate that sustainable modal shift is not the result of isolated measures but emerges from the multifaceted interaction of structural, cultural, and technological factors. Transforming PT therefore requires long-term, socially balanced, and technologically adaptive strategies. Looking ahead, digital innovations, autonomous driving, and integrative subsidy structures will be key components of a mobility culture that aligns ecological objectives with social participation and everyday functionality. This dissertation thus contributes to the theoretical foundation and empirical analysis of the mobility transition and identifies central avenues for future national and international research.

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Related Publications

As part of this doctoral research, I have published articles in internationally recognised academic journals and presented selected findings at scientific conferences.

Study 1 (Section X): Hahn, A., Pakusch, C. & Stevens, G. (2020). Die Zukunft der Bushaltestelle vor dem Hintergrund von Mobility-as-a-Service – Eine qualitative Betrachtung des öffentlichen Personennahverkehrs in Deutschland. HMD 57, 348–365. <https://doi.org/10.1365/s40702-020-00589-9>

Study 2 (Section X): Hahn, A., Pakusch, C., & Stevens, G. (2023). The impact of service expansion on modal shift from private car to public transport. A quantitative analysis in the Bonn/Rhein-Sieg area, Germany. *Journal of Urban Mobility*, 4, 100064.

Study 3 (Section X): Hahn, A., Pakusch, C., & Stevens, G. (2024). Was the low-fare public transport in Bonn a success? An evaluation of the climate ticket users and lessons for transportation companies. *Case Studies on Transport Policy*, 101158.

Study 4 (Section X): Hahn, A., Pakusch, C., & Stevens, G. (2024). Low-fare public transport and modal shift–Lessons from Bonn, Germany. *Journal of Urban Mobility*, 6, 100082.

Study 5 (Section X): Hahn, A., Pakusch, C., & Stevens, G. (2024). Avoidance rather than change: What influence does the price shock for mineral oils have on the mobility behaviour of users of motorised private transport in Germany? *Transportation Research Procedia*

International Conferences

50th European Transport Conference (ETC) 2022, 07- 09 September 2022, Mailand, Italien. The impact of service expansion on modal shift from private car to public transport. A quantitative analysis in the Bonn/Rhein-Sieg area, Germany.

16th World Conference on Transport Research (WCTR) 2023, 17 –21 July 2023, Montreal, Canada. Avoidance rather than change: What influence does the price shock for mineral oils have on the mobility behaviour of users of motorised private transport in Germany?

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List of Abbreviations

AI	Artificial Intelligence
AVs	Autonomous Vehicles
CO ₂	Carbon Dioxide
EU	European Union
FRG	Federal Republic of Germany
FFPT	Fare-Free Public Transport
GDPR	General Data Protection Regulation
HR	Human Resources
IHK	Chamber of Industry and Commerce
MaaS	Mobility as a Service
MOD	Mobility-on-Demand
NO ₂	Nitrogen Dioxide
PMT	Private Motorised Transport
PT	Public Transport
SPSS	Statistical Package for the Social Sciences
ULEZ	Ultra Low Emission Zone
VDV	Association of German Transport Companies

I THEORETICAL FRAMEWORK

1 Introduction

1.1 Research Motivation

In the aftermath of the Second World War, the reconstruction of German cities was profoundly shaped by the planning principles articulated in the Charter of Athens, which promoted the spatial separation of residential and commercial areas. This vision, championed by Le Corbusier, fostered the ideal of the “car-oriented city” that came to define the urban form of post-war Germany (CORBUSIER, 1933; Le Corbusier, 1957). Today, however, in view of the considerable challenges posed by anthropogenic climate change and the transport sector’s contribution to carbon dioxide (CO₂) emissions demands renewed scrutiny. Albert Einstein’s perceptive observation that “problems cannot be solved with the same mindset that created them” resonates strongly in this context. Advancing towards sustainable transport systems therefore requires new intellectual vantage points that recognise the intertwined technological, social and economic currents shaping contemporary mobility.

Achieving this transformation necessitates more than the expansion of infrastructure; it requires deliberate and informed management of individual mobility behaviour. Such behaviour is influenced by a complex constellation of factors – from cost and time considerations to personal attitudes, habitual preferences and perceptions of environmental impact. In urban settings such as Bonn, situated within the Rhineland metropolitan region, PT constitutes a particularly powerful lever of mobility governance.

Mobility behaviour itself is highly individualised. People make decisions based on their specific mobility needs, drawing upon a diverse repertoire of transport modes: walking, cycling, driving, travelling by PT and, increasingly, adopting

newer forms of mobility such as e-scooters, car sharing or ride-sharing services. These decisions are framed by monetary and temporal constraints, infrastructural conditions and the actions of other road users. Municipal administrations thus have a pivotal role in shaping urban mobility, establishing the structural, digital and regulatory frameworks through subsidies, digitalisation, infrastructural initiatives and pricing instruments such as parking fees or congestion charges.

These modes of transport do not exist in isolation, but rather in mutual interdependence. Reducing car use while maintaining overall mobility requires the expansion and enhancement of alternative modes, notably PT and cycling. Recognising these interdependencies is indispensable for effective mobility management, particularly under conditions of limited public resources.

The city of Bonn is a particularly interesting example for examining sustainable mobility governance, not least because initiatives such as the Lead City project have markedly prioritised the promotion of PT. Through targeted shifts towards more sustainable modes, the city seeks to reduce CO₂ emissions and enhance the quality of urban life. This context provides valuable insights into how politically induced changes in structural conditions shape the personal considerations underlying individual transport mode choice.

Yet, despite numerous interventions intended to steer mobility behaviour, significant gaps persist within the scientific discourse on sustainable mobility. It is still inadequately understood which measures are capable of generating sustained and meaningful shifts towards more sustainable travel patterns. While current approaches encompass subsidies, digitalised management tools and infrastructural development, comprehensive analyses examining their optimal design, effectiveness and interaction remain scarce.

Against this backdrop, this dissertation seeks to systematically analyse existing mobility structures and services, identify the determinants of transport mode choice and switching behaviour, and develop evidence-based strategies for the

promotion of sustainable mobility. Particular attention is given to political-institutional frameworks, technological innovation and the behavioural patterns of mobility users. The overarching aim is to identify concrete pathways for transforming the mobility sector that reconcile ecological, economic and social imperatives within a holistic understanding of sustainability.

By developing and evaluating effective governance instruments, this dissertation contributes substantively to addressing the mobility challenges of modern cities. It underscores the necessity of sustainable mobility governance within an evolving ecological and societal landscape, offering insights that enrich academic discourse and support the practical design and implementation of innovative mobility strategies.

1.2 Research Context

The analysis and advancement of sustainable mobility strategies within German PT constitute the core of this dissertation. Particular attention is given to the interplay between innovative mobility concepts, pricing mechanisms and technological developments, and to their combined influence on mobility behaviour, the acceptance of sustainable modes of transport and the future design of transport systems.

Fare-free PT (FFPT) represents one such innovative concept and has been trialled in nearly one hundred international pilot projects. Findings from these experiments point to both promising opportunities and significant challenges. Scholarly analyses, including those by Kębłowski et al. (2019), indicate that FFPT can promote social equity and environmental benefits, yet also highlight structural and contextual limitations, particularly in relation to modest modal-shift effects and financial sustainability. The relevance of this topic arises from the increasing need for adaptive mobility strategies in light of growing ecological and societal demands.

The formulation of the research question in this dissertation is guided by the key dimensions of the PEST¹ framework, which provides a structured lens for examining the wider macro-environment. Within the political dimension, mobility governance and the implementation of innovative transport concepts by policy makers, such as the City of Bonn, play a decisive role. The economic dimension encompasses subsidy structures that support both service expansion and fare reductions in PT.

Sociocultural factors, including demographic trends and societal developments, also form an important part of the analytical framework. Studies focusing on specific groups, such as commuters or the millennial generation, provide differentiated insights into mobility preferences and behavioural patterns. These developments further underscore the growing demand for skilled personnel, such as bus drivers, alongside the increasing need for digital mobility solutions. Finally, the technological dimension is shaped by the acceptance of innovations such as digital bus stops and autonomous buses, which are indispensable prerequisites for their broader implementation.

Taken together, these factors illuminate the complexity and multi-layered nature of the challenges faced by PT systems and form the basis for articulating the overarching research question:

“How do innovative mobility concepts, price mechanisms and technological developments influence mobility behaviour, the acceptance of sustainable modes of transport and the future design of PT in Germany?”

To address this question, the dissertation is structured into two thematic clusters, **Subsidies** and **Digitalisation**, each engaging with distinct aspects of the research framework:

¹ PEST stands for Political, Economic, Social and Technological factors and is used in this dissertation as an analytical framework to systematically assess how macro-level contextual conditions shape mobility systems, travel behaviour and the feasibility of sustainable transport transformations.

- **Subsidies**

Through the provision of subsidies, the state can actively intervene in the mobility market and enhance the attractiveness of PT. However, such measures are associated with substantial costs and are often only financially sustainable in the short term (Coulombel & Monchambert, 2023). Studies 1 to 3, which constitute this cluster, examine the interaction between three critical determinants: service provision, pricing and individual mobility preferences.

The study on PT service expansion investigates whether improved service quality, such as increased frequency, network extensions and the introduction of additional night and early-morning services, can meaningfully influence mobility behaviour and contribute to improved air quality in German cities. Despite stringent European Union (EU) limits, air quality in many large urban areas remains below required standards. Accordingly, we sought to understand the extent to which an expansion of PT services could support compliance with environmental regulations.

In addition to subsidising transport operators, we also examined direct fare subsidies. The Climate Ticket, a two-year project supported by the Federal Republic of Germany (FRG) within the framework of Lead City, served as a prominent case study to test measures aimed at reducing transport-related nitrogen dioxide (NO₂) emissions. Two further studies approached subsidies from opposite perspectives: the user perspective (demand) and the transport operator perspective (supply). This dual lens provides a comprehensive evaluation of both the effectiveness and acceptance of subsidy measures.

From the perspective of PT, the private car represents a substitute mode for meeting mobility needs. Accordingly, we also examined the effects on fuel prices in early 2022 which were a result of the war in Ukraine. The war and the ensuing global economic instability contributed to sharply rising inflation, significantly reducing the purchasing power of German households (Statistisches Bundesamt, 2023b). A major factor in this trend was the steep increase in mineral oil prices.

Independent of ecological considerations, the sudden fuel price rise highlighted the substantial influence of economic factors on mobility behaviour.

Public debates on sustainable mobility often emphasise the strong environmental consciousness of younger generations (Circella et al., 2016). Consequently, two of our studies on the mineral oil price shock extended the analysis to the millennial generation to determine whether the severe economic burden affected the status of the private car as the most frequently used mode of transport.

Our studies demonstrate that while subsidies can play a central role in promoting sustainable mobility by enhancing the attractiveness of PT and supporting improved air quality, economic shocks, such as the Ukraine war, underscore the vulnerability and complexity of mobility behaviour and of the broader mobility transition.

- **Digitalisation**

Beyond short-term market interventions, the long-term enhancement of PT attractiveness depends fundamentally on digitalisation (Butler et al., 2020). The second cluster, Studies 4 to 6, therefore examines the challenges and potentials of emerging technologies and the associated labour market implications within the PT sector. Transport operators face the task of developing sustainable mobility solutions that meet the expectations of modern consumers while providing the high degree of flexibility they have come to expect from other service industries. Contemporary Mobility as a Service (MaaS) concepts and mobility innovations increasingly question the centrality of traditional, timetable-based PT systems—and with them, the future role of the conventional bus stop (Wong et al., 2020).

One of our studies on the future of bus stops explored the opportunities and challenges arising from these modern mobility concepts, including their interaction with autonomous mobility. Autonomous driving, particularly in PT, constitutes another important strand of this dissertation. Autonomous buses hold the potential

not only to accelerate the mobility transition but also to mitigate the effects of demographic change on the availability of driving personnel. The cost savings made possible through automation could, furthermore, be reinvested by PT operators to enhance travel quality, thereby increasing the attractiveness and efficiency of PT services.

Our research ultimately reveals that digitalisation is a key determinant of the long-term viability and appeal of PT. The development and implementation of modern mobility solutions can help reduce the ecological footprint of mobility while meeting the evolving demands of a changing society.

1.3 Dissertation Structure

The structure of this dissertation is systematically designed to address the overarching research question. Figure 1 illustrates the organisation of the main components and highlights the thematic focal points underpinning the work.

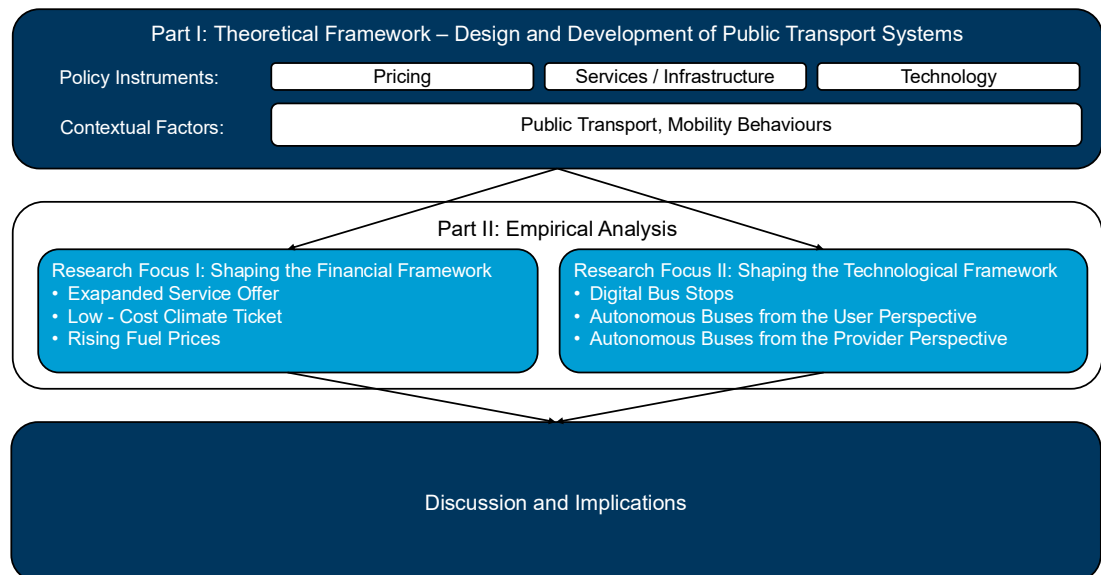


Figure 1: Structure of the Dissertation

Source: Author's own compilation.

It consists of an introductory section followed by an extensive literature review. Within this framework, financial instruments, namely pricing and service provision, represent key levers for shaping the development of PT through subsidies, while technological progress constitutes the central driver within the field of digitalisation. Building upon this theoretical foundation, a series of quantitative and qualitative studies were conducted and subsequently embedded within the broader research context of this dissertation.

Part II forms the core of the dissertation and presents the empirical studies conducted on the two principal instruments of mobility governance: subsidies and digitalisation. It comprises six distinct study areas aligned with these overarching dimensions. Each study is structured according to the sections Introduction, Methodology, Findings, Discussion and Limitations, ensuring a coherent and systematic presentation of the empirical results.

In the concluding discussion, the findings of the individual studies are placed and classified within the wider scientific discourse. This final section also identifies the limitations inherent in the dissertation, highlighting areas that warrant further investigation. The work concludes with a summary of the key insights and the formulation of practical recommendations for policy makers, transport operators, PT users and researchers in the field of mobility behaviour.

2 State of the Art

Chapter 2 systemises the current state of research on sustainable mobility. It begins by discussing the role of PT within the broader sustainability discourse (Section 2.1), followed by an examination of theoretical models and empirical insights into mobility behaviour (Section 2.2). Building on this foundation, Section 2.3 provides an analysis of key policy measures, with particular emphasis on subsidies and digitalisation as complementary instruments of mobility governance. Finally, Section 2.4 integrates the findings within the scientific debate and offers an outlook on future research and practical implications.

2.1 Public Transport and Sustainability

Over recent decades, sustainability has become a key concept in transport studies and environmental policy research. Within academic discourse, sustainability is predominantly understood through the lens of the so-called three-pillar model, which integrates ecological, economic and social dimensions (Figure 2) (Aloui et al., 2021).

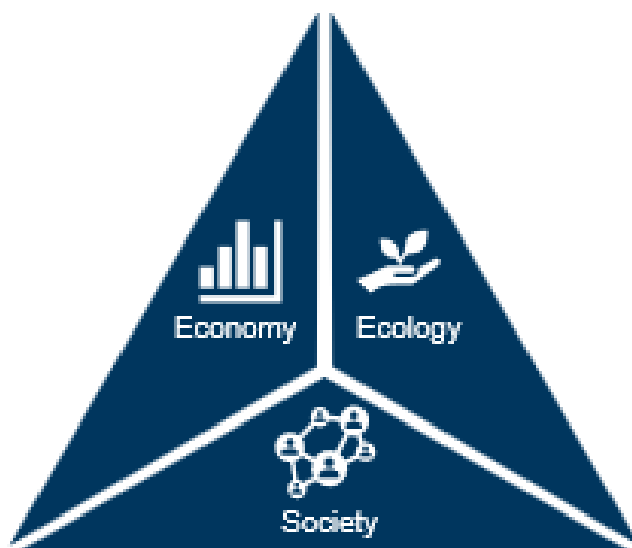


Figure 2: The three dimensions of sustainability: Economy – Ecology – Society

Source: Author's own compilation.

This model implies that sustainable mobility systems must not only reduce emissions and resource consumption, but also remain financially viable and socially inclusive. Mobility constitutes a fundamental need of modern societies, intrinsically linked to economic development, social participation and ecological resilience (Stock & Bernecker, 2014).

Against this backdrop, the transport sector is widely regarded as one of the pivotal levers for achieving sustainability objectives. In Germany, it accounts for roughly one fifth of total greenhouse gas emissions, while showing comparatively limited progress in emission reduction relative to other sectors (Umweltbundesamt, 2020b). Moreover, it generates substantial external costs, ranging from air and noise pollution, and land use to accident-related impacts, that encompass ecological, health-related and economic dimensions (Litman, 2020). These considerations demonstrate that transforming the transport sector extends far beyond technological optimisation and requires a profound reconfiguration of existing structures.

Within this transformation, PT occupies a central position. In contrast to PMT, its collective nature provides significant efficiency advantages: while the average private car carries only 1.4 occupants, buses and trams can transport many times that number without a proportional increase in emissions (Cheranchery et al., 2019). Studies show that buses and trams emit up to 60 per cent fewer greenhouse gases per passenger-kilometre than private vehicles (Statista Research Department, 2023). Beyond reducing CO₂ emissions, PT alleviates congestion, limits land take and mitigates noise pollution (Gössling & Humpe, 2020). It is therefore not only an environmentally beneficial mode of transport, but also a crucial instrument in urban and transport planning aimed at creating more liveable and climate-resilient cities.

In addition to its ecological significance, PT fulfils essential social functions. It provides mobility for individuals without access to a private vehicle, whether due to age, income or health constraints, thereby reducing social inequalities and enabling participation in public life (Sommer & Deutsch, 2021). PT also contributes

to economic performance by ensuring access to employment, education and essential services, and by enhancing the attractiveness of cities and regions (Statistisches Bundesamt, 2024). Particularly in times of increasing urbanisation, PT has emerged as an indispensable element of sustainable urban development (Newman & Kenworthy, 2015).

The promotion of PT can therefore be justified from two perspectives: first, from the ecological imperative to decarbonise the transport sector and meet national and international climate targets; and second, from the social responsibility to secure mobility as a public good accessible to all segments of society. This dual role distinguishes PT from other modes and elevates it to a key area of political action. Public subsidies, fare reforms and infrastructure investment are thus not merely economic instruments, but expressions of the societal recognition of its central function (Federal Government, 2020).

Digitalisation additionally opens up new opportunities to strengthen the sustainability of PT. Real-time data, multimodal mobility platforms and autonomous technologies can enhance user experience, improve operational efficiency and increase competitiveness compared with PMT (Noussan & Tagliapietra, 2020). In combination with innovative mobility concepts, such as on-demand systems or Mobility-as-a-Service offerings, these developments contribute to a more flexible, user-centred PT system capable of advancing ecological and social sustainability goals.

Taken together, it becomes clear that academic and policy debates on promoting PT must not reduce it to a mere mode of conveyance. Rather, it constitutes an integral component of sustainable mobility systems, uniquely combining ecological, economic and social dimensions. Its promotion is therefore not solely a matter of transport engineering efficiency, but a foundational instrument for shaping sustainable societies.

2.2 Mobility Behaviour

The term mobility behaviour refers to the patterns, routines and decision-making processes that shape the travel and transport practices of individuals and population groups. These behaviours arise from complex interactions between personal preferences, infrastructural conditions and broader societal structures. In scientific analysis, mobility behaviour is typically examined along three key dimensions: the distribution of transport modes (modal split, Section 2.2.1), the individual decision-making processes underlying mode selection (mode choice, Section 2.2.2) and the resulting changes in transport mode use over time (modal shift, Section 2.2.3). Kaufmann's mobility concept (Section 2.2.4) further enriches this framework by adding a social dimension and enabling a more nuanced interpretation of mobility behaviour, including generational differences (Section 2.2.5).

Modal split offers a macroscopic perspective by describing the statistical distribution of transport mode use across a population, thereby providing a foundation for strategic decisions in transport planning. In contrast, mode choice provides a microscopic perspective, focusing on the individual decision processes that guide the selection of a specific mode of transport.

The interdependence of these concepts becomes apparent through the causal linkage between individual and collective dynamics: aggregated shifts in the modal split can be interpreted as the cumulative outcome of individual mode choices. Modal shift, in turn, captures the temporal evolution of these collective patterns and reflects systematic changes in individual decision-making behaviour.

The reciprocal relationships between these concepts are illustrated schematically in Figure 3.

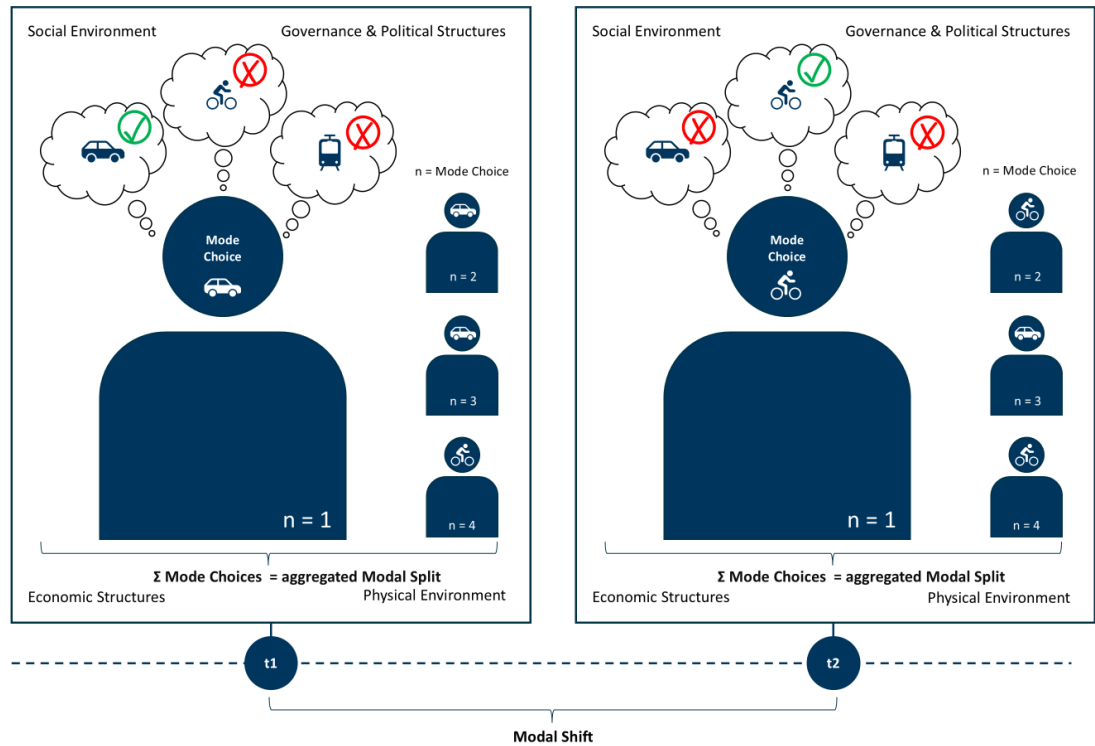


Figure 3: Interrelationship between mode choice, modal split, and modal shift

Source: Author's own compilation.

Each individual makes a *mode choice* during a journey by weighing the available alternatives against relevant contextual factors. The aggregation of these individual decisions produces the overall *modal split*. Changes in this aggregate structure arise from shifts in individual decisions across two points in time, an evolution commonly interpreted as *modal shift*. From an applied research perspective, a deeper examination of mode choice is therefore indispensable for understanding the mechanisms through which changes in mobility behaviour can be induced. Central to behaviourally oriented mobility research are the questions of how mode choices emerge, how they stabilise and under what conditions they may be altered.

Whereas classical approaches to mode choice typically consider the decision as a rational cost-benefit calculation, Kaufmann expands this perspective by defining mobility as a form of “capital” encompassing both spatial and social motility. This theoretical framework has informed the empirical studies in this dissertation

and is discussed in greater detail in Section 2.2.4. Kaufmann's mobility concept enriches traditional decision theory by introducing a socio-cultural dimension.

The findings from the existing literature and the empirical studies presented here demonstrate that mobility behaviour is strongly shaped by generation-specific preferences and needs, necessitating a differentiated analytical perspective within mobility research (Section 2.2.5). This integrative understanding opens new pathways for the development of sustainable, user-centred and socially equitable mobility strategies.

2.2.1 Modal Split

The modal split describes the aggregated distribution of transport mode choices within a defined population and reflects the proportion of different modes in the total volume of travel. As a statistical measure, it captures the current state of transport mode use, which emerges from the sum of individual mode-choice decisions, and thus represents a central reference point for transport policy and urban planning. In this capacity, the modal split offers valuable insights into the distribution of travel across various modes, such as PMT, PT, cycling and walking. Changes in the modal split, commonly referred to as modal shift, result from a dynamic process in which users alter their modal preferences, thereby reshaping the distribution of travel demand over time (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2021).

Empirical data indicate that PMT, still predominantly reliant on fossil fuels, continues to hold a dominant position within Germany's modal split. Approximately 80 per cent of passenger transport performance is attributable to PMT, whereas the environmental alliance, comprising PT, cycling and walking, accounts for only 18 per cent, despite its ecological advantages (Umweltbundesamt, 2024). The pandemic-related decline in PT use temporarily amplified this imbalance. At the same time, the modal split reveals considerable potential for modal shift, as a substantial share of current car-based travel could, in principle, be transferred to more sustainable modes.

The evolution of the modal split in passenger transport between 2017 and 2021 is shown in Figure 4.

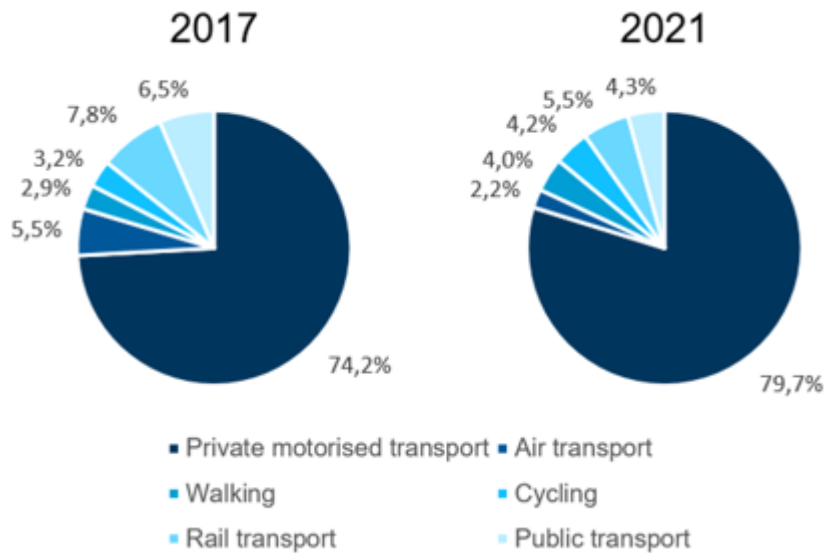


Figure 4: Modal split of passenger transport performance

Source: Author's own compilation.

International pilot projects such as Vienna's €365 annual ticket and the numerous FFPT field trials conducted worldwide demonstrate that pricing strategies, when combined with infrastructural expansion and restrictive measures aimed at reducing the attractiveness of PMT, can shift the modal split in favour of more sustainable modes. When implemented in isolation, however, such measures have only limited impact. Meaningful change requires comprehensive structural adjustments, ranging from the promotion of multimodal mobility to enhanced network integration and increased PT capacity. Accordingly, the modal split not only reflects prevailing travel patterns but also serves as a strategic governance instrument for the implementation of integrated and environmentally oriented transport policies (Umweltbundesamt, 2024).

2.2.2 Mode Choice

Mode choice refers to the individual decision to select a particular mode of transport for a specific trip, shaped by personal preferences and external conditions such as time, cost, comfort, availability and environmental awareness. It constitutes a central component of mobility behaviour and captures the deliberation between private and public mobility options, including newer alternatives such as car sharing, e-scooters and bike-leasing schemes (Anagnostopoulou et al., 2020).

Analyses of mobility behaviour in Germany reveal that mobility decisions arise from a complex interplay of individual needs, technological innovation and socio-economic conditions. In an increasingly multimodal society, transport mode choice and mobility habits are often no longer confined to a single mode. Instead, the resulting mobility mix reflects an interaction between personal preferences and external constraints (Deschaintres et al., 2021). Within this context, multimodality describes the use of different transport modes in varying situations, whereas intermodality refers to the deliberate combination of several modes within a single trip (Figure 5) (TU Dresden, 2010).

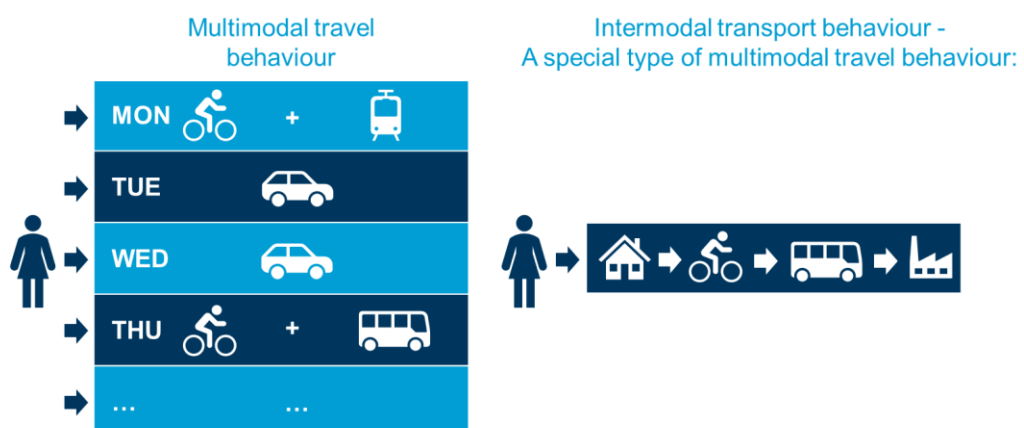


Figure 5: Illustration of multimodal and intermodal travel behaviour

Source: Author's own compilation based on TU Dresden (2010).

The strong preference for the private car as the primary mode of transport has led to the dominance of PMT within Germany's modal split (Nobis & Kuhnimhof, 2018). However, multimodal concepts are gaining importance in light of technological progress and the emergence of new mobility services. Modern transport options, such as ride-sharing and car-pooling, are increasingly complementing traditional forms of mobility. By shifting travel from private car use towards more collective modes of transport, multimodal offerings can contribute to relieving road congestion and reducing emissions (Aguiléra & Pigalle, 2021). Given the negative externalities associated with widespread car dependence, including congestion, noise, emissions and resource consumption, targeted interventions are required to accelerate the transition towards more sustainable transport modes (González et al., 2019).

Cycling has emerged as a significant component of urban mobility in recent years. Rising energy prices, technological advancements in e-bikes and infrastructural measures aimed at promoting cycling have all contributed to this shift (Bourne et al., 2020). The COVID-19 pandemic further reinforced this trend by highlighting the advantages of individual, contact-free modes of transport (Schaefer et al., 2021). Policy strategies that expand cycling infrastructure and reconfigure urban spaces underscore the growing role of the bicycle within the modal split.

Mode choice is often shaped by long-term decisions involving substantial financial commitments. Purchasing a car, an e-bike or an annual PT pass represents such a decision, influencing mobility habits for years (Aarts & Dijksterhuis, 2000; Al-Busaidi, 2019). External factors—such as the introduction of new charges or changes in the cost of alternative mobility options—can affect these decisions and the willingness to shift towards more sustainable modes (Litman, 2017).

Major life events, such as relocation, vehicle replacement or changes in one's financial situation, can act as catalysts for reorienting mobility behaviour (Grzelec & Jagiełło, 2020). In urban areas in particular, such moments create opportunities for targeted policy and economic incentives to encourage shifts towards PT or other sustainable alternatives.

The behavioural patterns and decision-making processes underlying mode choice reveal key leverage points for promoting sustainable mobility. Innovative mobility concepts and technological developments can help establish multimodal and intermodal forms of travel. At the same time, financial and infrastructural measures remain indispensable for enhancing the attractiveness of alternative modes and overcoming entrenched preferences for PMT. Only through an integrated and strategically coordinated combination of these approaches can a sustainable transformation of the mobility landscape in Germany be achieved.

2.2.3 Modal Shift

The term modal shift refers to the redistribution of travel between different modes of transport, for example, from PMT towards PT or cycling. This dynamic process is triggered by changes in external conditions, such as improved infrastructure for alternative modes, the introduction of environmental zones or adjustments to fare structures, as well as by evolving user preferences, including heightened environmental awareness. The primary objective of modal shift is typically to promote more sustainable forms of mobility and thereby reduce environmental impacts (Rodrigue, 2020).

Modal shift results from changes in individual mode-choice decisions and, over time, leads to a reconfiguration of the modal split, which reflects the overall distribution of travel across different transport modes.

Encouraging modal shift is a central element of contemporary transport policy and plays a pivotal role in the transition towards sustainable mobility systems. While case studies from various regions across the world have examined the potential of such shifts, the analysis conducted in Bonn illustrates the specific opportunities for modal reallocation within a defined urban catchment area (Beil & Putz-Egger, 2022).

Debates surrounding the promotion of modal shift frequently highlight the role of price mechanisms, particularly fare structures. FFPT, that is, the abolition of ticket

prices, has been widely tested in numerous trials. Although eliminating fares can increase PT use, the long-term effects remain contested. Critics argue that FFPT may lead to inefficient mobility patterns and undermine the financial stability of transport systems (Cervero, 1990; Storchmann, 2003). Conversely, successful examples such as Vienna's €365 annual ticket demonstrate that targeted fare adjustments, when combined with complementary measures, such as restrictive parking policies, can substantially contribute to encouraging modal shift (Sommer & Bieland, 2018).

2.2.4 Kaufmann's Mobility Concept

In 2002, the sociologist Vincent Kaufmann introduced the concept of motility, which he systematically articulated in his seminal work *Re-Thinking Mobility: Contemporary Sociology* (Kaufmann & Mobility, 2002). The term describes the capacity of individuals and social groups to access and appropriate mobility options—essentially, their potential for movement (Flamm & Kaufmann, 2006). In contrast to traditional mobility concepts, Kaufmann does not focus solely on physical movement through space. Rather, he emphasises the social dimension of mobility: individuals do not move arbitrarily, but in connection with specific social activities, expectations and roles. Mobility is therefore not merely a spatial phenomenon but also a socio-structural variable, enabling different forms of participation and differentiation within society. Crucially, an individual's mobility potential, meaning their theoretical capacity to move, is not necessarily translated into actual travel; it often remains a latent resource (Kaufmann et al., 2004).

Kaufmann's mobility concept provides a central theoretical framework for analysing the interplay between individual decisions, resources, infrastructures and societal norms. It underpins our understanding of transport mode choice, the aggregated patterns that emerge as modal split, and the dynamic processes that generate modal shift. These constructs are linked in a hierarchical and causal relationship that elucidates the connections between individual decision-making, social norms and policy strategies.

Analysing mobility behaviour in the context of sustainable transport requires a multidimensional perspective that integrates individual preferences, structural conditions and technological developments. Building upon insights from mode-choice research, Kaufmann's framework enables the identification of significant behavioural patterns and refines them through its conceptual lens (Kaufmann et al., 2021). The notion of motility conceptualises mobility as a form of capital encompassing both spatial and social motility (Wilde, 2013). Through its three dimensions, access, skills and cognitive appropriation (see Figure 6), the model offers a coherent structure for examining the factors that shape mobility behaviour (Hamidi & Zhao, 2020).

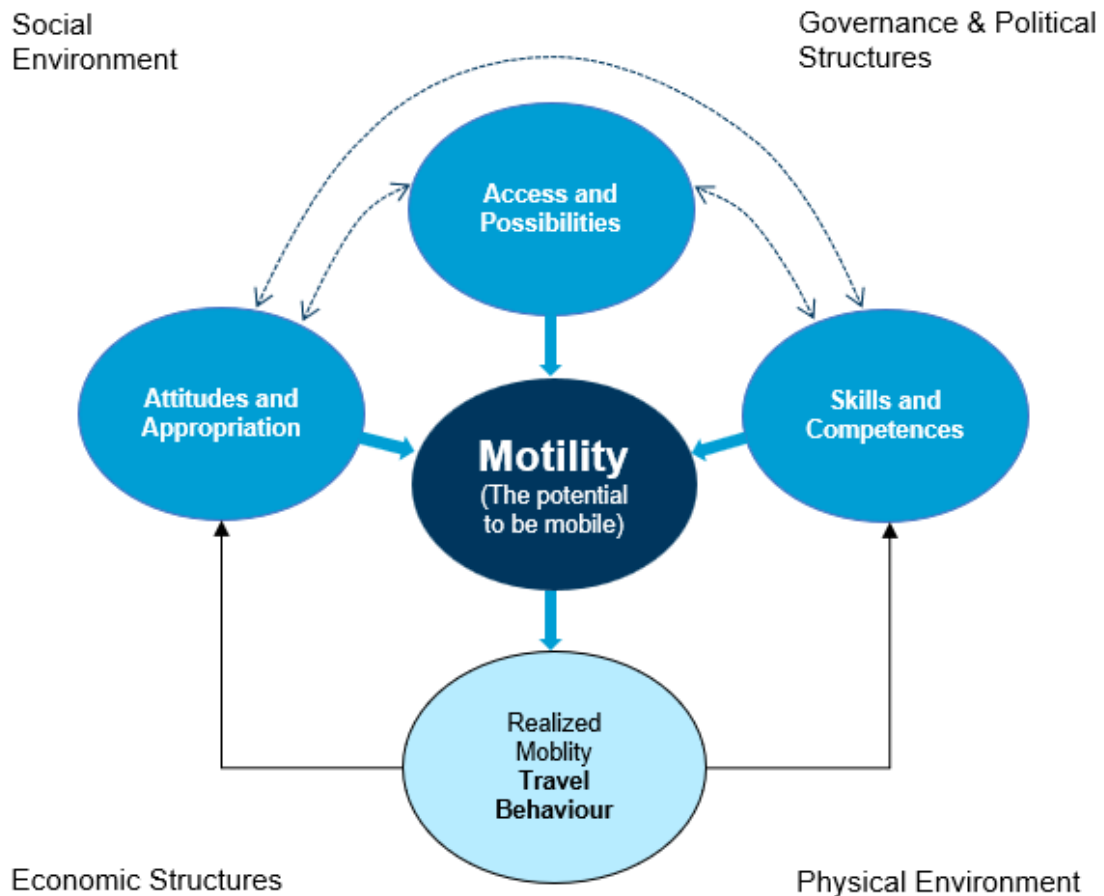


Figure 6: The motility framework, developed by Flamm and Kaufmann (2006)

Source: Author's own compilation based on (Hamidi & Zhao, 2020).

To capture the complexity of individual travel behaviour within a structured analytical framework, the empirical analyses in this dissertation are grounded in Kaufmann's theoretical model (Kaufmann, 2002). According to Kaufmann, mobility research must identify the potential factors that determine whether an individual undertakes, or refrains from undertaking, a particular journey. The primary purpose of travel is, fundamentally, to move from point A to point B in a manner that aligns with one's behavioural routines and contributes to a sense of eudaemonic well-being (Shliselberg et al., 2020).

Kaufmann identifies three categories of factors that determine whether a person undertakes a journey: *access*, *skills* and *cognitive appropriation*. Together, these dimensions constitute an individual's "movement potential" (Kaufmann et al., 2010). This framework enables a broader conceptualisation of mobility that highlights how multiple interrelated factors shape travel decisions and mode choice (De Witte et al., 2013). It is the situational interaction of these factors that ultimately results in observable travel behaviour (Hamidi & Zhao, 2020).

The motility concept has been applied in a range of empirical studies as a theoretical foundation. Research has used it to understand phenomena such as migration (Ofer, 2017), identity (Arp Fallov et al., 2013) and gender (Akyelken, 2013; Didero et al., 2021). In the context of mobility, the concept has informed studies on cycling (Aldred, 2015), methodological development (Tyfield & Blok, 2016) and commuter behaviour in Brussels (De Witte et al., 2013). Hamidi and Zhao (2020) applied it to explore mobility from a subjective user perspective.

Access

In Kaufmann's framework, *access* refers to the diverse ways in which individuals can make use of available transport options and participate in different mobility processes (Kaufmann et al., 2004). Access varies depending on individual circumstances and is influenced by factors such as cost and time, which shape the ability to utilise specific options. These factors include both the possession of

physical resources, for example, private vehicles or reserved parking spaces and membership in flexible mobility services such as car-sharing or PT systems.

Individuals assemble personal portfolios of mobility-related resources, thereby shaping their motility, which is conceived as a form of capital comparable to social, cultural or economic capital (Kaufmann et al., 2004). Access therefore constitutes a fundamental element of motility and informs an individual's ability to optimise travel behaviour. A well-developed urban infrastructure provides physical access to a variety of transport modes, thereby expanding the possibilities for tailored mobility (Flamm & Kaufmann, 2006).

Household characteristics can also influence access. Households with adult children often possess several vehicles, enabling coordinated car-based travel (De Witte et al., 2008). Financial and temporal constraints likewise affect mode choice. Studies show that travel demand is income-dependent, shaping the use of different modes (Dijst & Van Wee, 2002). People with lower incomes often rely more heavily on PT due to limited budgets (Bondemark et al., 2021), a finding supported by evidence of a negative correlation between income and PT use (De Witte et al., 2008). A likely explanation is that individuals often consider only variable costs (mainly fuel) while discounting fixed costs such as insurance, vehicle tax and depreciation (Hine & Scott, 2000).

It is important to take into consideration that for the individual the trip must strike the right balance between financial resources and time available. Sociological studies have demonstrated that travellers attempt to optimise travel time by combining it with other activities (Kaufmann & Montulet, 2016). In a digitalised world, time spent on PT can often be used productively for work or leisure.

Skills

In Kaufmann's framework, *skills* refer to the knowledge and competencies required to use different transport modes effectively. This includes both acquired

knowledge and organisational abilities needed to plan travel, search for information and adapt to unexpected changes (Flamm & Kaufmann, 2006). Navigating transport systems requires complex cognitive and psychomotor skills: mastering movement patterns, anticipating the actions of other road users and adhering to rules such as traffic regulations or timetables.

Skill requirements vary across modes, from vehicle proficiency to understanding operational concepts in PT. Competence develops through practical experience and encompasses not only the mastery of transport spaces and time management but also emotional regulation and the ability to cope with stress in traffic environments (Kaufmann, 2017).

Research shows that mobility behaviour is shaped by age and lifestyle factors (Axhausen et al., 2001). Older and higher-income individuals tend to rely more on cars (Balac et al., 2017). Rising education and occupational prestige correlate with higher income and greater vehicle ownership (Pickery, 2005). Gender differences also play a role: women often travel shorter distances and make greater use of PT (W-S & Acker, 2018).

Spatial connectivity is another important determinant. In rural areas, low service frequency makes PT less attractive (Flamm & Kaufmann, 2006). Commuters travelling between rural homes and urban workplaces frequently rely on combined travel patterns, such as driving to a well-served rail station. Shifts from PMT to active modes, such as walking to the nearest PT stop, also yield health benefits (van Soest et al., 2020).

Access and *skills* are mutually reinforcing. Lifestyle choices affect access to transport alternatives, while access to certain modes influences the development of mobility skills (De Witte et al., 2008).

Appropriation

Appropriation constitutes the third dimension of Kaufmann's model and represents the process through which individuals interpret, internalise and evaluate their mobility options within a network of potential choices (Kaufmann, 2021). It encompasses the strategies, representations, values and habits shaped by societal norms. Individuals form perceptions about the usefulness of different modes and develop mental schemas that influence their willingness, or reluctance, to use certain options.

Beyond functional suitability, transport modes carry symbolic and personal meanings. Reliability and safety consistently emerge as the two dominant factors shaping appropriation, as they influence mobility behaviour and reflect broader lifestyle organisation (Flamm & Kaufmann, 2006).

Perceptions of access, skills and mode characteristics jointly shape mode choice decisions (Kaufmann, 2016). Financial expenditure on mobility reflects accumulated experience and established habits. Routine journeys, such as commuting, are often performed automatically (Friman et al., 2019), though situational changes can prompt behavioural adjustments (De Witte et al., 2013).

Environmental consciousness is increasingly relevant in decision-making processes. While ecological considerations still play a subordinate role in everyday mode choice, movements such as *Fridays for Future* may elevate their significance in the future.

Figure 7 illustrates how Kaufmann's model extends classical decision logic by integrating a socio-cultural dimension.

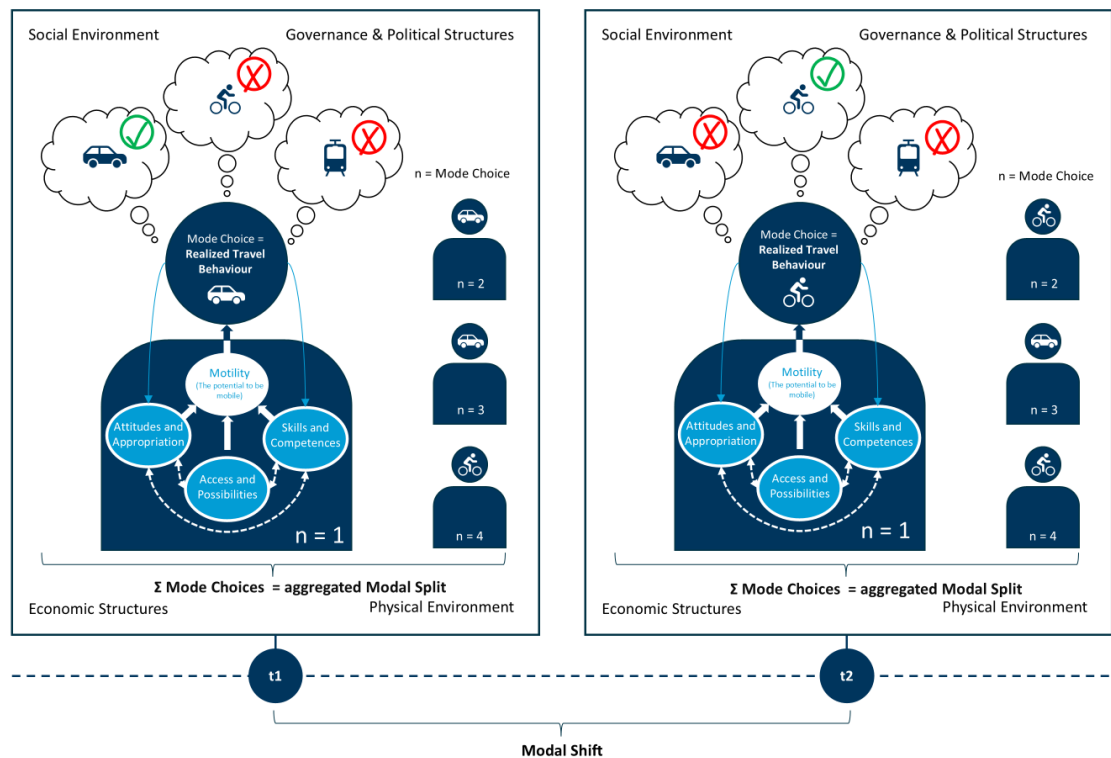


Figure 7: Interrelationship between mode choice, modal split, modal shift, and Kaufmann's mobility concept

Source: Author's own compilation.

Kaufmann's mobility concept provides a robust analytical framework for examining the multifaceted determinants of mobility decisions and for deriving targeted interventions. It underscores that mobility behaviour is shaped not only by external structural conditions but also by subjective perceptions and individual competencies. Systematically integrating these insights into the planning and implementation of sustainable mobility strategies can play a decisive role in ensuring the future viability of PT and in strengthening the acceptance of environmentally friendly modes in Germany.

2.2.5 Generations

Mobility behaviour is profoundly shaped by generational affiliation. Generational differences influence not only individual mobility decisions, but also structurally

affect the modal split, mode choice and, ultimately, modal shift. Although Kaufmann does not explicitly address generational effects within his motility framework, his model clearly implies that age is a decisive factor in determining the three central dimensions of mobility, which are access, skills and cognitive appropriation (Kaufmann et al., 2018).

Age affects access to mobility options, for example through infrastructural barriers or gaps in digital competence that may disproportionately affect older population groups. It also influences the ability to use innovative mobility services, as technological affinity and readiness to adopt new solutions vary considerably between generations. Finally, age shapes the cognitive appropriation of mobility, given that mobility needs evolve dynamically across the life course, for instance, during the transition from working life to retirement or through changing family responsibilities.

Empirical research, including the Brussels commuter study by De Witte (2008) and my own analyses conducted as part of the Lead City project, supports these observations. The findings demonstrate that age functions as a significant predictor within the skills dimension of motility. Kaufmann's model thus provides a theoretical foundation for analysing and explaining generational differences in mobility behaviour (De Witte et al., 2008; Hahn et al., 2023, 2024b).

Incorporating a generational perspective into mobility research adds an essential sociodemographic dimension. Mobility behaviour in Germany exhibits marked generational patterns shaped by cohort membership. The baby boomers, Generation X, Generation Y and Generation Z differ not only in their modal preferences, but also in their willingness to adopt innovative mobility concepts and sustainable modes of transport. These distinctions arise from the interplay of formative societal events and individual life circumstances.

The variability of modal-shift potential, meaning the theoretical and practical capacity to change transport modes, highlights the necessity for considering age structure when designing long-term mobility strategies (Nybom & Stuhler, 2024).

Figure 8 outlines the formative events and birth cohorts associated with each generation.

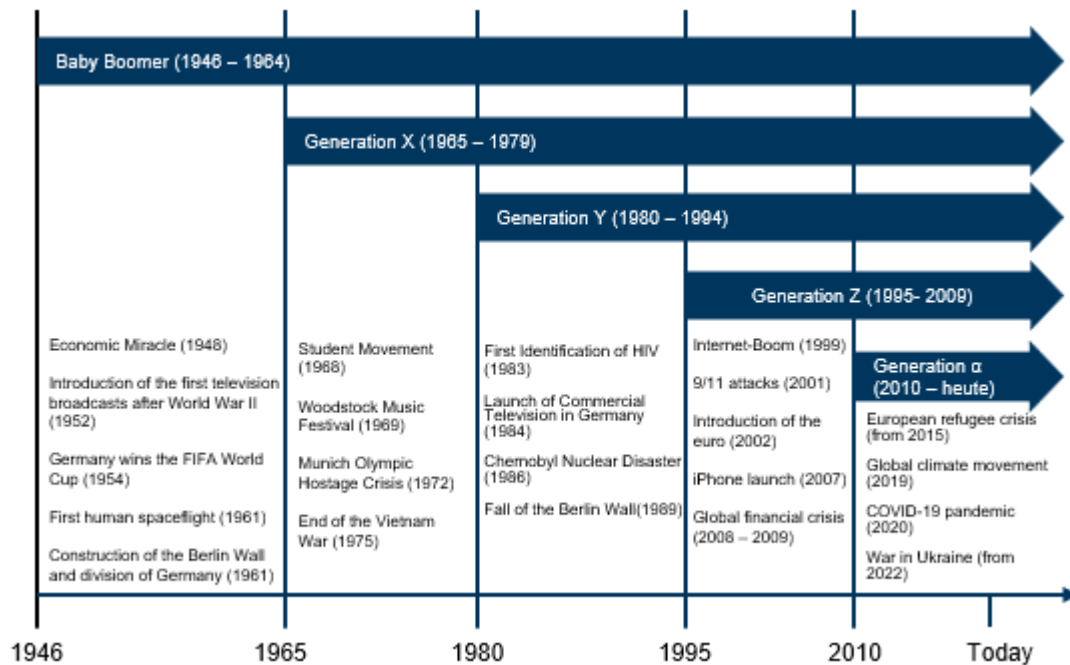


Figure 8: Formative Socio-Historical Experiences Across Generations

Source: Author's own compilation based on (Statista, 2024).

The baby boomer generation, born between 1946 and 1964, is now partly retired or approaching retirement age and exhibits characteristic mobility needs and patterns closely linked to notions of autonomy and quality of life in later adulthood (Maresova et al., 2023). For this generation, the private car plays a central role—not only as a practical mode of transport, but also as a status symbol representing freedom and social standing (Institut für Verkehrsforschung, 2020). Studies indicate that more than 80% of baby boomers use a car on a regular basis for everyday journeys, including commuting, leisure activities and shopping (Arend, 2023).

With advancing age, however, age-related limitations increasingly emerge, such as reduced visual acuity, slower reaction times and declining physical mobility, all of which can impair driving safety. Research conducted by the Federal Highway Research Institute shows that older drivers are proportionately more often

involved in accidents linked to such impairments (Bundesanstalt für Straßenwesen, 2024).

At the same time, many baby boomers —particularly those living in urban areas— recognise the advantages of PT. Approximately 40% regularly use buses and trains, particularly when services are reliable and accessible (Verband Deutscher Verkehrsunternehmen, 2020). The desire to remain mobile throughout one's life is a central priority for this cohort. Studies highlight the importance of maintaining driving competence while also expanding alternative mobility options, such as demand-responsive buses or senior-specific mobility services (Institut für Zukunftsstudien und Technologiebewertung, 2022). Safety training and age-friendly infrastructure, such as well-lit, secure pedestrian routes, are regarded as essential measures to support mobility in later life (Stiftung Warentest, 2024).

The so-called Generation X, born between 1965 and 1979, experienced a period of profound technological and societal transformation shaped by digitalisation and the globalisation of markets (Dorie & Loranger, 2020). These transitions have left a lasting imprint on their mobility behaviour. Their mobility is highly diversified, combining traditional and modern modes. A study by the German Institute for Economic Research shows that motorised individual transport, particularly the private car, remains the preferred mode for many individuals in this cohort, especially for commuting and leisure-related journeys (Deutsches Institut für Wirtschaftsforschung, 2020). Vehicle ownership is perceived as a symbol of independence and flexibility.

Nevertheless, a significant proportion of Generation X also makes use of PT, especially in cities. According to research by Verkehrsbetriebe Zürich, around 30% of this generation use PT regularly, particularly for intra-urban travel (Verkehrsbetriebe Zürich, 2021). Their decision to use PT is often shaped by pragmatic considerations such as travel time, cost and service availability.

As demographic and technological shifts continue, the mobility needs of Generation X are changing. Research from the Institute for Futures Studies and Technology Assessment emphasises the growing relevance of multimodal mobility concepts that seamlessly integrate different modes of transport (Institut für Zukunftsstudien und Technologiebewertung, 2022).

Generation Y, commonly referred to as millennials, is comprised of those born between 1980 and 1994 and represents a substantial share of the German workforce, with 15.88 million individuals in 2021 (Statista, 2024). This generation is characterised by strong environmental awareness and a close connection with digital technologies (Belz et al., 2022). Academic studies suggest that millennials consider themselves to be key players in shaping sustainable, future-oriented mobility systems (Schipperges et al., 2016). Their commitment to reducing CO₂ emissions is reflected in a marked preference for low-emission transport modes such as PT and cycling (Kuhnimhof et al., 2011; Newbold et al., 2005).

Millennials are known for their pronounced multimodality, selecting modes flexibly according to purpose and efficiency. Their increasing integration of new mobility forms, such as e-scooters, highlights their adaptability and openness to innovation (Circella et al., 2017; Delbosc & Nakanishi, 2017).

Within this generation, mobility preferences vary significantly across life stages. Younger millennials, still in education or early employment, tend to favour cost-efficient modes such as PT or cycling, often postponing obtaining a driving licence or purchasing a car (Klein & Smart, 2017). With increasing age, family formation and rising income, reliance on the private car tends to grow, while PT use declines, reflecting the increased need for flexibility and time efficiency (Buehler & Nobis, 2010).

Millennials also show a high propensity to use modern mobility services such as car sharing and express greater openness towards autonomous vehicles (Avs) than previous generations (Becker et al., 2017; Pakusch et al., 2020). Their pos-

itive attitudes extend to autonomous taxis and buses (Payre et al., 2014). Satisfaction with local mobility is closely tied to high-quality infrastructure: good PT provision and cycling infrastructure strongly support the uptake of sustainable mobility alternatives (Nobis, 2019).

Place of residence likewise plays a critical role. While younger millennials often reside in urban areas, or remain in the parental home, families increasingly move to suburbs or small towns due to housing costs and availability.

Millennials therefore are a pivotal group for future mobility transitions. Their environmental awareness, preference for multimodal solutions and openness to new technologies offer significant potential for advancing sustainable and innovative mobility strategies. Ensuring that PT and other eco-friendly modes remain attractive is essential for accelerating the mobility transition.

Generation Z, born between 1995 and 2009, comprises roughly twelve million people in Germany, representing 14.3% of the population (Kring & Hurrelmann, 2022). As the first true “digital natives”, they have grown up fully immersed in digital technologies, which profoundly shape their communication patterns, consumption habits and mobility expectations (Hesse & Mattmüller, 2015; Michalk & Ney, 2018).

Generation Z exhibits highly multimodal mobility behaviour, embracing a wide spectrum of modes ranging from PT and bicycles to contemporary solutions such as car sharing, e-scooters and on-demand mobility services (Movin’On Mobility Survey, 2020). This variety reflects not only their adaptability but also their pragmatic approach to mobility, in which mode choice is heavily situation-dependent.

Digital technologies play a decisive role in their mobility practices. Smartphones serve as central tools for trip planning and execution, whether through navigation apps, ticketing services or ride-sharing platforms. This technological fluency supports seamless intermodal journeys and promotes the uptake of integrated mobility platforms (Hesse & Mattmüller, 2015).

Compared to earlier generations, particularly millennials, Generation Z displays an even stronger shift away from traditional car ownership. Rather than viewing the car as a status symbol, they prioritise flexibility and cost efficiency. Research indicates that many members of this cohort prefer shared mobility services, such as car sharing or ride-hailing, which they perceive as flexible, affordable and environmentally responsible alternatives (Dobbelstein & Walz, 2021).

Future mobility needs among Generation Z will be strongly influenced by technological innovation and the advancement of sustainable mobility solutions. Developments in AVs and improvements to urban transport infrastructure are likely to play key roles in meeting the expectations of this technologically proficient and environmentally conscious generation (Movin'On Mobility Survey, 2019). The combination of technological progress and ecological awareness presents considerable potential for fostering a sustainable and future-oriented mobility landscape.

2.3 Policy Measures

Building on the significance of sustainable mobility outlined in Section 2.1 and the behavioural insights presented in Section 2.2, the central question arises as to which concrete measures can effectively promote a society-wide modal shift from motorised individual transport (MIT) towards environmentally friendly alternatives, particularly PT. Such a shift requires an analytical foundation that transcends purely technical or economic evaluation criteria and instead conceptualises mobility as a socially differentiated form of action potential.

In this context, subsidies and digitalisation measures are gaining increasing importance as political management tools. However, these tools only reveal their full effect when they are designed and implemented, not merely on the basis of technical or economic considerations, but also with regard to social, cultural and infrastructural conditions (Hekler et al., 2022). Vincent Kaufmann's mobility concept provides a differentiated theoretical framework for this purpose, as it con-

ceptualises mobility not simply as spatial movement but as an expression of socially distributed mobility capital (Flamm & Kaufmann, 2006; Kaufmann et al., 2004).

To analyse potential policy levers for facilitating a modal shift, the following section systematically categorises selected political measures. These are classified into pull instruments (incentive-based measures that enhance the attractiveness of PT) and push instruments (restrictive measures that reduce the attractiveness of MIT). In addition, each measure is assessed in Sections 2.3.1 Subsidies and 2.3.2 Digitalisation in relation to the three dimensions of Kaufmann's mobility concept - Access, Skills and Appropriation and is presented in accordance with the structure shown in Table 1.

Table 1: Classification of measures within Kaufmann's three mobility dimensions

Source: Author's own compilation.

Measure	Access	Skills	Appropriation
Subsidies	Price reductions, Access to Funding	Supported Mobility Training	Incentives, Rewards, Mobility Budgets
Digitalisation	Digital Platforms, Realtime Information	Barrier Free Apps, Usability	Gamification, Personalised Incentives

The analytical focus lies on two particularly effective fields of intervention: **subsidies** and **digitalisation**. Both areas are of particular interest as they can function, depending on their specific design, as either incentive-based or restrictive instruments. Moreover, they possess the potential to transform the structural conditions of mobility in a lasting and meaningful way.

The purpose of this section is to illustrate, by way of example, how political measures can influence behaviour through various channels of impact and, in the long term, contribute to a modal shift in favour of sustainable forms of mobility.

2.3.1 Subsidies

PT is structurally non-viable without government subsidies, and transport operators in almost all regions of the FRG operate at a deficit. Subsidies encompass

both positive subsidies (Section 2.3.1.1), which function as pull effects, for example, through reduced fares or service expansion, as well as negative subsidies (Section 2.3.1.2), which act as push effects, such as when the deliberate non-subsidisation of fossil-fuel-based modes indirectly results in rising costs. In this sense, subsidies constitute a central policy instrument for steering the transition towards sustainable mobility. Within Kaufmann's mobility concept, subsidies play a pivotal role.

The transformation of mobility behaviour in the FRG takes place within a field of tension shaped by economic conditions, technological innovation and political price mechanisms. Subsidies serve as a regulatory tool for influencing demand—either by providing financial incentives to encourage the use of PT, or by reducing the indirect privileges associated with MIT.

2.3.1.1 Pull Effects of Subsidies

This section examines those measures which, in the sense of pull effects, increase the attractiveness of PT through state subsidisation. The classification follows Kaufmann's (2002) theoretical framework, which conceptualises mobility along the three dimensions of Access, Skills and Appropriation. On this basis, the analysis illustrates how different forms of subsidisation may influence mobility behaviour and which steering impulses can be derived from them. The theoretical considerations presented in this section also constitute the conceptual foundation for the empirical analyses in Chapter 4.

Government Measure: Reduced PT Fares / Subsidised Ticketing

Government subsidisation of PT fares is a central instrument for increasing the attractiveness of PT and lowering financial barriers to access. A prominent example is the Deutschlandticket, introduced in 2023, which, owing to its low flat-rate price, has financially unburdened broad segments of the population and significantly increased PT use, particularly among low and middle income commuters (Berschin & Böttger, 2023). Comparable models, such as Austria's Klimaticket (climate ticket) or Luxembourg's transition to entirely fare-free PT, demonstrate that subsidised fares not only contribute to the economic viability of PT, but also serve as a strategic steering mechanism in the transition towards sustainable mobility (Gössling & Dolnicar, 2023).

Within Kaufmann's mobility concept (2002), measures such as reduced PT fares can be differentiated across the three core dimensions of mobility—Access, Skills and Appropriation. The strongly discounted Klimaticket introduced in Bonn and the nationwide monthly Deutschlandticket represent paradigmatic examples of interventions capable of exerting transformative effects across all three dimensions (Hahn et al., 2023).

- **Access: Financial relief as a prerequisite for access**

Reducing PT fares significantly lowers the financial barriers to accessing PT. The Bonn Klimaticket considered in our empirical studies was subsidised by the federal government, and the nationwide Deutschlandticket (€49/month) introduced in 2023 is jointly financed by the federal and state governments. According to the Federal Ministry for Digital and Transport, the required governmental compensation amounts to approximately €3 billion annually (Bundesministerium für Digitales und Verkehr, 2023). Such measures represent a key condition for inclusive mobility access, particularly for low-income households, young people and senior citizens. Numerous studies confirm that price is a decisive factor in mode choice (Cools et al., 2016).

International evidence underscores this effect: in Tallinn, where a fare-free model has been in place since 2013, PT usage increased by up to 14% (Cats et al., 2017). Luxembourg has pursued a nationwide fare-free PT system since 2020, aligning ecological, social and transport-policy objectives in a coherent manner (Carr, 2019). Subsidised fares thus reduce users' financial burden while simultaneously promoting structural equality in access to mobility (Carr & Hesse, 2020).

- **Skills: Subsidised simplification of fare structures to reduce cognitive and organisational barriers**

A simplified and nationally applied fare system reduces the cognitive and organisational effort required to use PT, particularly for occasional users, tourists and socially disadvantaged groups. Eliminating complex zone and pricing structures positively affects the skills dimension in Kaufmann's sense. Users must devote less time and fewer cognitive resources to navigating the PT system in everyday life (International Transport Forum, 2024).

Studies by Buehler et al. (2017a) and Guzman et al. (2021) highlight fare complexity as a key entry barrier in many regions. Standardised solutions such as the Deutschlandticket considerably enhance system usability. This is particularly relevant in suburban and rural areas where familiarity with PT systems tends to be lower; simplified structures can therefore be crucial in reaching new user groups.

- **Appropriation: Legally enshrined subsidies supporting long-term appropriation, identification and societal anchoring**

Beyond access and ease of use, subsidised PT fares also influence the symbolic and cultural appropriation of PT. Reduced prices can fundamentally reshape the perception of PT, from being regarded as a "fallback option" for those without cars to representing a socially fair and environmentally responsible mode of everyday mobility (Sahling, 2022). This shift can strengthen personal identification with PT.

Such cultural revaluation not only increases societal acceptance but also enhances the political legitimacy of PT provision. Examples from Luxembourg and Tallinn illustrate that fare-free or strongly subsidised PT leads not only to changed demand patterns but also to shifts in public discourse surrounding mobility (Carr & Hesse, 2020). Reduced fares thus function not only as an economic incentive, but also as a socio-cultural instrument within a broader sustainable mobility transition.

Government Measure: Expansion of PT Services

The expansion of PT services is based on government investment in both infrastructure and operations. Key financing instruments include the *Gemeindeverkehrsfinanzierungsgesetz*, the implementation of regional PT plans, and additional funding provided by the federal states. European funding streams, such as the European Regional Development Fund, further support network expansion projects. These measures reflect an active form of state intervention that influences the supply side structurally, while indirectly stimulating demand for PT (Bundesministerium für Digitales und Verkehr, 2023; Fearnley, 2013). Within the broader context of the mobility transition, service expansion is therefore more than a technical adjustment: it functions as a political instrument for promoting spatial equality, social participation and the ecological transformation of urban, as well as rural, mobility systems (Hahn et al., 2023; Macharis et al., 2006).

- **Access: Expansion of availability and accessibility as prerequisites for access**

Service expansion increases the spatial and temporal availability of PT through higher service frequencies, new routes and improved connectivity to previously underserved areas. In rural regions in particular, where a pronounced “PT gap” has long existed, the state-supported extension of networks creates substantial improvements in mobility opportunities (Buehler et al., 2017a). This significantly strengthens physical accessibility, a core aspect of Kaufmann’s Access dimension (Macharis et al., 2006).

- **Skills: Reduction of planning effort through increased service density**

A denser service network reduces waiting times and enables more flexible and spontaneous use of PT. For user groups that have previously relied on lengthy planning times or low service frequencies, cognitive and organisational burdens decrease significantly. As a result, not only is the planning effort reduced, but the everyday usability of PT increases, aligning with the notion of a system that is “readily available” (Buehler & Pucher, 2012; Guzman et al., 2021). The measure therefore directly addresses the skills dimension by enhancing user competence not through explicit training but through structural improvements in service provision.

- **Appropriation: Normalisation of PT as an everyday mobility option**

In the long term, service expansion supports the perception of PT as a reliable and equal alternative to MIT. The denser the network and the greater the availability, the more strongly PT becomes embedded in people’s everyday mobility practices. This cultural appropriation is essential for establishing long-term habits and transforming mobility routines. Users begin to perceive PT not as an emergency solution, but as an integral and self-evident element of their mobility biography (Carr, 2019; Sahling, 2022).

Government Measure: Enhancing the Attractiveness of the Bus-Driving Profession

Ensuring high service quality in PT is fundamentally dependent on the availability of sufficient personnel. In light of increasing staff shortages, high turnover rates and a demographically driven shortage of skilled workers, enhancing the attractiveness of the bus-driving profession requires targeted governmental interventions. These include wage adjustments, improved working conditions, dedicated qualification programmes and image campaigns supported by federal states, transport associations and, in part, EU funding instruments (Federal Ministry for

Digital and Transport, 2023). Politically, this measure is not only relevant in labour market and social policy terms; it also constitutes a structural precondition for a successful mobility transition. Without a sufficient number of well-trained drivers, a high-quality PT system cannot be guaranteed (Association of German Transport Companies, 2023b).

- **Access: Ensuring service quality through availability of sufficient staff**

A higher number of qualified staff increases the spatial and temporal reliability of PT services. Shortages resulting from cancelled services or reduced frequencies can be mitigated, thereby improving system dependability for the population. This is particularly crucial in regions experiencing growth in demand, where personnel availability is a core precondition for actual accessibility within Kaufmann's Access dimension. Recent studies show that staff and skill shortages have already compelled several PT operators in the FRG to restrict services, reporting, for instance, that operations had to be "temporarily reduced due to staffing constraints" (Association of German Transport Companies, 2024). The Federal Environment Agency likewise emphasises that the reliability of PT, such as predictable, non-cancelled connections, is strongly linked to staffing levels and operational stability (Umweltbundesamt, 2020).

- **Skills: Quality assurance through service expertise**

An improved staffing ratio reduces workload and enables higher levels of service orientation. Kindness, assistance and passenger support help lower cognitive barriers, particularly for occasional users, older adults and tourists. This not only enhances the functional usability of PT but also strengthens its user-friendliness. Empirical evidence consistently shows that perceived service quality is a key determinant of PT acceptance (Buehler & Pucher, 2012). Consequently, increased service expertise directly supports the Skills dimension within Kaufmann's framework by making PT easier, more intuitive and more supportive to use.

- **Appropriation: Symbolic upgrading of PT through professionalisation**

When users associate PT with professionalism, reliability and high service standards, a positive symbolic transformation occurs. PT is no longer perceived primarily as a “low-cost alternative”, but rather as a modern, professional system worthy of trust (Sahling, 2022). This contributes to long-term appropriation, fostering positive identification with PT and strengthening its cultural and societal anchoring.

Government Measure: Accessibility and High-Quality PT Stops

Investments in accessibility and the qualitative upgrading of PT stops are core pillars of an inclusive mobility transition. Governmental programmes, implemented through the Disability Equality Act, federal state funding schemes or EU initiatives supporting barrier-free infrastructure, create the structural conditions for socially equitable mobility provision. Attractive, safe and comfortable stops enhance not only the objective usability of PT but also users’ subjective experience of it (Fearnley, 2013). Barrier-free access points, guidance systems, well-designed waiting environments and standardised infrastructure requirements increase comfort and, indirectly, the acceptance of PT services (Veisten et al., 2024). Such measures, therefore, strengthen the Access dimension within Kaufmann’s framework while simultaneously supporting Skills and Appropriation, as they lower usage barriers, improve the user experience and foster sustained usage intentions.

- **Access: Reducing physical and social access barriers**

Barrier-free PT stops, which are equipped with ramps, lifts, tactile guidance systems or acoustic announcements reduce barriers to access, in particular for older adults, persons with disabilities and families with children. These measures expand the number of individuals who can use PT independently and without exter-

nal assistance. As such, they constitute a central prerequisite for designing inclusive access conditions in line with Kaufmann's Access dimension (Macharis et al., 2006).

- **Skills: Reducing cognitive and physical effort**

Barrier-free and aesthetically upgraded stops lessen physical strain and simplify orientation. For passengers, this results in reduced cognitive and organisational effort when entering the system, for instance through clearly understandable passenger information or intuitive wayfinding. Empirical studies demonstrate that low-barrier, visually coherent environments significantly decrease mental workload when navigating PT systems and improve the efficiency of route decisions (Ma & Yan, 2021). By mitigating these sources of strain, the measures reinforce the Skills dimension, as they reduce the skills required of passengers to use the system effectively (Guzman et al., 2021).

- **Appropriation: Strengthening comfort, safety and social inclusion**

Beyond functional use, the qualitative upgrading of stops generates symbolic added value. Comfortable, safe and aesthetically appealing PT environments foster feelings of welcome, dignity and social inclusion. This supports not only the use of PT but also its positive appropriation (Appropriation). International analyses show that PT and its infrastructures carry distinct symbolic and status-related meanings across cultures and that improved design and equipment can significantly influence public perceptions and attitudes towards PT (Ashmore et al., 2019). This enhances the cultural embedding of PT as a public space rather than merely a means of transport (Carr, 2019; Sahling, 2022).

A concise overview of the discussed measures and their allocation to Kaufmann's three mobility dimensions is presented in Table 2.

Table 2: Positive Subsidies to Enhance PT Attractiveness (Pull Measures)

Source: Author's own compilation.

Measure	Access	Skills	Appropriation
Reduced PT fares	Lower financial barriers	Simplified fare structures	Increased acceptance and identification with PT
PT service expansion	Greater spatial–temporal availability	Reduced planning effort	PT perceived as a viable and reliable alternative
Improving the attractiveness of the bus-driver profession	More stable service provision	Enhanced customer service and support	Stronger perception of professionalism and service quality
Barrier-free, high-quality PT stops	Lower physical and social access barriers	Reduced physical and cognitive demands	Increased comfort, safety and positive user perception

2.3.1.2 Push Effects of Subsidies

When making mobility decisions, users weigh the characteristics of different transport modes according to individual preferences, cost structures, and situational conditions. A modal shift in favour of PT can therefore be achieved not only through attractiveness-enhancing measures in the sense of pull effects (see Section 2.3.1.1), but also through negative subsidies that reduce the relative advantage of PMT. Negative subsidies include the removal of existing benefits for PMT use, as well as targeted fiscal or regulatory burdens that increase the cost of car travel. The following section classifies these measures along Kaufmann's (2002) three mobility dimensions, Access, Skills and Appropriation and outlines their potential modes of action.

Government Measure: Cost-Based Restrictions

The state-driven increase in the cost of car use is considered one of the most effective instruments for reducing car dependence and is included in virtually all climate-policy scenarios as a central steering mechanism (Eliasson & Mattsson, 2006). Cost-based restrictions encompass fiscal measures that increase the financial burden of PMT use, such as parking fees, congestion charges, higher

vehicle taxes, increased fuel costs or inflation-driven price adjustments. Empirical evidence shows that particularly short urban car trips are highly price elastic and therefore react strongly to such measures (Goodwin et al., 2004).

- **Access: Economic barriers as a control instrument**

Cost-based restrictions reduce the economic accessibility of PMT use by increasing both entry and operating costs. A prominent example is the London Congestion Charge, where traffic volumes in the city centre decreased by around 20% shortly after its introduction (Leape, 2006). In Stockholm, congestion charging reduced travel times by 30% and stabilised car traffic in the long term (Eliasson, 2009). In Milan, the Area C charge contributed to a measurable decline in CO₂ emissions (Percoco, 2014).

These cases demonstrate that monetary barriers have an immediate impact on access by making spontaneous PMT use less attractive, while alternative modes, PT, cycling, walking, gain appeal in relative terms.

- **Skills: Increasing the need for planning and budget management**

Rising costs compel households to reconsider their mobility routines. Users must evaluate which trips justify PMT use and integrate alternative transport options into their planning. This process has been described as “forced skill acquisition” (Goodwin, 2012), in which multimodal capabilities become stronger. A widely cited example is SFpark in San Francisco, where dynamic, demand-responsive parking fees encouraged users to adapt their behaviour. As a result, they shifted to PT, or reduced their parking times which led to a measurable reduction in the traffic looking for parking spaces (Pierce & Shoup, 2013). Such mechanisms create a planning pressure that ultimately strengthens users’ skills in incorporating alternative modes into everyday mobility.

- **Appropriation: Cultural re-evaluation of automobility**

Over time, cost-based restrictions reshape the cultural meaning of car use. The PMT is increasingly perceived as economically inefficient, inconvenient, or even irrational (Schwedes, 2018). Singapore's Certificate of Entitlement (COE) system, which ties car ownership to extremely high costs, illustrates how fiscal policy can transform the car from an everyday commodity into a luxury product (Phang & Toh, 2004).

In many European cities, congestion charging and rising parking fees have contributed to a decline in the social legitimacy of everyday car use. Conversely, PT, cycling and shared mobility services gain symbolic and cultural value (Santos, 2017). Thus, economic disincentives become an engine for cultural distancing from automobility.

Government Measure: Spatial and Physical Restrictions (road space reallocation, parking removal, parking bans)

Physical interventions in urban infrastructure rank among the most effective push measures, as they directly diminish the attractiveness and habitual ease of car use (Banister, 2008). They include the reallocation of road space, the removal of parking facilities, parking bans, and the creation of car-free zones (Newman & Kenworthy, 2015). Such interventions constitute visible and lasting signals of the transport transition, shifting structural conditions in favour of sustainable modes.

- **Access: Reduced physical availability**

Road space reallocation and the removal of parking facilities directly reduce the spatial accessibility of car use by constraining spontaneity and everyday convenience. In Barcelona, the introduction of the "superblocks" led to entire street segments being closed to PMT traffic, resulting in traffic reductions of up to 21% within the affected areas and a marked increase in urban liveability (Mueller et al., 2020). Similar effects were observed in Copenhagen, where the progressive

removal of parking spaces has contributed to over 60% of inner-city trips now being made by bicycle (Pucher & Buehler, 2008). These cases illustrate that restricting physical space for PMTs weakens the competitive position of the car relative to cycling and PT.

- **Skills: Increased planning pressure without generating new competences**

Spatial–physical restrictions impose additional planning pressure on car users, such as longer parking searches or the need for alternative routing. While these measures do not directly foster new multimodal skills, they increase everyday complexity and reduce convenience. In Paris, the conversion of major Seine riverbank roads into car-free promenades compelled drivers to plan their mobility more deliberately, for instance, by switching modes or through greater reliance on park-and-ride facilities (Boussauw & Vanoutrive, 2017). International studies confirm that such restrictions generate “induced planning efforts” (Cairns et al., 1998; Kent, 2022), undermining the habitual ease of PMT use even if they do not actively build new competences. Consequently, spatial interventions act as daily frictions that destabilise entrenched routines and gradually erode the practical and cultural dominance of the car.

- **Appropriation: Reframing the car as inconvenient and burdensome**

By reducing parking and road space, the cultural perception of the car shifts fundamentally. Instead of being perceived as flexible and convenient, it increasingly appears inconvenient and burdensome (Sheller & Urry, 2000). In the Netherlands, decades of systematic road space reallocation since the 1970s have contributed to the declining centrality of the car in cities such as Utrecht and Groningen, where cycling has not only gained functional relevance but has been culturally normalised (Durand et al., 2018). Similarly, Oslo’s removal of all on-street parking in the city centre in 2019 illustrates how spatial and physical restrictions can delegitimise PMT use while simultaneously enhancing the social and ecological value of public space (Christiansen et al., 2017).

Government measure: Regulatory interventions (driving bans, restrictive purchase conditions, strengthened climate targets)

Regulatory interventions address the legal and political framework conditions of mobility and represent some of the most powerful push measures, as they restrict car use not only economically or spatially, but structurally (Creutzig et al., 2016). They include driving bans in low-emission zones, restrictive registration requirements for high-emission vehicles, and ambitious climate targets that regulate automobility in the long term. In contrast to purely economic instruments, regulatory interventions exert direct and immediate effects through legal exclusions and restrictions. International research shows that such command-and-control regimes are particularly effective when combined with clearly defined policy pathways and robust monitoring mechanisms (Schwanen et al., 2012). As a result, regulatory interventions do not merely create incentives; they reshape the structural opportunity space of mobility itself.

- **Access: Restriction of availability**

Regulatory requirements directly reduce the physical and legal accessibility of PMTs. In many European metropolitan areas, including Berlin and Milan, entry into low-emission zones is permitted only for vehicles that meet specific environmental standards. Evidence shows that the introduction of such zones reduced the number of high-emission PMTs in German cities by more than 50% (Umweltbundesamt, 2019). Norway offers another example: sustained regulation aligned with ambitious climate targets and restrictive support mechanisms increased the share of electric vehicles in new registrations to more than 70% within only a few years (Figenbaum, 2024). Overall, regulatory interventions clearly restrict access to PMTs as an always-available transport option.

- **Skills: Required information seeking and adaptation**

Regulatory interventions create a substantial need for information processing and behavioural adjustment. Motorists must familiarise themselves with complex

rules concerning driving bans, emission classes, or updated registration conditions. This requires the acquisition of administrative and regulatory competences that exceed the mere operation of a PMT (Marsden & Rye, 2010). In France, the introduction of the mandatory Crit'Air sticker system in urban low-emission zones obliged millions of drivers to understand and classify their vehicles according to specific emission categories (Morton et al., 2021). Likewise, the necessity to consider climate-related requirements in purchase decisions has reshaped user competences, shifting behaviour from habitual use towards deliberate planning and regulatory compliance.

- **Appropriation: PMTs as regulated and climate-damaging goods**

Regulatory interventions significantly alter the cultural perception of PMTs. Cars increasingly lose their taken-for-granted status and become associated with regulation, restriction, and climate-related problems (Schwedes, 2017). This is particularly evident in California, where Zero Emission Vehicle mandates have exerted considerable pressure on internal combustion vehicles. These policies not only accelerated the growth of electric mobility but also undermined the societal legitimacy of traditional PMTs (Venegas et al., 2021). In the FRG, debates on speed limits, diesel bans and stricter emission regulations further contribute to reframing the PMT as a regulated, politicised and no longer self-evidently available mode of transport. As a result, the symbolic dominance of the PMT is gradually eroding, while its use becomes embedded within a more normatively charged and environmentally scrutinised context.

Government measure: Promotion of alternatives (bike streets, multimodal prioritisation)

The promotion of attractive alternatives constitutes a central complement to restrictive push measures. While fiscal or regulatory instruments limit the use of PMTs, infrastructural investments in cycling, walking, and multimodal hubs simultaneously increase the attractiveness of sustainable mobility options (Buehler & Pucher, 2021). Studies show that high-quality cycling infrastructure, such as

protected cycle lanes or bike streets, not only improves safety but can also induce substantial shifts from PMTs to bikes (Aldred et al., 2016). Examples including the systematic introduction of bike streets in the Netherlands or the prioritisation of PT at signalised intersections in Zurich illustrate the dual effect of such measures: they reduce the functional and temporal convenience of PMT use, while strengthening the cultural normalisation of environmentally friendly mobility (Kębłowski & Bassens, 2018).

- **Access: Reprioritisation of infrastructure**

The reallocation of street space in favour of cyclists and PT reduces the relative accessibility of PMTs. Bike streets, signal priority and multimodal hubs diminish the physical space and symbolic precedence of cars, while simultaneously making alternative modes more visible and convenient (Pucher & Buehler, 2008). International research demonstrates that high-quality cycling infrastructure produces substantial modal-shift effects and systematically weakens the competitive position of PMTs (Marshall & Ferencak, 2019). In Copenhagen, where around 62% of residents regularly commute by bike, the high quality and prioritisation of the cycling network is the result of long-term government support and consistent planning (Gössling, 2020). This creates infrastructural asymmetry that structurally disadvantages PMTs while strengthening sustainable modes both culturally and functionally.

- **Skills: Acquisition of new mobility competencies**

The enhanced integration of cycling and multimodal nodes fosters the development of new mobility skills and expands users' capacities to act in daily mobility. By expanding bike lanes, sharing services and intermodal transfer points, users increasingly learn to switch flexibly between modes, combine bikes or e-scooters with PT and plan multimodal routes with routine ease (Banister, 2008). Empirical studies show that the development of multimodal infrastructure significantly broadens mobility options, particularly for previously car-oriented populations (Böcker et al., 2016). In cities such as Paris, which has invested heavily in bike

lanes, bike streets and sharing systems, marked behavioural changes have been observed: formerly car-dependent users adopt new routines, integrate multiple modes into their everyday mobility, and internalise multimodal travel as a natural competence (Gras Gentiletti et al., 2025).

- **Appropriation: Cultural revaluation in favour of sustainable mobility**

With the visible prioritisation of sustainable modes, the cultural perception of PMT use changes. Cars lose symbolic dominance, while cycling and multimodal mobility are increasingly internalised as modern, climate-friendly and socially desirable (Urry, 2004). In Barcelona, the introduction of bike streets and superblocks not only reduced PMT traffic but also transformed the urban identity: the city is increasingly perceived as a liveable public realm in which mobility is embedded within a sustainable and community-oriented urban fabric (Mueller et al., 2020). Such infrastructural transformation triggers a cultural revaluation in which PMTs no longer enjoy automatic acceptance but gradually recede into the background as secondary modes.

A summarising overview of the described measures and their classification along the three mobility dimensions according to Kaufmann is presented in Table 3.

Table 3: Negative subsidies to reduce the attractiveness of PMTs (Push Measures)

Source: Author's own compilation.

Measure	Access	Skills	Appropriation
Cost-based Restrictions	Higher Usage Costs	Incorporating Alternatives into Everyday Planning	Car as a less Economical Option
Spatial and Physical Limitations	Reduced Reachability	Greater Need for Planning	Car as a less Practical Option
Regulatory Interventions	Limited Availability	Adapting to New Rules	Car as Regulated Option
Demand for Alternatives	Priority Shift in Favour of other Modes	Expanded Cycling and Multimodal Practices	Alternatives as Attractive Routine

2.3.2 Digitalisation

Digitalisation is a key driver of the transformation of PT and opens up extensive opportunities to enhance its attractiveness within a sustainable mobility transition. Digital innovations generate pull effects, for example through mobility-on-demand (MoD) services, digital guidance and information systems, MaaS, or AVs, all of which provide measurable gains in comfort and efficiency. At the same time, they may also create push effects, insofar as they reduce the relative attractiveness of PMT.

Within Kaufmann's mobility framework (2002), digital measures operate across multiple dimensions and contribute both to improved individual access conditions and to the collective steering of modal shift. The following subsections differentiate these effects according to pull effects (2.3.3.1) and push effects (2.3.3.2) and classify them systematically.

2.3.2.1 Pull Effects of Digitalisation

Digital innovations enhance the attractiveness of PT by improving access, comfort and user-friendliness. For the purposes of this dissertation, several central measures have been identified, including MoD models, digital guidance and information systems, MaaS platforms, digital ticketing and booking systems as well as autonomous buses. Their effects can be classified along the three dimensions of Kaufmann's mobility framework (2002): Access, Skills, and Appropriation. The following section analyses their potential for promoting sustainable mobility.

Government measure: Mobility on Demand (MoD)

On-demand mobility services, commonly grouped under the term Mobility on Demand (MoD), comprise digital, flexible and frequently shared transport services that respond to real-time demand. Typical formats include demand-responsive buses, on-demand shuttles, and algorithmically optimised ride pooling services (Jiang et al., 2020). They function as a connective interface between conventional

PT and individual mobility and address, in particular, the “last mile” as well as service gaps in suburban or rural areas where fixed-route services can only be provided with limited efficiency. International experience, such as ViaVan in Berlin or the Finnish Kutsuplus pilot in Helsinki, demonstrates that MoD services can substantially increase the attractiveness of PT when they are technically and organisationally integrated into existing networks (Smith, 2020).

Within Kaufmann’s framework (2002), MoD can be analysed across the three dimensions Access, Skills, and Appropriation, illustrating how MoD both reduces structural access barriers, enables new user capabilities, and fosters a cultural adoption of digitally supported, flexible mobility.

- **Access: Flexibilisation of reachability and spatio-temporal mobility**

MoD services expand access to public mobility by providing flexible, demand-responsive transport solutions. Particularly in rural areas, where fixed-route services are sparse, digital on-demand shuttles offer a low-threshold addition that structurally enhances the physical and temporal reachability of mobility (Mulley & Nelson, 2016). In Germany, such services are increasingly integrated into transport associations, enabling passengers to use MoD with a standard PT ticket.

International case studies highlight this effect: in Helsinki, the Kutsuplus pilot increased overall accessibility, allowing passengers to book trips individually while algorithms calculated flexible routes (Sochor et al., 2018). MoD therefore establishes a key access prerequisite, especially for population groups that previously depended on PMT due to limited PT coverage.

- **Skills: Digital booking and operability as prerequisites for new user competencies**

MoD requires users to employ new skills related to digital applications, particularly app-based booking systems. At the same time, intuitive user interfaces substantially reduce cognitive barriers traditionally associated with complex timetables or fare systems. Consequently, MoD addresses the Skills dimension in a dual manner: it presupposes a certain level of digital competence while simultaneously simplifying everyday mobility through clear and easy-to-navigate platforms (Pangbourne et al., 2020).

Empirical evidence confirms this effect: in the United States, app-based ride pooling systems significantly reduced the planning burden for users who had previously been confronted with highly irregular bus services (Erhardt et al., 2022). These experiences illustrate that MoD not only expands physical availability but also markedly lowers mental and organisational barriers to mobility.

- **Appropriation: Cultural adoption of flexible, shared mobility systems**

Over time, MoD reshapes the cultural perception and appropriation of mobility. In many regions where PT is perceived as rigid or inflexible, MoD conveys the image of a modern, digital, and user-centred mobility solution. This contributes to greater societal acceptance of shared mobility and relativises the car as the dominant symbol of individual freedom (Shaheen & Chan, 2016).

In New York, for example, ride pooling services such as Via have become firmly integrated into everyday mobility and are regarded as an attractive and socially accepted complement to conventional PT (Cohen & Shaheen, 2018). Such cultural reinterpretation, shifting from the car as the only flexible mobility option towards digitally coordinated collective mobility, strengthens the social legitimacy of PT systems and represents a significant contribution to the mobility transition.

Government measure: Digital guidance and information systems (real-time data, passenger information)

Digital guidance and information systems are considered a key factor in enhancing the attractiveness and reliability of PT. They include real-time displays at stops, app-based information services with live data, dynamic passenger information during disruptions, and multimodal journey planners (Gündling et al., 2020). Their purpose is to increase transparency and predictability within the mobility system and to reduce uncertainties in travel planning. Particularly in complex urban networks, reliable real-time information is crucial for improving the perceived quality of PT and intermodal services (Watkins et al., 2011).

International case studies underline this effect: in London, the introduction of real-time information via the *TfL* app resulted in a measurable increase in ridership and a reduction in perceived waiting times (Tang & Thakuriah, 2012). In Stockholm, digital real-time services were shown to increase PT use, especially among occasional users (Dziekan & Kottenhoff, 2007). Within Kaufmann's mobility framework (2002), these measures can be analytically positioned along the dimensions Access, Skills, and Appropriation.

- **Access: Improving reliability and predictability of mobility**

Digital guidance and information systems lower structural barriers to public mobility by reducing uncertainties regarding departure times, connections, and disruptions. Real-time information allows users to adapt their travel behaviour to situational conditions and to perceive PT as a dependable and predictable alternative to the car (Watkins et al., 2011). For commuters and users in regions with low service frequency, reliable data represent a decisive lever for making mobility options genuinely accessible.

An example from Los Angeles highlights the relevance of digital information systems for social equity. Equity analyses by LA Metro and local planning agencies demonstrate that structural challenges such as long waiting times or unreliable

service are particularly pronounced in disadvantaged communities (Doyle & Nabayan, 2024). Digital information systems therefore contribute to more inclusive mobility by reducing access barriers created by uncertainty and information deficits.

- **Skills: Reducing cognitive load through intuitive navigation**

Digital guidance and information systems simplify the use of complex transport networks by reducing users' cognitive and organisational load. Instead of having to interpret intricate timetables, route networks, or fare structures, travellers can determine optimal routes with only a few clicks. As such, real-time information strengthens the Skills dimension within Kaufmann's framework by enabling broader participation among occasional users, tourists, and individuals with limited experience of PT (Lyons & Urry, 2005).

Studies from New York and Chicago show that real-time apps not only improve planning efficiency but also enhance subjective trust and comfort (Brakewood et al., 2014). For people with limited local knowledge, including migrants and visitors, digital information systems significantly reduce barriers to using PT actively and regularly.

- **Appropriation: Symbolic adoption of transparency and digital modernity**

Beyond access and operability, digital information systems also carry cultural significance: they transform the image of PT from a slow, unreliable system into a modern, data-driven and user-centred service (Cottrill et al., 2013). Real-time information fosters new forms of trust and identification by presenting mobility as transparent, predictable, and controllable.

In Singapore, the systematic use of digital real-time data is an integral element of urban innovation policy and contributes to positioning PT as a globally recognised, "smart" transport system (Tan et al., 2018). This symbolic elevation not

only strengthens societal acceptance but also reinforces the political legitimacy of public investments in digital mobility technologies. Thus, digital guidance and information systems act not only as technical tools but also as cultural catalysts that fundamentally reshape the relationship between society and PT.

Government measure: Mobility-as-a-Service concepts and integrated platforms

MaaS refers to the integration of different transport modes, such as PT, car sharing, bicycle sharing, e-scooters and taxis, into a single digital platform offering seamless journey planning, booking, and payment (Lyons et al., 2019). The objective is to make multimodal mobility as convenient as private car use, thereby encouraging a shift towards more sustainable transport modes. By bundling diverse mobility services into one coherent ecosystem, MaaS provides a highly flexible, user-centred alternative, capable of substituting car travel without sacrificing individual flexibility (Kamargianni et al., 2016).

International examples highlight this potential: in Helsinki, the MaaS app *Whim* launched in 2016 and has since become a global reference case. Studies show that *Whim* users significantly reduced their car use and increasingly relied on shared and multimodal options (Jittrapirom et al., 2017). Similar effects were observed in Vienna with *WienMobil* and in Gothenburg with *UbiGo*, where MaaS increased the attractiveness of intermodal travel (Sochor et al., 2018). Within Kaufmann's mobility framework (2002), MaaS can be analytically located along the dimensions Access, Skills, and Appropriation.

- **Access: Integrated platforms as structural access to multimodal mobility**

MaaS reduces structural access barriers by consolidating different transport services within a single digital entry point. Users no longer need to navigate multiple

platforms, pricing systems or access conditions; instead, they can organise multimodal journeys through one app. This increases convenience, predictability and ease of integration into daily routines (Giesecke et al., 2016).

The Helsinki example shows that Whim increases the attractiveness of PT by embedding it seamlessly into the intermodal chain. Research confirms that such a structural ‘one-stop-shop’ principle substantially lowers barriers to sustainable mobility and can be decisive for encouraging former car users to shift modes (Matyas & Kamargianni, 2021).

- **Skills: Reducing cognitive and organisational complexity**

The primary strength of MaaS lies in its ability to reduce organisational and cognitive load. Instead of coordinating timetables, availability, booking and payment across different providers, users can rely on an intuitive, integrated interface. As a result, the Skills requirements defined by Kaufmann (2002) are significantly lowered, enabling participation by groups with limited mobility experience (Hensher et al., 2021).

The UbiGo pilot in Gothenburg demonstrated that users built trust through simple usability and transparent pricing structures and increasingly adopted multimodal options. For individuals with little PT experience, including tourists and older adults, MaaS substantially reduces entry barriers to intermodal mobility (Sochor et al., 2018).

- **Appropriation: From ‘ownership’ to ‘use’ — a cultural shift**

MaaS entails not only technical, but also cultural transformations. It supports a paradigm shift from ownership-based mobility to usage-based mobility. Instead of the privately owned car as a status symbol, flexible, digital and shared modes become markers of modern urban life. Mobility is thus reinterpreted not only as an economic resource but also as a cultural one (Kamargianni & Matyas, 2017).

In Helsinki, Whim users did not merely alter their travel behaviour; they also re-assessed mobility itself. The app became associated with a modern, ‘smart’ lifestyle (Aarhaug & Olsen, 2018). Such symbolic appropriation can reinforce the legitimacy of public investments in multimodal systems and support a societal shift away from car-centric norms.

Government measure: Digital ticketing and booking systems (app, smart-card, contactless)

The introduction of digital ticketing and booking systems is one of the central strategies for making access to PT more user-friendly and efficient. Smartphone apps, smartcards and contactless payment options reduce transaction costs, shorten waiting times and increase comfort (Buehler & Pucher, 2012). Digital platforms also facilitate the seamless integration of multimodal services, including PT, bicycle sharing and car sharing, within a unified booking environment (Shaheen & Cohen, 2019b).

International experiences confirm their impact: in London, the contactless Oyster card, introduced in 2003, led to a significant decline in cash handling, improving both operational efficiency and the attractiveness of PT (Ford et al., 2015). In Singapore, integrated digital payment and booking tools form a core component of the country’s *Smart Mobility* strategy, recognised as a benchmark across Asia (LTA Annual Report, 2019).

- **Access: Lower transaction costs and accelerated entry**

Digital ticketing systems lower access barriers by making ticket purchase faster, more flexible and independent of location. Users no longer need to queue at machines or navigate complex fare structures; instead, they can book journeys via mobile devices in real time. Research shows that this particularly increases use among occasional travellers and tourists (Liljamo et al., 2018).

Data from Travel in London reports and from Visa and McKinsey confirm that contactless payment (card + smartphone) became the dominant method for pay-as-you-go travel only a few years after its introduction (Transport for London, 2015; Verma, 2017).

- **Skills: Simplified operation and reduced cognitive barriers**

Digital ticketing apps and smartcards reduce fare complexity and improve usability. Automatic fare calculation and the integration of several transport modes mean that users require less knowledge about timetables or pricing systems (Buehler & Pucher, 2012). The Whim impact study (Ramboll, 2019) shows that Whim users in Helsinki exhibit a significantly higher PT usage share than the general population (73 % vs. 48 %). Integrating multimodal booking within a single app therefore not only shifts trips but also attracts users who would otherwise seldom choose PT.

- **Appropriation: Symbolic modernisation and societal embeddedness**

The digitalisation of ticketing carries symbolic value: it modernises the image of PT and enhances its competitiveness relative to digitally driven services such as ride-hailing or car sharing. Several studies suggest that smartcards and app-based payment systems can strengthen user loyalty, as PT is perceived as more contemporary and technologically advanced. Smartcards also store unique user identities, enabling detailed analyses of mobility patterns (Lizana et al., 2023).

Government measure: Autonomous buses and automated transport systems

Autonomous buses and automated transport systems are regarded as key technologies for the future of PT, offering more efficient resource use and enabling service provision in areas that have previously been underserved. Early pilot projects in Europe, Asia and North America illustrate this potential. In Switzerland,

PostAuto AG trialled autonomous minibuses in Sion from 2016, including deployments in tourist areas (PostBus, 2017). Singapore has conducted several trials involving NTU, Volvo and the Land Transport Authority, with plans to expand services in residential districts (Sustainable Bus, 2019). In China, cities such as Shenzhen have already introduced autonomous buses in regular or pilot operations (Shenzhen Bus, 2024).

However, these technologies remain contested, with debates focusing on high investment costs, regulatory challenges, safety concerns and potential labour market implications.

- **Access: Expanded provision through flexible and cost-efficient services**

Autonomous shuttles offer promising opportunities to extend mobility services in regions where traditional PT is cost-intensive or demand is low. Research shows that such systems improve access to essential services, especially for older adults and individuals with mobility impairments (Nordhoff et al., 2018).

Pilot projects in Norway and other European countries demonstrate their potential as First and Last Mile Solutions. Studies from Stavanger and Kongsberg indicate that automated shuttles strengthen interconnected mobility and can increase overall PT use (Bellone et al., 2021).

- **Skills: New demands and opportunities for technological competence**

Using autonomous shuttles requires trust in the technology and a willingness to learn new interaction modes. As the traditional interaction with drivers disappears, digital access modes, such as app-based booking, automated passenger information and sensor-based boarding processes, become more important.

Empirical studies show that older adults often approach these technologies with initial caution, yet supported pilot trials can produce significant learning and trust-building effects. Research from Europe and North America suggests that supervised test rides increase perceived safety and support stable long-term acceptance of autonomous services (Becker & Axhausen, 2017; Nordhoff et al., 2018; Salonen & Haavisto, 2019). This highlights the importance of competence-building strategies and user-oriented introduction processes.

- **Appropriation: Transforming the image of PT and symbolic adoption**

Autonomous shuttles reshape not only access but also the cultural meaning of PT. They symbolise innovation, modernity and sustainable technological progress, potentially strengthening the societal legitimacy of PT. Research on social acceptance emphasises the importance of public discourse, institutional support and perceived advantages over conventional vehicles (Brell et al., 2021).

At the same time, experts warn that unequal deployment may lead to new socio-spatial divides, with high-tech shuttles concentrated in affluent districts while peripheral or economically weaker areas lag behind (Carrese et al., 2023). The Appropriation dimension is therefore essential for ensuring long-term cultural embedding.

A concise overview of the measures presented, as well as their classification along the three mobility dimensions according to Kaufmann, is provided in Table 4.

Table 4: Pull effects promoting PT

Source: Author's own compilation.

Measure	Access	Skills	Appropriation
Mobility on Demand	Greater Accessibility	App-based Planning Routine	Individual Perception of Public Transport
Digital Guidance and Information Systems	Less Uncertainty	Multimodal Orientation	Greater Sense of Reliability
MaaS Concepts	Seamless Mobility Access	Combination of Various Modes	Multimodality as Everyday Practice
Digital Ticket & Booking Systems	Easier Access	Less Need for Tariff Knowledge	Digital Public Transport as a Standard of Comfort
Autonomous Buses & Automated Systems	Extended Access to Offers	Trust in New Technology	Experience of Innovation and Modernity

2.3.2.2 Push Effects of Digitalisation

Digital technologies can not only enhance the attractiveness of PT but also intentionally diminish the appeal of private car use. Key instruments include digital traffic-management systems, intelligent parking management, city-toll and road-pricing systems, electronic access-restriction controls, and the digital integration of bicycle and micro mobility services. These measures exert a regulatory effect on mobility behaviour by making individual car use more difficult in specific contexts while simultaneously facilitating access to alternative transport modes.

The following subsections classify these instruments according to Kaufmann's (2002) mobility concept and analyse their presumed mechanisms along the dimensions of Access, Skills, and Appropriation.

Government measure: Digital traffic-control systems

Digital traffic-control systems use sensor data, real-time information and algorithmic optimisation to adjust traffic flows dynamically. They include the targeted prioritisation of PT and bicycle traffic, e.g., through adaptive signal timings or dy-

namic lane allocation, as well as the deliberate regulation of car traffic via prolonged red phases or restrictive signal logic. As such, these systems function not only as technical control instruments but as core components of strategic transport policy aimed at decarbonising urban mobility (Papa & Bertolini, 2015).

International case studies illustrate their effectiveness. Copenhagen's digitally coordinated "green waves" for cyclists significantly increased bicycle travel speeds and contributed to a measurable rise in bicycle mode share (Nielsen et al., 2013). Singapore combines comprehensive digital traffic management with its Electronic Road Pricing system, reducing car volumes and effectively stabilising congestion levels (Xie & Olszewski, 2011). Empirical evidence shows that integrated traffic-control measures, especially those involving dynamic pricing or adaptive signals, can reduce emissions and support a systematic shift towards sustainable modes (De Palma & Lindsey, 2011).

- **Access: Prioritisation of PT and bicycle traffic, reduced car flow**

Digital traffic-control systems reshape access to urban space by prioritising sustainable modes and deliberately slowing car traffic. Bus priority measures, adaptive signal control and green waves for bicycles increase travel speeds for the environmental transport modes, while limiting the temporal accessibility of cars. Evidence shows that temporal constraints can be as powerful as monetary measures (Fosgerau & De Palma, 2013). In Copenhagen, prioritising bicycles increased their average travel speed by 10–20 %, while car traffic experienced measurable delays (Nielsen et al., 2013). This shifts the structural balance of power in favour of sustainable mobility and diminishes the relative attractiveness of the car.

- **Skills: Drivers must plan alternative routes**

Digital traffic-control systems also alter the skills required for everyday mobility. Drivers must adjust established routines by planning alternative routes, relying more heavily on digital navigation tools, or considering multimodal options.

Marsden & Reardon (2017) show that such structural interventions trigger learning processes that sharpen awareness of changed mobility conditions and increase openness to alternative modes. In Singapore, the combination of digital control and dynamic road pricing led to observable skill development regarding multimodal travel (Xie & Olszewski, 2011). Thus, these systems not only structure behaviour but also cultivate competencies needed to navigate complex mobility environments.

- **Appropriation: Declining cultural appeal of car travel**

At the appropriation level, digital traffic-control systems shift the cultural valuation of the car. When driving becomes increasingly associated with delays, unreliability and congestion, the car loses its longstanding dominance as a comfortable default mode. Meanwhile, PT and bicycle travel gain symbolic appeal as modern, efficient and urban forms of mobility. Banister (2018) describes this as a cultural transformation in which the car gradually loses its role as a dominant mobility mode. Evidence from Amsterdam and Copenhagen shows that the consistent prioritisation of sustainable modes alters not only behaviour but also urban norms and identities (Oldenziel & Trischler, 2015).

Government measure: Intelligent parking management (digital monitoring, dynamic pricing)

Intelligent parking management includes digital systems that monitor, regulate and dynamically price urban parking spaces. This includes occupancy-based pricing, sensor-supported real-time availability information and automated enforcement via cameras or ground sensors. The goal is to make spontaneous car use less attractive and regulate access to scarce urban space more efficiently. International research, most notably the SFpark programme in San Francisco and cases in Stockholm, shows that dynamic pricing reduces cruising for parking and improves urban space efficiency (Millard-Ball et al., 2014).

- **Access: Reduced spontaneous car use through higher costs and limited availability**

The primary mechanism is the regulation of access to inner-city parking. Higher, demand-responsive fees and reduced availability increase the opportunity costs of car use substantially. Parking costs are among the most effective levers for reducing inner-city car trips (Kelly & Clinch, 2009). SFpark reduced the average time spent searching for a parking place by as much as 43 %, alongside substantial declines in associated traffic (Pierce & Shoup, 2013). As spontaneous car use loses attractiveness, access to city centres becomes more structured around sustainable modes.

- **Skills: Users engage more intensively with PT alternatives**

Intelligent parking management requires drivers to continuously adapt their mobility strategies and thereby develop new competencies. These include the anticipatory planning of trips, the use of digital parking and routing applications, and the active evaluation of alternative transport modes. Such regulatory impulses create a learning environment in which multimodal capabilities emerge: in order to avoid rising parking costs, limited parking availability or stricter enforcement. Users increasingly engage with the functionality and advantages of PT, bicycle travel and sharing services. Empirical studies from London and Stockholm show that restrictive parking management contributes to the long-term stabilisation of multimodal routines by compelling users to question established habits and to acquire and apply alternative mobility options (Börjesson & Eliasson, 2014). As a result, not only individual mobility behaviour changes, but also the underlying competence base of travellers, which is a core prerequisite for sustainable modal-shift processes.

- **Appropriation: The car is increasingly perceived as inefficient**

At the level of appropriation, intelligent parking management contributes to a fundamental re-evaluation of the private car. While the car has traditionally been

regarded as a symbol of freedom, flexibility and spontaneity, increasing parking regulation leads to it being perceived in everyday life as inefficient, costly and inconvenient. This altered experiential reality means that users no longer consider the car a dominant default option but rather a situational one. Long-term observations from European cities such as Zurich and Vienna, which have pursued restrictive parking policies for decades, show that this has fostered a distinct urban mobility culture in which PT and bicycle travel have become the central everyday modes (Buehler et al., 2017b). Thus, parking management not only exerts regulatory influence but also supports a cultural shift: the car gradually loses its symbolic primacy and is increasingly perceived as less compatible with urban lifestyles and sustainability norms.

Government measure: City tolls and digital road-pricing systems

The introduction of city tolls and digital road-pricing systems are among the most effective regulatory interventions to reduce MPT in urban areas. Technically, these systems rely on digitally enabled detection and billing technologies, such as automatic number plate recognition (ANPR), GPS tracking, or transponder devices that allow for precise monitoring, enforcement and dynamic pricing. Their objective is to reduce car traffic in congested city centres through financial steering mechanisms, to alleviate congestion, and decrease environmental burdens in a sustainable manner. International reference cases include the London Congestion Charge (since 2003), the Stockholm Congestion Tax (since 2007), and the Electronic Road Pricing system in Singapore (since 1998). Empirical evidence consistently shows that such systems reduce traffic volumes by 15–30%, alongside notable decreases in emissions, travel times and congestion intensity (Börjesson & Eliasson, 2014).

- **Access: Establishes financial barriers to entering city centres**

City toll systems directly affect access to urban spaces by introducing a financial entry threshold that makes spontaneous car trips into highly congested areas less

attractive. As a result, decisions for or against MPT become more strongly influenced by cost considerations. In London, the introduction of the Congestion Charge led to a reduction of approximately 30% of car trips into the city centre (Leape, 2006). Stockholm experienced a similar effect: entries into the central area fell by around 22%, accompanied by a significant increase in PT demand (Börjesson & Eliasson, 2014). Thus, the city tolls functions, not only as a regulatory mechanism, but as a systemic mobility filter that structurally favours sustainable modes, particularly PT and bicycle travel.

- **Skills: Drivers must take into account complex rules**

The introduction of digital road-pricing systems requires drivers to engage with increased cognitive and planning demands. They must familiarise themselves with geographic charging zones, time and location-dependent tariffs, exemption rules and, occasionally, digital registration or billing systems. These requirements fundamentally alter the logic of modal decision-making. In practice, many users reassess their routines under dynamic pricing and regulatory conditions, evaluating whether a car trip is necessary or whether multimodal alternatives may be more cost-effective or convenient.

Empirical analyses confirm that traffic and pricing regulations, such as road pricing, not only reduce trip volumes but also trigger adaptive behavioural change: users adjust departure times, choose alternative routes or shift to PT and multimodal options (Schönfelder et al., 2007). These developments generate new mobility competencies and support a transition towards more sustainable and flexible mobility strategies.

- **Appropriation: Car use becomes increasingly associated with regulation**

At the level of appropriation, city tolls and road-pricing systems contribute to a cultural redefinition of car travel. While MPT has historically been associated with personal freedom, flexibility and social status, the introduction of toll systems

shifts these symbolic meanings. Car use is becoming increasingly linked to regulation, financial burden and restricted access to urban spaces.

Empirical studies show that these perceptions stabilise after implementation, in particular. In London, initially critical public attitudes transformed within a few years into broad acceptance of the Congestion Charge, which is now widely viewed as a fair and effective tool for reducing congestion and improving environmental quality (Schuitema et al., 2010). Stockholm exhibits a similar cultural transformation: public opposition reversed following the trial phase, as perceived benefits outweighed the symbolic costs of car use (Eliasson, 2014).

Consequently, road-pricing systems operate not only as behavioural regulatory tools but as catalysts for a broader normative shift: the car gradually loses its status as the self-evident default mode of mobility, while PT, bicycle travel and multimodal combinations become increasingly perceived as modern, urban-compatible and socially responsible alternatives.

Government measure: Electronic driving-ban enforcement systems (e.g., low-emission zones with sticker or camera systems)

Electronic driving-ban enforcement systems constitute an essential instrument of contemporary urban and environmental regulation. Their purpose is to restrict access to heavily polluted urban areas, for high-emission vehicles, thereby promoting both public-health and ecological objectives. Technically, these systems rely on digital sticker schemes, automated number-plate recognition, or camera-based detection technologies that immediately register violations and enable automated enforcement.

Across numerous European cities, including more than 50 low-emission zones in the FRG, the Italian *Zone a Traffico Limitato* in Milan and Rome, the French *Crit'Air* system in Paris, and the London Low Emission Zone and Ultra Low Emission Zone, low-emission systems form the regulatory backbone for managing urban traffic volumes.

Scientific studies demonstrate that low-emission zones can measurably improve air quality. Holman et al. (2015) document significant reductions in NO₂ concentrations across European low-emission zones, while Boogaard et al. (2012) empirically show substantial declines in particulate matter levels in Dutch zones. More recent evaluations confirm the effectiveness of large-scale schemes such as the London ultra-low emission zone (ULEZ), which has led to notable reductions in emissions and traffic-related mortality risks.

- **Access: Legally restricts access to urban areas**

Electronic driving-ban enforcement systems directly affect access to urban spaces by denying high-emission vehicles the legal right to enter. In low-emission zones in the FRG, entry is restricted to vehicles displaying a green sticker, while London's ULEZ has imposed considerably stricter emission thresholds since 2019. Empirical studies confirm the steering effects of such access restrictions: in Milan, the introduction of the Zona a Traffico Limitato reduced MPT in the city centre by around 30% and improved air quality measurably (Rotaris et al., 2010). As such, electronic enforcement systems establish a clear regulatory barrier that directs mobility choices structurally towards lower-emission alternatives.

- **Skills: Drivers require additional knowledge about restrictions**

Beyond restricting physical access, digital enforcement systems also alter the cognitive requirements associated with car use. Drivers must increasingly familiarise themselves with regulatory frameworks, sticker or certification rules, and technical retrofitting or inspection requirements in order to make compliant mobility decisions. This shifts the skill demands of everyday mobility: whereas MPT was previously possible without extensive regulatory knowledge, the system now requires additional understanding of digital control mechanisms, environmental regulations and available alternative transport options.

Empirical studies from London and Paris show that such systems prompt users to rethink their mobility patterns, switch more frequently to PT, or retrofit or replace vehicles with low-emission models (Ellison et al., 2013).

- **Appropriation: Establishes digital and low-emission PT as a comfortable, “state-of-the-art” mobility option**

At the level of appropriation, electronic enforcement systems contribute to a cultural shift in how urban mobility is perceived. As MPT becomes increasingly associated with regulation, costs and restricted access, digital and low-emission modes, especially PT, gain social prestige. Research from London shows that digital access systems and real-time information position PT as modern, comfortable and reliable, thereby diminishing the symbolic appeal of the car (Croci, 2016). Similar effects have been observed in Paris, where the tightening of low-emission regulations has strengthened public acceptance of car-sharing and PT services.

Accordingly, driving-ban enforcement systems support not only environmental objectives but also the cultural appropriation of sustainable mobility forms. They shift mobility norms by reframing low-emission transport modes as contemporary and future-oriented, while positioning car use as increasingly regulation-dependent and less self-evident (Manderscheid, 2014).

Government measure: Digitalisation of bicycle and micromobility services (sharing apps, docking systems)

The digitalisation of bicycle and micromobility services constitutes a central governmental intervention to systematically reduce dependence on the MPT in urban areas. Digital platforms, mobile sharing apps and automated docking or free-floating systems provide low-threshold, time and location-independent access to bicycles, e-bicycles, e-scooters and other micromobility services. International systems such as CitiBike in New York, Santander Cycles in London, Nextbike in several cities in the FRG and Mobike in China illustrate the global scale of these

services. Empirical research shows that bicycle and micromobility sharing solutions generate substantial substitution effects for short trips and thus contribute measurably to the modal shift away from the car (Shaheen & Cohen, 2019). Moreover, these systems support the structural integration of sustainable modes into multimodal mobility chains by closing spatial and temporal gaps in PT provision and fostering new mobility routines (Ricci, 2015).

- **Access: Enhances visibility and ease of access to alternative modes**

The digitalisation of bicycle and micromobility services significantly lowers access barriers by providing real-time information on availability, location and booking through mobile applications. Such low-threshold usability enables spontaneous decisions in favour of sustainable modes that were previously often reserved for MPT. Empirical studies demonstrate that digital bicycle-sharing systems significantly reduce the likelihood of car use on short urban trips and trigger immediate modal-shift effects (Buck & Buehler, 2012). Evidence from Paris and Barcelona further confirms that the expansion of digitally supported sharing infrastructures correlates with measurable declines in MPT volumes (O'Brien et al., 2014). As a result, digital access systems not only increase the visibility of sustainable mobility options, but also establish them as realistic and attractive alternatives to the car.

- **Skills: Development of multimodal competences through digital sharing systems**

Using digital bicycle and micromobility services requires users to acquire new mobility-related skills. These include operating mobile applications, using digital payment systems and integrating multimodal route planning into everyday mobility. This expansion of competences facilitates mode-switching and promotes a more multimodal mobility practice. Empirical studies from the United States demonstrate that users of bicycle and e-scooter sharing services, switch modes more frequently and reduce their dependence on private cars (Shaheen et al.,

2014). In Chinese cities, the large-scale introduction of digitally supported platforms such as Mobike or Ofo has fostered a new mobility culture, in which micro-mobility and PT are functionally intertwined (Zhang & Mi, 2018). Digital sharing systems thus operate as learning environments, in which individuals acquire practical capabilities that enable everyday mobility without reliance on a car.

- **Appropriation: Declining automotive dominance and cultural normalisation of sustainable mobility**

At the level of appropriation, the digitalisation of micromobility services contributes significantly to a cultural shift in urban mobility. Whereas, the car, has traditionally symbolised individual freedom and social distinction (Urry, 2004), bicycle and micromobility modes increasingly gain social prestige through digitally supported sharing systems. In European metropolitan areas such as Paris and Barcelona, large-scale bicycle sharing programmes have strengthened the cultural status of the bicycle and entrenched its perception as a modern and urban mode of transport (Midgley, 2011). Empirical evidence from New York likewise shows that systems such as CitiBike enjoy high levels of acceptance, not only among tourists, but also in everyday commuting, thereby enhancing the societal legitimacy of sustainable mobility (Fishman, 2016). Digital accessibility thus shapes not only usage practices but also symbolic meaning: micromobility is perceived as contemporary, efficient and compatible with urban life and therefore as an integral component of a sustainable mobility culture.

A concise overview of the measures discussed and their allocation to the three mobility dimensions according to Kaufmann is presented in Table 5 below.

Table 5: Push effects of digitalisation

Source: Author's own compilation.

Measure	Access	Skills	Appropriation
Digital Traffic Control Systems	Priority for Other Modes	Route Adjustment	Car as less Comfortable Option
Intelligent Parking Space Management	Less Car Availability	Orientation to Alternatives	Car as less Efficient Option
City Congestion Charges and Digital Road Pricing	Financial Barriers to Access	Taking New Rules into Account	Car as less Regulated Option
Electronic Driving Ban Checks	Restricted Access	Knowledge about Restrictions	Alternative Mode as Comfortable Option
Digitalised Bike and Micromobility	Visible, Easily Accessible Alternatives	Multimodal Change	Normalisation of Sustainable Option

2.4 Scientific Classification and Outlook

Chapters 2.1 to 2.3 form the theoretical and conceptual foundation of this thesis and thereby make a substantial contribution to the scholarly grounding of the subsequent empirical analyses. They systematise key explanatory approaches for analysing mobility behaviour and integrate transport-scientific, sociological and technological perspectives into a coherent analytical framework.

At the centre lies the triad of modal split, mode choice and modal shift as an analytical structure for describing, explaining and predicting mobility patterns. The modal split provides an aggregated view of the distribution of transport modes, whereas mode choice examines the individual decision-making logic underpinning these choices. Modal shift, finally, captures the dynamic changes in mobility behaviour over time, which is an increasingly relevant phenomenon in the context of shifting political, technological and social conditions.

This classical transport-scientific typology is expanded by Kaufmann's mobility concept, which conceptualises mobility as a form of social capital. By distinguishing the three dimensions of Access, Skills and Appropriation, the model offers a

deeper, structurally informed perspective on the conditions under which individuals are able to integrate mobility options into their everyday lives. It allows for a differentiated analysis of behaviourally relevant factors while emphasising social disparities and the potential for targeted support.

The role of PT is thereby understood not merely as a functional element within a multimodal mobility system, but as a core component of sustainable and socially inclusive urban development. PT not only reduces emissions and land consumption but also enables social participation for population groups for whom motorised individual mobility is structurally restricted. At the same time, the high degree of subsidisation highlights the need for clear transport and social policy frameworks, particularly with regard to long-term funding structures and questions of justice in access.

Against this backdrop, Chapter 2.3 develops a systematic matrix of government measures, distinguishing political steering instruments across two central fields of action: subsidies and digitalisation. Building on Kaufmann's model, each measure is evaluated according to its effects on Access, Skills and Appropriation and classified according to its push and pull effects. This heuristic systematisation not only provides conceptual structure, but also is an analytical template for assessing the behavioural steering potential of political interventions in the empirical part of the thesis.

Within the field of subsidies, the analysis of exemplary measures, such as fare reductions in PT, extensions of service provision, initiatives to professionalise and improve the attractiveness of the bus driver occupation and investments in barrier-free and high-quality stops, demonstrates that government support must not be conceptualised in isolation, but must be considered complementary. Alongside the dimensions of Access, Skills and Appropriation, it becomes evident that these measures address distinct entry barriers (economic, spatiotemporal, cognitive, physical and cultural) and reinforce each other in their effect. Empirical cases from Tallinn, Luxembourg and the FRG illustrate that such positive subsidies do not merely generate additional demand but can also reshape the symbolic

meaning of public mobility. At the same time, negative subsidies, such as cost-based restrictions, spatial-physical limitations or regulatory interventions, exert a complementary steering effect by systematically decreasing the attractiveness of car use. Only through the combination of push and pull effects can both short-term behavioural change and long-term cultural transformation towards sustainable mobility be achieved. Subsidies thus function not purely as compensatory mechanisms but as integral components of an active transport-transition strategy.

The second central pillar concerns digitalisation, which unfolds a dual steering potential within mobility transition. On the one hand, it generates pull effects, as digital ticketing and booking systems, Mobility-as-a-Service platforms, real-time information and autonomous systems simplify access to PT and culturally elevate it. On the other hand, it creates push effects through digital traffic control, dynamic road pricing and the monitoring of driving bans, which collectively challenge the structural dominance of the car. In light of Kaufmann's mobility concept, digitalisation operates across all three dimensions: it reduces access barriers to sustainable modes (Access), requires and fosters new competences (Skills) and shifts the cultural meanings associated with mobility (Appropriation). International case studies, from Whim in Helsinki to Singapore and Luxembourg, demonstrate that digital measures not only improve functional performance, but also have symbolic and discursive effects by framing sustainable mobility as modern and forward-looking.

Integrating subsidy instruments and digitalisation within a coherent push and pull strategy highlights that an effective modal shift cannot be achieved solely through technological innovation or financial incentives. Rather, it requires a differentiated combination of political measures that dismantle economic, structural and cultural barriers while simultaneously establishing new mobility norms. Subsidies and digitalisation thus constitute essential building blocks of a policy mix that not only sets immediate behavioural impulses but also creates the long-term conditions for a sustainable, inclusive and digitally supported mobility transition.

3 Research Methodology

This dissertation aims to provide a comprehensive analysis of innovative mobility approaches. To achieve this, a mixed-methods research design combining quantitative (Section 3.1) and qualitative (Section 3.2) methodologies was employed in order to capture the mechanisms through which different factors influence mobility behaviour.

Studies 1 to 3 draw on quantitative survey data examining service expansions, the introduction of a climate ticket, and the impact of fuel prices. These surveys provide empirical insights into user behaviour and preferences. Complementing this, Studies 4 to 6 employ qualitative interviews focusing on digital bus stops and autonomous buses from both user and provider perspectives. This qualitative data offer deeper insights into the technological and organisational challenges faced by mobility providers.

Figure 9 presents an overview of the methodologies applied.

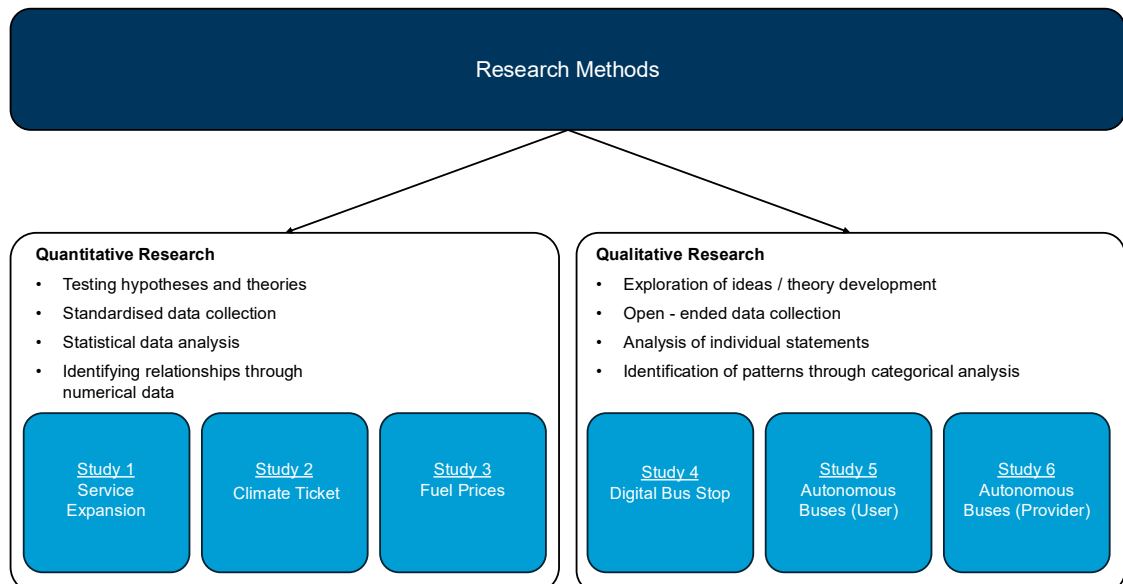


Figure 9: Research Methods

Source: Author's own compilation.

Subsequently, the individual research questions are presented, followed by the identification of the research gap and the research objectives (see Section 3.3).

3.1 Quantitative Research

The studies on service expansion, the climate ticket, and the effects of mineral oil prices necessitate the use of quantitative research methods, in order to analyse key determinants of mobility behaviour and the acceptance of sustainable modes of transport. Structured surveys were employed to obtain systematic data that allow for the identification of correlations between the variables under investigation, as well as the assessment of causal relationships. Innovative mobility concepts, such as the introduction of a climate ticket, are examined, not only with regard to their immediate impact on the use of sustainable transport modes, but also concerning long-term behavioural changes and their strategic relevance for sustainable transport governance.

The methodological approach is characterised by a precise study design that ensures both the validity and reliability of the collected data (Washington et al., 2020). The use of standardised questionnaires enables the systematic measurement of relevant influencing factors, including price sensitivity and individual preferences, thereby providing a robust foundation for inferential statistical analyses. Procedures such as variance and regression analysis are applied to quantitatively assess the effects of specific pricing mechanisms, such as the climate ticket, in comparison with fluctuations in mineral oil prices (Wang et al., 2020). These statistical techniques generate essential insights into the interplay between economic incentives and behavioural decision-making, contributing to a deeper understanding of underlying dynamics (McFadden, 2021).

The insights gained form the basis for the development of targeted recommendations aimed at optimising mobility services. They take into account both economic incentives and technological innovations, thus enabling the design of sustainable and future-oriented PT strategies (Agresti & Finlay, 2009). The empirical

evidence regarding the effectiveness of service expansions and pricing mechanisms provides important contributions to evidence-based transport policy, which integrates economic efficiency with ecological sustainability (Fahrmeir et al., 2016).

Quantitative research, thereby, offers a structured and methodologically rigorous framework for addressing scientific questions. Through robust study designs, validated survey instruments, and advanced statistical procedures, it generates objective and generalisable findings (Backhaus et al., 2016). The ability to identify and quantify numerical relationships with precision is fundamental for the advancement of scientific theory and supports the development of well-founded statements on complex phenomena (Eid et al., 2015). Quantitative methods thus make an essential contribution to the progression of scientific knowledge and the design of innovative mobility concepts.

3.2 Qualitative Research

The studies on the introduction of digital bus stops and the use of autonomous buses, from both user and provider perspectives, and with the aim of analysing technological and organisational dimensions of PT, require the application of robust qualitative research methods. Qualitative approaches make it possible to gain in-depth insights into the complex dynamics and perceptions associated with the implementation of innovative mobility solutions. In particular, expert interviews provide valuable information on the experiences, opinions and assessments of relevant stakeholders, thereby contributing to the development of well-founded theories and policy recommendations (Flick, 2022).

The exploratory character of qualitative research makes it particularly suitable for understanding emerging technologies such as autonomous buses in their social and organisational dimensions. In contrast to standardised quantitative methods, qualitative research employs a flexible design that adapts to the specific context of the phenomena under investigation. Narrative interviews and open-ended questioning serve as central instruments for capturing the subjective experiences

and individual perspectives of participants in a detailed and nuanced manner (Denzin & Lincoln, 2011).

The study design is characterised by a high degree of adaptability, allowing researchers to follow up on unexpected themes that may arise during the research process. This is especially relevant when technologies are still in a pilot or trial phase and their societal and organisational implications remain largely unexplored. Owing to the open and iterative nature of qualitative data collection, researchers are able to thoroughly examine key topics such as user acceptance, technical challenges and organisational integration (Patton, 2014).

The analysis of the collected data follows a multi-stage coding process in which recurring themes and patterns are identified and categorised. This methodological structure enables researchers to reveal implicit meanings and interrelationships and to transfer them to the specific application context. For example, statements relating to uncertainties in the use of autonomous buses may be condensed into categories such as technical trust or safety concerns, thereby supporting the development of targeted intervention strategies (Strauss & Corbin, 1998).

The findings of the qualitative studies make a substantial contribution to understanding the technological and organisational dimensions of innovative mobility concepts. They provide a foundation for the development of practice-oriented strategies that address both user needs and provider requirements. By revealing the nuances of human interaction and perception, qualitative research plays an indispensable role in the scientific examination and continued advancement of future-oriented transport solutions (Creswell & Poth, 2016).

Through the combination of exploratory data collection, detailed analytical procedures and context-sensitive theory development, qualitative research offers an essential approach for addressing the complex challenges and opportunities associated with the mobility transition. As such, it contributes not only to knowledge

generation, but also to the formulation of evidence-based solutions for a sustainable mobility future (Merriam & Tisdell, 2015).

3.3 Research Gap, Objectives and Research Questions

This dissertation examines how innovative mobility concepts, economic incentive mechanisms and technological progress influence mobility behaviour and the acceptance of sustainable modes of transport. The focus is on analysing the interactions between these factors and assessing their implications for the future design of a low-emission, socially inclusive PT system in Germany. Figure 10 presents an overview of the research questions addressed in each study and illustrates how they connect to the overarching research question guiding this dissertation.

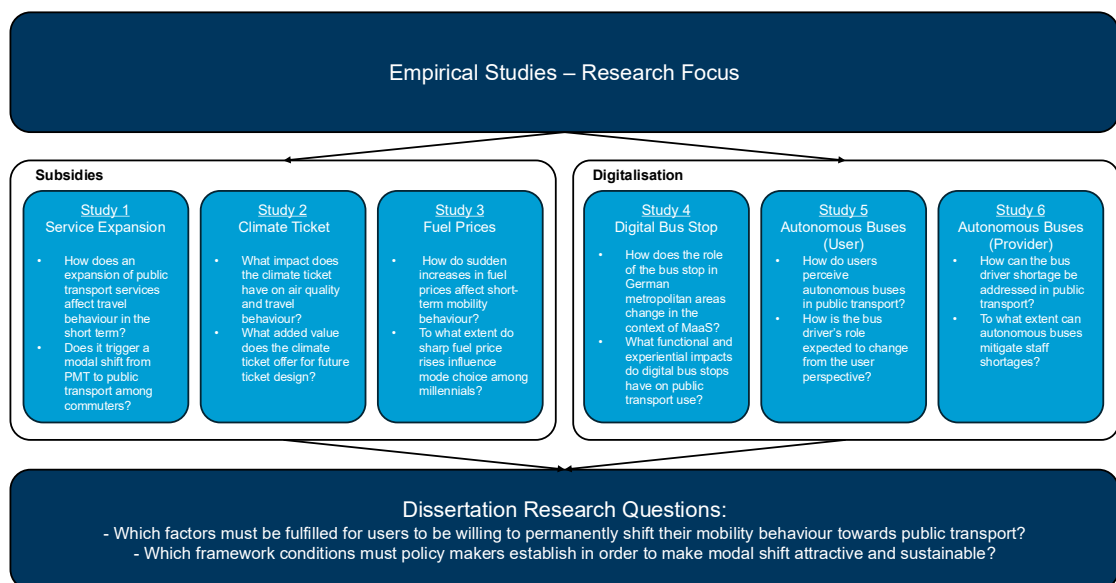


Figure 10: Overview of Research Questions

Source: Author's own compilation.

The studies conducted provide insights into which subsidy and digitalisation-based approaches support modal shift and where limitations exist that require

further research. To address the identified research gap, the findings of the individual studies were synthesised into a broader analytical framework, from which overarching conclusions were derived. The following sections summarise the core studies and their specific research questions.

Study 1 investigated the effects of expanding PT supply through the introduction of the climate ticket. The analysis focused particularly on whether this expansion influences short-term mobility routines and triggers a modal shift from private car use towards PT among commuters.

Study 2 examined user perceptions and evaluations of the climate ticket. Central questions included how a shift in the modal split towards more environmentally and climate-friendly PT use can be promoted, and what contribution the Bonn climate ticket makes to air quality improvements and mobility behaviour. Furthermore, the study analysed the added value of the ticket for future fare product design and the relationship between users' attitudes, skills and access conditions.

Study 3, situated within the domain of subsidies, analysed the consequences of an acute fuel price shock on mobility behaviour. Particular attention was paid to the Millennial cohort, which represents the largest share of the working population and therefore plays a central role in shaping future mobility. The research question centred on how the mode choices of this age group changed following the price increase compared with the overall sample.

Study 4 examined the transformation of bus stops in German metropolitan areas resulting from the integration of MaaS concepts. This study is particularly relevant for the future development of digitally supported and intermodally connected PT infrastructures.

As AVs become increasingly relevant to PT, **Study 5** explored the future professional role of bus drivers in the context of autonomous driving technologies. The

study analysed how the role may evolve and whether Millennials can imagine autonomous buses becoming an established part of PT operations.

Study 6 approached autonomous mobility from the employer perspective, focusing on HR and recruitment experts in transport companies. Given the ongoing shortage of qualified bus drivers, the study examined which strategies might alleviate this issue and whether autonomous bus systems could represent a viable solution for PT providers.

II EMPIRICAL ANALYSIS

4 Studies on (Non)-Subsidisation

In the theoretical section, a matrix of relevant measures was developed that systematises both subsidisation and non-subsidisation as policy instruments. Building on this analytical framework, three empirical studies were conducted, each examining a central dimension of these measures. Study 1 analyses an exemplary expansion of PT services using the case of Bonn (Section 4.1), while Study 2 investigates the introduction of the climate ticket (Section 4.2) as an instrument for increasing price attractiveness. Complementing these, Study 3 examines the effects of the non-subsidisation of mineral oil prices (Section 4.3) in the context of the substantial price increases following the Ukraine conflict.

As outlined in Chapter 2.3, these measures cannot be viewed in isolation; rather, their impact is displayed in a network of interdependencies and complex interactions. Accordingly, the three studies do not provide a selective picture of individual measures. Instead, they capture the interplay of measures within the dynamic configuration of pull effects (enhancing the attractiveness of PT) and push effects (reducing the relative attractiveness of private car use). This integrated perspective is essential for understanding how subsidisation and non-subsidisation operate collectively to influence mobility behaviour and support modal shift processes.

4.1 Study 1: Service Expansion

Study 1 examines the expansion of PT services in Bonn and evaluates the theoretically anticipated effects derived from Kaufmann's model. On the Access dimension, improved spatial and temporal availability reduces key barriers to PT use. Concerning Skills, shorter waiting times significantly decrease the planning effort required from users. Finally, in terms of Appropriation, PT is increasingly perceived as a fully viable and attractive alternative to private car use (PCU).

These theoretically derived assumptions form the basis of the empirical investigation.

The research design, data collection and statistical analysis are presented in Section 4.1.1, while the key results and their interpretation are discussed in Section 4.1.2. Methodological constraints and limitations are critically reflected in Section 4.1.3.

4.1.1 Research Design

The expansion of PT services in the Bonn–Rhein-Sieg district forms part of the Lead City funding programme. The objective of this study is to determine the short-term effects of the service enhancement on mobility behaviour and to assess whether the measure generates a modal shift from PMT towards PT among commuters.

PT in Germany is, by international comparison, highly successful and widely used (Buehler & Pucher, 2012). In Bonn, Stadtwerke Bonn, a 100% subsidiary of the Federal City of Bonn, is responsible for PT operations. Service frequencies and the overall scope of mobility provision are defined in close coordination with political decision-makers in the city council. PT primarily serves the entire Bonn urban area, but also extends into parts of the surrounding Rhein-Sieg district and the neighbouring Cologne region.

Bonn's underground network consists of two main lines and one branch line, complemented by tram services, running above ground. In addition, a comprehensive bus network connects all outlying districts with the city centre. The bus fleet comprises approximately 200 vehicles, predominantly mild hybrid or fully electric models. As in other major cities, the gradual conversion to low-emission vehicles aims to contribute to sustainable environmental improvements (Jahn et al., 2020).

The increase in PT attractiveness under the Lead City project was achieved through four key measures:

1. Shorter waiting times on major lines during weekdays for both buses and trams,
2. Expanded timetable services at weekends,
3. Improved interconnections between peripheral areas, and
4. Enhanced links between peripheral districts and the city centre through newly established routes.

The high volume of PMT in central urban areas leads to congestion and is a primary cause of excessive NO₂ levels along major traffic corridors. A modal shift from PMT to PT is therefore essential to achieving sustainability targets (Urbanek, 2021). In Bonn, this initial pilot project was subsidised with €37.6 million until the end of 2020. The measures sought to achieve substantial and lasting environmental improvements and to reduce NO₂ concentration levels. The principal intervention of the Lead City project was the expansion of PT services, including increased frequencies and improved accessibility, particularly for suburban and rural areas through the creation of additional stops.

To address the research questions, an online survey was conducted. Following Kaufmann's theoretical framework, the results were categorised according to the three principal dimensions - Access, Skills and Appropriation - and supplemented with additional subcategories. Table 6 presents the factors relevant to the service expansion study.

Table 6: Mobility concept

Source: Author's own compilation.

Access	Skills	Appropriation
Information on the supply	Educational level	Assessment of change
Size of the household	Age	Experience with public transportation
Car availability in the household	Gender	Evaluation Lead City Bonn
Residential situation		

In line with Kaufmann's theoretical framework, we identified the predictor variables relevant to our study and categorised them into the three dimensions Access, Skills and Appropriation, as shown in Table 6. The selection of relevant variables was guided by the research context and forms the basis for answering the research question. To this end, we carried out a logistic regression analysis using the nominal variable avoidance of car trips as the dependent variable. The predictor variables in the study are categorical. The results of the logistic regression are presented using reference categories to facilitate interpretation, and their necessity and influence on the study are discussed.

Data collection

The empirical basis of the investigation is a citizen survey evaluating the Lead City mobility measure. This survey provides information on the overall effects of the intervention. For this research, a written, quantitative online survey was conducted to evaluate the impact of changes in PT service provision in the city of Bonn and in parts of the Rhein-Sieg district.

In total, 264,740 households in the city of Bonn and the relevant neighbouring municipalities were contacted by post and invited to participate in the online survey. The survey was carried out in August and September 2019. A total of 14,296 individuals – corresponding to 5.4% of the addressed households – took part in the survey. The data from this full sample ($N = 14,296$) were analysed statistically in order to draw conclusions about the effectiveness of the measure and the associated changes in mobility behaviour in the region.

As the responses displayed distortions in the age structure of participants, a random sample of 2,000 cases was drawn for further statistical analysis (Table 7). This sample reflects the average demographic age profile of the Bonn population and was generated using a random selection procedure.

Table 7: Demographics of survey participants

Source: Author's own compilation.

Characteristic	Number	Percent
Survey participants by age		
up to 18 years:	347	2.5%
19-25 years:	1,068	7.7%
26-45 years:	4,711	33.8%
46-60 years:	4,456	32.0%
61 and older:	3,344	24.0%
Gender		
Women:	6,760	48.0%
Men:	7,310	52.0%
Place of residence		
Bonn:	9,339	66.7%
Adjacent municipalities:	4,673	33.3%

The total population comprises N = 14,296 respondents. Deviations from this total are attributable to “don’t know” responses or invalid entries. Accordingly, for the predictor variables age (370 cases), gender (226 cases) and place of residence (284 cases), unusable responses were recorded. The percentages refer to the valid responses for each predictor and always add up to 100%.

Statistical data analysis

Prior to the main data analysis, the survey data were carefully cleaned and prepared to ensure the quality and reliability of the results. For the initial examination and to obtain an overview of the dataset, fundamental methods of descriptive statistics were applied, including the calculation of frequencies and mean values. As part of the exploratory data analysis, the dataset was systematically reviewed to identify potentially unusual observations, extreme values, missing data or other irregularities (Döring et al., 2016).

To answer the research question, inferential statistical methods were employed in addition to descriptive statistics. These methods enable conclusions about the population to be drawn based on the results of the sample (Eid et al., 2017).

Correlation analyses were also conducted to examine relationships between the relevant variables.

For the statistical assessment of the research question, logistic regression analyses were prepared and executed using a statistical package for social sciences (SPSS) 27. The study examined the relationship between multiple predictors from the three categories Access, Skills and Appropriation, together with PT usage as independent variables, and the binary dependent variable avoidance of car trips.

The output of the Omnibus Test of Model Coefficients provides the result of the likelihood ratio test, expressed through the chi-square statistic and the associated significance level (p-value). The Model Summary includes quality measures such as the 2 log-likelihood, the Cox & Snell R^2 , and the modified Nagelkerke pseudo R^2 , the latter indicating how much variance in the dependent variable (avoidance of car trips) is explained by the independent variables across the four categories (Backhaus et al., 2018). To assess the magnitude of this explained variance, the effect size was calculated based on Cohen's (1992) formula.

$$f^2 = \frac{R^2}{1 - R^2}$$

The coefficient table contains information on the model and the independent variables, including the estimated regression coefficients, the corresponding standard errors, the Wald test, odds ratios (OR) and the 95% confidence intervals (CI) (Cohen, 1992). The results of the described analysis are presented in Table 8, and the interpretation of the significant p-values is discussed in the accompanying text.

4.1.2 Findings and Discussion

4.1.2.1 Effect of measure

The objective of the effectiveness assessment was to determine whether respondents who indicated on the scale that they used PT “somewhat more frequently” had, as a consequence, reduced their car trips, thereby contributing to a partial relief of the critical pollution corridors Belderberg and Reuterstraße. This applied to 2,948 individuals. Excluding “don’t know” responses, nearly four out of five respondents reported that they had refrained from car use due to an increased utilisation of PT. This corresponds to 2,413 individuals, representing almost 17% of the entire sample. A closer examination of this subset yields further insights: 854 of the 2,413 respondents stated that the trips they avoided would have involved the aforementioned high-exposure routes, equivalent to 6% of the full sample. Moreover, 604 respondents reported refraining from car use more than five times per week. However, these individuals had already been PT users before the measure (45 persons), had no car available in their household (32 persons), or made comparatively frequent use of a subsidised job ticket (29 persons).

Based on the research question, it can be concluded that the service expansion resulted in a modal shift. Car trips were reduced, and a measurable alleviation of traffic in Bonn’s city centre as well as along the two critical corridors was achieved. This key finding into the modal shift achieved, aligns with the overall assessment of the intervention and with the results of prior studies (Carroll et al., 2019; Giuffrida et al., 2021).

A total of 6,890 respondents (62.5%) rated the service expansion as “rather good” or “very good” on a five-point Likert scale. In contrast, 870 evaluated it as “rather poor” and 260 as “very poor”. Together with neutral responses, these figures indicate that 33.8% of participants expressed negative or indifferent evaluations. The resulting mean score of 3.52 lies within the neutral range.

Overall, the results reflect a positive general sentiment. The expanded service was perceived as making PT more attractive. However, the analysis of the sample also indicates that, despite the positively perceived service improvements, the ticket price level in Bonn and the Rhein-Sieg district was widely considered too high. For a sustained modal shift, the service offering must therefore be accompanied by financially attractive fare structures.

Applying Kaufmann's mobility framework and the reference categories developed for this study allows the results of the logistic regression to be systematically assigned to the three core dimensions Access, Skills and Appropriation. This structuring provides additional explanatory value and supports a more nuanced interpretation of the findings. The explanations for the observed differences in individual travel behaviour are derived from the dataset, enabling preliminary forecasts regarding future mobility behaviour under the enhanced PT service provision.

4.1.2.2 Logistic Regression Analysis

The logistic regression analysis comprises, in addition to the three models Access, Skills and Appropriation according to Kaufmann, a fourth block capturing transport mode use. The results present a combined model in which all four blocks were integrated using the variable entry method in SPSS. The legend of Table 8 reports the chi-square statistic, the model significance and the coefficient of determination. It becomes evident that with each additional model and the inclusion of further independent variables, the explained variance increases. At the same time, the number of statistically significant variables declines substantially.

Overall, the complete model demonstrates a strong relationship between the dependent variable (avoidance of MIT use) and the independent variables, with a comparatively high explained variance of 27.3%. Potential spurious significances were minimised by the relatively high R^2 value. Following Cohen's (1992) approach to effect size calculation, we examined our R^2 of 0.273. The resulting effect size of 0.376 indicates a strong effect for the regression model.

Table 8: Results of the logistic regression analysis

Source: Author's own compilation.

Model	Variable	b	S.E.	Wald	p	OR	CI .025	CI .975
Access	Household_2	-,083	,210	0,157		0,920	0,610	1,388
	Household_3	,283	,272	1,079		1,327	0,778	2,262
	Household_4	-,090	,315	0,081		0,914	0,493	1,696
	Availability_occasional	,021	,270	0,006		1,021	0,602	1,733
	Availability_almost_always	,940	,243	15,000	***	2,559	1,591	4,118
	Evaluation information expansion of services	-,026	,087	0,090		0,974	0,822	1,155
Skill	Education_main_school	,458	1,110	0,170		1,581	0,179	13,932
	Education_secondary_school	,481	,934	0,266		1,618	0,260	10,086
	Education_high_school	-,019	,878	0,000		0,981	0,176	5,480
	Education_university	-,065	,876	0,005		0,937	0,168	5,214
	Education_other	-,555	1,073	0,268		0,574	0,070	4,700
	Residence_Bonn	-,583	,248	5,518	*	0,558	0,343	0,908
	Gender	-,062	,172	0,130		0,940	0,671	1,317
	Age	,018	,006	9,741	**	1,018	1,007	1,029
Appropriation		,804	,258	9,694	**	2,234	1,347	3,705
	Change_assessment_more_no							
	Change-assessment_more_yes	1,836	,291	39,908	***	6,271	3,548	11,086
		2,287	,345	43,923	***	9,845	5,006	19,362
	Change_assessment_yes							
	Comparison: Public transport current/before	,220	,072	9,418	**	1,246	1,083	1,434
Modal Shift	Evaluation Lead City Bonn	,055	,070	0,633		1,057	0,922	1,212
	Car_less_1_month	-,592	,317	3,484		0,553	0,297	1,030
	Car_1_to_3_month	,299	,264	1,284		1,349	0,804	2,263
	Car_1_to_3_week	,434	,249	3,033		1,544	0,947	2,516
	Car_daily	,773	,310	6,208	*	2,167	1,179	3,982
		,126	,785	0,026		1,134	0,244	5,282
	PT_less_1_month							
		1,304	,759	2,947		3,683	0,831	16,317
	PT_1_to_3_month							
		1,160	,748	2,408		3,191	0,737	13,814
	PT_1_to_3_week							
		1,226	,749	2,679		3,408	0,785	14,800
	PT_daily							
		,237	,229	1,067		1,267	0,809	1,986
	car_passenger_less_1_month							
		,353	,226	2,434		1,423	0,914	2,216
	car_passenger_1_to_3_month							
		,560	,280	4,016	*	1,751	1,012	3,029
	car_passenger_1_to_3_week							
		,443	,540	0,672		1,558	0,540	4,492
	car_passenger_daily							
		,424	,373	1,294		1,528	0,736	3,172
	Bicycle_less_1_month							
		-,011	,294	0,001		0,990	0,556	1,761
	Bicycle_1_to_3_month							
		-,080	,265	0,091		0,923	0,549	1,552
	Bicycle_1_to_3_week							
		-,116	,257	0,205		0,890	0,538	1,473

*p<.05, **p<.01, ***p<.001

Cumulative values as a large model

Model 1: $X^2(6) = 44.219$, $p < .001$, $R^2 = .058$

Model 2: $X^2(8) = 31.070$, $p < .001$, $R^2 = .097$

Model 3: $X^2(5) = 110.189$, $p < .001$, $R^2 = .229$

Model 4: $X^2(16) = 38.717$, $p < .001$, $R^2 = .273$

The interpretation of the logistic regression results is undertaken and discussed within the respective reference categories of the individual variables of our theoretical model, according to Kaufmann.

4.1.2.3 Access

In this study, the dimension of Access refers to the contextual conditions that enable individuals to make use of mobility services. Access to comprehensive information on the new PT offer was provided through an extensive marketing campaign aimed at raising awareness of the benefits of PT among residents of Bonn and the surrounding region. The actual use of the transport services, in turn, depends on factors such as the accessibility of the network. Additional access-related factors include household size, the corresponding number of available cars, and place of residence.

Information on the service expansion. The logistic regression results initially indicated a significant effect of the independent, variable information assessment on the service expansion within the Access model. However, this relationship disappeared once the categories Skills, Appropriation and use of transport modes were added block-wise in the regression. Thus, a positive evaluation of the information campaign does not translate into a higher likelihood of avoiding car use.

The expansion of the service offer was accompanied by an information campaign. Media outlets in Bonn and neighbouring municipalities reported widely on the measure, which was also promoted through various communication channels. Approximately 79% of respondents reported having received information on the expanded PT offer, and 46.5% expressed satisfaction or high satisfaction with

the campaign. Direct mailings constituted the most important source of information. A media resonance analysis confirmed the broad reach of the campaign: 66.7% of participants stated that they were informed via direct mail, and many indicated that this was their sole source of information.

Additional communication channels also played a role: local newspapers (4,571 mentions), radio reports (1,915), television reports (1,528), social networks (1,441), the internet (1,476) and advertising within the PT environment (posters at stops, in buses and trams). The study revealed heterogeneous patterns of media perception across age groups.

Both the perception and the evaluation of the information campaign as well as the prior knowledge of respondents strongly correlate with their attitude towards PT in Bonn. Participants who evaluated the PT system as rather attractive perceived the information more frequently, rated the campaign, and the direct mailing in particular, more positively, and were generally familiar with the main contents of the programme even before the survey.

Household size. Household size did not show a significant effect on car avoidance in the logistic regression. However, a Kendall's tau-b correlation analysis revealed a positive association between household size, car availability and transport mode options.

According to the Federal Statistical Office, single-person and couples make up the majority of households in Bonn and the Rhein-Sieg district. This is also reflected in our sample, where these groups account for almost 56% of respondents.

There is also a relationship between household size and place of residence: urban living is particularly attractive for couples without children, and many single respondents prefer central locations and choose to forego car ownership. Families, by contrast, tend to live in suburban or peripheral areas, largely due to financial considerations, housing needs and lifestyle preferences. Larger households

also tend to have more than one car. The number of cars correlates with total household wealth, which is often higher in households where adult children still live with their parents. At the same time, such household structures often create multiple drivers and, given suburban geography, a stronger reliance on PMT and a reduced use of PT. Higher household income is thus associated with greater mobility opportunities (Dargay, 2007).

Car availability in the household. Respondents with low car availability did not show a significant effect on car avoidance. Their trips appear difficult to replace by PT due to factors such as residential location, connections to the PT network or the time of travel. A strong, significant relationship was observed for high car availability: the odds ratio of 2.559 indicates that the likelihood of reducing car trips increases by 155.9%.

Since the expansion of the service offer was temporary, it is not expected that car availability itself changed. Car ownership represents a long-term commitment to PMT and can only be reduced if PT becomes permanently attractive. Our study indicates that higher car availability is associated with more car trips, but also with a greater probability of reducing those trips when attractive PT alternatives exist.

Research has long confirmed the relevance of car availability. Daly et al. (1977) showed that socio-economic variables strongly influence car ownership, while PT cost and convenience affect mode choice. Cools et al. (2016) found that car availability is decisive for individuals and that free PT can promote mode shift. In Greater Copenhagen, PT expansions reduced car ownership (Mulalic & Rouwendal, 2020). Higher population density, proximity to PT and fewer cars per household correlate with lower levels of car use (Buehler & Pucher, 2012).

In our survey, 93.6% of respondents held a driving licence, and 70.2% of them had unrestricted access to their own car or to car-sharing vehicles. Around 30% reported only occasional or no access to a car. In total, 79.6% of households had access to at least one car, and almost 30% had access to two or more cars. The more cars a household owns, the more likely it is that car travel will be preferred

to PT (Dargay, 2007). Beirão and Cabral (2007) showed that attitudes towards PT significantly influence everyday mobility and car use.

Company cars are an important factor: they provide a “mobility flat rate” for long-distance commuting at low personal cost. Employees who prefer driving tend to have company cars. In our sample, roughly one in ten respondents had access to a company car. Users of company cars are generally difficult to motivate to shift to PT, even when it is offered free of charge (De Witte et al., 2008).

Place of residence (district). The logistic regression shows a significant negative effect of living in Bonn on car avoidance (OR = 0.558). Thus, the likelihood of avoiding car trips is 44.2% lower for respondents living in Bonn compared to those living in the surrounding municipalities.

This indicates that urban residents often have shorter travel distances and readily available multimodal options, while residents of neighbouring municipalities were more likely to reduce car trips. Place of residence thus strongly influences the feasibility of using different transport modes. These findings are consistent with European studies (Chatterjee et al., 2020).

The service expansion did not affect place of residence; however, 66.7% of respondents live in Bonn and 33% in the surrounding municipalities. While housing costs are high across the region, they remain lower in the neighbouring municipalities. Consequently, urban areas offer better PT access and shorter travel distances, while rural areas provide fewer alternatives and longer commutes. The expansion of PT thus created new opportunities for commuters living outside Bonn to reach the city centre without using a car.

The importance of accessibility for sustainable transport systems is well documented (Saghapour et al., 2016). Within Bonn, respondents were distributed across the city’s four administrative districts: Bonn-City (47.5%), Bad Godesberg (18.7%), Beuel (21.4%) and Hardtberg (8.6%). Differences in rental and property

prices contribute to socio-economic disparities in car ownership. In lower-income districts, fewer households own cars and PT use is more commonly relied upon.

4.1.2.4 Skills

An individual's mobility-related skills are shaped by past mobility experiences, the knowledge they have accumulated, and their attitudes towards the available modes of transport. Decisions regarding mode choice must align with an individual's lifestyle and life stage. In the household survey, skills were operationalised, analogous to the study by De Witte (2008) in Brussels, via indicators such as employment status, educational level, age and gender (De Witte et al., 2008).

Employment status. The service expansion has no direct influence on the employment status of respondents. In our sample, approximately 72% (10,151 individuals) were in employment, of whom 7,253 worked full-time and 2,274 part-time. In addition, the sample includes 270 interns, 20 job seekers, and 309 respondents in other forms of employment, each representing only a small proportion.

The remaining 28% of respondents not in employment consisted mainly of retirees, students, and homemakers. Students in Bonn and the surrounding region typically have access to free PT across North Rhine-Westphalia through their student ID, including the option to bring a companion in the evening or at weekends. Socially disadvantaged groups such as retirees or unemployed persons benefit from discounted social tickets, which serve to facilitate affordable PT access. Furthermore, many employers in Bonn offer job tickets as part of employer branding strategies to increase their competitive attractiveness.

Educational level. Within the skills model, the statistical analysis shows no significant relationship between educational level and the avoidance of private car trips. Nevertheless, the variable contributes meaningfully to the explanatory power of the model and is therefore essential for its overall interpretive quality.

Education is closely linked to lifestyle and thus to mobility choices. De Witte (2008) showed that commuters in Brussels with lower educational levels were more likely to use the train than those with higher levels of education (De Witte et al., 2008). This corresponds with findings from other studies indicating that highly-educated individuals frequently occupy positions of responsibility with tight schedules. For this group, time is often the dominant factor, making the private car the preferred mobility option due to its flexibility, regardless of monetary or non-monetary considerations (Pickery, 2005).

Our survey reveals that Bonn and the surrounding region are characterised by a high proportion of highly qualified professionals. Many work for large companies such as Deutsche Post AG or Deutsche Telekom AG, which commonly provide company cars, effectively offering a mobility flat rate for PMT at the employer's expense. This group predominantly relies on PMT and shows relatively limited interest in PT.

In our sample, nearly 58% hold a university or university of applied sciences degree, followed by 23.6% with A-levels. Fewer than 19% reported having no qualification, a vocational certificate, or lower secondary qualifications. Contrary to earlier research from Brussels and other European contexts, our results confirm that education is not a decisive factor for reducing private car trips in Bonn and its surrounding municipalities.

Gender. Gender shows no significant influence on the avoidance of private car trips. Germany exhibits a slight female-majority population due to higher female life expectancy. In Bonn, the population of 332,769 consists of 160,753 men and 172,016 women. Our sample reverses this distribution slightly, with 52.0% male and 48.0% female respondents.

International findings, however, demonstrate a more nuanced picture. A Japanese study found gender-specific variability in PT travel patterns, with women showing higher intra-personal variability (Liu et al., 2013). In India, gender differ-

ences in mobility are strongly shaped by socio-economic conditions: women predominantly walk or use PT as their socio-economic status increases, while men more commonly rely on motorised modes (Saigal et al., 2021). Research in Delhi by Jain & Campbell (2022) further highlights substantial gender-specific mobility differences.

4.1.2.5 Appropriation

Appropriation refers to the behavioural patterns that individuals derive from the mobility options available to them. In this study, a high level of public awareness of the service expansion was achieved through targeted communication campaigns. Participants not only received extensive information but also had the physical opportunity to integrate different transport options into their daily routines, either by using the PT network, or by relying on private cars available within their household. Access, combined with individual skills, determines actual travel behaviour and the utilisation of mobility services.

Experience with PT. The statistical analysis within the appropriation model shows that individuals' assessment of the changes brought about by the service expansion has a significant influence on the avoidance of private car trips. Of particular interest are the odds ratios associated with a generally positive assessment: a "rather positive" evaluation yields an OR of 6.271, representing more than a five-fold increase in the likelihood of reducing private car use. A "positive" assessment results in an OR of 9.845, meaning that the probability of avoiding private car trips increases by 884.5%.

The service expansion enabled users to gain new experiences with PT, and the significant regression results for the independent variable comparing "PT earlier vs. today" confirm that a stronger use of PT and the avoidance of private car trips are likely behavioural outcomes. Respondents' general experiences with PT in Bonn and the Rhein-Sieg District, however, present a heterogeneous picture: while 33.9% found PT attractive and satisfactory, 26.7% perceived it as unattractive. The mean evaluation of 3.11 lies in the neutral range.

A closer look at user groups shows that employed respondents rated their PT experience considerably more negatively than those not in employment. Among the 10,151 employed participants, 67.8% did not describe PT as explicitly attractive, whereas 41.8% of non-employed respondents perceived it as attractive. These differences are largely attributable to the timing of PT usage: peak-hour travel, especially in the morning and evening, is characterised by delays and high occupancy, which strongly influences perceived service quality.

Travel habits. The statistical analysis initially indicated a significant relationship between the evaluation of the Lead City measure and private car avoidance. However, this effect did not hold once all independent variables were included in the full model. The variable “PT earlier vs. today” remained significant, with an OR of 1.246, indicating a 24.6% increase in the likelihood of avoiding private car trips.

Travel habits are shaped by regular and recurring mobility decisions. The daily commute, for example, is not reassessed every day but is typically based on a long-term weighing of advantages and disadvantages (De Witte et al., 2008). Habitual patterns can change, but usually only in response to substantial positive or negative impacts on the individual. In the case of the service expansion, a modal shift towards PT was observed. Since the expansion was temporary, it remains to be seen whether this behavioural change will persist once the measure ends. Incentives have been shown to be effective in altering travel habits (Ben-Elia & Ettema, 2011).

However, sustainable effects, as intended by the campaign, were viewed critically by respondents. Although many believed that a permanent improvement in the PT offer would increase the willingness to switch modes, a total of 5,376 participants reported that no long-term behavioural change towards PT should be expected after the project ended. Excluding the 663 respondents who answered “don’t know/undecided”, 38% expressed critical views. These were primarily attributed to expected reductions in service levels as well as concerns about reliability, such as delays and cancellations.

Conversely, 4,234 participants stated that they planned to continue using PT in the future. These respondents were predominantly those who had already used PT prior to the service expansion. Notably, nearly 30% of all participants reported an increased environmental awareness, and among the 25-year-olds, the project was particularly successful: younger respondents were comparatively more willing to continue using PT beyond the project period.

4.1.2.6 Use of Transport Modes

In addition to Kaufmann's three-category model, a fourth analytical dimension, use of transport modes, was incorporated into the overall framework to examine the relationship between mode choice and the avoidance of private car use. For this purpose, respondents were asked not only about their frequency of private car and PT use but also about bicycle use and trips undertaken as car passengers.

Within this model component, the analysis reveals that infrequent private car use has no significant influence on the avoidance of private car trips. This finding is plausible, as these individuals are likely to have limited access to a private car or may be unable to substitute their trips with PT. By contrast, daily private car use exhibits a significant association with the dependent variable. With an OR of 2.167, individuals who drive daily have a 116.7% higher likelihood of avoiding private car trips as a result of the service expansion.

A further significant relationship was identified among car passengers who ride 1–3 times per week. This group shows an odds ratio of 1.751, representing a 75.1% increase in the likelihood of avoiding private car use. These individuals appear to demonstrate a comparatively higher readiness to shift towards PT.

Initial results suggested that infrequent PT use and daily bicycle use might exhibit significant effects; however, these results did not hold once the full model was specified. In the final combined model, neither PT use nor bicycle use shows a significant influence on private car avoidance.

Among respondents, 22% (3,049 individuals) reported that they almost never use a private car, and a further 20% use a private car less than three times per month. In contrast, nearly 30% reported daily private car use, and 27.1% used a private car at least weekly. This distribution illustrates the considerable balance between PMT users and PT users in the sample and highlights the potential for further modal shift towards PT.

Approximately 56% of participants stated that they ride as a car passenger less than once per month, while only 3% reported daily car-passenger travel. This finding indicates that most respondents either travel alone in their private car or use alternative modes of transport.

With regard to PT, 4,000 respondents reported using PT less than once per month, suggesting that private car use constitutes the primary mode of transport for this group. Conversely, 45.1% of participants use PT daily or at least weekly, underscoring the importance of PT for a substantial share of the population.

Bicycle use, considered as an independent mode of transport, exhibits considerable variation: nearly 22% of respondents do not use a bicycle at all, while 34% report daily use. Bicycles often serve as a complementary mode to PT, particularly for first and last mile connections. However, the statistical analysis found no significant association between bicycle use and the avoidance of private car trips.

4.1.3 Limitations

When interpreting the overall results, it should be noted that although this study reached a total of 14,296 households, the city of Bonn has a population of 338,396 residents (as of 01.01.2023). Accordingly, the findings cannot be directly generalised to the entire population. It must also be considered that the survey was conducted exclusively in Bonn, and that Germany's transport system and mobility-related consumption patterns differ from those in many other countries (Pakusch et al., 2018). The present study therefore reflects case specific insights shaped by the particular characteristics of Bonn and its local transport conditions.

As a former federal capital, Bonn benefits from a highly developed network structure and an extensive PT offering. Even after the relocation of federal institutions to Berlin, several authorities and two DAX-listed companies have retained their headquarters in Bonn. According to a recent study by Allianz pro Schiene (06/2023), Bonn exhibits the best accessibility to PT in Germany (Allianz pro Schiene, 2023). The study concludes that both the inner city and the surrounding rural areas have exceptionally good access to PT services.

In addition to favourable geographical conditions, a strong ecological, political orientation supports the transition towards sustainable mobility. The Lead City Project, as a temporary but strategically aligned intervention, reinforced the political commitment to shifting mobility patterns away from private cars towards low-emission PT.

However, PT providers face a number of structural challenges, including limited infrastructure capacity, shortages of buses and trains, rising fuel prices, and persistent staffing shortages. Even if financial support is available during project phases, these constraints must be addressed to ensure a successful long-term transition. In particular, rising operating costs and workforce shortages due to demographic change require targeted solutions. Beyond additional service expansions, monetary aspects must be examined, and questions arise such as how technological innovations can reduce operational costs and help mitigate personnel shortages.

Although a modal shift is politically desired, the necessary conditions and levels of attractiveness must be created to enable it to materialise sustainably.

4.2 Study 2: “Climate Ticket”

The second study examines the introduction of a subsidised ticket, referred to as the climate ticket, in the city of Bonn and empirically tests the theoretically assumed effects derived from Kaufmann’s model. At the Access level, economic entry barriers are substantially reduced through significantly discounted fares.

Regarding Skills, the simplification and standardisation of the fare structure lead to a notable reduction in perceived complexity. Within the dimension of Appropriation, PT is increasingly internalised as a socially just and equitable mobility option.

These theoretically derived mechanisms constitute the core of the empirical investigation. The research design, data collection and statistical procedures are presented in Section 4.2.1, while the key findings and their interpretation are discussed in Section 4.2.2. The methodological limitations and constraints of the study are critically reflected in Section 4.2.3.

4.2.1 Research Design

The second major area of investigation concerns the climate ticket. Study 2 focuses on assessing this subsidised ticket from the perspective of its users. The central research questions were how a shift in the modal split towards more environmentally and climate-friendly PT can be achieved, and what contribution the Bonn climate ticket makes to air quality and mobility behaviour in the transport sector. Furthermore, the study evaluates the effectiveness of the climate ticket by analysing its added value for the operational design of future ticketing schemes and by examining the relationship between users' attitudes, skills and access to the climate ticket.

The Lead City Project consisted of three main components. The first pillar was the introduction of the climate ticket. Residents of Bonn who had held no PT season ticket during the 12 months prior to the measure were given the opportunity to purchase an annual ticket for the city of Bonn at a subsidised rate of €365 per year. The motivation for introducing this instrument was the assumption that price constitutes one of the most influential factors in promoting a modal shift towards PT. The climate ticket was intended to allow residents to test PT at the low cost of "one euro per day", with the expectation that such a trial phase might induce a behavioural change in favour of PT. The ticket could be used within a limited validity period of two years, with the final tickets expiring on 31 December 2020.

Given the anticipated increase in passenger numbers, the second pillar of the project consisted of a service expansion. Beyond price, the attractiveness of PT journeys was to be increased, particularly by ensuring that door-to-door travel times approached those of the private car. The third pillar involved the expansion of the corporate (job ticket) scheme; however, this element played only a minor financial and behavioural role in the overall Lead City project.

The Lead City Project was funded over two years by a total of €39.34 million from the Federal Government (Bundesstadt Bonn, 2018). Of this amount, €18.31 million was allocated to the climate ticket, €18.79 million to the service expansion, and €2.24 million to the extension of the job ticket scheme.

The funding framework allowed for a maximum of 17,000 tickets, based on previous revenues from monthly season tickets. Initially, communication efforts were limited due to the expectation of a rapid sell-out. However, after a slow start, extensive information and marketing campaigns were launched. In total, 6,000 climate tickets were sold over the full project duration (Rheinische Post Online, 2019).

The questionnaire aimed to assess, on the basis of seven core statements on ticket use and price, how users evaluated the short and long-term impact of the climate ticket on the modal shift towards PT and whether the measure contributed to sustainable environmental improvements. These seven statements were measured on a metric scale. Furthermore, the use of transport modes (PMT, PT and bicycle) before and after the expiration of the climate ticket was compared. Based on the observed changes in mobility behaviour, it was possible to determine whether, and to what extent, car trips were avoided.

The study also sought to identify in which areas the climate ticket enabled the most substantial improvements from the users' perspective, and whether the climate ticket constitutes a viable long-term instrument for the transport transition. To this end, users' attitudes towards the climate ticket were measured metrically,

and socio-demographic characteristics, including income, place of residence, occupation, age, gender, as well as household size, car ownership and car availability were collected.

Table 9: Assignment of the independent variables to the three motility categories

Source: Author's own compilation.

Access	Skills	Appropriation
Income	Educational level	Attitudes towards public transport/climate ticket
Size of the household	Age	
Car availability in the household	Gender	Travel Habits (before, within, and after the climate ticket period)
Cars of the household		
Residential situation		

Building on Kaufmann's theoretical framework, we derived the relevant subcategories for our study from previous empirical research. Table 9 presents the assignment of the individual measured factors to the three motility dimensions, which are access, skills and appropriation.

Within the access category, we include the variables *income*, *household size* (Hamidi & Zhao, 2020), *car availability in the household* and *residential situation*, following the operationalisations used in earlier applications of Kaufmann's model (De Witte et al., 2013; De Witte et al., 2006; De Witte et al., 2008; Macharis et al., 2006). In addition, and based on Hahn et al. (2023), we incorporate *car ownership* as an additional access variable (Hahn et al., 2023).

The skills category contains *employment status* and *age*, again following the operationalisations used by De Witte and colleagues (De Witte et al., 2013; De Witte et al., 2006; De Witte et al., 2008; Hamidi & Zhao, 2020; Macharis et al., 2006). Consistent with earlier studies (Akyelken, 2013; Hamidi & Zhao, 2020; Turdalieva & Edling, 2018), we also include *gender* as a skills-related variable.

Within the appropriation category, and following the same studies (De Witte et al., 2013; De Witte et al., 2006; De Witte et al., 2008; Macharis et al., 2006), we

examine the constructs *attitudes* and *travel habits*. To operationalise these constructs in more detail, attitudes and habits were measured through three and four items, respectively.

Attitudes

Participants were asked to evaluate the following statements:

- *My attitude towards travelling by PT has improved due to the climate ticket.*
- *I purchased the climate ticket solely because of the price advantage compared to the regular tariff.*
- *The climate ticket should be introduced permanently.*

Travel Habits

Relative to the time before the climate ticket

- *Due to the climate ticket, I travel more frequently by PT.*
- *Due to the climate ticket, one or more car trips (PMT) were avoided.*

Absolute frequencies during the validity of the climate ticket

- Frequency of **PMT** use
- Frequency of **PT** use
- Frequency of **bicycle** use

Prospective changes after the climate ticket

- *Without the climate ticket, I will make the same number of PT trips.*
- *Without the climate ticket, I will use the car more frequently.*

In addition, we were interested in the general preference structure across transport modes. Participants were therefore asked to rank the three main modes, PMT, PT and bicycle, according to their personal usage frequencies both during and after the climate ticket offer.

Data Collection

The evaluation was conducted as a written quantitative online survey carried out retrospectively after the expiration of the climate ticket, at three distinct points in time. This approach allowed for the systematic assessment of the overall impacts of the measure. In total, 3,430 climate ticket users from the city of Bonn and the relevant neighbouring municipalities were contacted by post and invited to participate in the online survey.

The first survey wave took place at the end of February 2020. At this stage, 1,530 individuals were contacted, of whom 699 respondents completed and returned the questionnaire in full, corresponding to a response rate of 46%. It should be noted that although responses were possible until April 2020, the majority of questionnaires were completed prior to the COVID-19 shutdown, meaning that pandemic-related effects on the first wave can largely be excluded.

The second survey wave, conducted in August 2020, yielded a considerably lower response rate of 30%. In this wave, 900 individuals were invited to participate, of whom 270 respondents completed the survey. Although COVID-19 incidence rates were substantially lower during the summer compared to the lockdown period, it cannot be ruled out that pandemic-related changes in mobility behaviour influenced the survey results.

The third survey wave was conducted in January 2021. Of the 1,000 individuals contacted, 346 respondents completed the questionnaire, resulting in a response rate of 35%. Responses were accepted until February 2021, a period that coincided with a further COVID-19 lockdown, which must be taken into account when interpreting the results.

Across all three survey waves, a total of 1,315 distinct climate ticket users participated in the evaluation. The datasets of this sample (N = 1,315) were subjected to statistical analysis in order to draw conclusions regarding the effectiveness of the measure and the resulting mobility behaviour of users in the region.

Table 10 provides an overview of the survey participants by age, gender and place of residence.

Source: Author's own compilation.

Characteristic	Count	Percent
Survey participants by age:		
up to 18 years:	8	0.6%
18-29 years:	94	7.3%
30-49 years:	486	37.6%
50-64 years:	430	33.3%
65 and older:	275	21.3%
Gender:		
Women:	859	65.3%
Men:	434	33.0%
Non-binary:	4	0.3%
Place of residence:		
Bonn:	1,239	94.2%
Adjacent municipalities:	59	4.5%

The total sample comprises N = 1,315 respondents. Deviations from this total are attributable to “don’t know” responses or invalid answers. Accordingly, non-valid responses were recorded for the predictors age (22 cases), gender (18 cases) and place of residence (17 cases). All percentages reported refer exclusively to the valid responses for each predictor and therefore sum to 100% within each category.

Data Analysis

Prior to data analysis, the survey data were cleaned and prepared in order to ensure the accuracy and reliability of the results. To obtain an initial overview of the dataset, descriptive statistical methods were applied, including the calculation of frequencies and means. As part of the exploratory data analysis, the dataset was examined for unusual observations, outliers, missing values and other potential irregularities (Döring & Bortz, 2016).

In addressing the research question, inferential statistical methods were applied in addition to descriptive statistics, allowing conclusions to be drawn from the sample to the broader population (Eid et al., 2017). Furthermore, correlation analyses were conducted in order to identify relationships between the relevant variables.

To statistically examine the research question, the ecological contribution of the measure was first analysed using logistic regression. In this context, the predictor car trip avoidance was examined in relation to the core statements of the survey. The analysis of mobility practices captures the effects associated with the use of different transport modes, car (PMT), PT and bicycle, both with and without the climate ticket.

All statistical analyses were prepared and conducted using the data analysis software SPSS version 27.

4.2.2 Findings and Discussion

4.2.2.1 Policy Effects

In total, 1,315 respondents participated in the survey. After excluding 160 invalid responses, 1,155 valid questionnaires remained for analysis, corresponding to approximately 88% of all responses. Overall satisfaction with the climate ticket

was high: 52.9% of respondents reported being very satisfied and *24.5% satisfied. A further 7.5% assessed the measure as neutral, while only 2.5% evaluated it as poor and *0.5% very poor.

Based on the assessment of the measure, users were asked to evaluate the benefits and pricing of the climate ticket using seven key statements. These statements were designed to capture both current usage patterns and anticipated future effects, allowing for an analysis of how mobility behaviour changed in the short term as a result of the measure and how it may evolve in the long term, either with or without the climate ticket.

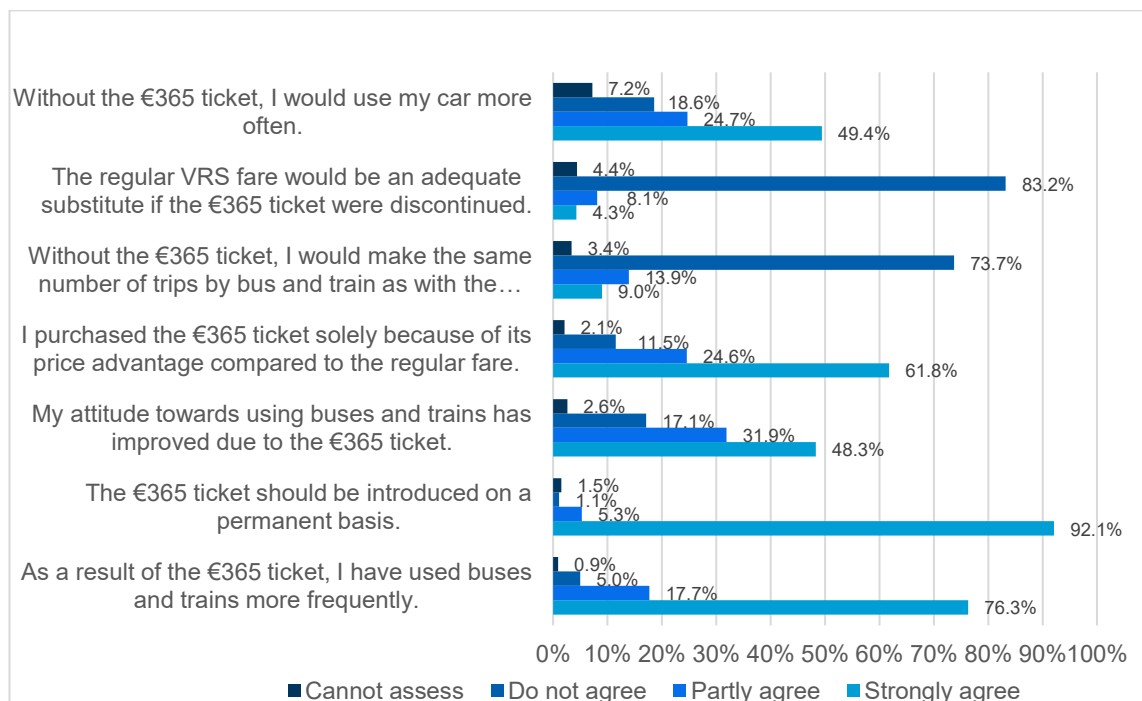


Figure 11: Statements on the climate ticket

Source: Author's own compilation.

With regard to the impact of the climate ticket on mode use, the results indicate a clearly positive effect on PT usage. A substantial majority of respondents (76%) reported using PT more frequently than before the introduction of the climate ticket. The low price proved to be a decisive factor for purchase, with 62% of

respondents stating that cost considerations were the primary reason for acquiring the ticket. Accordingly, 83% indicated that the regular fare does not represent an adequate substitute for the climate ticket.

Looking ahead, 74% of respondents stated that they would use PT less frequently once the climate ticket is no longer available, while only 9% indicated an intention to maintain their current level of PT usage. At the same time, almost half of the respondents (49%) reported that they would increase their car use (PMT) following the end of the measure.

Importantly, 48% of participants reported that their attitude towards PT had improved as a result of the climate ticket. Support for the policy measure was exceptionally strong: 92% of respondents stated that the climate ticket should be introduced on a permanent basis.

4.2.2.2 Logistic Regression Analysis

Previous studies by De Witte et al. (2013) and Hahn et al. (2023) have identified car trip avoidance as a key indicator of the contribution of transport policies to sustainable mobility and climate protection. Accordingly, this variable has been widely used as a central outcome measure in empirical research on modal shift and behavioural change. Given its high analytical relevance and its substantial impact on sustainable development, car trip avoidance was selected as the dependent variable in the present study.

To examine the research question, data from all three survey waves were pooled and analysed using a binary logistic regression model, focusing on the core statements of the climate ticket evaluation as explanatory variables. This approach allows for an integrated assessment of the measure's effects over time and ensures sufficient statistical power to identify robust behavioural patterns.

The output table reports the results of the regression model, including the eight independent variables, the estimated regression coefficients, standard errors,

Wald statistics, odds ratios (OR), and 95% confidence intervals (CI). The results of the analysis are presented in Table 11, while the interpretation of statistically significant effects (p-values) is discussed in detail in the subsequent text.

Table 11: Logistic regression results for the dependent variable car trip avoidance

Source: Author's own compilation.

State- ment	Variable	b	S.E.	Wald	p	OR	CI .025	CI .975
1	Increased use of public transport	-0,763	0,167	20,959	***	0,466	0,336	0,646
2	Trips with or without climate ticket	0,188	0,136	1,898		1,206	0,924	1,575
3	Return car	-1,535	0,117	171,671	***	0,215	0,171	0,271
4	Standard tariff as a substitute	-0,074	0,185	0,159		0,929	0,646	1,336
5	Price advantage climate ticket	-0,031	0,129	0,056		0,970	0,753	1,250
6	Attitude public transport	-0,282	0,131	4,669	*	0,754	0,584	0,974
7	Permanent climate ticket	0,016	0,213	0,005		1,016	0,669	1,541
	Evaluation climate ticket	-0,064	0,148	0,188		0,938	0,702	1,253

*p<.05, **p<.01, ***p<.001

Model 1: $\chi^2(8) = 369.973$, $p < .001$, $R^2 = .480$

The binary logistic regression model indicates that the model makes a statistically significant contribution to explaining variance ($\chi^2(8) = 369.973$, $p < 0.001$, $R^2 = 0.48$, $f^2 = 0.92$). Accordingly, 48% of the variance in the dependent variable can be explained by the model. According to Cohen, this corresponds to a large effect size.

The estimated coefficients show that the nominally scaled dependent variable *avoidance of car trips* yields statistically significant results. In particular, car trips were most strongly reduced among respondents who increased their use of PT as a result of the climate ticket. Respondents who indicated that they would use the car more frequently again after the expiration of the climate ticket also exhibit a statistically significant relationship with car trip avoidance. Furthermore, an improvement in attitudes towards PT attributable to the climate ticket shows a significant effect on the reduction of private car use.

An overview of all statistically significant effects across the three survey waves reveals noticeable differences between the individual waves. In particular, the

results of Waves 2 and 3 may have been influenced by the impacts of the COVID-19 pandemic.

Table 12: Significance levels (p-values)

Source: Author's own compilation.

Variable	Whole Model	1 Wave	2 Wave	3 Wave
Increased use of public transport	***	**		**
Trips with or without climate ticket				
Return car	***	***	***	***
Standard tariff as a substitute				
Price advantage climate ticket				
Attitude public transport	*	*		
Permanent climate ticket				
Evaluation climate ticket				

4.2.2.3 Multiple Linear Regression Analysis

Multiple linear regression analysis examines whether a systematic relationship exists between several independent variables and a single dependent variable. In the present study, the evaluation of the climate ticket constitutes the dependent variable, whose variation is analysed as a function of multiple independent factors.

Four separate regression models were estimated, in which the explanatory variables were entered block-wise in accordance with the conceptual structure derived from Kaufmann's mobility framework. Specifically, the variables were introduced sequentially along the four blocks Access, Skills, Appropriation, and Travel Behaviour. This stepwise modelling approach allows for an assessment of the incremental explanatory power of each conceptual dimension and facilitates a differentiated interpretation of their respective contributions to the overall model.

Table 13: Multiple linear regression results for the full model

Source: Author's own compilation.

Model	Variable	b	β	t	p	VIF
<i>(Constant)</i>		-0,15		-0,21		
Access						
	Income	-0,04	-0,05	-1,31		1,219
	Number of persons in the household	-0,03	-0,05	-1,13		1,561
	Number of cars in the household	-0,03	-0,02	-0,48		1,2
	(ref category: none) Car availability	-0,01	-0,01	-0,15		1,202
Skills						
	Age 30-49 years	-0,04	-0,03	-0,36		5,247
	(ref category: 18-29) 50-64 years	0,007	0,005	0,06		5,138
	65 and older	-0,03	-0,01	-0,15		7,613
	(ref category: male) Gender	0,137	0,088	2,327	*	1,263
	(ref category: urban) Residential situation	-0,11	-0,03	-0,78		1,085
	Profession Working part-time	-0,03	-0,02	-0,39		1,463
	(ref category: no. of full-time employed) School/study/training	0,279	0,06	1,663		1,155
	Head of household	-0,15	-0,04	-1,1		1,241
	Parental leave / Maternity leave	-0,01	-0	-0,03		1,195
	Not employed	-0,65	-0,1	-2,8	**	1,108
	Retired	0,059	0,032	0,422		4,972
Appropriation						
Attitudes						
	Purchase because of price advantage	0,032	0,032	0,929		1,066
	Improved attitude towards public transport	0,221	0,231	5,963	***	1,321
	Climate ticket permanent	0,365	0,196	5,115	***	1,293
Travel habits						
<i>Relatively compared to the time before of the climate ticket</i>						
	Increased PT usage	0,351	0,245	6,154	***	1,397
	(ref category: none) ≥ 1 PMT trip avoided	-0,35	-0,07	-1,87	0,06	1,116
<i>Absolutely within the time of the climate ticket</i>						
	PMT daily	0,016	0,005	0,082		2,785
	Usage several times a week	0,098	0,055	0,598		7,463
	(ref category: never) several times a month	0,002	0,001	0,011		8,867
	less often	-0,09	-0,06	-0,55		8,925
	PT daily	0,147	0,097	0,235		149,26
	Usage several times a week	0,396	0,258	0,632		146,89
	(ref category: never) several times a month	0,279	0,106	0,441		50,965
	less often	0,426	0,092	0,658		17,231
	PMT daily	0,214	0,083	2,031	*	1,468
	Usage several times a week	-0,03	-0,02	-0,33		1,759

	(ref category: never) several times a month	0,032	0,018	0,407	1,642
	less often	-0,02	-0,01	-0,21	1,548
<i>Prospectively regarding the time after the climate ticket</i>					
	Unchanged public transport use	0,063	0,047	1,2	1,364
	Increased car use	-0,04	-0,04	-1,06	1,325
	Load axes	0,043	0,027	0,751	1,149
*p<.05, **p<.01, ***p<.001					
model1: F(df,df2)=, R ² , p, f ²					
model1: F(df,df2)=, R ² , p, f131					
model1: F(df,df2)=, R ² , p, f132					

The multiple regression model applied demonstrates a statistically significant contribution to explaining variance ($F(36, 580) = 9.424$, $p = 0.001$, $R^2 = 0.384$, $f^2 = 0.62$). Accordingly, 38.4% of the variance in the evaluation of the study can be explained by the variables included in the model. According to Cohen (1992), this corresponds to a large effect size. By applying the mobility concept, the results of the individual categories are interpreted and embedded within the context of existing research.

4.2.2.4 Application of the Mobility Concept

Based on the data analysis using Kaufmann's motility framework, insights into subsidised PT tickets can be derived along the three core dimensions Access, Skills, and Appropriation. Structuring the analysis according to this framework facilitates the interpretation of the data and enables conclusions to be drawn regarding future mobility behaviour under an expanded transport offer.

Access

In this study, Access refers to the structural conditions that enable individuals to use mobility options. Access to PT is closely linked to income and financial resources, i.e. the ability to afford mobility. PT use further depends on factors such as network accessibility. Additional access-related factors include household size, the number of cars per household, and the resulting level of car availability.

The multiple regression analysis indicates no statistically significant relationships between the four variables in this category and the dependent variable evaluation of the measure. Nevertheless, the individual variables warrant closer examination.

Income. The majority of climate ticket users reported coping very well (367; 28.6%) or well (556; 43.3%) with their financial resources. A further 314 respondents (24.5%) assessed their income as moderately satisfactory. In contrast, only 38 participants (3.0%) reported poor and 8 (0.6%) very poor financial conditions.

This relatively high level of financial capacity can partly be attributed to Bonn's economic structure as a former federal capital, which remains the headquarters of several federal ministries as well as major DAX-listed companies such as Deutsche Post and Deutsche Telekom. The climate ticket was therefore utilised across socio-economic groups, largely independent of income.

Previous studies suggest that individuals with lower incomes tend to use PT more frequently (Guzman et al., 2021; Tirachini & Proost, 2021). However, this pattern was not observed among climate ticket users. One possible explanation is that lower-income groups were already holders of PT season tickets prior to the intervention and were therefore excluded from eligibility for the climate ticket.

Household Size. The sample composition, primarily couples (473; 36.5%), single person households (356; 27.5%), and families with one (202; 15.6%) or two children (199; 15.4%), reflects official statistics indicating a predominance of single person households and couples in Bonn and the Rhein-Sieg district. These groups account for approximately 64% of respondents. Larger households with three or more children were comparatively rare.

Bonn's geography shows that families predominantly reside in peripheral or suburban areas, partly due to financial constraints and lifestyle preferences. Larger households also tend to own multiple cars, often resulting from adult children still living at home. This increases the number of potential drivers and, particularly in

peripheral areas, reinforces reliance on PMT rather than PT. Rising household income is therefore associated with increased mobility levels (Dargay, 2007).

Number of Cars per Household. A total of 801 respondents (61.1%) owned one car, while a further 234 (17.8%) owned multiple cars. Approximately 21% of respondents reported owning no car.

Car ownership levels are consistent with reported car availability. Despite Bonn's dense inner-city structure and extensive alternative mobility options (e-scooters, bike sharing, car sharing, ride sharing), the temporary nature of the climate ticket did not result in observable behavioural change. In the longer term, however, measures such as reduced parking supply or driving restrictions in urban areas could decrease the attractiveness of car use.

Car Availability. Car availability was reported as unrestricted by 900 respondents (68.8%), while 314 (24.0%) had occasional or negotiated access. Only 95 participants (7.2%) reported no access to a car.

High car availability reflects the region's economic conditions and the prevalence of company cars linked to major employers. At the same time, Bonn's extensive range of alternative mobility services, particularly in inner-city areas, offers numerous opportunities for flexible, demand-oriented mobility independent of private car ownership.

It is unlikely that temporary service expansion or the climate ticket altered car availability. Car ownership represents a long-term commitment to PMT (Al-Busaidi, 2019) and can only be reduced through a permanently attractive PT offer.

Skills

Individual skills are shaped by lived mobility experiences, knowledge, and attitudes towards available transport modes. Mode choice decisions must align with

lifestyle and life stage. In the climate ticket survey, skills were operationalised, following De Witte (2008) and Hahn et al. (2023), using employment status, age, and gender. The multiple regression results indicate significant relationships for gender and employment status.

Age. Climate ticket use was observed across all age groups. Respondents under 30 years accounted for only around 8%, reflecting the availability of alternative flat-rate PT schemes for students and pupils. The largest group was aged 30–49 (486; 37.6%), followed by those aged 50–64 (430; 33.3%), and those aged 65+ (275; 21.3%).

Life-course effects are evident: central living locations are preferred in early adulthood, while family formation often leads to suburban relocation and increased travel distances from less well-connected areas. In older age groups, car ownership remains high but usage may decline due to age-related constraints (Dargay, 2007).

Gender. Climate ticket users were predominantly female (66.2%), with males accounting for 33.5% and a small number identifying as non-binary. This distribution exceeds demographic expectations and reflects higher general PT usage among women (Beirão & Cabral, 2007). Women also evaluated the climate ticket slightly more positively (+0.137 units), a statistically significant difference ($t = 2.327$, $p < 0.05$).

Place of Residence. Most respondents lived in Bonn (95.5%). As the climate ticket was a city-specific measure, its use was primarily urban. Evaluation did not differ significantly between city residents and those from surrounding municipalities, indicating broad acceptance. In rural contexts, reliable PT is particularly relevant for reducing commuting distances and emissions (Chatterjee et al., 2020).

Employment Status. Full-time employees constituted the largest group (41.4%), followed by part-time workers (22.1%) and retirees (22.7%). Non-employed respondents evaluated the climate ticket significantly less positively than full-time

employees (−0.645 units). This may reflect lower daily mobility requirements and the availability of alternative subsidised tickets

Appropriation

Appropriation refers to attitudes towards mobility options and the corresponding travel habits.

Attitudes towards PT. The survey indicates that the climate ticket was predominantly purchased due to its price advantage compared to the regular fare. Accordingly, nearly 62% of respondents fully agreed with this statement, while a further 25% partly agreed. Only 12% did not consider the subsidised price to be a decisive factor in their decision to use the climate ticket. However, the regression analysis shows that this primarily monetary incentive does **not** have a statistically significant effect on the overall evaluation of the measure ($t = 0.929$, $p > 0.05$).

The climate ticket enabled residents of Bonn to gain a comprehensive impression of PT and to accumulate new experiences. In this context, 1,046 respondents (80.2%) reported that the climate ticket led to an improved attitude towards PT. The remaining 258 respondents (19.8%) did not report any improvement in their perception of PT as a result of use. An improved attitude towards PT had a positive effect on the evaluation of the measure: when attitudes improved, the evaluation score increased by 0.221 units. This observed relationship is statistically significant ($t = 5.963$, $p < 0.001$).

An overwhelming majority of respondents—1,205 individuals (97.4%)—also expressed support for the permanent introduction of the *climate ticket*. Only 15 respondents (1.1%) opposed this, while 19 respondents (1.5%) did not provide an answer. Support for permanent implementation is associated with a more positive evaluation of the measure: respondents favouring a permanent *climate ticket* rated the measure 0.365 units higher on average. This relationship is statistically significant ($t = 5.115$, $p < 0.001$).

Travel Habits. Travel behaviour can be analysed relative to the period before the climate ticket, during its validity, and prospectively after its expiration.

Relative to the period before using the ticket. With regard to changes in mobility behaviour, 94.1% of respondents reported that they had at least partly increased their use of PT as a result of the climate ticket. In contrast, 5% stated that they did not intensify their PT use despite owning the ticket. The remaining 0.9% did not provide an assessment. The analysis shows that respondents who reported increased PT use evaluated the Lead City measure 0.351 units more positively. This increase is statistically significant ($t = 6.154$, $p < 0.001$).

However, increased PT use does not translate to the same extent into a reduction of PMT trips. Only 73.7% of respondents stated that they avoided one or more car trips per week due to the climate ticket; among these, 49.0% avoided three or more car trips per week. The regression analysis reveals no statistically significant relationship between the avoidance of PMT trips and the evaluation of the measure ($p = 0.063$). Respondents who avoided one or more PMT trips rated the climate ticket on average 0.353 units lower.

Absolute use during the validity period of the ticket. Usage frequencies of different transport modes during the validity of the climate ticket were also assessed. Overall, 23.0% of respondents reported using a car daily or several times per week (median = 2.70). In contrast, 84.8% used PT daily or several times per week (median = 4.25), while 34.7% reported using a bicycle daily or several times per week (median = 2.87). These usage patterns are reflected in stated preferences for the three main transport modes: PMT, PT, and cycling.

The analysis shows a statistically significant effect only for bicycle use: respondents who cycled daily evaluated the climate ticket 0.214 units more positively than those who did not cycle. This relationship is statistically significant ($t = 2.031$, $p < 0.05$). In contrast, neither car use nor PT use, measured by usage frequency or preferred main mode, exhibited a statistically significant relationship with the evaluation of the measure.

Prospective behaviour after the expiration of the climate ticket. Respondents were also asked to assess their mobility behaviour after the discontinuation of the climate ticket. Approximately 23% stated that they would continue to use PT more frequently even without the ticket. The remaining 77% indicated that they used PT primarily because of the climate ticket. Overall, 83.2% of respondents considered the traditional fare structure prior to the introduction of the climate ticket to be non-competitive compared to PMT. Accordingly, 74% reported that they would increase their car use once the climate ticket expired. The analysis shows that these prospective assessments of future mobility behaviour do not have a statistically significant relationship with the evaluation of the measure.

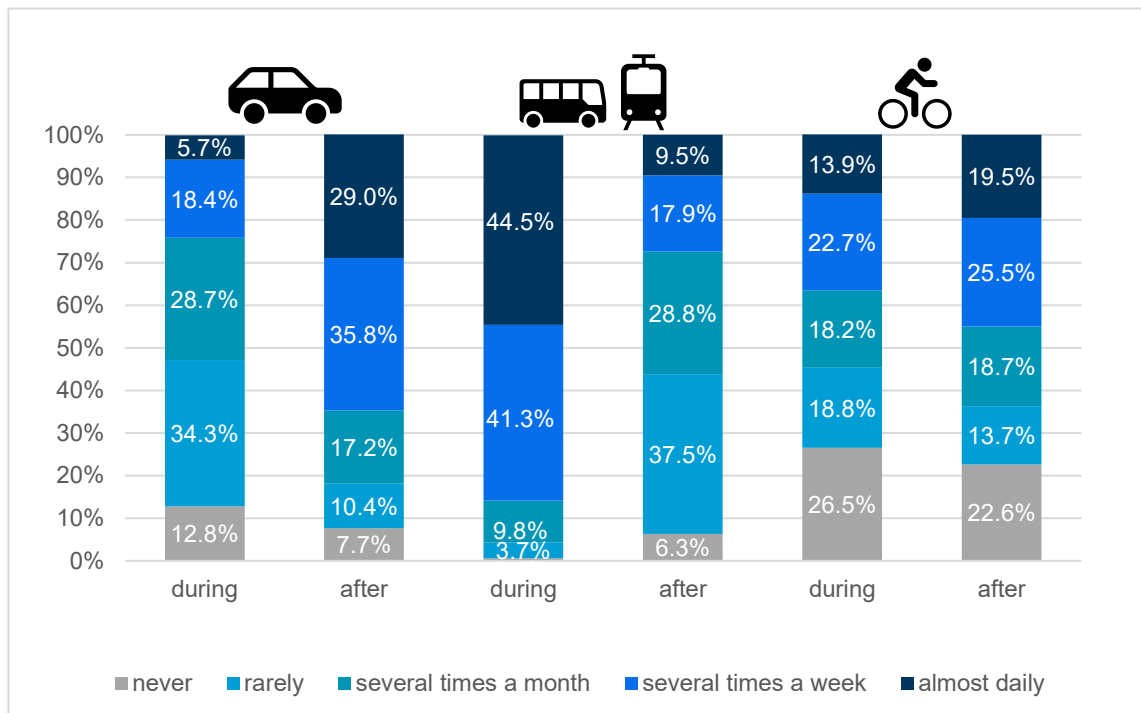


Figure 12: Impact on the mode preference during and after the ticket period

Source: Author's own compilation.

As the survey was conducted in several waves, it was possible to capture mode preferences both during and after the period of *climate ticket* usage (see Fig. 12).

With regard to mode preference, the results show that during the validity period of the *climate ticket*, PT ranked first as the main mode of daily travel, ahead of

the car and the bicycle. After the expiration of the measure, the ranking shifts again, with the car regaining the leading position, followed by the bicycle and PT.

This finding indicates that, among *climate ticket* users, a genuine modal shift towards PT occurred during the period of the intervention. However, this shift was not sustained over time. After the end of the measure, PT usage declines markedly, while car use increases again.

These results suggest that price plays a more decisive role than appropriation processes or the development of competencies related to organising daily mobility using PT. While such competencies are likely to persist beyond the period of the €365 ticket, they are not sufficient to compensate for the monetary deterioration of PT once the measure expires. This interpretation is consistent with the strong demand among *climate ticket* users for the permanent introduction of an affordable PT ticket.

4.2.3 Limitations

The survey of climate ticket users was conducted in three waves, during which unforeseen external factors, most notably the effects of the COVID-19 pandemic, may have influenced the results. While the first wave was largely completed before the onset of the first “lockdown”, a certain degree of pandemic-related bias cannot be entirely ruled out. The third wave, conducted during the strict lockdown in early 2021, shows only marginal effects on the survey outcomes; however, response rates in waves two and three (30% and 35%, respectively) were significantly lower than in wave one (46%). These differences may be attributed both to the reduced relevance of the climate ticket during the pandemic period and to uncertainty regarding its continuation.

The survey period coincided with profound social and economic disruptions. At the beginning of the third wave, it was unclear to what extent PT would continue to be used under conditions of mandatory contact restrictions and whether the climate ticket would remain a meaningful policy instrument. Following an initial

recovery in passenger numbers, the war in Ukraine and the resulting inflation generated new challenges, particularly for socio-economically vulnerable groups. Economic pressure increasingly manifested in fundamental trade-offs between spending on mobility and essential goods, such as food. At the same time, PT operators faced rising operating costs, most notably due to increased fuel prices, which could not be directly passed on to customers.

The Lead City project highlights the tension between political objectives and the operational realities of transport providers. While political decision-makers define strategic priorities and allocate public funding, transport companies must cope with structural challenges such as insufficient infrastructure, staff shortages and rising operating costs. The long-term implementation of such projects therefore requires not only financial support, but also structural adjustments to ensure a sustainable transition in the transport sector. These challenges are further intensified by demographic change and increasing costs associated with vehicle operation and maintenance.

The COVID-19 pandemic has also fundamentally altered mobility patterns, particularly through the widespread adoption of home-office arrangements. These developments temporarily associated PT use with health-related concerns, leading to substantial revenue losses across the sector. Many transport operators became dependent on public subsidies to maintain operations, clearly illustrating the sector's vulnerability in times of crisis. Nevertheless, climate change remains a central long-term challenge, making a structural transformation of PT indispensable, even if short-term economic pressures currently dominate policy debates.

4.3 Study 3: Fuel Prices

The third study examines cost-based restrictions resulting from the non-subsidisation of rising fuel prices and analyses their effects within the framework of Kaufmann's mobility model. At the level of access, the increased recurring and one-off costs substantially reduce the economic accessibility of car use. With regard to skills, users are compelled to actively integrate alternative modes of transport

into their everyday planning. In terms of appropriation, the private car is increasingly perceived as an economically inefficient and financially risky mobility option.

These model-based effects constitute the core of the empirical analysis. The research design, data collection and statistical data analysis are presented in Section 4.3.1, while the key findings and their discussion are outlined in Section 4.3.2. The limitations of the study are reflected upon in Section 4.3.3.

4.3.1 Research Design

The third empirical study within the field of (non-)subsidisation examines the impact of a current price shock on consumers' mobility behaviour. Based on two empirical analyses, it is demonstrated how sharp fuel price increases have affected travel behaviour. In addition to analysing the full dataset, a comparative focus is placed on the millennial generation, which is strongly embedded in working life and frequently characterised in the literature as particularly sustainability-oriented.

Study 3 explicitly addresses the effects of non-subsidisation. While the climate ticket represents an active public investment in collective transport aimed at increasing attractiveness and encouraging modal shift through pull effects, the fuel price shock does not promote PT use through direct financial incentives. Instead, it targets PMT indirectly. The sharp increase in petrol prices renders car use more expensive and, in relative terms, makes PT economically more attractive. In this context, the state deliberately refrains from subsidising fuel prices, as continued reliance on PMT is politically undesirable. This mechanism therefore constitutes an indirect push effect in favour of PT.

The separate consideration of millennials is motivated by their pronounced environmental awareness and strong commitment to climate targets (Cavagnaro et al., 2018). Beyond ecological concerns, millennials play a key role in driving digital transformation and the adoption of new mobility forms (Dwidienawati et al., 2021). This life phase is characterised by multiple tensions between economic

constraints, ecological values and the reconciliation of work, lifestyle and family life. Employment is expected to be flexible and compatible with a carefully balanced work–life arrangement (Buzza, 2017). Owing to their comparatively high levels of formal education, millennials represent a central workforce cohort. Commuting trips account for a substantial share of overall mobility demand and are shaped by individual living and working conditions.

Following the outbreak of the war in Ukraine in early 2022, fuel prices increased sharply (Onour & Abdo, 2022). This rise in the cost of PMT became immediately visible to car users at petrol stations and led to noticeable financial pressure on mobility-related expenditure. The long-standing attachment of the German population to the private car as the dominant mode of transport (Ruhrort, 2019) was thus put to the test. At the same time, prices for essential goods such as electricity, gas and food also increased. This raises the question of where households adjust their spending under tighter budget constraints and whether existing mobility patterns remain affordable. In this context, the rising costs of PMT relative to PT and cycling, both of which are independent of fuel prices, represent a key explanatory factor.

Previous research on price elasticity and mobility behaviour was largely based on theoretical assumptions (Caldara et al., 2019). The present empirical analysis allows these assumptions to be examined under real-world conditions during the initial phase of the Ukraine crisis. Building on the question of whether there is a general willingness to reduce PMT trips, respondents were asked about alternative strategies, including trip avoidance or substitution by PT, which at that time had not yet experienced comparable fare increases. In addition, the study investigates whether the price shock led to changes in mode preference. Participants were therefore asked to rank the modes car, PT and bicycle according to their personal frequency of use before and after the price shock. Furthermore, mode choice was evaluated along key attributes: travel time, reliability, cost, environmental friendliness and health, using Likert-scale assessments.

Finally, key socio-demographic variables were collected, along with indicators commonly applied in earlier studies (Akyelken, 2013; De Witte et al., 2006, 2008, 2013; Macharis et al., 2006; Turdalieva & Edling, 2018). These included gender, income, household size, car availability in the household, education, age, number of cars, ownership of an electric vehicle, experience with PT and residential situation. The variable residential situation additionally captured aspects of spatial and occupational context, such as travel time to work by car and PT, as well as the weekly frequency of commuting trips by car.

Data Collection

The quantitative online survey was conducted using the Unify survey platform between March and April 2022 with a nationwide sample of users in Germany. This timing ensured that the effects of the price shock of 24 February 2022 had already been perceived by respondents and could therefore be captured promptly through the survey. In total, 1,330 individuals participated in the survey. At the outset, respondents were asked whether they used a private car. If this question was answered in the negative, the questionnaire was terminated. Overall, 611 complete datasets were obtained from respondents whose primary mode of transport was a private car. The key characteristics of the participant sample are presented in Table 14.

Table 14: Sample characteristics by age, gender, and place of residence.

Source: Author's own compilation.

Characteristic	Number	Percent
Survey participants by age:		
Gen. Z (1995-2009)	75	12.3%
Gen. Y (1980-1994)	358	58.6%
Gen. X (1965-1979)	105	17.2%
Gen. baby boomer (1946-1964)	73	11.9%
Gender:		
Women:	279	45.7%
Men:	329	53.8%
Non-binary:	3	0.5%
Place of residence:		
< 5,000	145	23.7%
5,001 – 20,000	108	17.7%
20,001 – 100,000	157	25.7%
> 100,000	201	32.9%

From the overall user sample, 358 datasets could be assigned to the millennial generation. This subgroup includes participants born between 1980 and 1994. For this specifically analysed target group, key characteristics such as gender, number of persons in the household and ownership of a company car are summarised in Table 15.

Table 15: Overview of survey participants by gender, persons in household and company car

Source: Author's own compilation.

Characteristic	Count	Percent
Gender:		
Women:	160	44.7%
Men:	196	54.7%
Non-binary:	2	0.6%
Persons in household:		
1	57	15.9%
2	129	36.0%
3	87	24.3%
4	67	18.7%
>4	18	5.0%
Company car:		
Yes	45	12.6%
No	313	87.4%

Statistical data analysis

First, the dataset was cleaned and erroneous or incomplete responses were excluded from further analysis. The evaluation comprised descriptive statistics, such as the calculation of frequencies and means, as well as inductive methods for exploratory data analysis (Döring et al., 2016). During data inspection, unusual values, outliers, missing data and other irregularities were identified. The aim was to derive robust and comprehensive insights for the entire sample in order to answer the research question (Eid et al., 2017). In addition, statistically significant variables were identified using logistic regression analysis, revealing substantial relationships with the avoidance of PMT trips. All statistical analyses were conducted using the data analysis software SPSS 27.

4.3.2 Findings and Discussion

4.3.2.1 Mode preference

Figure 13 illustrates the ranking of preferences for the PMT, PT and bicycle before and after the fuel price increase. The results show that the car loses attractiveness relative to both PT and cycling as a consequence of the price increase. Nevertheless, despite the sharp rise in fuel prices, the car remains the most preferred mode of transport, followed by PT and the bicycle in second and third place, respectively. Furthermore, the gap between PT and cycling in second place narrows after the price increase. One possible explanation is that consumers anticipate price increases in PT as well, whereas cycling is not affected to the same extent by fuel price developments.

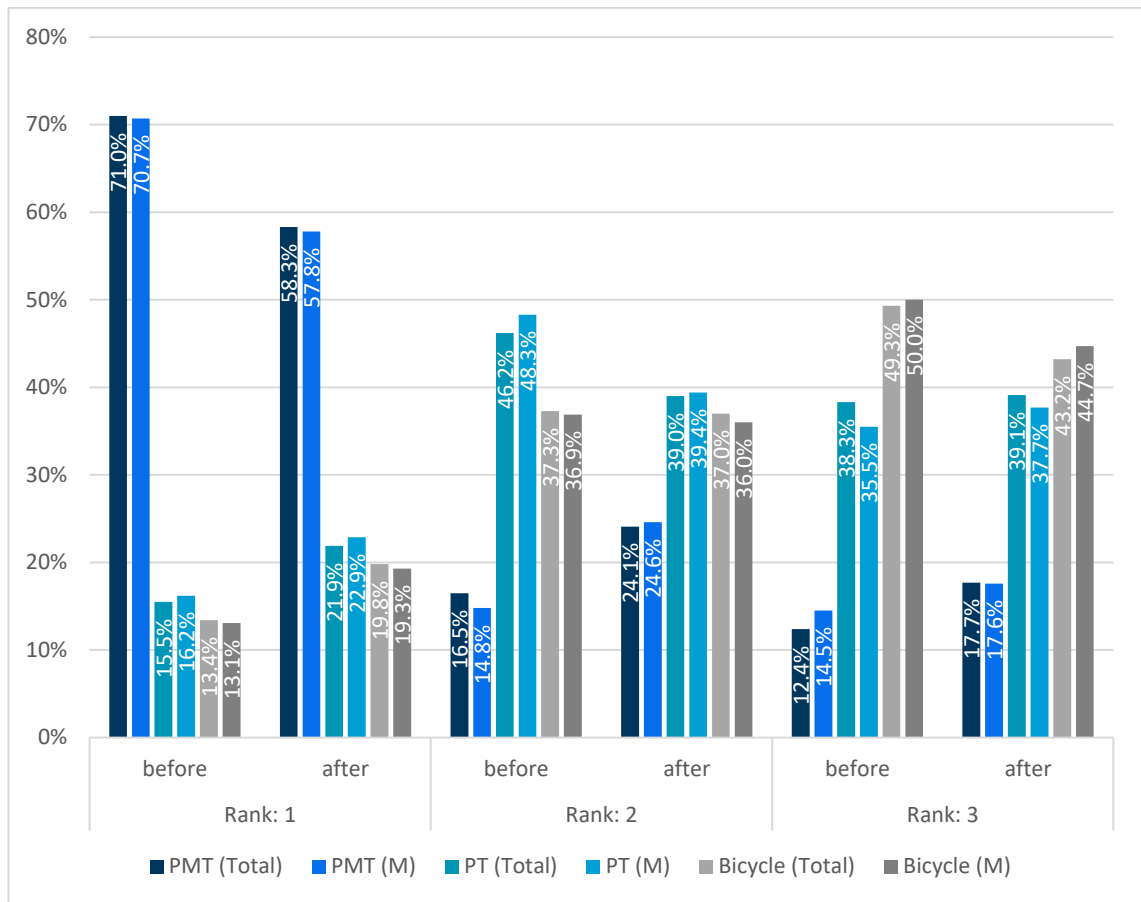


Figure 13: Ranking of preferred mode of transportation (before and after price increase)

Source: Author's own compilation.

The ranking of the main transport modes for the entire sample corresponds closely with the preferences observed for the target group of millennials. Only marginal differences in percentage values can be identified; however, the overall pattern and core findings are fully consistent.

With regard to mode choice: journey time and reliability emerge as the primary determining factors. Time is a scarce resource, particularly for individuals with long working hours, and therefore plays a decisive role in transport decisions. Price, environmental friendliness and health considerations constitute additional key factors, although they are of comparatively lower importance.

Figure 14 illustrates the weighting of these five main criteria for mode choice using a five-point Likert scale. The scale ranges from 1 = extremely important to 5 = not at all important.

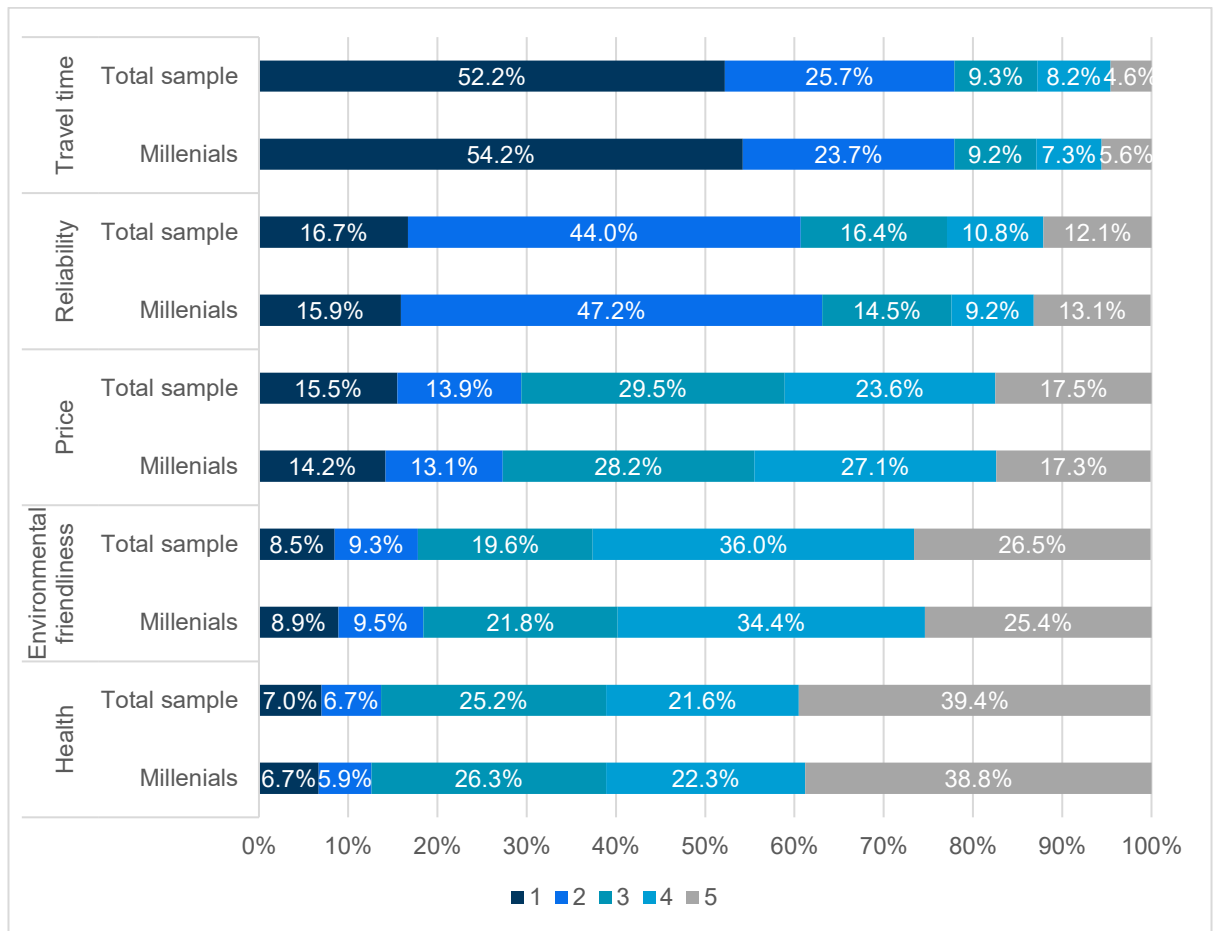


Figure 14: Factors influencing mode choice

Source: Author's own compilation.

The results indicate that travel time (mean = 4.12) and reliability (mean = 3.43) are the dominant determinants of mode choice, followed by price (mean = 2.90), environmental friendliness (mean = 2.39) and health (mean = 2.21). Thus, despite the fact that millennials are commonly associated with heightened environmental awareness and sustainability-oriented attitudes, no substantial deviations from the overall sample can be observed.

4.3.2.2 Impact on mode use

Changes in mode preference are also reflected in the actual use of the three main transport modes, namely PMT, PT and bicycle. The effects of the fuel price shock on mode use are presented in Figure 15.

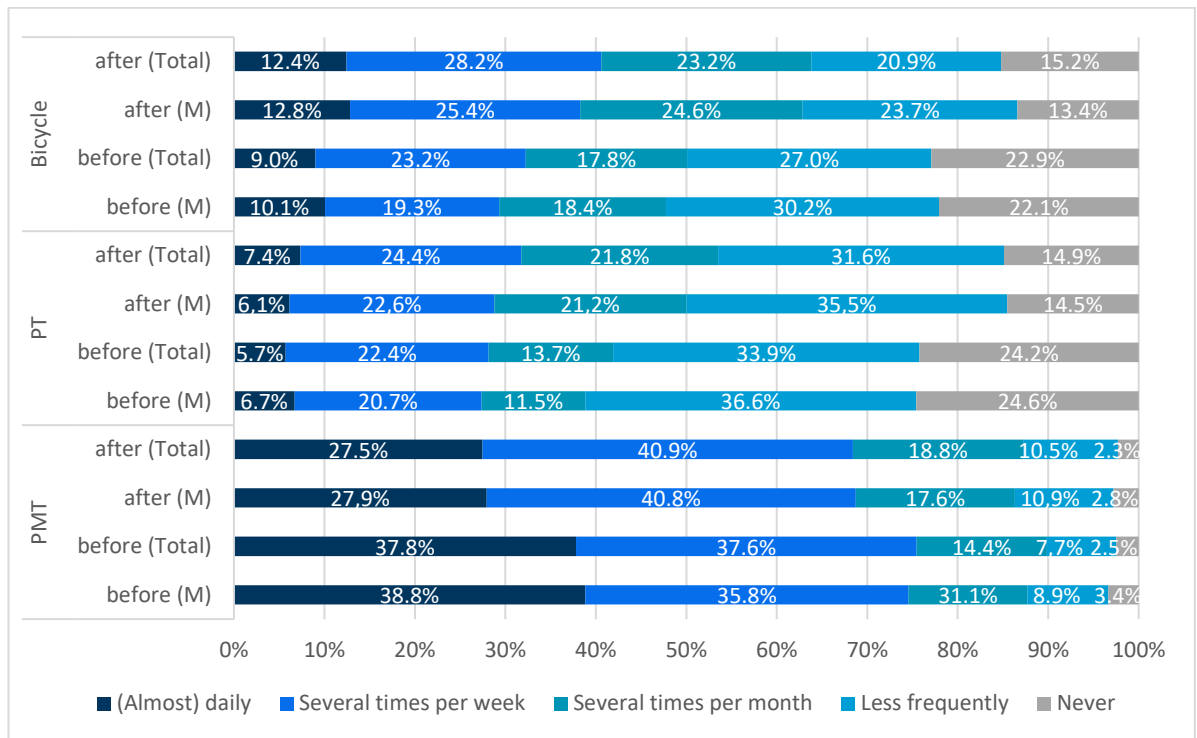


Figure 15: Travel Behaviours

Source: Author's own compilation.

The results reveal a highly differentiated picture of how the increase in fuel prices affected PMT use. With regard to the avoidance of PMT trips, of the 611 respondents, 55 (9.0%) reported avoiding one trip, 108 (17.7%) two trips, 74 (12.1%) three trips, 26 (4.3%) four trips, and 66 (10.8%) more than four trips. Overall, 329 respondents (53.9%) stated that they had reduced PMT trips since the price shock, while 282 respondents (46.1%) reported no change in their car use. Among millennials, nearly 52% indicated unchanged PMT use, whereas 48% reported avoiding car trips. Contrary to assumptions derived from previous studies, the results suggest that millennials avoided fewer PMT trips than the overall sample.

Regarding alternative transport modes, 239 respondents (39.1%) indicated that switching to PT was a feasible option for them, whereas 372 respondents (60.9%) stated that they could not envisage such a change. The cross-tabulation presented in Table 16 shows that willingness to switch has a significant impact on PMT trip avoidance: 70.7% (169 out of 239) of those willing to switch reported

actually avoiding PMT trips, compared to only 43.0% (160 out of 372) among those unwilling to switch. Among millennials, willingness to switch to PT was markedly lower at 37.2%, while 62.8% were not prepared to change to PT.

Table 16: Cross-tabulation: Willingness to switch to PT versus avoidance of PMT trips

Source: Author's own compilation.

		Willing to switch to using public transport			Millennials
		Yes	No	Total	Total
Avoid car journeys	Yes	169 (70.7%)	159 (43.0%)	328 (53.9%)	133 (37.2%)
	No	70 (29.3%)	213 (57.0%)	283 (46.1%)	225 (62.8%)
	Total	239	372	611	358

Another option in response to sharply rising costs is to forego trips altogether. Of the 611 respondents, 328 stated that refraining from travel was a viable option for them. At 51.6%, the willingness to abandon trips entirely is therefore higher than the willingness to switch to PT (39.1%). The cross-tabulation in Table 17 indicates that this willingness has a substantial influence on PMT trip avoidance: 71.7% (227 out of 316) of those willing to forgo travel reported actually avoiding PMT trips, whereas only 34.8% (101 out of 295) of those unwilling to do so reduced their PMT use.

Among Millennials, the willingness to avoid car-based travel entirely is noticeably lower, at 51.1%.

Table 17: Cross-tabulation of trip avoidance versus reduction of PMT trips.

Source: Author's own compilation.

		Willing to forgo travelling			Millennials
		Yes	No	Total	Total
Forgo PMT journeys	Yes	227 (71.7%)	101 (34.8%)	328 (53.9%)	175 (48.9%)
	No	89 (28.3%)	194 (65.2%)	283 (46.1%)	183 (51.1%)
	Total	316	295	611	358

Overall, the analysis shows that participants for whom PT represents a viable alternative react more sensitively to increases in mineral oil prices. They either forgo trips or shift to PT. The findings further indicate that, despite higher mineral

oil prices, PT is considered a realistic alternative by only 39.1% of respondents (239 out of 611). Accordingly, in this study the shift towards PT does not primarily depend on the price of mineral oil.

These results are consistent with observations on mobility behaviour reported in previous studies (e.g. Cats et al., 2014; Kębłowski et al., 2019), which likewise show that even comparatively low PT fares do not lead to a comprehensive modal shift towards PT. For population groups that do not perceive PT as a feasible alternative, the remaining option is to reduce PMT-related trips by abstaining from trips altogether. As commuting trips are generally determined by employment obligations, it can be assumed that car trips undertaken for leisure purposes are more likely to be eliminated entirely or substituted by cycling or walking.

4.3.2.3 Logistic Regression Analysis

In the previous section, we demonstrated that 53.9% of all respondents avoided PMT trips as a result of the price increase. Numerous earlier studies (e.g. De Witte et al., 2013; Hahn et al., 2023, 2024a, 2024b) have identified the avoidance of PMT trips as a key indicator of a meaningful contribution to climate mitigation. For this reason, a logistic regression analysis was conducted to examine which variables influence whether individuals reduce trips or maintain their existing mobility behaviour despite rising mineral oil prices.

In addition to the dependent variable “avoidance of PMT trips”, the independent variables relevant to this study were derived from prior empirical research and operationalised accordingly in the questionnaire. First, key socio-demographic characteristics as well as detailed information on mobility forms and mobility practices were collected. These included the variables gender (Akyelken, 2013), age (Turdaliev & Edling, 2018), education (De Witte et al., 2006, 2008, 2013), income (Hamidi & Zhao, 2020), household size (Hamidi & Zhao, 2020), place of residence (Macharis et al., 2006), mobility resources (car, electric car, PT, working context), as well as mobility practices (Hahn et al., 2023, 2024a, 2024b).

The results of the logistic regression analysis are presented in Table 18, while the interpretation of statistically significant p-values is discussed in the accompanying text.

Table 18: Results of the logistic regression analysis for the dependent variable “PMT trip avoidance”

Source: Author’s own compilation.

Model	Variable	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B) Lower Upper
Gender	Female	.559	.202	7.663	**	1.749	1.177 2.598
Age	Age	.002	.009	.031		1.002	.983 1.020
Education	Grammar school	.153	.559	.075		1.166	.390 3.485
	Completed vocational training	-.137	.407	.113		.872	.393 1.937
	University graduation	.307	.572	.288		1.359	.443 4.168
	Bachelor study	-.311	.445	.489		.733	.306 1.752

	Diploma Study	.172	.488	.124		1.187	.456	3.088
	Master study	-.266	.471	.320		.766	.304	1.928
	Doctorate	.277	.633	.191		1.319	.381	4.559
Income	1,001-2,000	-.476	.600	.627		.621	.192	2.016
	2,001-3,000	-.150	.563	.071		.861	.285	2.595
	3,001-4,000	-.361	.564	.410		.697	.231	2.105
	4,001-5,000	-.741	.581	1.628		.477	.153	1.487
	> 5,000	-1.007	.564	3.185	*	.365	.121	1.104
Household size	2 persons	.224	.320	.489		1.251	.668	2.344
	3 persons	.297	.361	.677		1.346	.663	2.732
	4 persons	.043	.385	.012		1.044	.491	2.220
	> 4 persons	-.213	.567	.141		.808	.266	2.457
Inhabitants	5.001 - 20.000	-.564	.308	3.344		.569	.311	1.041
	20.001 - 100.000	-.231	.287	.646		.794	.452	1.394
	> 100.000	-.643	.296	4.715	*	.526	.294	.939
Car	Car anytime available	-.862	.504	2.920		.422	.157	1.135
	2 cars in household	1.253	1.249	1.005		3.500	.302	40.510
	3 cars in household	1.585	1.274	1.549		4.880	.402	59.236
	4 cars in household	1.569	1.313	1.428		4.804	.366	63.011
	> 4 cars in household	2.222	1.492	2.216		9.222	.495	171.786
E-cars	2 E-cars in household	-.280	.321	.760		.756	.403	1.418
	> 2 E-cars in household	-1.056	1.318	.643		.348	.026	4.602
Public transport	Access to public transport	-.038	.125	.095		.962	.754	1.229
	Public transport experience	-.064	.130	.244		.938	.727	1.210
	Attractiveness of public transport	.109	.130	.713		1.116	.865	1.438
Working context	Duration of car journey to work	-.001	.009	.029		.999	.982	1.015
	Duration of public transport journey to work	-.004	.004	.807		.996	.988	1.004
	1 car trip to work per week	-.132	.340	.149		.877	.450	1.708
	2 car trips to work per week	.413	.334	1.528		1.511	.785	2.907
	3 car trips to work per week	.231	.359	.414		1.260	.624	2.545
	4 car trips to work per week	.510	.456	1.255		1.666	.682	4.069
	> 4 car trips to work per week	-.671	.319	4.412	*	.511	.273	.956
Mobility practices	Use car several times a week	.493	.260	3.590		1.638	.983	2.727
	Use car several times a month	1.092	.333	10.765	***	2.980	1.552	5.722
	Use car rarely	.872	.384	5.157	*	2.392	1.127	5.078
	Use car never	.387	.662	.342		1.473	.403	5.390
	Use public transport several times a week	-1.089	.500	4.744	*	.337	.126	.897
	Use public transport several times a month	-1.329	.509	6.817	**	.265	.098	.718
	Use public transport rarely	-1.450	.511	8.062	**	.235	.086	.638

	Use public transport never	-1.662	.565	8.635	**	.190	.063	.575
	Bicycle several times a week	-.102	.348	.086		.903	.457	1.786
	Bicycle several times a month	-.720	.356	4.079	*	.487	.242	.979
	Bicycle rarely	-.678	.367	3.413		.507	.247	1.042
	Bicycle never	-.755	.387	3.802	*	.470	.220	1.004

*p<.05, **p<.01, ***p<.001

The estimated binary logistic regression model makes a statistically significant contribution to explaining variance in PMT trip avoidance ($\chi^2(12) = 45.389$, $p < .001$). The model explains 26.8% of the variance in the dependent variable. According to Cohen (1988), this corresponds to a large effect size ($f^2 = .37$). Overall, the model yields statistically significant results.

Specifically, the independent variables gender, income, place of residence, frequency of PMT trips for commuting purposes, as well as the use of PMT, PT, and cycling, exert a statistically significant influence on the likelihood of avoiding PMT trips. These factors are discussed in greater detail in the following section.

4.3.2.4 Significant Variables

Gender. The analysis reveals that women show a significantly higher willingness to avoid PMT trips or shift towards PT. A change from male to female increases the odds of avoiding a PMT trip by a factor of 1.749, corresponding to a 74.9% higher probability of trip avoidance. Gender therefore represents a key determinant of PMT trip reduction.

Table 19: Cross-tabulation of gender and PMT trip avoidance

Source: Author's own compilation.

		Gender			Total
		Female	Male	Non-binary	
Avoid PMT trips	Yes	172 (61.6%)	156 (47.4%)	0 (0%)	328 (53.9%)
	No	107 (38.4%)	173 (52.6%)	3 (100%)	283 (46.1%)
	Total	279	329	3	611

This significant result is also reflected in women's actual avoidance of PMT trips. Accordingly, 172 women (61.6%) reported having reduced PMT trips. The pattern among men is markedly different. As shown in the cross-tabulation in Table 19, only 156 men (47.4%) reported avoiding PMT trips. None of the three respondents identifying as non-binary reported any reduction in PMT trips.

Overall, it can be concluded that women exhibit a substantially higher willingness to refrain from PMT trips than men. This tendency is consistent with findings from earlier studies, including the qualitative study *Understanding attitudes towards PT and private car use* by Beirão and Cabral (2007). That study identifies costs and financial capacity as key drivers underlying women's higher propensity to switch away from PMT.

Against this background, gender was analysed in conjunction with income. The results indicate that women in our sample are disproportionately represented in the two lowest income brackets (up to €2,000). Of the 31 respondents with a household income below €1,000, 23 were women and only 8 were men. By contrast, in the two highest income categories, €4,001 - €5,000 (33 women / 66 men) and above €5,000 (64 women / 95 men), men are clearly overrepresented, indicating that men in our sample generally have higher household incomes.

Given that income has a substantial influence on the willingness to reduce PMT trips, this income disparity provides a plausible explanation for the lower trip-avoidance propensity observed among men. In summary, women demonstrate a significantly higher readiness to reduce PMT trips, a finding that can be attributed, at least in part, to their comparatively lower income levels.

Household income. The results of the logistic regression indicate a statistically significant association between a household income exceeding €5,000 per month and the avoidance of PMT trips. Compared with a reference income of less than €1,000 per month, a household income above €5,000 is associated with an odds ratio of 0.365. This corresponds to a reduction in the probability of PMT trip avoidance by 64.5%.

The income distribution within the sample is highly heterogeneous. A total of 26.4% of respondents report a net household income exceeding €5,000 per month. In contrast, 14.2% have a household income below €2,000, including 5.1% with less than €1,000 available per month. Among the intermediate income categories, 22.4% earn between €2,001 and €3,000, 20.8% between €3,001 and €4,000, and 16.2% between €4,001 and €5,000.

Cross-tabulation analysis linking household income to avoided PMT trips reveals a clear income gradient. Among the 351 participants (57.4%) with a household income below €4,000, avoided PMT trips outnumber continued PMT trips. By contrast, among the 260 participants (42.6%) with a household income above €4,000, this pattern reverses, with fewer PMT trips being avoided than undertaken. Thus, the willingness to reduce PMT trips decreases as income rises.

This trend is particularly pronounced at the lower end of the income distribution. Of the 31 respondents earning less than €1,000 per month, 24 individuals (77.4%) reported avoiding PMT trips. In contrast, within the highest income group (above €5,000 per month), only 46.6% (75 out of 161 respondents) avoided PMT trips. These findings underline the strong role of economic capacity in shaping behavioural responses to cost increases in PMT.

Table 20: Cross-tabulation of household income and avoidance of PMT trips

Source: Author's own compilation.

		Household income						Total
		< 1.000	1.001 - 2.000	2.001 - 3.000	3.001 - 4.000	4.001 - 5.000	> 5.001	
Avoid PMT trips	Yes	24 (77.4%)	33 (58.9%)	74 (54%)	75 (59.1%)	47 (47.5%)	75 (46.6%)	328 (53.7%)
	No	7 (23.6%)	23 (41.1%)	63 (46%)	52 (40.9%)	52 (52.5%)	86 (53.4%)	283 (46.3%)
	Total	31	56	137	127	99	161	611

This mobility behaviour is consistent with the factors influencing mode choice. Travel time emerges as the most decisive criterion, and individuals with particularly high incomes typically have limited leisure time and are therefore less willing to switch from the car to alternative modes of transport. This finding is in line with

earlier research (Cornut & Madre, 2017), which shows that higher-income groups have sufficient financial resources available and consequently do not need to reduce PMT trips for economic reasons.

Place of residence, as an influential component of access, is a decisive factor in mode choice, particularly with regard to the use of PMT or alternative mobility options such as PT. Especially in rural areas, total travel time to the workplace plays a crucial role. In our study, a significant effect was identified for residents of cities with more than 100,000 inhabitants. Specifically, a negative association emerges between PMT trip avoidance and residence in cities with more than 100,000 inhabitants. When the number of inhabitants increases from fewer than 5,000 to more than 100,000, the probability of avoiding PMT trips decreases by 47.4%.

Table 21: Cross-tabulation: Place of residence versus PMT trip avoidance

Source: Author's own compilation.

		Residence				
		< 5.000	5.001 - 20.000	20.001 - 100.000	> 100.000	Total
Avoid PMT trips	Yes	79 (54.5%)	55 (50.9%)	94 (59.9%)	100 (49.8%)	328 (53.7%)
	No	66 (45.5%)	53 (49.1%)	63 (40.1%)	101 (50.2%)	283 (46.3%)
	Total	145	108	157	201	611

The place of residence of our study participants shows a well-balanced distribution between rural and urban contexts. 145 participants (23.7%) reside in small areas with fewer than 5,000 inhabitants, while 108 participants (17.7%) live in small towns with between 5,001 and 20,000 inhabitants. In medium-sized cities with 20,001 to 100,000 inhabitants, 157 individuals (25.7%) are represented, whereas the largest share of the sample, 201 participants (32.9%), live in large cities with more than 100,000 inhabitants.

The cross-tabulation in Table 21 indicates that place of residence influences the avoidance of PMT trips: 54.5% (79 of 145) of participants living in rural areas with fewer than 5,000 inhabitants report that they have indeed avoided, PMT trips. By

contrast, among participants living in urban areas, only 46.8% (100 of 201) report having avoided PMT trips.

This finding, that people living in large cities avoided fewer PMT trips than those living in rural areas, is somewhat surprising. Bergstad et al. (2011), for example, showed that households in larger cities, compared to those in rural areas, use cars significantly more frequently. Moreover, cities typically offer a wider range of mobility options as alternatives to PMT, and travel distances (e.g., to work) are often shorter. Against this background, one might initially expect PMT trip avoidance and modal shifts to other modes to be more pronounced in urban than in rural areas.

One possible explanation is that urban residents often undertake longer individual trips, making each PMT trip more carefully considered, as fuel costs per trip are perceived to be higher. In rural areas, by contrast, fuel costs often constitute a larger share of overall living expenses. Another explanatory factor may lie in the effects of the COVID-19 pandemic: our survey confirms a strong preference for home working. Especially for individuals with longer commuting distances, home working became increasingly attractive during the pandemic. This tendency to shift work into home office arrangements has been further reinforced by rising fuel prices for economic reasons.

PMT trips to work. There is a statistically significant relationship between the avoidance of PMT trips and the number of trips made to the workplace. In particular, for respondents who commute to work daily and do not make use of home working, a negative association is observed. As the number of PMT trips to work increases, from exclusively working from home to more than four PMT trips to the workplace per week, the probability of avoiding PMT trips decreases by 48.9%.

Table 22: Cross-tabulation: PMT trips to work versus avoidance of PMT trips

Source: Author's own compilation.

		PMT trips to the workplace						
		0	1	2	3	4	>4	Total
Avoid PMT trips	Yes	89	43	69	45	23	59	328
		(61.4%)	(55.8%)	(68.3%)	(58.4%)	(62.2%)	(33.9%)	(53.7%)
	No	56	34	32	32	14	115	283
		(38.6%)	(44.2%)	(31.7%)	(41.6%)	(37.8%)	(66.1%)	(46.3%)
Total		145	77	101	77	37	174	611

Trips to the workplace, in the context of the recent shift between on-site presence and home working, exhibit a highly differentiated pattern. A total of 145 respondents (23.7%) reported not commuting to the workplace at all and working exclusively from home. At the other end of the spectrum, 174 respondents (28.5%) commute to the workplace on a daily basis. At the time of the survey, the temporary home working mandate introduced by the German federal government had already been lifted; however, many organisations continued to offer home working arrangements.

With regard to PMT trips avoided since the price increase, the results show that among respondents who work entirely from home, as well as those making up to four PMT trips per week, the number of avoided PMT trips exceeds the number of non-avoided trips. By contrast, among respondents commuting daily to the workplace, only 59 out of 174 individuals (33.9%) reported avoiding PMT trips. This finding highlights the strong dependence on the car, which is perceived as a reliable and individual mode of transport offering short travel times.

Due to the high requirement for physical presence at the workplace, these respondents are highly dependent on PMT. Consequently, avoiding PMT trips without viable alternatives is not feasible, and substitution through PT is perceived as insufficiently attractive.

Mobility practices. Within the sub-domain of mobility practices, statistically significant effects are observed for all three main modes of transport—PMT, PT, and cycling.

PMT. When PMT is the primary mode of transport, the analysis shows that a reduction from daily PMT use to PMT use several times per month increases the likelihood of avoiding a PMT trip by 198%. In the case of even less frequent PMT use, the probability of avoiding a PMT trip increases by 139.2% compared with daily PMT use.

Table 23: Cross-tabulation: Primary mode PMT versus avoidance of PMT trips

Source: Author's own compilation.

		Main mode of transport PMT					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trips	Yes	55 (32.7%)	144 (57.6%)	81 (70.4%)	41 (64.1%)	7 (50%)	328 (53.7%)
	No	113 (67.3%)	106 (42.4%)	34 (29.6%)	23 (35.9%)	7 (50%)	283 (46.3%)
	Total	168	250	115	64	14	611

Daily use 168 (27.5%) and several times a week 250 (40.9%) are by far the most common patterns in our sample. This is understandable, as use of the PMT was a prerequisite for participation in our survey. The significant results of several times a month 115 (18.8%) and less frequently 64 (10.5%) relate to 179 participants who show very high values per avoidance of PMT journey.

For participants who use the PMT frequently, it is therefore difficult to avoid PMT journeys, as the PMT cannot be adequately compensated for. Less frequent use of the PMT, on the other hand, suggests that there is less dependence on the PMT and offers

Public transport. Daily use of public transport shows significant negative correlations with all other characteristics. A reduction in daily public transport use to several times a week (-66.3%), several times a month (-73.5%), less frequently (-76.5%) or never (-81%) shows the decreasing probabilities of avoiding PMT journeys listed in brackets. In general, the less frequently public transport is used, the greater the decrease in the probability of avoiding PMT journeys.

Table 24: Cross-tabulation: Primary transport mode PMT versus avoidance of PMT trips

Source: Author's own compilation.

		Public Transport					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trips	Yes	38	93	68	93	36	328
		(84.4%)	(62.4%)	(51.1%)	(48.2%)	(39.6%)	(53.7%)
	No	7	56	65	100	55	283
		(15.6%)	(37.6%)	(48.9%)	(51.8%)	(60.4%)	(46.3%)
Total		45	149	133	193	91	611

Within our sample, 45 participants (7.4%) use PT on a daily basis, 149 participants (24.4%) several times per week, 133 participants (21.8%) several times per month, 193 participants (31.6%) less frequently, and 91 participants (14.9%) never use PT. The pattern of PMT trip avoidance is therefore reversed in this context. Infrequent PT use (48.2%) or no use at all (39.6%) is associated with a comparatively low level of PMT trip avoidance. By contrast, using PT several times per month (62.4%) and, in particular, daily use (84.4%) is associated with a substantially higher likelihood of avoiding PMT trips.

For the purposes of this study, individuals who did not use PMT were excluded from the survey at an early stage. Consequently, car use constitutes the baseline condition for participation in the survey. Against this background, it is unsurprising that PT use is considerably lower than the use of the car as the primary mode of transport.

Cycling. The results of the model indicate that using a bicycle several times per month (−51.3%) as well as not using a bicycle at all (−53%) are associated with statistically significant negative effects compared with daily bicycle use, with respect to the avoidance of PMT trips. Overall, cycling is the least frequently used primary mode of transport among the three options: PMT, PT, and bicycle. The bicycle is therefore often used as a complementary mode of mobility, particularly as a feeder mode for the first and last segments of a trip.

Table 25 Cross-tabulation: Primary mode of transport (bicycle) versus avoidance of PMT trips

Source: Author's own compilation.

		Bicycle					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trips	Yes	50 (65.8%)	109 (63.4%)	68 (47.9%)	58 (45.3%)	43 (46.2%)	328 (53.7%)
	No	26 (34.2%)	63 (36.6%)	74 (52.1%)	70 (54.7%)	50 (53.8%)	283 (46.3%)
	Total	76	172	142	128	93	611

In total, 76 respondents (12.4%) use a bicycle daily, 172 respondents (28.2%) several times per week, 142 respondents (23.2%) several times per month, 128 respondents (20.9%) less frequently, and 43 respondents (15.2%) never use a bicycle. With regard to the avoidance of PMT trips, daily bicycle use (65.8%) and use several times per week (63.4%) exhibit a positive balance in terms of PMT trip avoidance. By contrast, bicycle use several times per month (47.9%), infrequent use (45.3%), or no use at all (46.2%) show a slightly stronger tendency to continue PMT trips unchanged.

4.3.2.5 Logistic Regression Analysis: Millennials

To enable a more detailed examination of the millennial generation, the following binary logistic regression model analyses the relationship between the dependent variable avoidance of PMT trips and the independent variables identified as relevant for the model.

Participants were able to respond with yes or no, meaning that the dependent variable is nominally scaled. This variable was analysed with respect to the independent variables derived from the questionnaire, and statistically significant relationships were identified. The independent variables were measured on either metric or categorical scales. Their selection is based on the relevance identified in the literature review of previous empirical studies.

The variables income, place of residence, number of persons in the household, number of electric vehicles, working context, gender, education, and travel behaviours related to the three main transport modes (PMT, PT, and cycling) were identified as key explanatory factors and included in the binary logistic regression model.

The main findings of the binary logistic regression analysis are presented in Table 26:

Table 26: Binary logistic regression results for the millennial generation

Source: Author's own compilation.

Model	Variable	B	SD	Wald	Sig.	Exp(B)	95% CI for EXP(B)	
							Lower value	Higher value
Income	< 1.000	Reference category						
	1.001 - 2.000	1,782	1,472	1,465	0,226	5,943	0,332	106,449
	2.001 - 3.000	1,582	1,437	1,212	0,271	4,866	0,291	81,413
	3.001 - 4.000	1,34	1,42	0,89	0,345	3,819	0,236	61,77
	4.001 - 5.000	1,991	1,43	1,939	0,164	7,324	0,444	120,775
	>5,000	1,707	1,42	1,446	0,229	5,514	0,341	89,167
Inhabitants	< 5.000	Reference category						
	5.001 - 20.000	0,747	0,449	2,77	0,096	2,11	0,876	5,084
	20.001 - 100.000	0,106	0,391	0,073	0,786	1,112	0,517	2,393
	>100,000	0,59	0,401	2,169	0,141	1,804	0,823	3,956
Household size	One person	Reference category						
	Two persons	0,522	0,434	1,446	0,229	0,593	0,254	1,389
	Three persons	0,833	0,456	3,34	0,068	0,435	0,178	1,062
	Four persons	0,253	0,501	0,255	0,613	0,777	0,291	2,071
	Five persons	0,441	0,766	0,332	0,564	1,555	0,347	6,971
Number of E-cars	No E-car	Reference category						
	1 E-car	1,201	0,501	5,743	0,017	3,323	1,244	8,873
Working context	Company car	0,817	0,433	3,569	0,059	0,442	0,189	1,031
	Driving time to work	0,011	0,011	1,089	0,297	1,011	0,99	1,032
	Access to public transport	0,014	0,121	0,013	0,908	0,986	0,779	1,249
	Travel time public transport to work	0	0,005	0,001	0,979	1	0,99	1,011
	Possibility of working from home	0,344	0,355	0,935	0,333	0,709	0,354	1,423
	Work in the company	0,223	0,189	1,396	0,237	1,25	0,863	1,81
	Work at home	0,003	0,207	0	0,987	0,997	0,664	1,496

	No car trips to work per week	Reference category						
	1 car trip to work per week	0,111	0,439	0,064	0,8	1,118	0,473	2,643
	2 car trips to work per week	-0,558	0,437	1,631	0,202	0,572	0,243	1,348
	3 car trips to work per week	-0,277	0,47	0,348	0,555	0,758	0,302	1,903
	4 car trips to work per week	-0,43	0,59	0,532	0,466	0,651	0,205	2,066
	5 car trips to work per week	0,251	0,491	0,262	0,608	1,286	0,491	3,365
Gender	Female	Reference category						
	Male	0,274	0,267	1,047	0,306	1,315	0,779	2,22
Education	Secondary school	Reference category						
	Technical college degree	-1,7	1,059	2,577	0,108	0,183	0,023	1,456
	Grammar school	-1,151	1,103	1,088	0,297	0,316	0,036	2,749
	Completed vocational training	-0,863	0,785	1,208	0,272	0,422	0,091	1,965
	Bachelor study	-0,677	0,8	0,717	0,397	0,508	0,106	2,435
	Diploma Study	-1,361	0,894	2,317	0,128	0,256	0,044	1,479
	Master study	-0,787	0,815	0,933	0,334	0,455	0,092	2,248
	Doctorate	-1,516	0,938	2,612	0,106	0,22	0,035	1,38
Travel Behaviours	Use car daily	Reference category						
	Use car several times a week	-0,818	0,354	5,338	0,021	0,441	0,221	0,883
	Use car several times a month	-1,327	0,448	8,759	0,003	0,265	0,11	0,639
	Use car rarely	-1,029	0,513	4,015	0,045	0,357	0,131	0,978
	Use car never	-1,167	0,802	2,118	0,146	0,311	0,065	1,499
	Use public transport daily	Reference category						
	Use public transport several times a week	1,481	0,696	4,532	0,033	4,398	1,125	17,2
	Use public transport several times a month	1,783	0,702	6,449	0,011	5,947	1,502	23,545
	Use public transport rarely	1,362	0,69	3,899	0,048	3,904	1,01	15,087
	Use public transport never	1,462	0,771	3,594	0,058	4,315	0,952	19,566
	Bicycle daily	Reference category						
	Bicycle several times a week	-0,411	0,454	0,821	0,365	0,663	0,272	1,613
	Bicycle several times a month	0,509	0,476	1,143	0,285	1,663	0,655	4,223
	Bicycle rarely	0,187	0,467	0,16	0,689	1,206	0,483	3,012
	Bicycle never	-0,132	0,53	0,062	0,803	0,876	0,31	2,476

*p<.05, **p<.01, ***p<.001

Model 1: $X^2(47) = 81.602$, $p < .001$, $R^2 = .272$

The binary logistic regression model conducted for the millennial cohort demonstrates a statistically significant contribution to explaining variance

($\chi^2(47) = 81.602$, $p < 0.001$, $R^2 = 0.272$, $f^2 = 0.37$).

Accordingly, 27.2% of the variance in the dependent variable can be explained by the model. According to Cohen's classification, an effect size of $f^2 = 0.37$ represents a strong effect.

The estimated coefficients indicate that the nominally scaled dependent variable, avoidance of PMT trips, yields substantive and meaningful results. In particular, the independent variables ownership of an electric vehicle, ownership of a company car, as well as PMT and PT usage, exert a significant influence on the likelihood of avoiding PMT trips.

4.3.2.6 Significant variables

Electric cars. The results of the logistic regression indicate a statistically significant relationship between ownership of an electric vehicle (EV) and the avoidance of PMT trips. Compared with respondents who do not own an EV, those who do own an EV exhibit an odds ratio of 3.323. Accordingly, the probability of avoiding PMT trips increases by 232.3%.

Within the millennial subsample ($n = 358$), 33 participants reported owning one EV in their household, and two participants reported owning two EVs. Overall, 323 participants, more than 90%, did not own an EV. In contrast, ownership of conventional cars is widespread: four participants reported owning no car, 152 participants owned one car, just over half of the sample (182 participants) owned two cars, 19 participants owned three cars, and one household reported owning more than three cars.

The cross-tabulation illustrates the relationship between EV ownership and PMT trip avoidance. Among the 323 participants without an EV, a marginal tendency

towards PMT trip avoidance can be observed, with 162 respondents avoiding PMT trips compared to 161 who did not.

Table 27: EV ownership versus avoidance of PMT trips

Source: Author's own compilation.

		E-Cars			
		0	1	2	Total
Avoid PMT trips	Yes	162	9	1	172
		(50.2%)	(27.3%)	(50%)	(48%)
	No	161	24	1	186
		(49.8%)	(72.7%)	(50%)	(52%)
Total		323	33	2	358

Table 27 indicates that ownership of an EV is associated with a lower willingness to avoid PMT trips. This relationship is plausible, as EVs are not directly affected by fuel price increases at petrol stations. In Germany, substantial expansion of renewable energy infrastructure has been promoted in recent years through federal subsidy programmes. The installation of photovoltaic systems in combination with wall boxes for EV charging has therefore become particularly attractive for environmentally conscious households with sufficient financial resources.

In households owning two EVs, however, PMT trip avoidance can still be observed despite the relative independence from petrol prices. This behaviour may be explained by rising electricity prices, particularly in cases where households do not operate their own photovoltaic systems.

In general, the purchase of an EV is associated with significantly higher upfront costs compared to conventional vehicles. Consequently, the decision to acquire an EV is often driven by ecological motivations rather than short-term economic considerations. Nevertheless, the sharp increase in variable mineral oil costs relative to electricity prices has narrowed the cost differential between conventional PMT use and electric mobility.

Working context. The analysis of the working context does not reveal statistically significant effects; nevertheless, it yields noteworthy insights regarding company car ownership in relation to the dependent variable *PMT trip avoidance*.

A company car effectively constitutes a flat-rate arrangement for car use and implicitly encourages frequent utilisation. Under such conditions, economic considerations are unlikely to influence behavioural change. Accordingly, a negative association is observed between company car ownership and the avoidance of PMT trips. The incentive to reduce PMT trips is therefore minimal among this group. Within our sample, 45 participants (12.6%) reported having access to a company car, whereas 313 participants (87.4%) did not.

Table 28: Company car ownership versus avoidance of PMT trips

Source: Author's own compilation.

		Company car			
		Yes	No	Total	
Avoid PMT trips	Yes	13	159	172	
		(28.9%)	(50.8%)	(48%)	
	No	32	154	186	
		(71.1%)	(49.2%)	(52%)	
	Total		45	313	358

Of the 45 respondents who had access to a company car, only 13 individuals (28.9%) reported having avoided PMT trips. The remaining 32 respondents (71.1%) indicated no change in their mobility behaviour following the fuel price increase. As the use of a company car entails no direct personal financial consequences for its users in the context of rising fuel prices, any reduction in PMT trips among this group cannot be attributed to economic factors. Instead, such behaviour is more plausibly explained by ecological or social motivations.

Travel behaviours. The results of the logistic regression analysis corroborate the descriptive findings regarding changes in the use of cars and PT as primary

modes of transport. The regression results demonstrate that individual travel behaviour exerts a statistically significant influence on whether PMT trips were avoided as a consequence of the price increase.

PMT. With regard to PMT as the primary mode of transport, the analysis indicates that a reduction from daily PMT use to PMT use several times per month is associated with a 60.9% decrease in the probability of avoiding a PMT trip.

Table 29 Primary mode of transport (PMT) versus avoidance of PMT trips

Source: Author's own compilation.

		Primary mode of transport PMT					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trip	Yes	30 (30.0%)	76 (52.1%)	39 (61.9%)	22 (56.4%)	5 (50.0%)	172 (48%)
	No	70 (70.0%)	70 (47.9%)	24 (38.1%)	17 (43.6%)	5 (50.0%)	186 (52%)
Total		100	146	63	39	10	358

The daily use of PMT by 100 respondents (27.9%) and several times per week use by 146 respondents (40.8%) represent by far the most frequent usage patterns within the sample. This is unsurprising, as the use of PMT was a prerequisite for participation in the survey. The proportion of respondents who avoided PMT trips is comparatively low (30%) among daily users, but increases to over 50% in all subsequent frequency categories and, apart from daily use, constitutes the dominant share in each group. The highest proportion of avoided PMT trips is observed among respondents who use PMT several times per month (61.9%).

These findings can be interpreted as follows: for respondents who rely heavily on PMT, avoiding PMT trips is difficult, as PMT cannot easily be substituted by alternative modes of transport. Conversely, individuals who reduced their PMT use to a low level or ceased using PMT altogether during the crisis are likely to have

already used PMT infrequently prior to the price increase. Consequently, this group exhibits only limited additional potential for further reductions in PMT trips.

Up to this point, the analysis has focused exclusively on PMT use. In the following section, we turn our attention to the mobility behaviour of multimodal users, that is, individuals who routinely make use of different transport modes in their daily travel behaviour (Wang et al., 2014).

PT. Daily use of PT exhibits statistically significant *negative* associations compared with reduced usage frequencies, such as several times per week or several times per month.

Table 30: Public transport versus avoidance of PMT trips

Source: Author's own compilation.

		Main mode of transport public transport					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trip	Yes	17	42	30	59	24	172
		(77.3%)	(51.9%)	(39.5%)	(46.5%)	(46.2%)	(48%)
	No	5	39	46	68	28	186
		(22.7%)	(48.1%)	(60.5%)	(53.5%)	(53.8%)	(52%)
Total		22	81	76	127	52	358

In our sample, 22 participants (6.1%) use PT on a daily basis, 81 participants (22.6%) several times per week, 76 participants (21.2%) several times per month, 127 participants (35.5%) less frequently, and 52 participants (14.5%) never. As individuals who do not use PMT were excluded from the study by design, it is plausible that PT usage is substantially lower than the use of PMT as the primary mode of transport.

Cycling. A similar pattern can be observed for cycling as for PT, albeit less pronounced. In this case, the logistic regression analysis does not reveal any statistically significant associations between the categories of cycling frequency and the dependent variable.

Table 31: Cycling versus avoidance of PMT trips

Source: Author's own compilation.

		Main mode of transport bicycle					Total
		(almost) Daily	Several times a week	Several times a month	Less frequently	Never	
Avoid PMT trip	Yes	25	52	34	35	26	172
		(54.3%)	(57.1%)	(38.6%)	(41.2%)	(54.2%)	(48%)
	No	21	39	54	50	22	186
		(45.7%)	(42.9%)	(61.4%)	(58.8%)	(45.8%)	(52%)
Total		46	91	88	85	48	358

The results for bicycle use are relatively balanced with regard to the avoidance of PMT trips. Overall, the study indicates that the willingness to switch to cycling has increased as a result of the fuel price rise. However, millennials do not emerge as clear frontrunners of a dominant shift towards bicycle use (Konietzka & Neugebauer, 2023).

The distribution between daily bicycle use (46 respondents; 12.8%) and no bicycle use at all (48 respondents; 13.4%) is almost identical. The most frequently reported category is bicycle use several times per week (25.4%), followed by use several times per month (24.6%) and less frequent use (23.7%).

Overall, it can therefore be concluded that cycling behaviour as an alternative mode of transport does exert an influence on the avoidance of PMT trips. However, among millennials this influence is less pronounced than that observed for PT.

4.3.3 Limitations

The survey was addressed exclusively to PMT users. Of the total 1,330 accesses to the questionnaire, 611 participants met this criterion and completed the survey in full.

Mobility behaviour is typically shaped by long-established routines, and the purchase of a car represents a long-term modal choice. The survey was conducted in March and April 2022, i.e., shortly after the sharp price increase at the end of February 2022. It therefore cannot be stated with certainty whether, at that point in time, the financial pressure on PMT users was already sufficiently strong to induce adjustments in trip behaviour from an economic perspective. Financial effects are often only reflected in household budgets after several weeks or months.

At the time of the survey, there was considerable uncertainty as to whether the economic consequences of the war in Ukraine would be of a short-term or long-term nature. Following data collection, inflation continued to rise and exceeded 5%, significantly constraining the financial leeway of many households. In this context, decisions regarding basic expenditures, such as refuelling a vehicle or purchasing food, increasingly became existential challenges.

In particular, the sharp increases in gas and electricity prices constituted an additional burden that could not be offset in the short term by wage adjustments. These developments had substantial effects on the resources available for mobility and highlighted the growing necessity of managing financial resources efficiently. Against this background, any assessment of mobility-related expenditure must take into account the increasingly adverse socio-economic framework conditions.

In the period following the survey, political decision-makers introduced subsidies to provide temporary relief to the population. Within the mobility sector, both PMT users and PT users were addressed. PMT users benefited from a temporary fuel

rebate in the form of a subsidised fuel price below €2 per litre, while PT could be used nationwide for €9 per month.

The focus of the study was on the three main modes of transport: PMT, PT, and cycling. Given the increasing importance of ecological considerations and the general objective of substantially reducing traffic in inner cities, future research should also include walking as a mode of transport. Further research avenues include a more detailed classification of trips and the identification of supporting measures (e.g., home working).

Current economic conditions are characterised by considerable uncertainty, which complicates a precise assessment of measures aimed both at relieving households and at supporting the transport sector. In this context, it appears essential to systematically analyse price dynamics and changing framework conditions in future research.

A renewed investigation of these factors is crucial in order to derive robust and targeted implications for the design of economically and socially acceptable measures in the transport sector. Such analyses could contribute to increasing both the acceptance of sustainable mobility solutions and their long-term effectiveness.

5 Studies on Digitalisation

Within the field of digitalisation, a matrix of key measures was developed in the theoretical section, encompassing both pull effects aimed at increasing the attractiveness of PT and push effects intended to relatively reduce private car use. Building on this framework, three empirical studies were conducted, each addressing different facets of digital transformation processes. Study 4 focuses on the future of the digital bus stop (Section 5.1), while Study 5 examines the potential of autonomous buses from the users' perspective (Section 5.2). Study 6 likewise addresses autonomous driving, but shifts the focus to the providers' perspective (Section 5.3). As outlined in Section 2.3, the identified measures—analogue to those in the area of subsidies—should not be considered in isolation, but rather unfold their effects through complex interactions and structural interdependencies. It is therefore important to emphasise that, although not every individual measure was examined in a separate study, the action fields presented in the theoretical matrix are reflected across the three studies and analysed in terms of their interplay.

5.1 Study 4: Digital Bus Stop

The study on the digital bus stop examines, by way of example, measures such as mobility on demand, digital guidance and information systems, and MaaS concepts, and assigns them to the categories of Kaufmann's framework. Within the dimension of access, digital bus stops expand spatial and temporal availability, particularly in peripheral areas; uncertainty and waiting times are reduced, and access to seamless multimodal mobility chains is facilitated. With regard to skills, users acquire competencies in flexible, app-based mobility planning and in handling multimodal options, thereby strengthening their ability to combine different transport modes. In terms of appropriation, PT is increasingly internalised as a reliable and individually adaptable alternative; it is perceived as modern, and sustainable mobility becomes more firmly embedded in everyday routines. These hypothesised effects in the sense of Kaufmann constitute the core focus of the study. A concise presentation of the research design, data collection and analysis

(Section 5.1.1), followed by the key findings (Section 5.1.2), the subsequent discussion (Section 5.1.3), and the limitations (Section 5.1.4), completes the analysis.

5.1.1 Research Design

In connection with the increasing preference of people to live in large cities and the resulting continuous growth of urban centres, a rising demand for highly individualised and flexible mobility solutions can be observed (Moeckel & Nagel, 2016). The consequences of these changing demands necessitate a shift towards modern and integrated mobility concepts in order to ensure an efficient provision of mobility in densely populated urban areas. Policymakers, urban and transport planners, as well as PT operators are therefore confronted with the challenge of designing these concepts in a future-oriented, sustainable, and at the same time economically efficient manner.

PT operators, in particular, are tasked with handling a substantial share of collective passenger transport through their bus and rail services. Alongside PMT, PT is increasingly undergoing digital transformation. Through the digital interconnection of mobility providers and users, MaaS concepts become feasible (Arsenio et al., 2016; Kamargianni & Matyas, 2017). These MaaS concepts integrate public and private transport services via a unified digital access platform. A core component of such MaaS concepts consists of individualised, dynamic, and flexible mobility solutions that are tailored to the specific needs of users and offer customised mobility options for each trip.

These concepts, together with innovations in mobility such as fully automated driving, fundamentally challenge the traditional, schedule-oriented PT system and, consequently, the very existence of conventional bus stops. Bus stops function as locations that enable passengers to board and alight from PT vehicles and thus serve as collection points for customers within collective PT systems. From the passenger's perspective, stops represent a visible and tangible interface of

transport operators. At present, passengers can only access PT services if they use a fixed stop.

In addition to spatially bringing together mobility supply and demand, stops primarily serve to inform passengers about timetables, route networks, fares, tickets, and operational disruptions. Some stops are increasingly being utilised as marketing instruments. Within the context of this scientific study, we examine the role and potential transformation of bus stops in German cities against the backdrop of increasingly flexible mobility concepts. Currently, passenger transport without fixed stops is not feasible. However, ongoing digitalisation in mobility has the potential to rapidly alter this status quo, potentially leading to the partial or complete abolition of fixed stops.

The central research question guiding this study is therefore: **“How will bus stops in German cities change in the context of Mobility as a Service concepts?”**

To address this research question, qualitative interviews were conducted with eight subject matter experts. The aim of these interviews was to consolidate expert knowledge from different professional perspectives in order to assess future developments, trends, and technological innovations as comprehensively as possible. Based on the findings of these interviews, future visions for the bus stop were derived within the context of MaaS concepts. The selection of experts was guided by the objective of incorporating well-founded expertise from diverse fields, including passenger information systems, infrastructure, operations, and marketing within PT operators, in order to capture a wide range of perspectives and analytical viewpoints.

Data Collection

In selecting the experts, care was taken to ensure that they were drawn from major cities in different regions of Germany. All interviewees were senior or top-level managers of German PT operators who, in their strategic and operational

roles, are directly involved with issues related to bus stops. The interviews therefore incorporated the expertise of decision-makers from, among others, four German metropolitan cities with populations exceeding one million inhabitants.

Table 32 provides an overview of the managers interviewed as well as the size of the respective cities served by their transport operators. The chosen methodological approach consisted of semi-structured, guideline-based interviews. Due to geographical distance, seven of the eight interviews were conducted by telephone, while one interview was carried out face to face. The interview guide was made available to the experts prior to each interview in order to facilitate a broader and more in-depth discussion.

During the individual interviews, the discussion initially addressed the overarching themes of digitalisation, multimodal bus stops, and stop design, drawing on the current discourse in mobility research. Subsequently, the megatrends of digitalisation and innovative mobility were discussed in relation to the future development of bus stops. With regard to the research question, three fundamental scenarios were considered as possible outcomes: the persistence, transformation, or disappearance of the bus stop. The experts were asked to apply their professional expertise to describe and analyse short, medium, and long-term developments of bus stops within these scenarios.

Table 32: Overview of the experts

Source: Author's own compilation.

Expert	Position	Job description	Gender	Age	Number of inhabitants	Duration of the interview (in h)
Expert 1	HoD	Travel information systems	m	40-50	600.000-700.000	01:35
Expert 2	HoD	Travel information systems	m	50-60	1.000.000-1.100.000	01:34
Expert 3	HoD	Travel information systems	m	30-40	300.000-400.000	01:23
Expert 4	CEO	Business management	m	40-50	1.800.000-1.900.000	01:06
Expert 5	CEO	Business management	w	50-60	300.000-400.000	00:48
Experte 6	HoDiv	Infrastructure	m	50-60	500.000-600.000	01:01
Experte 7	HoD	Supply bases	m	30-40	3.600.000-3.700.000	01:00
Experte 8	HoD	Transport telematics	m	40-50	1.500.000-1.600.000	01:00

The interviews lasted between 48 and 95 minutes. All interviews were audio recorded, subsequently transcribed verbatim, and analysed using a thematic approach.

Data Analysis

For the content analysis of the dataset, we followed a thematic analysis procedure based on Braun and Clarke (2006). Thematic analysis enables the identification of similarities and differences across datasets and also allows for the generation of unforeseen and novel insights. It is widely used for the analysis of qualitative data and is characterised by a high degree of flexibility, as it is not bound to a specific theoretical framework.

In our analysis, we first familiarised ourselves thoroughly with the material. Subsequently, themes and sub-themes were coded. The iteratively developed coding framework was then systematically applied to all interviews.

5.1.2 Findings

5.1.2.1 Short-term scenario: Expected changes at bus stops

Digitalisation

Real-time information. Across German cities, bus stops exhibit a largely standardised design and are therefore highly recognisable to the public. Despite ongoing advances in digital infrastructure, experts anticipate that timetable information will continue to be provided in paper form in the short term, as regulatory requirements stipulate that passengers must also be reached through non-digital channels. Nevertheless, there is broad consensus among the experts that the continued expansion of digital and IT-based infrastructure will, in the medium term, enable a fully paperless stop. In this context, experts identify two key objectives: first, the digitalisation of passenger information, particularly timetables, accessible both at the stop itself and via mobile applications; and second, the development of an ecologically efficient, “green” bus stop. Equal access to passenger information must continue to be guaranteed for all user groups.

Real-time passenger information provided directly at stops is beneficial for all target groups. However, as not all passengers are able or willing to access digital media, information will continue to be disseminated via multiple channels. In addition to digitally available information through travel information systems, printed timetables will therefore remain in place. In particular, many older citizens who rely on PT in inner-city areas are not adequately reached through digital media alone. At bus stops, this sizeable user group must continue to have access to comprehensive information without requiring a smartphone.

According to the experts, bus stops will, in the short term, be widely equipped with digital departure displays (“DFI lights”) that present dynamic real-time passenger information in a clearly visible manner. These displays provide passengers with all information relevant to their trip, thereby reducing the need to consult additional information sources while waiting at the stop. Integration into existing

signage systems can be achieved with relatively low technical effort and financial expenditure. Moreover, no expansion of power supply infrastructure is required, as these displays can be operated using batteries or solar modules. Existing ICT infrastructure is sufficient to ensure continuous real-time information on bus departures.

In addition, intermodal transport control systems allow supplementary information, such as announcements of upcoming events or the results of major sporting competitions, to be displayed at stops alongside timetable information. However, it must be ensured that such additional content does not detract from the primary function of providing clear departure information. Navigation systems that display transfer connections represent a further extension of passenger information services. During transfers, passengers require clear and effective orientation aids. After alighting from a vehicle, rapid orientation must be supported through effective signage at stops, available in both digital and printed formats.

While stop signage continues to provide static information, this is increasingly complemented by dynamic real-time information displayed on monitors. Digital media are intended to enable time-efficient boarding and transfers. Beyond information provided directly at stops, mobile applications play a crucial role as an information medium. PT operators provide real-time information through their apps, allowing passengers to access relevant departure information independently of location. As a result, passengers are already aware of departure times before arriving at the stop, which can significantly reduce waiting times.

In order to generate ecological added value, a transition towards the concept of the “green” bus stop is envisaged. The costs associated with expensive infrastructure and the maintenance of LCD technology can be reduced through the use of new e-paper technologies. Such green stops primarily rely on renewable energy sources, including solar panels and environmentally friendly battery-powered displays. At major interchange stops, particularly at interfaces with rail services, large-format LCD displays will continue to play an important role in managing transfers effectively.

ICT supported marketing. The experts confirm that, in principle, bus stops can be equipped with fast Wi-Fi access; however, implementation strategies differ considerably across regions. Some major cities plan to introduce area wide public Wi-Fi at bus stops in the short term. The provision of free internet access is generally assessed as a substantial added value for passengers.

Expert 7 emphasised: *“By providing Wi-Fi access, the bus stop becomes a marketing instrument for public transport operators, enabling more targeted, individualised and demand-oriented advertising.”* This creates additional opportunities to position the transport operator as a recognisable brand. Via Wi-Fi, passengers could, for example, receive advance information about their upcoming trip. Subject to compliance with the EU General Data Protection Regulation (GDPR), it would even be conceivable to display a brief profile of the bus driver or specific vehicle information in order to foster a more personal connection.

Other cities, however, intend to provide Wi-Fi access at bus stops only if a viable business model can be established. In such cases, partnerships with private companies are required to ensure adequate financing. One option discussed is the outsourcing of bus stop management to an external service provider.

At major interchange stops, particularly those with high tourist volumes or direct connections to airports, Wi-Fi access is considered to generate substantial additional value. One expert expressed concerns that open Wi-Fi networks might attract socially disadvantaged groups to bus stops and potentially increase vandalism-related costs.

Through Wi-Fi connectivity, an even closer integration between bus stops and vehicles becomes possible. Vehicle capacity levels can be monitored in real time and communicated to passengers, indicating current passenger loads. In cases of overcrowding, alternative routes or vehicles can be suggested. A further technical innovation discussed by the experts is the installation of USB charging ports, enabling passengers to charge their smartphones while waiting.

Multimodal Bus Stops

In the short term, according to the unanimous opinion of the experts, there will be no widespread introduction of virtual stops. In particular for high-capacity passenger transport, bus stops will remain fixed and visible elements of the urban landscape in German cities. Only in especially innovative cities are virtual stops expected to emerge in the near future, primarily as on-demand services offered by third-party providers as a supplement to conventional PT. The experts do not believe that German PT operators themselves will establish or operate such virtual stops. Instead, subsidiaries of European automotive manufacturers have increasingly focused on this new business model. As Expert 2 noted:

“These innovative shuttle-on-demand systems are being tested in pilot projects and are gradually being expanded as smart, intelligent transport systems.”

The future topic of electromobility offers two key advantages. First, electric buses can be charged directly at bus stops; second, charging infrastructure for EVs used by PT customers can be provided at park-and-ride facilities. The experts identify significant potential to equip bus stops, particularly in peripheral areas, with charging facilities powered by renewable energy sources, such as solar panels. However, implementation requires comprehensive urban planning concepts to allocate and manage the necessary space.

Design of Bus Stops

The experts anticipate that, in the short term, bus stops will undergo only minor visual changes and will remain a permanent feature of city centres. Increasing passenger volumes must be considered from a safety perspective, requiring appropriate adjustments to stop spacing. Expert 5 confirmed:

“An additional technical option is the use of beacons for visually impaired passengers at bus stops, enabling passenger information to be read aloud.”

Such beacons are already available at some stops and are increasingly becoming an integral part of stop reconstruction projects, ensuring improved accessibility and optimised boarding conditions.

The most substantial short-term changes are expected in payment systems. Many bus stops currently feature ticket vending machines, which incur high operating and infrastructure costs. In the near future, these machines are likely to be progressively removed from large cities. Passengers will be required to purchase tickets exclusively via modern payment systems (e.g., mobile applications) or directly on board vehicles. The primary objective of these modern payment systems is to simplify procedures for customers and to reduce barriers to access.

5.1.2.2 Medium-term scenario: Expected changes to bus stops

Digitalisation

Real-time information. Urban bus stops will continue to exist with their core functions intact. Timetables will, however, be provided and maintained exclusively in digital form. In the medium term, the deployment of e-paper solutions at so-called “green bus stops” is expected to expand to peripheral areas as well, rendering printed timetables obsolete. It is conceivable that departure times will be projected directly onto the walls of bus shelters, ensuring good legibility for passengers. Transfer management will be handled via digital infrastructure, providing consistent information on diversions, disruptions and route changes.

From the experts’ perspective, real-time information based on GPS data from buses offers substantial added value due to its high degree of accuracy and timeliness. It can therefore be assumed that, in the medium term, PT operators will make vehicle GPS data visible to users via their mobile applications. This increased transparency allows passengers to track the real-time location of their desired services. Such a technical enhancement is particularly beneficial for route planning among passengers who are familiar with local conditions. As Expert 7 noted: *“Passengers are able to assess traffic light cycles and congestion patterns*

based on their individual experience.” This enables them to decide autonomously when to head towards the bus stop in order to catch their service with minimal waiting time.

Based on interactive network maps, the IT departments of transport operators are expected to introduce filter functions that enhance clarity by allowing users to select specific routes and time windows.

ICT supported marketing. In the medium term, experts anticipate that in large metropolitan areas, where bus stops have already been fully equipped with Wi-Fi in the short term, digital and personalised marketing will increasingly be managed via dedicated mobile applications. This will allow transport operators to deliver targeted advertising content directly to users. Location specific advertising for nearby shops and their promotional offers can be displayed at individual stops. Consumer information and user preferences may also be incorporated into the routing of advertising content.

The potential commercialisation of such data, or its use for research purposes, is conceivable, provided that all processes comply with the requirements of the EU GDPR. Within the framework of integrated and modern bus stop management, advertising content delivered via mobile applications may be complemented by promotional material displayed on digital departure boards, thereby becoming an integral component of a broader bus stop entertainment programme.

Multimodal bus stop

Even looking beyond a five-year horizon, experts do not foresee a radical transformation of the traditional bus stop. In increasingly densely populated city centres, the conventional bus stop will remain the central node for high-capacity PT. “Call for on-demand services will increase, but only to a limited extent,” emphasises Expert 2. Such services are expected to function primarily as feeders for areas without direct access to PT and to operate as part of MaaS based mobility solutions.

Virtual stops may be offered selectively alongside conventional stops for occasional services and major events, but not as a standard option for everyday passenger transport. In the medium term, a strengthened system of collective PT will be complemented by comprehensive MaaS concepts. Passenger volumes at traditional stops are expected to remain significantly higher than those at virtual stops. MaaS systems will be capable of generating precise forecasts based on quantitative and qualitative datasets, regarding nearby complementary mobility options such as bike-sharing schemes, e-scooters, or car-sharing services.

Design of bus stops

Experts consider a strengthening of the conventional bus stop in the medium term to be realistic. This involves a substantial expansion of existing central stops in inner-city areas, as well as targeted functional enhancements at highly frequented peripheral stops. These developments are expected to foster increased cooperation with companies from the service, logistics, and retail sectors, which may adopt the bus stop as a distribution and service interface.

For example, external service providers could offer laundry services at major interchange stops, enabling time-constrained users to conveniently have their business clothing cleaned. Secure drop-off and collection would be possible at any time of day or night via individual PIN codes. Strategically designed logistics concepts, including parcel lockers at bus stops, would relieve delivery services and simplify complex urban logistics processes.

Existing PT infrastructure would allow users to collect parcels according to their own schedules, independent of opening hours, while also enabling the return of unwanted goods. In addition to these service-oriented and logistical functions, so-called “smart walls” are expected to create an enhanced retail experience and serve as interfaces with local commerce. As Expert 1 notes: “Passengers can conveniently compile their shopping basket at the bus stop and order products via dedicated terminals.”

Goods would be professionally prepared, taking into account cooling, hygiene, and other requirements and placed in lockers at the stops, accessible via an app-based code. Non-perishable goods could be stored on site and dispensed immediately upon payment. These components may be bundled into so-called “use-store spaces”, providing a comfortable, weather-independent waiting environment. Such spaces would integrate further innovations, including flat screens offering entertainment in the form of short clips and news content, as well as recreational facilities such as gaming consoles. In this way, the bus stop becomes part of an experiential environment. At major hubs, marketing activities may be combined with events such as live cooking demonstrations, further enhancing the attractiveness of the location.

5.1.2.3 Long-term scenario: expected transformations of the bus stop

Digitalisation

Real-time information systems are expected to reach a high level of maturity and to constitute a stable and consistent component of PT infrastructure. Real-time data will be displayed across multiple digital interfaces. Arrival times will be calculated using distance-based indicators derived from detailed GPS data of buses, complemented by traffic metadata from private transport, thereby providing passengers with highly accurate predictions of vehicle arrival times.

Expert 3 emphasised: *“Passengers will have access to a visualised representation of the route and of the available mobility options.”* Precise vehicle localisation, combined with user-generated assessments, enables optimised route planning. In the long term, this routing will also incorporate the individual’s path from their current location to the nearest stop. The smartphone will serve as the primary access point to the digital infrastructure, displaying a virtual environment that guides users directly to the stop.

Any changes occurring during the trip will be immediately integrated into the routing process, resulting in continuous optimisation of the journey. The destination

remains fixed throughout navigation, while all mobility services dynamically adapt to this target location.

ICT supported marketing. From the experts' perspective, loss-making PT systems will increasingly depend on financial relief measures in the long term and will therefore seek to generate additional revenues through advertising and events at stops. In particular, the shift of marketing activities to passengers' personal devices is expected to generate new income streams and to create additional resources for passenger information services.

Given the limited profitability of certain locations, the experts anticipate the emergence of new operating models for peripheral or remote stops. Large companies, such as furniture retailers, DIY stores or major retail chains, may act as operators of their own stops, with the objective of ensuring access to their premises and attracting new customers. In such arrangements, transport operators could receive a fixed fee for serving these stops according to an agreed service frequency. The names of these stops would function as orientation aids and could be designated by the relevant operating company.

Multimodal Bus Stop

The experts agree that, in the long term, autonomous driving will be realised and will significantly affect PT accordingly. The maturation of self-driving technology opens up numerous possibilities for innovative passenger transport. As Expert 4 emphasised: *“For demand-oriented mobility, small autonomous shuttle buses could, for example, connect passengers from rural areas to high-capacity public transport services on an on-demand basis, thereby ensuring a flexible public transport system as the backbone of Mobility-as-a-Service.”*

A radical elimination of fixed bus stops would increase flexibility for individual users; however, it would also result in longer waiting times if vehicles deviate from scheduled routes, thereby increasing overall travel time. Each on-demand trip is

highly individualised and requires precise trip management. According to the prevailing expert assessment, it is therefore unlikely that on-demand services will constitute the sole form of mobility, even in the long term. High-capacity PT in inner-city areas will continue to rely on fixed bus stops.

Design of Bus Stops

Following the consolidation of innovations and the substantial expansion of existing central bus stops, experts anticipate further long-term developments, particularly in relation to demographic change, autonomous driving and video surveillance. The human user remains at the centre of mobility, and the bus stop continues to function as a place of connection. In the long-term scenario, older generations are expected to be familiar with smartphone-based functions, having grown up using such technologies.

Against this background, there will be an increased demand for care services and social support facilities that can be accessed at bus stops in the long term. Expert 3 highlighted key advantages: *“The mobility app will provide functions allowing users to request assistance at a bus stop or to register themselves as voluntary helpers.”* The experts firmly expect the widespread deployment of autonomous buses. The introduction of this technology will also necessitate structural changes at bus stops. Platform dimensions, boarding and alighting heights, and kerb design will be adapted to the technical requirements of AVs.

Comprehensive video surveillance at bus stops will record criminal activity and vandalism. These recordings will serve as evidence and are intended to enhance passengers' perceived sense of safety.

5.1.3 Discussion: Digital Bus Stop

The bus stop, which for decades has served as the central public-facing symbol of PT operators, is itself undergoing a significant transformation as a result of

technological developments and the introduction of contemporary MaaS concepts (Camacho et al., 2016). While the bus stop in its traditional form remained largely unchanged for a long period, the assessments of the experts interviewed indicate that noticeable modernisation processes can be expected in the near future, particularly in urban centres. A key driver of this development is comprehensive digitalisation, through which real-time information is being rolled out nationwide and complemented by innovative passenger navigation systems. In this context, the expansion of Wi-Fi access points at stops also opens up new opportunities for personalised marketing strategies and enhanced connectivity between the stop and the vehicle. Although “on-demand” services are already being piloted in some large cities, they should, in the short term, be understood primarily as a complementary element to conventional PT, rather than as a substitute for it (Shaheen & Cohen, 2018).

The experts agree that the conventional stop will continue to play a central role in urban areas in the short, medium and long term and cannot be replaced by on-demand services. This assessment is based on a cost-benefit consideration: although flexible and virtual stops enable demand-oriented and highly flexible use for passengers, they impose substantial temporal and financial burdens on transport operators due to the required detours (Darsena et al., 2022). One potential compromise could lie in the bundling of temporally and spatially correlated user requests, whereby several passengers are collected jointly at a defined location. In densely populated inner cities, however, fixed stops with average spacings of approximately 400 metres have proven to be highly efficient, making a departure from this system unlikely. Individual transport services, such as taxis, will therefore remain available as complementary but more cost-intensive options.

Building on these short-term developments, the experts also anticipate a further increase in the degree of digitalisation in the medium term. GPS-based real-time information enables continuous and highly accurate localisation of buses, which can be accessed by passengers at any time via mobile applications.

In addition, stops may be enhanced through targeted entertainment programmes and supplementary service offerings, with the commercialisation of advertising space expected to play an increasingly important role. A key challenge for transport operators will be to strike an appropriate balance between commercial content and the clear presentation of passenger information, an issue that is central to the design of contemporary mobility services. Previous studies indicate that the growing commercialisation of public spaces, including stops, through advertising or other monetisable services may lead to an overload of essential passenger information (Saghapour et al., 2016). To ensure passenger satisfaction, it is therefore crucial that relevant information, such as real-time timetables and navigation guidance, remains clearly visible and easily accessible. Insufficient information provision may result in uncertainty and frustration among users, which in turn can negatively affect PT use (Hamidi & Zhao, 2020).

From a long-term perspective, a more radical scenario could involve the complete abolition of conventional stops, particularly in rural areas, where virtual stops and “hotspots” might emerge based on demand-driven trip requests. In urban agglomerations, however, stationary stops are expected to remain highly relevant, especially in light of projected urban population growth and increasing demand for mobility services. For example, the United Nations estimate that by 2050 approximately 68% of the world’s population will live in cities, further intensifying pressure on urban transport systems and reinforcing the need for efficient PT solutions (United Nations, 2019).

Moreover, experts anticipate that PT will increasingly have to compete with PMT. In this context, it will be essential to highlight the advantages of PT over private car use through attractive and integrated mobility concepts, particularly with regard to urban challenges such as congestion, environmental regulations and diesel bans (Buehler et al., 2017).

Against this backdrop, the introduction of autonomous buses is widely regarded as inevitable. In the long term, experts expect a comprehensive redesign of stops to accommodate the operational requirements of autonomous services. Future

mobility solutions may also include autonomous drones or cable-based transport systems, which could help relieve road traffic while simultaneously creating new challenges for stop management (Cheranchery et al., 2019). As PT is likely to remain dependent on public subsidies, the involvement of financially strong partners and the outsourcing of stop operations may represent viable strategies to reduce investment and maintenance costs while generating additional revenue through expanded networks.

5.1.4 Limitations

Despite the contributions discussed above, several limitations need to be acknowledged. The findings are based on expert assessments and therefore represent projections of future developments. Short and medium-term changes can be anticipated with a relatively high degree of confidence, as the expected innovations are largely technically feasible, albeit not yet fully market ready. Long-term developments, however, cannot be predicted with certainty in terms of their occurrence likelihood, as prerequisite technologies must first be successfully tested, implemented and deployed at scale.

The short-term introduction of comprehensive, innovative payment systems offers passengers modern options to purchase tickets across transport association boundaries, for instance via smartphones. At the same time, the gradual removal of ticket vending machines at stops may create access barriers for certain user groups. PT, as a core component of services of general interest, should remain accessible to all citizens without restrictions. Furthermore, the EU GDPR has increased public awareness regarding the careful handling of digital identities. The growing prevalence of fake news and cyberattacks increasingly affects both users and transport operators. In particular, targeted cyberattacks on critical infrastructure impose limits on digitalisation efforts and may constrain the innovative capacity of PT stops.

In addition, it must be considered that energy availability and natural resources are finite. Should specific technologies become unavailable due to resource scarcity, alternative solutions will be required. Innovations that initially appear promising may ultimately fail to gain user acceptance, necessitating a fundamental reorientation by decision-makers within transport organisations. Given the dynamic nature of the mobility sector, even experts can only project long-term scenarios while accounting for significant uncertainties. Consequently, the development of future PT stops requires accompanying user-centred research.

According to the experts, the large-scale introduction of autonomously operated buses is expected to occur in the long term. This transition will have profound implications for both the transport sector and stop infrastructure. In this context, PT systems, often operating at a deficit, may realise cost savings and potentially evolve into more economically viable market segments. This could support municipal budgets and, through more affordable PT services, create additional incentives for shifting trips away from PMT.

Autonomously operated drones and cable car systems represent further mobility options that may gain relevance in the long term. Climate change and its consequences have contributed to a more sustainability-oriented attitude within the German population regarding the use of natural resources. Ongoing debates on the introduction of CO₂ taxes or the expansion of emissions trading schemes aim to reduce air traffic volumes and are likely to be closely linked to environmentally friendly technologies. PT stops will need to be adapted and redefined in line with these technological developments.

The findings of this study demonstrate that the PT stop constitutes an indispensable link between the population and mobility services. In light of this insight, the authors argue that the stop is underrepresented in the academic literature and offers substantial potential for further research. In particular, experts highlight an increased need for modern MaaS concepts in rural regions.

5.2 Study 5: Autonomous Buses from the User Perspective

The study on autonomous buses from the user perspective examines the impacts of this future-oriented technology along the dimensions of Kaufmann's conceptual framework. With regard to Access, autonomous buses and shuttles create new forms of accessibility, particularly in peripheral and low-density areas, thereby expanding the spatial and temporal access profile of PT.

In terms of Skills, their use primarily requires a basic level of technological affinity in handling digital booking and information systems, meaning that digital competences increasingly become a prerequisite for access.

Appropriation, finally, only unfolds once users internalise autonomous buses as safe, comfortable and trustworthy, and consequently accept them as a self-evident mobility option. These assumed effects, in line with Kaufmann's framework, constitute the empirical focus of the study.

The analysis is structured by a presentation of the research design, data collection and data analysis (Section 5.2.1), the key findings (Section 5.2.2), the subsequent discussion (Section 5.2.3), and the limitations of the study (Section 5.2.4).

5.2.1 Research Design

The use of artificial intelligence (AI) is steadily gaining importance. AI can support people in a wide range of contexts and offers numerous fields of application. In addition to, for example, surgical robots in medicine, the transport sector is increasingly being shaped by the deployment of AVs. Worldwide, both the development and prevalence of automated driving are progressing through a variety of pilot projects and field trials. These developments give rise to modern technological opportunities that can support the achievement of climate targets and the envisaged transport transition. Enhancing and increasing the attractiveness of PT

represents a key lever for reducing PMT. In this context, AVs can make a meaningful contribution.

While autonomous trams are already in regular operation in some countries (e.g. Germany, France and Italy), the technology for autonomous buses has not yet reached full series maturity. Autonomous buses offer a wide range of opportunities and can, among other things, help to safeguard mobility provision and address the existing shortage of bus drivers. At the same time, transport operators are confronted with substantial challenges. In addition to technical, legal and financial barriers, another obstacle has so far received comparatively little attention: societal acceptance of AVs. Without public acceptance, the potential of these innovations cannot be fully realised or utilised. For the successful establishment of autonomous buses, it is therefore essential to actively involve society in this process. Previous studies (e.g. Kaiser & Malanowski, 2020; Statista, 2021) indicate that older generations often feel overwhelmed by such technological innovations and are therefore more likely to be deterred. Younger generations, by contrast, have grown up with digital technologies and may approach the use of autonomous buses in PT with greater openness and curiosity.

Against this background, the present study aims to investigate how the millennial generation evaluates autonomously driven buses. How do millennials perceive autonomous buses in PT? How do participants envisage the future of bus travel?

In the first step, this study adopts a qualitative research approach in order to gather in-depth insights into an innovative and still emerging topic. The objective is not to test hypotheses on the basis of a large, representative sample, as would be the case in quantitative research, but rather to develop initial propositions based on a smaller sample (Brüsemeister, 2008). To this end, ten individual interviews were conducted with participants belonging to the millennial generation. The interviewees were selected according to defined criteria. First and foremost, all participants had to belong to the millennial generation, meaning they were born between 1980 and 1994 (Grubb, 2016). In addition, care was taken to en-

sure a broad range of life situations in order to capture a diverse set of experiences and perspectives. Accordingly, individuals of different ages and genders were included.

The table below provides an overview of the key sociodemographic characteristics of the participants, which are of central relevance for the analysis. The majority of respondents are in the lower third of the millennial age range, with a mean age of 30.4 years.

Table 33: Overview of respondents

Source: Author's own compilation.

Respondent (anonymised)	Gender	Age	Residence	Education Level	Profession
Respondent 1	Male	24	Rural	A levels	Trainee office management assistant
Respondent 2	Male	42	Urban	Technical A levels	Medical Documentalist
Respondent 3	Male	26	Rural	Secondary school leaving certificate	Trainee office management assistant
Respondent 4	Female	34	Urban	Bachelor of Science in health economics	Medical Documentalist
Respondent 5	Female	40	Rural	Business administration specialist	Financial Administrator
Respondent 6	Male	23	Urban	Trainee as salesperson	Investment Client Advisor
Respondent 7	Female	26	Urban	Master of Science in Global Business and Sustainability	social and environmental impact reporter
Respondent 8	Female	35	Rural	Master of Arts in social work	Social worker
Respondent 9	Male	28	Urban	Master of Science in sports science	Gym management
Respondent 10	Female	26	Rural	Business Economist	Real estate agent

Data Collection

To obtain the required insights, this study employed the semi-structured interview method following Helfferich (2011). The interviews were conducted on the basis of an interview guide developed using Helfferich's SPSS method, which is provided in the appendix. This guide served as a structured framework while allowing sufficient flexibility for individual follow-up questions.

The interview guide was divided into several sections. It began with sociodemographic questions (e.g., age, gender, level of education, or occupation). This was followed by three general introductory questions related to the topic under investigation. Subsequently, the interviews addressed the three thematic areas of mobility behaviour, bus drivers, and autonomous bus operation in PT.

After the introductory questions, participants were first asked about their mobility behaviour in order to examine in which situations and how frequently they use buses within PT. In this context, participants were also asked what they dislike about bus travel, what they appreciate, and what they would like to see changed.

The next section focused on the role of the bus driver. This part explored, among other aspects, the importance of personal interaction with drivers, the level of trust placed in them, and perceptions of the profession's image within society. Participants were also invited to suggest how the occupation of bus driver could be made more attractive. In addition, they reported both positive and negative experiences they had previously had with bus drivers.

The final part of the interview addressed autonomous buses in PT in greater detail. The aim was to explore participants' attitudes towards this topic. They were asked whether they had already had any direct experience with autonomous buses and, if so, to describe these experiences. Furthermore, the discussion covered whether participants would generally be willing to use autonomous buses and under which circumstances. Questions also addressed trust in the technology and the potential contribution of autonomous driving to improving PT. In addition, participants were asked to reflect on how the occupation of bus driver might change in the future and to what extent they could imagine autonomous buses being deployed as a regular component of PT services. Finally, they were invited to express their overall position on autonomous bus operation, stating whether they were generally in favour of or opposed to it.

Data Analysis

The ten individual interviews were conducted via the video conferencing platform Webex, with recordings made using the integrated Webex recording tool. The duration of the interviews ranged between 25 and 65 minutes, depending on the participants' willingness to speak and their speaking pace, with an average interview length of approximately 37 minutes. The interviews were subsequently transcribed using the qualitative data analysis software MAXQDA. To ensure a consistent preparation and systematic analysis of the data, the transcription followed the guidelines proposed by Kuckartz (2021).

For the analysis of the transcribed material, qualitative content analysis according to Mayring was applied. This method enables a systematic, theory-guided and rule-based evaluation of communicative content and allows for flexible adaptation to the specific research object and the underlying data material. The analytical focus was placed on inductive category development, a technique aimed at the condensed summarisation of content. The analytical procedure followed the established six-step model of the method (Mayring, 2022).

First, the entire material, comprising all ten transcripts, was defined as the unit of analysis. In an initial cycle of analysis, the material was reduced using Mayring's Z1 to Z4 reduction rules. Subsequently, categories were developed inductively and relevant statements were assigned to these categories. After coding approximately 40% of the material, the category system was reviewed, refined and adjusted where necessary. This process included the merging of similar categories, the revision of category labels and the verification of the assignment of statements.

Following this interim review, the coding process was continued and completed. The final category system was subjected to a concluding validation step by cross-checking it against the original material and resolving any remaining inconsistencies. The resulting system reflects the core contents of the data in a condensed form and constitutes the basis for the subsequent interpretation and analysis. All

stages of coding and data reduction were carried out using the MAXQDA software, ensuring a transparent, systematic and reproducible analytical process.

5.2.2 Findings

5.2.2.1 Contents of the category system

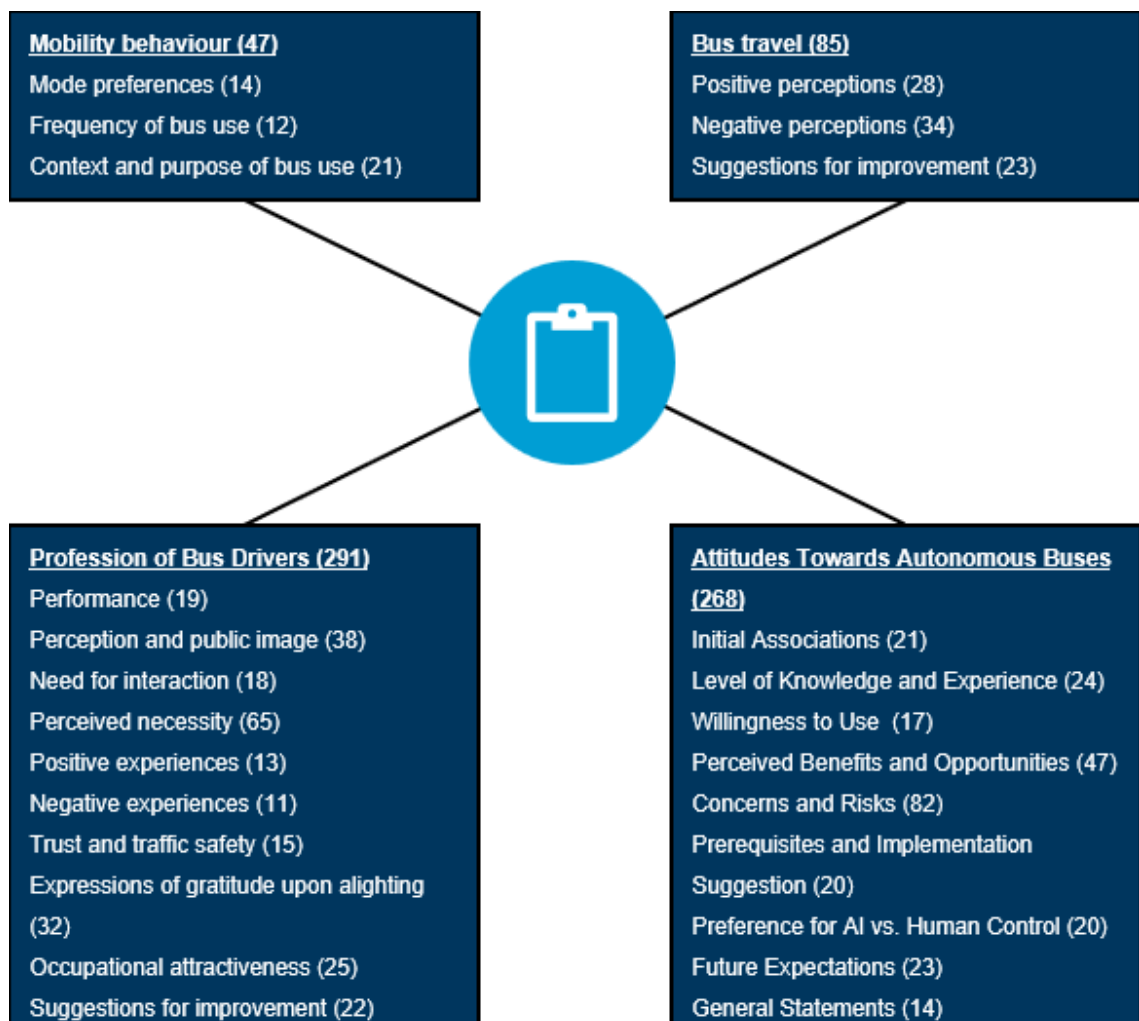


Figure 16: Overview of main and subcategories: Autonomous buses

Source: Author's own compilation.

5.2.2.2 Main Category: Mobility Behaviour

PMT was highlighted by the respondents as the preferred mode of transport due to its flexibility and independence from fixed stops or timetables. These advantages are particularly relevant for participants with children; accordingly, four respondents identified PMT as their primary mode of transport. In addition, cycling and walking, especially in urban areas, were mentioned three times as preferred modes of travel. The main reasons for these choices relate to opportunities for physical activity as well as lower costs compared to motorised modes of transport.

PT was preferred by two participants, with one respondent reporting equal use of the tram. These modes were described as simple, stress-free, fast, and more affordable compared to the car. Another respondent expressed a particular preference for the tram, as it provides better connectivity to their place of residence than the bus. Respondent 4 emphasised a general reluctance to use the bus compared to other modes of transport and stated that, whenever possible, alternative modes would always be chosen:

“Honestly, no. I find the other modes of transport almost always a bit better than the bus. If there are other options available, I would always choose those.”

Accordingly, the bus is frequently used as an alternative to PMT when the latter is not available, for example due to alcohol consumption or traffic restrictions. It is particularly used as a substitute when congested traffic conditions make car use inconvenient or when independence from parking availability is prioritised. For large-scale events or service disruptions, respondents often rely on shuttle buses or rail replacement services. Furthermore, the bus serves as a substitute for other modes such as cycling or tram travel when these options are not feasible.

Two respondents stated particularly clearly that the bus represents a last-resort option for them, used only when no other means of reaching the desired destination is available. In other cases, the bus is chosen due to better connectivity, enabling faster access to the destination. One respondent reported a general preference for the bus over PMT regardless of efficiency considerations, as it is perceived to be a more sustainable mode of transport. Overall, the bus is primarily used for work or school-related trips, visits to friends, shopping activities, and mobility in unfamiliar cities during holiday or business trips.

5.2.2.3 Main Category: Bus Travel

Bus travel was perceived predominantly positively by the participants in terms of relaxation and stress reduction. This is primarily attributed to the fact that responsibility for driving is transferred to the bus driver, allowing passengers to relax during the trip. This assessment is also reflected in the statement of Participant 8, who emphasised the relaxing nature of bus travel: “Travelling by bus is actually a very pleasant experience. I can relax on the bus, I can sit down, focus on my children or observe my surroundings [...]. And I do not have to concentrate on traffic myself.” In addition, comfort was frequently highlighted as a positive aspect, with bus travel often perceived as more comfortable than tram travel. Several participants described the bus service as useful and necessary, particularly for people with limited mobility. In this context, buses were perceived as sustainable, efficient and practical.

Overall, participants’ perceptions of bus travel ranged from positive to neutral, reflecting a balance between favourable and unfavourable aspects. However, one participant stated that they perceived no positive aspects of bus travel at all.

Negative experiences reported by participants primarily related to a lack of flexibility due to delays and unreliability, particularly in rural areas where the service was perceived as insufficient. Further criticism concerned the lower speed of buses compared to trams, as buses are subject to congestion and traffic-related delays. Due to this dependency on road traffic, buses were also perceived as less

reliable. Overcrowding was reported as a significant source of stress, particularly when combined with poor ventilation or malfunctioning air-conditioning systems. These conditions were perceived as especially uncomfortable during hot weather. Additional negative aspects included noise and unrest inside the vehicle, as well as a perceived lack of comfort, particularly in older bus models, which were described as poorly maintained. Cornering behaviour was also perceived as uncomfortable. Furthermore, the ticketing system in Germany was criticised for its complexity. One female participant expressed concerns regarding personal safety, particularly at night, as the risk of harassment by other passengers was perceived to be higher, especially for women.

With regard to suggested improvements, participants placed particular emphasis on improved ventilation systems and a general enhancement of comfort within buses. In addition, an expansion and improvement of bus services, especially in rural areas, was considered necessary. Faster and more transparent communication by transport operators in the event of delays or cancellations was also called for. Moreover, participants identified a need for improvements in transport infrastructure, particularly the expansion of dedicated bus lanes to improve traffic flow. From a sustainability perspective, respondents expressed a desire for increased use of electric, natural gas, or hydrogen-powered buses to replace diesel engines. Finally, participants emphasised that simplifying the ticketing system could significantly enhance the attractiveness of bus use, thereby contributing to a reduction in PMT usage and supporting broader climate protection goals.

5.2.2.4 Main Category: The Profession of Bus Drivers

With regard to bus driving as a profession, various aspects of interaction with bus drivers, their necessity, and the potential implications of deploying autonomous buses were addressed. The majority of participants (eight individuals) considered interaction with bus drivers to be of little or no relevance. Some respondents reported only brief greetings when boarding or alighting, as well as interactions related to ticket purchase or inspection. Conversations or more intensive forms of

contact were rarely desired. However, two participants attributed a certain relevance to interactions with bus drivers, for instance through short, regular conversations with familiar drivers. One participant recalled more frequent interactions with bus drivers during her school years.

Respondent 3 emphasised that the low level of appreciation for bus drivers may stem from an underestimation of the complexity of their work: “Many people think, ‘Well, I can drive a car too,’ or ‘They’re just driving a bus, how difficult can that be?’”

Nevertheless, the study clearly demonstrated that the presence of bus drivers was regarded as indispensable in certain situations. The most frequently cited reasons for their necessity related to intervention in conflicts or assaults among passengers, as well as contacting the police. Assistance with boarding for persons with reduced mobility was also considered crucial, with several participants reporting that they had regularly observed such situations. Furthermore, the provision of information, for example regarding connections or ticket purchases, was perceived as essential. Bus drivers were also viewed as important points of contact in medical emergencies, particularly with regard to first aid. In this context, participants highlighted the risk that other passengers might hesitate to intervene in critical situations or might not be present at all, potentially leading to escalation or significant difficulties for passengers with reduced mobility.

Female participants in particular emphasised that the presence of bus drivers, especially during evening or night-time journeys, conveyed a sense of security, as they could potentially prevent assaults by other passengers. Only three participants stated that they had never previously required assistance from a bus driver.

Respondent 9 criticised the service behaviour of some bus drivers, noting that they often depart quickly without waiting for passengers, which, while understandable in the context of delays, negatively affects customer service. He suggested that targeted training measures could improve this aspect: “I don’t think

this happens at every stop. But in terms of customer service, it would certainly be better if bus drivers were trained differently in this regard.”

A significant component of the analysis focused on the potential impacts of introducing autonomous buses into PT. While eight participants identified the existing staff shortage in the sector as a possible advantage of automation, negative assessments predominated. In particular, participants highlighted the risk of a decline or even the complete disappearance of the profession of bus driver, as autonomous buses could become more economically efficient in the long term due to the elimination of personnel costs. This was perceived as likely to result in job losses for many, if not all, bus drivers, potentially contributing to rising unemployment. Some respondents proposed redeploying bus drivers in supervisory or control centres for autonomous buses in order to mitigate job losses. It was also feared that the current uncertainty surrounding future developments in the sector already places a burden on bus drivers, potentially prompting them to leave the profession. Moreover, this uncertainty could discourage potential recruits from pursuing training in this field, thereby exacerbating the existing shortage of bus drivers before autonomous buses are deployed on a large scale.

5.2.2.5 Main Category: Attitudes towards Autonomous Buses

The analysis of acceptance of autonomous buses in PT indicates that the majority of participants had previously heard of autonomous buses. Only three out of ten respondents stated that they had no prior knowledge of this technology. However, only one participant had independently sought more detailed information on the topic, for instance by watching YouTube videos. None of the interviewees had any practical experience with autonomous buses, which limited the ability to assess this technology on the basis of personal experience.

Respondent 4 suggested that familiarisation with autonomous buses could follow a similar trajectory to the adoption of other new technologies, such as smartphones: “At first the idea feels strange, but once you’ve done it three or four

times, it becomes normal.” This assessment supports the assumption that, despite initial scepticism, positive adaptation to the technology may occur over time.

Nine out of ten participants expressed a general openness towards using autonomous buses. However, three of these respondents reported an initial sense of scepticism, which they believed they could overcome. Six participants described themselves as open-minded and curious, while only one participant expressed a fundamentally negative attitude towards the technology.

The potential advantages of autonomous buses were primarily associated with their ability to mitigate the existing shortage of personnel in PT and to improve service provision, particularly in rural areas or during peak hours. Six participants emphasised that autonomous buses could contribute to increased punctuality and a reduction in cancelled services. Further perceived benefits included cost efficiency, sustainability, and improved traffic flow through coordinated vehicle operation. Two respondents also highlighted the potential for enhanced road safety, arguing that the use of AI could reduce human error and thus lower accident rates. This was compared to the successful application of robots in surgery, underlining confidence in technological precision. Trust in self-driving cars was likewise cited as evidence of the technical feasibility of autonomous buses.

Despite these perceived benefits, numerous concerns were raised. Most participants identified the absence of a human contact person in the event of problems, particularly in emergencies such as assaults or medical incidents, as the most significant challenge. Especially female, but also male participants, expressed concerns regarding personal safety, as existing security and alarm systems were perceived as insufficient. The risk of escalation in conflict situations was highlighted, given that valuable time could be lost before the arrival of police or emergency services. Limitations of the technology were also identified in relation to assisting older passengers who may require support when boarding. In addition, the potential misuse of technical aids, such as ramp activation mechanisms, through vandalism was discussed.

Another central point of criticism concerned job losses. All ten participants feared that the introduction of autonomous buses could render the profession of bus drivers obsolete in the long term, leading to increased unemployment. As a consequence, bus drivers might already be leaving the profession, thereby exacerbating the existing staff shortage. These concerns stood in contrast to the potential efficiency gains associated with the deployment of autonomous buses.

Beyond practical issues, social and psychological aspects were also addressed. Half of the participants criticised the loss of human interaction and the growing depersonalisation associated with automation. Particularly in rural areas, where infrastructure for autonomous buses may be insufficient, the feasibility of implementation was viewed critically. Trust in the technology emerged as another key issue, as many respondents expressed apprehension regarding traffic safety and described travelling in an autonomous bus as unfamiliar and potentially frightening. Trust in human bus drivers was perceived as stronger due to long-standing habituation, although some participants acknowledged that this trust might evolve over time with positive experiences.

Furthermore, two participants raised concerns about the risk of cyberattacks on autonomous buses, as well as the complexity of legal frameworks, particularly with regard to liability in the event of accidents.

Respondent 5 articulated an ethical concern, questioning whether it is morally justifiable to replace human labour with machines solely because it is technically feasible: “Just because it’s possible doesn’t mean it’s right.”

5.2.3 Discussion: Autonomous Buses from the User Perspective

5.2.3.1 Main Category: Mobility Behaviour

The preferences regarding modes of transport indicate that the majority of respondents choose the private car as their preferred means of transport. Other

options, such as PT, cycling, or walking, were mentioned less frequently. The decisive reasons for mode choice were primarily convenience and the subjectively perceived comfort of use. These findings stand in contrast to previous studies that emphasise a higher level of environmental awareness among millennials. For instance, earlier research suggests that environmental protection constitutes a key decision criterion for millennials when selecting a mode of transport, leading them to forgo car use more frequently in favour of PT, cycling, or walking (Circella et al., 2017; Jamal & Newbold, 2020). Circella et al. (2017) further found that millennials are less likely to own a car than previous generations and, if they do own one, tend to use it less intensively.

Our study was unable to confirm these assumptions. The majority of the millennials surveyed preferred the car primarily for reasons of convenience, with considerations of sustainability rarely being articulated. Only one participant stated that she predominantly uses the bicycle or walks for reasons of environmental sustainability. Interestingly, the results also show that the bus is predominantly chosen when other modes of transport, particularly the car, are unavailable for specific reasons. Consequently, the bus is perceived by most participants as a fallback or last-resort option. The aforementioned environmentally conscious participant was the only one who reported preferring the bus as a regular mode of transport when cycling or walking is not feasible.

Overall, these findings suggest that the correlation between environmental awareness and the choice of more sustainable modes of transport, as assumed in earlier studies, is not evident to the same extent within this sample of millennials. Instead, convenience and pragmatic considerations continue to dominate mode choice decisions.

5.2.3.2 Main category: Bus travel

Overall, the findings indicate that participants are largely dissatisfied with the current bus services. They found it considerably easier to identify negative aspects of bus travel than positive ones, and these negative aspects were also perceived

as more salient. As a comprehensive analysis of all PT operators in Germany would exceed the scope of this study, the criticism articulated by the participants was examined against data from Kölner Verkehrs-Betriebe AG (KVB). Owing to its size, KVB can be regarded as a representative example of urban PT operators in Germany. The KVB quality report for 2022 provides insights into actual service reliability, the development of bus services, vehicle quality, operating speeds, and measures related to climate protection.

The comparison between participants' criticisms and the data reported by KVB reveals a substantial convergence between passengers' perceptions and the company's self-assessment. The identified shortcomings are well known to the operator, and measures are already being implemented to enhance the attractiveness of bus travel. This alignment underscores that, despite ongoing improvement efforts, there remains a considerable need for further action, particularly in the context of advancing the mobility transition.

For the surveyed millennials, comfort emerged as a decisive factor in bus use, even for short trips. Improvements such as enhanced ventilation, especially during the summer months, comfortable and clean seating, and free Wi-Fi on buses were cited as potential measures to increase the attractiveness of bus travel. Such measures could strengthen PT as a viable alternative to private car use and thereby make a meaningful contribution to reducing private motorised traffic.

5.2.3.3 Main Category: The Profession of Bus Drivers

In the main category "*Profession of Bus Drivers*", various aspects were examined, with particular emphasis on the importance of the drivers' presence. Overall, participants reported a low need for interaction with bus drivers, which was largely confined to situations in which active assistance was required. These findings are consistent with results from a study on autonomous taxis, which showed that, for millennials, human taxi drivers provide no particular added value and that interaction with them is largely dispensable (Pakusch et al., 2020).

Although participants initially stated that they rarely relied on the assistance of bus drivers, closer examination revealed that drivers do, in fact, provide support more frequently across a range of situations. In particular, the de-escalation of conflicts on board was considered a key responsibility of bus drivers, as other passengers are often unwilling or lack the courage to intervene. This phenomenon can be explained by the so-called bystander effect, which suggests that the likelihood of offering help decreases as the number of people present in an emergency situation increases (Darley & Latané, 1968). This diffusion of responsibility leads individuals to refrain from intervening under the assumption that others will take action. Similarly, in situations where people with limited mobility or other assistance needs require support when boarding, passengers often do not perceive themselves as responsible.

Through targeted questions addressing experienced situations in which the assistance of bus drivers was required, participants became more aware of their own experiences. This, in turn, led to an increased appreciation of the importance of bus drivers' presence and to a desire for a clearly defined, accountable point of contact.

Another aspect of the analysis focused on the potential implications of autonomous buses for the occupation of bus drivers. While some participants recognised the potential of autonomous buses to mitigate staff shortages, others feared a complete decline of the profession or an exacerbation of existing labour shortages. It was emphasised that PT operators should clearly communicate the continued relevance of bus drivers in the coming years in order to reduce uncertainty and prevent a further intensification of the skills shortage. Transparent communication regarding plans for the introduction of autonomous buses is therefore crucial to alleviate concerns and avoid misunderstandings.

5.2.3.4 Main Category: Attitudes towards Autonomous Buses

Interestingly, the participants' initial associations with autonomous buses were predominantly neutral to negative, a tendency that became more pronounced

over the course of the interviews. Although almost all respondents reported a certain degree of curiosity and indicated that they would be willing to try an autonomous bus at least once, doubts and concerns clearly outweighed the perceived benefits of a regular deployment of autonomous buses. Overall, nearly twice as many statements referred to potential disadvantages as to advantages.

A particularly salient concern related to the absence of a human point of contact in autonomous buses and the resulting feeling of helplessness in critical situations. According to Pakusch et al. (2020), millennials are characterised by a high degree of independence and rarely demand additional services from drivers when using taxis. While this may partly apply to bus travel as well, participants in this study reported feeling considerably more vulnerable in autonomous buses due to potential threats posed by other passengers. Unlike taxi rides, where no unfamiliar individuals are present, participants feared conflicts or assaults in buses, especially during night-time trips. These concerns were articulated particularly strongly by female respondents. Existing safety and alarm systems in autonomous buses were widely perceived as insufficient, as immediate on-site assistance was considered essential in acute emergency situations. Participants expressed concerns that, in the event of an assault or a medical emergency, help might arrive too late to prevent serious consequences.

In this respect, a notable contradiction to the findings of Pakusch et al. (2020) emerged. In their study, participants did not perceive the absence of taxi drivers as problematic, even though emergency situations such as medical incidents are equally conceivable in that context. Notably, none of the 34 participants in their study expressed concerns of this kind (Pakusch et al., 2020).

In addition, several participants voiced doubts regarding the overall safety of autonomous buses, particularly with respect to the technology's ability to respond appropriately in unforeseen situations. While millennials often prefer to delegate responsibility to human bus drivers, they appeared to place less trust in AI. This scepticism stands in contrast to the fact that autonomous systems are, in many

cases, capable of reacting more precisely and rapidly than humans. Consequently, the concerns articulated by the participants contradict the assumption that millennials, due to their technological affinity, would be more open to innovations such as autonomous buses. Instead, the findings indicate a pronounced reluctance and scepticism towards their integration into PT.

At the same time, several participants assumed that a test ride could quickly alleviate their concerns. In line with this, Payre et al. (2014) found that individuals with an average age of 33.6 years generally hold positive attitudes towards autonomous driving, even in the absence of prior hands-on experience (Payre et al., 2014).

In conclusion, it can be hypothesised that the central challenge for the acceptance of autonomous buses lies less in a lack of trust in the technology itself and more in a lack of trust in society and its ability to interact responsibly with autonomous systems. In the long term, participants expressed greater concern about the erosion of social cohesion and human interaction, which they feared could be undermined by anonymity and the absence of supervisory personnel.

5.2.4 Limitations

The present study on millennials' attitudes towards autonomous buses is subject to several limitations that affect the representativeness and generalisability of the findings. First, it must be acknowledged that the results can only be considered partially representative of the millennial generation as a whole. In line with Helfferich (2011), qualitative research primarily aims to generate in-depth and nuanced insights into specific phenomena rather than to derive universally generalisable statements. Consequently, the limited sample size of this study restricts the extent to which the findings can be transferred to the broader millennial population.

Furthermore, several participants indicated that their opinions on autonomous buses were not yet fully formed. This uncertainty may be attributed to a lack of personal experience or insufficient information regarding the technology, which

could affect the validity and stability of the expressed attitudes. Existing research likewise reveals highly divergent findings, pointing to a broader societal uncertainty in dealing with autonomous transport systems. This uncertainty manifests itself in heterogeneous perceptions and assessments, which are also reflected in the current discourse on autonomous mobility.

5.3 Study 6: Autonomous Buses from the Provider Perspective

The study on autonomous buses from the provider perspective examines the expected impacts along the dimensions of Kaufmann's conceptual framework. With regard to Access, autonomous systems enable PT operators to design their services more efficiently and cost-effectively, thereby creating an expanded yet economically sustainable service structure.

In the dimension of Skills, the required competencies shift away from traditional driving personnel towards IT, data, and system-related skills, implying a fundamental transformation of organisational qualification requirements.

Appropriation, finally, necessitates the strategic integration of autonomous buses into existing operational, tariff, and platform structures in order to ensure their long-term incorporation and acceptance within regular PT operations.

These anticipated effects, understood in line with Kaufmann's framework, constitute the empirical focus of the study. Analogous to Study 5, this study follows a comparable structure. The core components include a presentation of the research design, data collection and data analysis (Section 5.3.1), the key findings (Section 5.3.2), the subsequent discussion (Section 5.3.3), and the limitations of the study (Section 5.3.4).

5.3.1 Research Design

While the demand for professional bus drivers in scheduled PT is evidently increasing, a substantial outflow of employees is expected by 2030 as large cohorts of the working population reach retirement age. This challenge is further exacerbated within PT operators by the fact that absenteeism among bus drivers is reported to be two to three times higher than in many other occupational groups (Kompier et al., 1990). According to statistics published by the Federal Statistical Office of Germany (2023), which compare the age distribution of all employed persons with that of bus and tram drivers in 2021, the average age in the PT workforce is significantly higher than that of the overall labour force. More than one third of the approximately 137,000 employees in PT are over the age of 55, a proportion that significantly exceeds that of most other sectors (Statistisches Bundesamt, 2023).

In the context of the ongoing mobility transition, transport companies are therefore confronted with the challenge, which is highlighted by the German Association of Transport Companies, of compensating for the retirement of around 80,000 employees by recruiting approximately 110,000 new staff by 2030 (Zandt, 2023). Despite the clearly identifiable shortage of skilled labour, the occupation of bus driver has not yet been formally classified as a skills shortage occupation by the Federal Employment Agency (Brandt, 2023).

Against this background, the present study examines how the current shortage of skilled labour in the profession of bus driving can be addressed and to what extent the deployment of autonomous buses in PT may contribute to mitigating this challenge. The primary objective of the study is to explore, through expert interviews, which measures German PT operators consider necessary to respond effectively to the existing shortage of professional bus drivers. In addition, the study aims to assess the potential of autonomous buses to alleviate the impacts of labour shortages within the sector. Based on these insights, the study seeks to derive practical recommendations for action to support transport operators in dealing with this structural challenge.

To date, the role of autonomous buses in addressing the shortage of bus drivers has only been discussed in a fragmented and largely superficial manner in the existing literature. Previous research approaches have primarily focused on isolated aspects and thus fail to capture the full complexity of the issue. For this reason, an exploratory research design was adopted, employing expert interviews as the primary methodological approach.

Data Collection

The expert interviews covered two core thematic areas: company-related characteristics and the potential deployment of autonomous buses. Based on the SPSS-based guideline development approach proposed by Helfferich (2022), the interview questions were subsequently designed (Helfferich, 2022). At this stage, a clear distinction was made in the formulation of the questions between PT operators with and without prior experience in the operation of autonomous buses in PT.

Ultimately, both interview guides comprised four guiding questions, each supplemented by a total of seven follow-up questions, which served to further specify and deepen the respective topics.

As part of the appointment scheduling process, the interview guide was provided to the experts in advance. The ten expert interviews were conducted by telephone between October 2023 and January 2024. The average duration of the nine expert interviews included in the analysis was approximately 36 minutes. Interviews with experts who already had practical experience with the deployment of autonomous buses were notably longer (approximately 42 minutes) than those conducted with experts without such experience (approximately 28 minutes).

The demographic characteristics of the expert sample are presented in Table 34.

Table 34: Demographic overview of the expert interviews

Source: Author's own compilation.

Experts (anonymised)	Gender	Age	Leadership responsibility	Experience with pilot projects	Number of residents
Expert 1	Female	37	Yes	Yes	550,000– 650,000
Expert 2	Male	28	No	Yes	150,000– 250,000
Expert 3	Female	58	No	Yes	250,000– 350,000
Expert 4	Female	36	Yes	Yes	150,000– 250,000
Expert 5	Female	45	Yes	No	150,000– 250,000
Expert 6	Female	59	Yes	No	250,000– 350,000
Expert 7	Male	54	Yes	Yes	250,000– 350,000
Expert 8	Female	42	Yes	No	550,000– 650,000
Expert 9	Female	44	Yes	No	> 1,000,000

The sample shows a slight predominance of experts who have already gained experience with autonomous buses through pilot projects conducted within their respective PT associations. In addition, a predominance of female participants can be observed within the sample. The majority of interviewees hold managerial positions within human resources (HR) departments and are therefore not exclusively engaged in the recruitment of new employees. Nevertheless, each interview participant is, or has been in the past, directly involved in the recruitment process of bus drivers.

Data analysis

The expert interviews recorded via audio were subsequently fully transcribed. The software MAXQDA was used to support this process. The focus of the transcription was exclusively on the substantive statements made by the interviewees; paralinguistic elements were not considered. The transcription system applied ensures transparent and traceable data preparation (Dresing & Pehl, 2010) and follows the recommendations of Kuckartz (2021).

Ten transcribed interviews served as the empirical material, one of which was excluded from the analysis due to a predefined exclusion criterion. The remaining nine interviews were analysed following the methodological approach of qualitative content analysis according to Mayring and Fenzl (2022) as well as Kuckartz and Rädiker (2021) (Kuckartz, 2021; Mayring, 2022).

In the first step of the structuring content analysis, main categories were deductively derived based on the research question and the interview guideline. These categories were assigned to the relevant text passages of the transcripts, while interview content not related to the research topic was excluded from further analysis (Kuckartz & Rädiker, 2021). The smallest coding unit consisted of individual relevant words, whereas the largest unit comprised several consecutive sentences conveying a coherent meaning.

In a subsequent step, subcategories were developed deductively, based on the empirical material. In addition, further main categories were added where relevant content had not yet been captured by the deductive category system. This procedure aimed to ensure the most comprehensive possible coverage of all content-relevant aspects of the expert interviews (Mayring, 2022). All text passages were then assigned to the corresponding deductively and inductively developed categories.

To ensure methodological consistency, a coding guide was developed that defined each category by means of a descriptive explanation and supplemented it with characteristic anchor examples (Mayring & Fenzl, 2019). This coding guide served as a binding reference for the application of categories throughout the entire analysis process.

Following completion of the content analysis, all data were anonymized in order to prevent the identification of the participating individuals and transport companies (Reichert, 2016). For this purpose, the method of strong abstraction was applied, providing an additional safeguard for anonymity (Meyermann & Porzelt, 2014).

5.3.2 Findings

5.3.2.1 Contents of the Category System

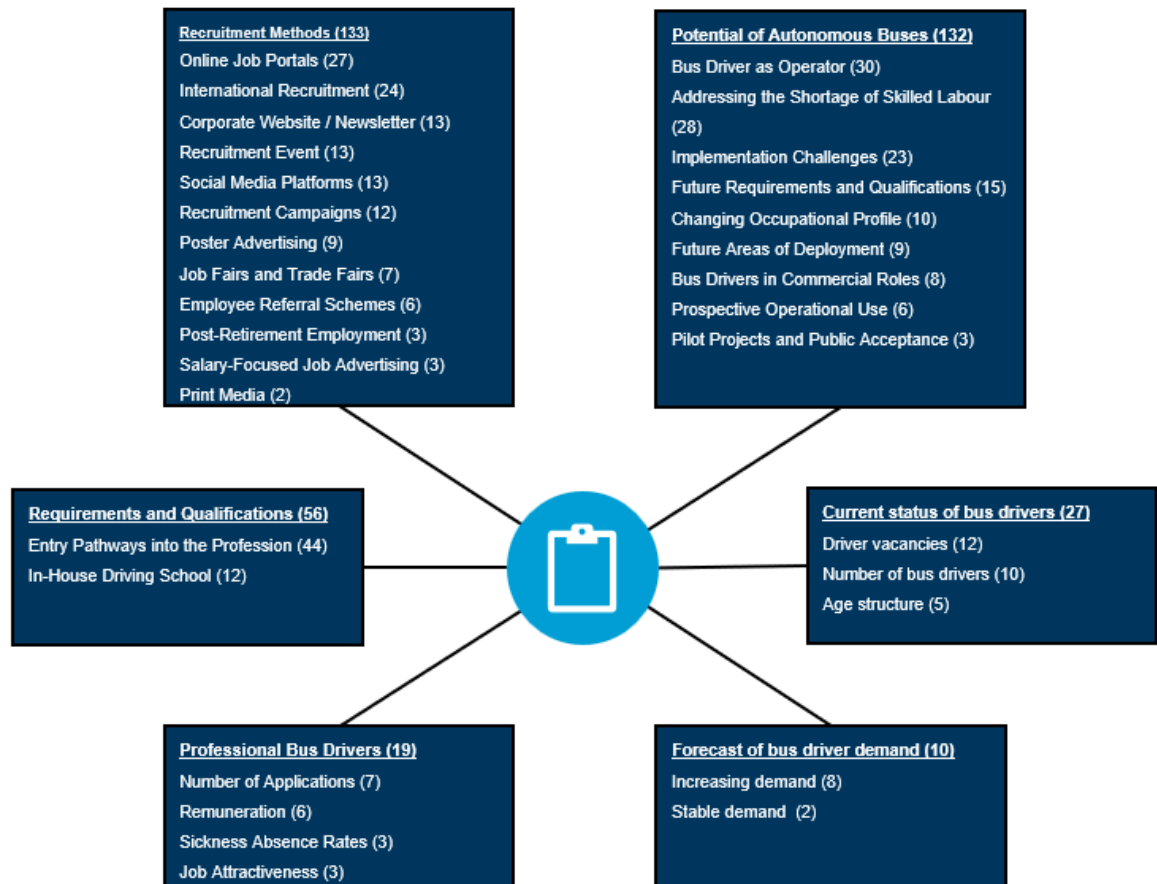


Figure 17: Overview of Main and Subcategories: Bus Driver Shortage

Source: Author's own compilation.

5.3.2.2 Main Category: Bus Drivers – Current Situation

The majority of the surveyed PT operators report a high number of vacant bus driver positions, which is primarily attributable to the demographic age structure of their workforce. A substantial proportion of current bus drivers are of advanced age, which is expected to lead to significant age-related staff turnover in the coming years. Expert 1 emphasised the challenge arising from demographic change as follows:

“We are massively affected by demographic issues; our average age is 48.”

Accordingly, a considerable increase in the number of bus driver positions to be filled is anticipated in the near future, as a large share of drivers will retire due to age. This assessment is corroborated by Expert 4, who predicts that more than half of the current bus driver workforce will need to be replaced within the next decade:

“In the next ten years, we will have to replace more than 50 per cent [of our drivers] due to demographic change.”

This development represents a substantial challenge for PT operators, as demographic change is likely to further exacerbate the existing labour shortage within the sector.

5.3.2.3 Main Category: Forecast of Bus Driver Workforce Development

Human resource planning within PT companies indicates a growing demand for bus drivers, a trend that is expected to intensify further in the coming years. This development is primarily driven by planned expansions of route networks as well as increasing sickness absence rates among staff. As explained by Expert 5, high levels of absenteeism constitute a significant factor that must be compensated through additional recruitment efforts:

“[...] we definitely have high sickness rates. This has to be absorbed, and in some cases that can only be done by hiring beyond the immediate demand.”

In contrast, the transport company represented by Expert 6 currently reports a comparatively lower number of vacant positions. This organisation aims to maintain a stable staffing situation through targeted personnel planning, replacing departing employees on a one-to-one basis:

“[...] as of today, this is intended to remain at a constant level, meaning that we essentially replace employees one-to-one.”

These differing approaches highlight that workforce planning strategies vary considerably between transport operators and are strongly influenced by operational conditions such as sickness rates and network expansion plans.

5.3.2.4 Main Category: Requirements and Qualifications

In light of the current challenges in the labour market, many PT operators increasingly rely on lateral entry as a key strategy to mitigate the shortage of bus drivers. This development is primarily attributable to the insufficient number of young skilled workers available to meet demand. As Expert 2 emphasises: “Unfortunately, we are simply unable to recruit enough young people to fully cover demand. That is why we also have to offer lateral entry.” Consequently, transport operators have lowered formal entry requirements, meaning that a completed vocational qualification is no longer mandatory for lateral entrants, as confirmed by Expert 9: “[...] we do not require a completed vocational qualification. In that respect, entering the bus driving profession is entirely feasible for career changers.”

Lateral entry enables transport companies to address a broad target group. In many cases, the only formal prerequisite is a standard car driving licence, allowing candidates, depending on the operator, to be trained as bus drivers within six to seven months. Truck drivers are considered particularly suitable lateral entrants due to their prior experience in handling large vehicles, which shortens training periods and facilitates faster integration into operational service. As Expert 7 notes: “The most obvious candidates are truck drivers. At least they already know how to handle a machine of that size.” To reach this group specifically, some operators even engage in targeted recruitment activities at motorway service areas, as reported by Expert 8.

Empirical insights from transport operators indicate that the majority of applications for bus driver positions originate from lateral entrants. Retention rates

among this group tend to be comparatively high, as career changers typically make a deliberate decision in favour of the profession. In contrast, apprentices often consider alternative career pathways, such as transitioning into administrative roles. To ensure the continued attractiveness of lateral entry, experts highlight the importance of already offering adequate remuneration during the training phase.

Despite the growing relevance of lateral entry, formal vocational training as a Skilled Worker in Transport Operations (Fachkraft im Fahrbetrieb) remains a crucial pillar for PT operators, particularly with regard to building an internal administrative reserve. This training pathway offers young people long-term career prospects, including part-time academic studies or further professional qualifications leading to positions such as certified business administrator or operations manager. As Expert 6 explains: “[Skilled workers in transport operations] are also our future leadership staff.” The deployment of so-called hybrid positions, which combine driving duties with administrative tasks, is regarded as an important instrument for enhancing the attractiveness of vocational training and securing long-term leadership capacity.

For lateral entrants, however, vocational training as a skilled transport worker is generally less attractive, as apprentice salaries are often insufficient to maintain an established standard of living. Consequently, lateral entrants typically opt for direct entry into driving services rather than pursuing a full vocational qualification.

Some transport operators nevertheless report difficulties in filling apprenticeship positions, as the profession of skilled transport worker remains insufficiently known and career development pathways after completion of training are often unclear. Operators with well-established training programmes therefore stress the need to expand apprenticeship capacities in order to strengthen internal administrative reserves and increase the availability of hybrid positions. Such reserves can be mobilised during crisis situations to temporarily alleviate driver shortages.

In this context, the establishment of in-house driving schools was also identified as a critical factor. These facilities enable faster training processes and reduce dependency on external driving schools, thereby significantly improving training efficiency. Expert 3 summarises this necessity succinctly: “As long as a transport operator does not train internally and does not operate its own driving school to develop its own workforce, it will never be able to cope with the required number of bus drivers.”

5.3.2.5 Main Category: Professional Bus Drivers

The occupation of bus driver is widely perceived within society as relatively unattractive. A central reason for this perception lies in irregular working hours and shift-based schedules, which make it difficult for employees to reconcile professional duties with private life, particularly family responsibilities or leisure activities. These structural working conditions substantially reduce the overall attractiveness of the profession. As Expert 1 emphasised: “We are all facing staff shortages, and we all have the problem of a lack of attractiveness.”

This limited attractiveness is also reflected in both the quantity and quality of job applications received by PT operators, which are increasingly described as insufficient. While the absolute number of applications varies between companies, a general decline in applicant quality can be observed. According to the experts, this trend is at least partly attributable to the low perceived attractiveness of the profession.

Another factor contributing to this situation is the collectively agreed wage structure. Bus drivers progress through four experience-based pay levels, with advancement occurring only at fixed intervals of five years. Accelerated progression, for example, in recognition of exceptional performance, is not possible, resulting in a rigid remuneration system. From the experts’ perspective, the level of pay does not adequately reflect the responsibility borne by bus drivers in their daily work. This imbalance is underscored by Expert 1, who highlighted the discrepancy between remuneration and responsibility: “If public transport actually

paid people according to the level of responsibility they carry, then a four-stop journey would not cost €3.50, but €18.40.”

In addition, PT operators are confronted with high sickness absence rates among bus drivers, which further exacerbates the existing shortage of skilled personnel. These elevated sickness rates are interpreted as a consequence of chronic work overload, itself intensified by persistent staff shortages. In response, companies attempt to compensate by recruiting beyond their calculated staffing requirements. This practice illustrates the deep-rooted structural challenges currently facing PT systems.

5.3.2.6 Main Category: Recruitment Methods

Recruiting bus drivers represents a substantial challenge for PT operators in the context of an increasingly acute shortage of skilled labour. A key starting point is the use of companies' own careers websites, where occupational profiles are promoted through testimonials and informative insights into everyday working practices. In addition, all interviewed transport operators make use of a wide range of online job portals in order to reach as broad an audience as possible, even though these platforms are not always specifically targeted at potential bus drivers. Social media channels, however, have proved particularly effective, as they allow companies to address relevant target groups directly and to generate interest in the bus driving profession through targeted advertising and detailed portrayals of daily work routines.

Despite the growing importance of a strong digital presence, most companies have largely abandoned traditional recruitment measures, such as job advertisements in print media, as these are generally regarded as no longer cost-effective.

A recent legislative change permitting retirees to continue working beyond the statutory retirement age without deductions from their pension offers transport operators an additional means of mitigating staff shortages. Nevertheless, this

option is rarely promoted proactively, as employees typically approach the companies of their own accord. Even so, this arrangement enables operators to alleviate staffing pressures, at least temporarily.

Another strategy pursued by the participating companies is the recruitment of bus drivers from abroad. As Expert 2 explains: “Given the overall shortage of skilled labour, we have to find alternative methods, international recruitment, for example.” However, this approach is associated with considerable legal and administrative obstacles, including the recognition of foreign driving licences and the requirement to pass the Chamber of Industry and Commerce (IHK) examination in German. These procedures often lead to delays, as prospective employees must first attend language courses. Consequently, companies regard the promotion of German language skills as a key prerequisite for successful integration and employment. As Expert 3 notes: “In around 30 cases, it ultimately failed because the migrants’ German was still too weak. They need to improve their written German, especially for the Chamber of Commerce exam, where written proficiency is simply essential.”

Employee referral schemes also constitute a well-established recruitment instrument. Recommendations made by existing staff, sometimes supported by financial incentives, have proven particularly successful, including in the context of international recruitment.

Moreover, many companies rely on self-initiated recruitment events, which have emerged as especially effective. These events are characterised by speed and efficiency, with job interviews sometimes conducted on site in order to accelerate the recruitment process. As Expert 7 emphasises: “They conduct ad hoc interviews straight away. Speed is the key factor at the moment—you simply cannot afford to wait.”

In addition, media campaigns and poster advertising, particularly on and inside buses, are intended to expand the reach of recruitment activities and to make career changes into the profession more attractive. Expert 6 illustrates this vividly:

“We drove through the city with these adverts, and suddenly applications came in from all kinds of different sectors.”

Transport operators also participate in externally organised job fairs to further enhance their visibility and engage with potential applicants. Finally, increasing transparency in job advertisements, especially with regard to collectively agreed pay scales, is regarded as an important step towards stimulating interest among prospective candidates and generating a higher volume of applications.

5.3.2.7 Main Category: Potential of Autonomous Buses

Within the context of pilot projects involving autonomous buses, the interviewed experts reflected on societal reception of this technology. While autonomous buses were generally perceived positively, criticism emerged primarily due to their low operating speeds. Some road users perceived these vehicles as obstructions to traffic flow, highlighting the challenges autonomous buses pose in shared public spaces.

Regarding future occupational requirements, the majority of interviewees agreed that the role of the bus driver will evolve with the introduction of autonomous buses. Nevertheless, the traditional profession is expected to remain relevant. As Expert 2 emphasises: “I am firmly convinced that the job of the bus driver will continue to exist in the foreseeable future.” Technological support may, however, alleviate certain aspects of the job. Some experts anticipate the emergence of modified qualification requirements, such as a reduced bus driving licence, while others foresee increased demands, particularly with respect to technical expertise and English language proficiency.

Assessments of the future attractiveness of the profession diverge notably between experts with and without experience in autonomous bus pilot projects. Those with practical experience tend to believe that AVs will enhance job attractiveness, whereas experts without such experience anticipate little change, citing persistent structural constraints, such as shift work, as limiting factors.

Many experts also consider it conceivable that bus drivers could increasingly assume commercial or administrative tasks in the future, although uncertainty remains. The most significant challenge identified in relation to autonomous buses concerns the German legislation. It is widely perceived as restrictive, particularly regarding future occupational requirements. As Expert 2 remarks: “We live in Germany, everything is regulated down to the smallest detail. The legislator will probably define exactly what an operator must know and be able to do.”

Experts with direct experience of autonomous buses were especially critical of regulatory constraints, whereas those without such experience addressed this issue less frequently. Safety considerations were also predominantly raised by experts involved in pilot projects, with mixed traffic involving PMT perceived as a particular risk. As Expert 8 notes: “For me, the real bottleneck is still individual traffic.”

Beyond regulatory and safety concerns, user acceptance, particularly among older populations, was identified as a potential barrier to implementation. The comparatively low speed of current autonomous shuttle buses was also regarded as problematic by some experts.

Opinions regarding the role of the bus driver as an onboard operator were divided. Some experts advocate for the continued presence of an operator within the vehicle to intervene in emergencies and provide passengers with a sense of security, as well as to maintain a service-oriented role. As Expert 4 states: “There still has to be an employee on board who can intervene if something happens.” Others, by contrast, envision future operators managing multiple vehicles remotely from a control centre.

While the long-term absence of an onboard operator is considered conceivable, it is not regarded as realistic in the medium term. There is consensus that autonomous buses will initially not be deployed in dense inner-city areas, but rather in peripheral zones, primarily to connect residential areas with central transport hubs. However, the timeframe for large-scale implementation remains uncertain.

With regard to the current shortage of bus drivers, experts agree that autonomous buses do not offer a short-term solution. As Expert 3 emphasises: “I don’t believe that autonomous driving or autonomous buses can already counteract the skills shortage. The technology simply isn’t mature enough yet.” Expert 4 similarly notes that the continued requirement for a category D driving licence will hinder mitigation efforts in the medium term. If an onboard operator remains necessary, Expert 9 argues that the labour shortage would merely shift to a different occupational group rather than being resolved.

In the long term, however, autonomous buses may contribute to addressing the shortage of skilled labour, provided that the identified regulatory, technical and social challenges can be successfully overcome.

5.3.3 Discussion: Autonomous Buses from the Provider Perspective

5.3.3.1 Main Categories: Bus Drivers – Current Situation and Forecast of Future Development

The findings of the present study clearly demonstrate that PT operators are significantly affected by age-related workforce attrition. These companies are confronted not only with the necessity to compensate for retirement-related departures but also with the need to increase the overall number of bus drivers. This requirement is particularly pronounced in the context of the planned transport transition and the associated climate policy objectives, both of which entail a substantial expansion of PT services.

This assessment is corroborated by a report of the Association of German Transport Companies (VDV), which highlights a growing demand for personnel in order to meet the future requirements of the mobility transition (Verband Deutscher Verkehrsunternehmen, 2023b). Consequently, the shortage of bus drivers must be understood as a structural challenge that extends beyond short-term labour market fluctuations.

5.3.3.2 Main Category: Requirements and Qualifications

With regard to requirements and qualifications, the findings indicate that access to the profession of bus driver is currently possible via several pathways: completion of formal vocational training as a professional driver, qualification as a specialist in transport operations, or participation in a lateral-entry training programme lasting approximately six to seven months. The expert interviews revealed that the availability of an in-house driving school significantly facilitates and accelerates the training process.

However, the study also highlights a structural limitation: only around 5% of PT operators currently operate their own driving schools. This severely restricts training capacities and increases dependency on external providers, which often leads to delays and inefficiencies. Expanding training capacities would therefore require transport operators to conduct driver training independently and in-house, thereby reducing bottlenecks and improving responsiveness to labour market shortages.

Furthermore, the experts emphasised the need for intensified promotion of vocational training in PT. According to the VDV, language barriers and communication skills, both of which are crucial in customer-facing roles, constitute the most significant obstacles in recruiting lateral entrants and internationally trained drivers (Association of German Transport Companies, 2023a). Despite these challenges, the experts identified considerable potential in international recruitment. To fully leverage this potential, targeted language training and a reduction of administrative entry barriers are deemed essential. This, in turn, requires active political support from the FRG to establish appropriate regulatory and integration frameworks for foreign labour.

5.3.3.3 Main Category: Professional Bus Drivers

The occupation of bus driver is widely perceived as unattractive within society, primarily due to irregular working hours and shift-based schedules that complicate the maintenance of a healthy work-life balance. In addition, bus drivers are disproportionately exposed to psychological and physical strain, which is not adequately compensated under the existing collectively agreed wage structures. Elevated sickness absence rates, which must be offset through additional staffing, further contribute to the chronic workload pressure experienced by driving personnel.

Looking ahead, the deployment of autonomous buses may offer some relief from existing stress factors, particularly with regard to the continuous demands on driver attention and vigilance (Taylor & Dorn, 2006). Moreover, qualification requirements for bus drivers could potentially be reduced (Kaiser & Malanowski, 2020), as autonomous systems increasingly assume driving-related tasks. The findings of this study suggest a likely shift in the occupational profile: while technical and system-related competencies are expected to gain importance, traditional driving skills may become less central. At the same time, a stronger emphasis on service-oriented competencies and customer interaction is anticipated.

Such developments could lower entry barriers to the profession and make the occupation accessible to a broader segment of the population. The potential deployment of smaller autonomous buses may further reduce psychological and practical barriers to entering the profession. However, it remains unclear whether overall qualification requirements will ultimately decrease or increase, as the long-term implications of autonomous bus deployment for the bus driver profession could not be conclusively determined within the scope of this study.

5.3.3.4 Main Category: Recruitment Methods

Despite, the expected transformation of occupational tasks through the introduction of autonomous buses, core structural conditions, such as shift-based work schedules and limited influence over duty rosters and timetable design, are likely to persist. These factors continue to represent significant psychological stressors (Taylor & Dorn, 2006). The experts interviewed in this study largely agree that these structural conditions will remain unchanged even with the implementation of autonomous bus systems.

This persistence necessitates an adjustment of recruitment strategies by PT operators, particularly with a view to attracting younger generations. The experts reported positive experiences with increased organisational presence on social media platforms such as Instagram, Facebook, TikTok and YouTube. These channels have proven to be effective means of reaching target groups relevant to bus driver recruitment.

In addition, company-initiated recruitment events were identified as a particularly successful instrument. A key success factor highlighted by the study is the speed and proactivity of recruitment processes. The opportunity to conduct job interviews directly during such events was perceived as especially promising, as it allows potential candidates to be addressed and recruited promptly.

5.3.3.5 Main Category: Potential of Autonomous Buses

Pakusch et al. (2020) discuss the potential threat to job security for bus drivers resulting from the introduction of autonomous buses. In contrast, experts with practical experience in autonomous bus operations emphasised that such vehicles are not intended to replace existing PT services, but rather to complement them. Their primary function lies in improving access to PT for residents of peripheral urban areas (Pakusch et al., 2020).

As autonomous buses are typically deployed on low-demand routes, their comparatively lower passenger capacity is not perceived as problematic (Kaiser & Malanowski, 2020). Furthermore, under current legislation, autonomous bus operations are prohibited under extreme weather conditions, necessitating the continued use of conventional buses in such cases (Kolb et al., 2020). This regulatory framework underscores the ongoing necessity of qualified bus drivers.

The VDV further stresses that employees in PT must meet both technical requirements and social competencies to ensure passenger safety (Verband Deutscher Verkehrsunternehmen, 2023a). According to the findings of this study, current technological standards do not yet permit safe autonomous operation without on-board supervision. At present, operational safety can only be ensured through the presence of an operator.

In the long term, however, continued technological advancement and improved safety standards may allow for autonomous bus operation without on-board operators, with monitoring carried out from central control centres. In the short to medium term, the deployment of autonomous buses does not constitute a viable solution to the existing shortage of skilled personnel. Over the long term, however, it may contribute to mitigating workforce shortages under appropriate regulatory and technological conditions.

5.3.4 Limitations

First, the sample size of the present study is limited to ten interviews, representing only a minimal level, slightly above methodological requirements. This limitation results from restricted personnel resources and the partial reluctance of transport companies to participate, often due to capacity constraints. Consequently, the findings can only be regarded as partially representative of the sector as a whole (Helfferich, 2022).

Second, the study focuses exclusively on the perspective of HR departments within transport companies. While these departments play a central role in bus

driver recruitment, they do not exert direct influence over operational driving activities. To gain a more comprehensive understanding of how autonomous buses might contribute to addressing the shortage of skilled labour, future research should incorporate expert interviews from additional organisational units and operational domains.

6 Discussion and Implications

The empirical investigations conducted within the thematic focal areas of subsidies and digitalisation allow for an integrated discussion of the extent to which public policy instruments and digital measures are capable of initiating changes in mobility behaviour and, consequently, of supporting a modal shift in favour of climate-friendly PT. The findings are analysed in light of the overarching research question, which seeks to explain how political and digital interventions influence the three dimensions of Vincent Kaufmann's mobility concept, Access, Skills, and Appropriation, and how these interventions may structurally enable processes of modal shift.

In order to systematise these insights, the results of the empirical studies are first synthesised and consolidated in Section 6.1, following the key patterns and recurring mechanisms identified across the individual studies. Building on this synthesis, Section 6.2 subsequently derives and discusses the implications in a target group specific manner, addressing the respective consequences for policy-makers, PT providers, and other relevant stakeholders.

6.1 Summary of the Study Results

The following table consolidates the key findings from Studies 6.1.1 to 6.1.6. Owing to substantive overlaps, the individual studies do not produce isolated insights; rather, they reveal interdependent patterns that can be meaningfully interpreted through the lens of Kaufmann's motility dimensions. Changes in Access, Skills and Appropriation frequently appear to be mutually reinforcing and point towards potential dynamics of long-term mobility transformation.

Table 35: Overview of Key Findings

Source: Author's own compilation.

Finding	Study	Conclusion
Price alters mobility behaviour	Study 1: Expansion of services Study 2: "Climate ticket" Study 3: Mineral oil price	Price acts as an incentive, but infrastructure determines the modal shift.
Individual transport dominates collective transport	Study 1: Expansion of services Study 2: "Climate ticket" Study 3: Mineral oil price	Economic incentives control mode choice – but permanent modal shift requires systemic mobility reforms.
Ecology not without economy	Study 1: Expansion of services Study 2: "Climate ticket" Study 3: Mineral oil price	Sustainable mobility is contingent on economic resilience – social disparities limit modal shift.
Digital solutions replace traditional offerings	Study 4: Digital bus stops	Digital innovations are transforming public transport into a user-centric, flexible and attractive system – both urban and rural.
Technical progress not without social acceptance	Study 4: Digital bus stops Study 5: Autonomous buses from the user's point of view Study 6: Autonomous buses from the provider's point of view	Social acceptance of AI is essential for technological transformation and sustainable efficiency increases in the transport sector.
Bus driver shortage, therefore autonomous buses	Study 5: Autonomous buses from the user's point of view Study 6: Autonomous buses from the provider's point of view	Autonomous driving as a strategic opportunity to ensure sustainable mobility while at the same time taking social concerns into account.

6.1.1 Price Signals as Triggers, Not Transformers of Mobility Behaviour

The study results indicate that price structures remain a central determinant of mode choice and therefore exert a direct influence on the modal split between PMT and PT. This finding corroborates a well-established assumption in mobility research: while economic incentives can influence mobility behaviour, their effects are often short-term in nature. This is illustrated by the climate ticket, which temporarily generated higher levels of PT use but did not lead to a sustained modal shift from PMT to PT (Hahn et al., 2024).

The limited impact of price-based measures can be explained by several structural and contextual factors. First, particularly in rural and suburban areas, persistent deficiencies in accessibility, service frequency and reliability of PT remain,

even under attractive pricing schemes. Secondly, external events such as the COVID-19 pandemic and the war in Ukraine mitigated the intended effects, as they led to increased use of individual and what were perceived as safer modes of transport.

Against this backdrop, the role of pricing measures can be interpreted more discriminatingly within Kaufmann's motility framework. While financial incentives primarily affect the Access dimension by lowering economic barriers to entry, they neither address the Skills required for effective use nor the culturally and socially embedded Appropriation of PT. Mobility, as conceptualised by Kaufmann, is not merely physical movement but a socially framed capacity for action, grounded in material, temporal and cultural resources (Kaufmann, 2017). A sole focus on pricing therefore remains conceptually insufficient.

The findings thus suggest that while price-based interventions can provide important impulses, their long-term transformative potential remains limited as long as infrastructural, qualitative and cultural barriers persist. In relation to the overarching research question, this points to the necessity of understanding subsidies not as isolated instruments, but as one component within a broader interplay of structural improvements and cultural change. These insights should not be interpreted as deterministic causal claims, but rather as plausible developmental trajectories derived from the empirical evidence.

6.1.2 The Structural Resilience of Private Motorised Transport

The findings further illustrate that PMT remains the dominant mode of transport, despite temporary behavioural adjustments. Although the low-cost climate ticket, in combination with an expanded PT offer, led to short-term measurable shifts towards collective and lower-emission modes, these effects largely dissipated once the subsidy expired. Subsequently, mobility behaviour reverted to pre-intervention levels, indicating a high degree of stability in individualised mobility routines.

At the same time, external economic impulses, particularly sharply rising fuel prices, contributed to more conscious mobility behaviour and were temporarily reflected in a reduction of PMT trips. These findings confirm that monetary incentives and cost increases can trigger situational behavioural adjustments, yet exert only limited influence on structurally entrenched mobility patterns (Chatterjee et al., 2020).

From the perspective of the research question, these results can be theoretically contextualised using Kaufmann's mobility concept. Economic interventions primarily address the Access dimension by altering financial barriers. However, the persistence of PMT dominance suggests that the Skills required for multimodal everyday mobility and the Appropriation of transport modes remain strongly oriented towards the private car. Kaufmann's framework thus helps explain why short-term incentive effects do not translate into sustained modal-shift processes (Flamm & Kaufmann, 2006).

Overall, the findings indicate that despite observable tendencies towards PMT reduction, the structurally, culturally and infrastructurally entrenched primacy of the private car has so far only been marginally challenged. Sustainable behavioural change appears less likely to be driven by isolated price-based measures than by long-term, systemic transformations of mobility structures. These conclusions represent cautious development perspectives derived from the data, without implying deterministic outcomes.

6.1.3 Environmental Intentions Require Economic Viability

The analysis reveals that although ecological motives are gaining importance in mobility behaviour, their practical implementation continues to depend heavily on individual and structural economic conditions. These conflicting priorities are particularly evident in the transport sector: willingness to shift towards lower-emission modes increases primarily when financial incentives are provided, such as

through subsidised PT fares. Empirical evidence confirms that such pricing instruments can induce short-term shifts in favour of collective mobility (Fearnley, 2013).

At the same time, these effects are significantly weakened during periods of economic strain, for example when there is high inflation or rising living costs. Social selectivity becomes clearly visible: the use of environmentally friendly transport modes remains closely linked to the financial capacity of different population groups (Schwanen et al., 2012). When subsidies are reduced or withdrawn, access barriers increase accordingly, limiting the reach of ecological policy measures.

Within Kaufmann's theoretical framework, economic incentives primarily affect Access. However, volatile economic conditions can simultaneously impede the development of Skills (such as stable multimodal routines) and the Appropriation of sustainable transport modes as culturally embedded practices (Kaufmann, 2002). As a result, the establishment of ecological mobility patterns remains fragile and highly susceptible to external economic fluctuations.

Against this backdrop, the findings point to tendential rather than deterministic change. A sustainable modal shift appears to be less a direct outcome of ecological awareness and more dependent on long-term, socially balanced, and economically stable framework conditions. In their absence, transport-related transitions towards low-emission mobility remain limited and discontinuous.

6.1.4 Digitalisation as a Catalyst for Reconfiguring Public Transport

The digitalisation of the transport sector encompasses a broad range of technological innovations that profoundly transform the mobility experience. Digital solutions such as mobile applications for route planning and ticket purchasing, digital guidance and information systems, and the provision of Wi-Fi in PT enable seamless, networked, and convenient mobility. Research demonstrates that such

technologies significantly enhance perceived service quality, reliability, and intention to use PT (Caiati et al., 2020).

This digital transformation points towards a paradigmatic shift in which traditional infrastructure elements are reorganised through digital innovation. In particular, central urban stops are increasingly evolving into multifunctional nodes offering additional services such as kiosks or laundry facilities. These so-called mobility hubs demonstrably increase both the quality of stay and acceptance of multi-modal mobility services (Liao et al., 2020). This development not only modernises urban mobility but also strengthens the interconnection between transport systems and everyday urban spaces.

At the same time, demand-responsive on-demand services are gaining relevance in rural areas. The deployment of algorithmically controlled, partially autonomous or autonomous vehicles to serve lower passenger volumes enables cost-efficient service provision while reducing empty runs in conventional fixed-route systems. Research indicates that on-demand systems can generate efficiency gains and user benefits in peripheral regions, provided they are embedded within regional mobility ecosystems (Martí et al., 2023).

Against the backdrop of demographic change, characterised by an ageing yet increasingly heterogeneous user base, the expansion of intuitively usable digital platforms is of strategic importance. Mobility apps developed by transport operators function as integrative tools that facilitate access to multimodal offerings and provide low-threshold orientation. Studies show that user-centred digital interfaces significantly reduce perceived complexity and enhance willingness to use PT across generations (Loos et al., 2020). The integration of digital technologies thus reflects the necessity of shaping PT as a dynamic and adaptive system capable of proactively responding to evolving societal demands.

6.1.5 Technological Innovation Depends on Social Acceptance

In the current discourse on the digitalisation of the transport sector, the deployment of AI occupies a central position. AI should not be understood as a substitute for human labour, but rather as a complementary resource that automates repetitive tasks and thereby frees up capacities for more complex, service-oriented activities. In particular, AI-supported guidance and information systems open up new potentials within PT in terms of process optimisation, real-time communication and user orientation. Empirical research demonstrates that AI-based assistance systems can significantly enhance both perceived service quality and operational efficiency (Lukic Vujadinovic et al., 2024).

At the same time, societal acceptance emerges as a critical success factor for the implementation of new technologies. Acceptance barriers can considerably slow down or even prevent the deployment of advanced systems. This is especially true for AI-based applications and autonomous buses, whose potential benefits are evaluated heterogeneously within the population. The empirical findings of this dissertation indicate that millennials in particular currently display an ambivalent or sceptical attitude towards autonomous shuttles. This result is consistent with the existing literature, which highlights generational differences in the perception of safety risks, loss of control and the social value of autonomous mobility (Abraham et al., 2017).

A key driver of this scepticism lies in concerns that increasing automation within the transport sector may lead to the rationalisation of jobs. Especially among younger generations, a pronounced sense of solidarity with bus drivers can be observed, pointing to the continued relevance of human presence and social interaction within PT. This finding aligns with studies demonstrating that social dimensions, such as perceived humanity, communication and situational support, represent central criteria for the acceptance of automated transport systems (Nordhoff et al., 2021).

Against this background, it is essential to communicate the societal benefits of AI in a clear and comprehensible manner. Measures aimed at increasing transparency, user information and participatory system design can help to reduce reservations and build trust. Without broad societal acceptance, the transformative potential of digital technologies remains limited, which may in turn constrain both the competitiveness of transport operators and the overall progress of the mobility transition.

6.1.6 Labour Shortages as a Structural Imperative for Autonomous Buses

The debate surrounding the potential replacement of human labour by automated systems represents a central challenge in contemporary mobility and transport research. The findings of this dissertation indicate that millennials, in particular, display heightened sensitivity towards the social implications of automation in PT. This generation expresses definite concerns regarding potential job losses in the bus driving profession and a perceived devaluation of human labour. Such reservations are also reflected in international research, which confirms that employment security constitutes a core element in the societal assessment of autonomous mobility systems (Nordhoff et al., 2018).

At the same time, these concerns are embedded within broader structural developments that increasingly shape the transport sector. Demographic change, the declining availability of skilled labour and the diminishing attractiveness of the bus driving profession, driven by shift work, limited flexibility, and comparatively low remuneration, are already leading to significant staff shortages. Existing studies suggest that autonomous transport systems are primarily discussed as a strategic complement under conditions of structural understaffing, rather than as an immediate substitute for human labour (Kyriakidis et al., 2019).

The empirical findings further indicate a gradual shift in the focus of public debate. While technological aspects remain relevant, questions of social acceptance and long-term labour market implications are becoming increasingly salient. The re-

sults suggest that autonomous buses should not be understood as threats to existing employment relationships, but rather as a potentially complementary solution, particularly in rural and peripheral areas where conventional service provision is difficult to sustain due to low demand or high operating costs. This interpretation aligns with international analyses that position autonomous minibuses as meaningful additions within niche markets and as integral components of multimodal mobility systems (Milakis et al., 2017).

Against this backdrop, a medium to long-term technological transition appears plausible, without implying immediate displacement effects. Transport operators are likely to have sufficient transition periods in which to adapt qualification profiles and strategically transform workforce deployment, for example, by gradually reducing the need to fill new driver positions while simultaneously developing competencies related to the supervision, control, and maintenance of autonomous systems. In this sense, automation not only opens up technological opportunities but also creates new organisational and occupational design spaces.

Overall, the findings indicate that the success of autonomous mobility solutions will crucially depend on the extent to which technological innovation can be aligned with societal acceptance and labour market integration. This perspective emphasises long-term developmental trajectories rather than deterministic conclusions and underscores the importance of a gradual, socially embedded transformation process.

6.2 Implications for Stakeholder Groups

The following table provides a comprehensive overview of the key action-oriented implications derived from the empirical findings for the relevant stakeholder groups (Sections 6.2.1–6.2.3) with regard to mobility behaviour.

Table 36: Overview of Implications

Source: Author's own compilation.

Stakeholder group	Implications
Policy Makers	1. Pricing as an accompanying element of a comprehensive mobility policy 2. Creating systemic framework conditions for long-term mobility shifts 3. Creating integrated funding architectures that combine social balance and environmental objectives 4. Creating a regulatory and financial framework for the digital mobility transition 5. Promoting technology acceptance through transparent communication and participatory design 6. Securing socially acceptable automation strategies through framework policies based on social partnership
Mobility Users	1. Use and co-creation as elements of active mobility participation 2. Translating economic awareness into sustainable mobility decisions 3. Making sustainable mobility decisions with an awareness of social responsibility 4. Actively use digital mobility services and contribute to the design of smart transport systems 5. Combining openness to new technologies with social awareness 6. Combining technological openness with social awareness and contributing constructively to change
Mobility Providers	1. Qualitative and structural offer optimisation as the basis for effective price incentives 2. Differentiate tariff models and strengthen service expansion as a strategic basis 3. Strategically integrating socially fair wage design and ecological responsibility 4. Strategically expand digital service and infrastructure innovations and make them user-centric 5. Implementing artificial intelligence as human-centred assistance technology 6. Establish strategic employee development and qualification initiatives to provide social support for autonomous systems

6.2.1 Implications for Policy Makers

The findings indicate that financial relief measures, such as subsidised fare schemes or discounted tickets can generate relevant short-term incentives but, in isolation, exert only limited influence on sustained behavioural change. For policy makers, this implies the need to design the framework conditions of sustainable mobility in a way that environmentally preferable options are perceived

in everyday life as being reliable, accessible, and practically viable. This particularly concerns structural factors such as the expansion of multimodal infrastructure, the coherent integration of spatial planning, transport, and climate policy, as well as the continuous decarbonisation of the transport sector. Only when collective mobility options perform consistently across these dimensions, does a more substantial and lasting modal shift appear realistic.

Moreover, the results underline that balancing ecological objectives with social equity remains a central challenge. Funding architectures designed exclusively around efficiency considerations risk reinforcing social inequalities in access to sustainable mobility. In line with the literature, fare models that incorporate social differentiation or income-dependent subsidies may enhance the inclusiveness and societal acceptance of mobility policies. However, the long-term viability of such instruments depends on resilient and reliable financing mechanisms.

With regard to the digital transformation of the transport sector, the findings suggest that digital mobility solutions, such as integrated platforms, open data interfaces, and demand-responsive services, are likely to assume an increasingly pivotal role in multimodal mobility systems. At the same time, it is essential to address issues of data protection, accessibility and social inclusion at an early stage in order to avoid exclusionary effects. A coherent digital strategy can therefore not only enable technological innovation but also establish the structural preconditions for flexible and low-emission mobility routines.

In addition, societal acceptance emerges as a critical determinant in the successful implementation of technological innovations. Scepticism towards AVs or AI-based mobility services highlights the heterogeneity of risk perceptions and trust levels among different user groups. Participatory formats and transparent communication processes offer important entry points for reducing acceptance barriers. Early engagement with diverse stakeholder groups, including those critical of technological change, as well as social partnership arrangements with employees in the transport sector, are likely to play a key role in shaping socially robust innovations.

Overall, the findings suggest that policy makers are increasingly required not only to set regulatory frameworks but also to act as proactive designers of a socially balanced and technologically future-proof mobility system. Steering mode choice, modal split and potential modal-shift processes require an understanding of mobility as a social benefit in Kaufmann's sense, shaped by the interaction of access, competence, and cultural appropriation. A systemically oriented and inclusion-focused mobility policy may thus create the long-term conditions under which sustainable mobility cultures can emerge and stabilise.

6.2.2 Implications for Mobility Users

Based on Kaufmann's understanding of mobility as social access, mobility is interpreted not only as physical movement but as an opportunity for social participation. For mobility users, this implies that individual transport mode choices not only shape personal scope for action but, in aggregated form, also influence collective mobility structures. An increased reliance on PT may therefore contribute, at least the tendency, to shifts in the modal split, without implying deterministic assumptions about the effects.

The findings further indicate that price-based incentives alone are insufficient to establish lasting changes in mobility behaviour. Instead, users appear to be called upon increasingly to reflect upon and actively shape their mobility routines, against the background of available offer structures. Instruments such as digital feedback tools, participatory formats or local mobility initiatives may provide valuable entry points for identifying qualitative deficits and articulating demands for improvement. In this sense, mobility emerges as a social practice whose transformative potential is strongly contingent upon the engagement of its users.

At the same time, economic considerations remain a relevant determinant of mobility behaviour. Changes in pricing structures can trigger sensitisation processes that prompt users to reassess their mode choices and mobility-related expenditures. In such situations, sustainable and socially compatible decisions may become more likely, albeit without necessarily leading to a long-term stabilisation of

such patterns. These dynamics are consistent with Kaufmann's perspective, which emphasises the close interrelation between mobility, social accessibility and distributive justice.

The ongoing digitalisation of the mobility system further reshapes the role of users. Digital tools, ranging from real-time information services and intermodal routing applications to user-based rating systems, not only expand individual action capacities but also enhance the adaptability of the overall system. Mobility users thus increasingly assume the role of informed players within a networked mobility ecosystem. Empirical research suggests that such digital interaction formats can contribute to higher efficiency and acceptance of PT systems, without necessarily inducing profound behavioural change.

Finally, technological developments such as AVs raise questions concerning social perceptions, safety expectations and normative frameworks. The results suggest that users adopt a differentiated approach in which technological openness is closely linked to demands for transparency, safety and social responsibility. A reflective and well-informed user perspective may therefore play a role in shaping the acceptance of future mobility technologies, although its impact should not be overstated.

Overall, mobility users should not be understood as passive elements within a predefined system, but rather as active participants whose decisions and interactions can contribute to the development of more sustainable mobility practices. These contributions, however, are invariably embedded within structural conditions, normative expectations and technological trajectories which shape the scope of possible courses of action.

6.2.3 Implications for Mobility Providers

The findings demonstrate that price-based incentive structures, such as heavily discounted tickets, may initiate short-term changes in mode choice, yet their effectiveness is majorly constrained by the structural and qualitative design of PT

services. For mobility providers, this implies that their role is increasingly shifting from the provision of conventional transport services towards the active co-design of comprehensive mobility offerings. This shift is particularly relevant given the persistent dominance of PMT.

With regard to a potential modal shift, strengthening the functional attractiveness of PT appears crucial. Factors such as service frequency, reliability, connection quality, and passenger comfort significantly shape usage decisions. A stable transition towards collective modes of transport is more likely where these attributes achieve a consistent level of performance, especially in rural or peripheral areas that have traditionally been characterised by service deficits. A flexible and resilient system may thus create the structural conditions under which pricing instruments can unfold their full effect.

Against this backdrop, fare differences are becoming increasingly important. Socially tiered or user group-specific pricing models can reduce access barriers and address heterogeneous mobility needs in a differentiated manner. This highlights that mobility providers operate, not only under economic constraints, but are also embedded within broader social and ecological frameworks. This multidimensional role corresponds to the traditional public service mandate of mobility providers and expands their strategic scope of action.

Within the theoretical framework of Kaufmann's mobility concept, it becomes clear that the provision of public mobility extends beyond physical infrastructure. Mobility is understood as a social space of possibilities shaped by structural access, acquired competencies, and processes of cultural appropriation. For mobility providers, this implies that transport services must increasingly be embedded within a broader understanding of mobility as a social good. The integration of physical, digital, and fare-related elements may thus be interpreted as a necessary, though not sufficient, condition for long-term changes in mobility behaviour.

Digital technologies and AI-based applications offer considerable potential for optimising operational processes, improving user information, and supporting multimodal mobility chains. Their effectiveness, however, depends on user-centred, low-barrier, and socially inclusive design. Digital innovation should therefore be understood not as an end in itself, but as an instrument to enhance the functional quality of public mobility and enable adaptive mobility systems.

Finally, autonomous transport systems open up prospects for more efficient and demand-responsive mobility provision, particularly in structurally weak regions. For mobility providers, this may imply the need to adjust qualification profiles and strategically align personnel development with the requirements of increasingly automated operations. Such a transition, however, presupposes that technological innovation is aligned with organisational and social processes.

Overall, the findings suggest that the role of mobility providers increasingly lies in the design of integrated mobility ecosystems. This transformation is unlikely to be achieved through isolated measures, but rather through the long-term alignment of infrastructure, organisation, and service logic with a mobility paradigm that considers functional efficiency, social accessibility, and cultural embeddedness equally.

7 Limitations and Further Research

The present dissertation is subject to a number of limitations that restrict the scope of its findings while simultaneously identifying avenues for future research.

The first limitation concerns data access. The increased emphasis on data protection resulting from the EU GDPR may have contributed to a certain reluctance among potential participants to take part in large-scale surveys. This reluctance may have reduced both the breadth and heterogeneity of the samples. In addition, the recruitment of expert participants, particularly from the HR departments of PT operators, proved challenging, thereby constraining the number and diversity of qualitative perspectives included. Consequently, the generalisability of the findings should be interpreted with appropriate caution.

Further methodological limitations arise from the specific study designs employed. The survey examining the effects of rising fuel prices was based exclusively on responses from users of PMT. Of 1,330 survey accesses, only 611 datasets could be fully analysed, which limits the statistical robustness of the results. The study on the digital bus stop, by contrast, relies primarily on expert assessments grounded in anticipated technological developments. While short-term innovation trajectories can be estimated with relative confidence, forecasts of long-term developments remain highly uncertain due to their dependence on upstream technological progress.

Thematic uncertainties are also reflected in several findings. A number of participants expressed ambivalent or undecided attitudes towards autonomous buses. This uncertainty may be attributable to limited personal experience or incomplete information. The existing academic literature similarly reports highly divergent results, pointing towards a broader societal ambiguity surrounding autonomous mobility. Such indeterminacy may affect the validity of the expressed assessments.

Another limitation relates to the qualitative data collection. Although the number of expert interviews meets minimum methodological requirements, it does not

allow for a comprehensive representation of the PT sector. Moreover, the primary focus on HR departments provides only limited insight into the operational realities of day-to-day transport services. Incorporating a wider range of organisational perspectives could yield a more differentiated assessment of the potential of autonomous buses to address labour shortages.

The analysis further indicates that PT stops represent a central yet under-researched element of the mobility system. Despite their role as critical interfaces between the population and mobility services, theoretical conceptualisations remain limited. This reveals substantial research potential, particularly with regard to the integration of digital services and the design of user-centred stop concepts.

Data collection on fuel price developments took place during a period of pronounced economic volatility (March-April 2022), shortly after significant price increases. At the time of the survey, it was unclear to what extent these cost developments had already translated into behavioural change. In addition, the macro-economic effects of the war in Ukraine and accelerating inflation introduced further uncertainty, the medium and long-term consequences of which were not yet foreseeable. Future studies should therefore adopt a more explicitly longitudinal perspective in order to capture such dynamics more adequately.

There are also limitations regarding the transferability of the findings. Although the study on service expansion reached 14,296 households in Bonn, it is not possible to generalise the results directly to the entire urban population or to other regions. The results reflect specific consumption patterns embedded within the German transport system and its regional contexts, which restricts the validity of international comparisons.

Finally, the study examining millennials' attitudes towards autonomous buses exhibits limitations typical of qualitative research. While the small sample size enables in-depth insights into perceptual structures, it does not permit representative

conclusions for the population cohort as a whole. Future research should therefore employ larger and more diverse samples in order to substantiate the identified tendencies through quantitative analysis.

8 Conclusion and Prospects

This dissertation demonstrates that shifts in mobility behaviour towards PT are shaped by a complex and interdependent interplay of economic, infrastructural and technological factors. Price structures, service quality, subsidy mechanisms and digital innovations do not operate in isolation; rather, they interact within a multi-layered system whose dynamics can only be understood holistically. Within this system, ecological objectives, social participation and economic constraints form an area of tension that necessitates mobility strategies which are not only environmentally sustainable but also socially inclusive and economically viable.

The empirical findings confirm that price-based incentives, such as subsidised fare schemes, are capable of triggering short-term behavioural adjustments. At the same time, they indicate that such effects tend to remain fragile in the absence of corresponding structural improvements in PT provision. The termination of temporary subsidies was repeatedly associated with a reversion to PMT, underscoring the central role of service reliability, accessibility and functional competitiveness. These dynamics are particularly pronounced in rural and suburban contexts, where limited-service coverage and low frequency significantly constrain the effectiveness of purely financial incentives.

Against this backdrop, the analysis highlights that the effectiveness of price as a control instrument is basically contingent upon the structural quality of the transport system itself. Disparities between urban and non-urban areas illustrate that economic incentives alone are insufficient to compensate for infrastructural deficits. A more promising perspective lies in integrated policy approaches that combine financial, organisational and infrastructural measures, thereby creating the technical and social preconditions for sustainable mobility choices.

Digitalisation emerges as a further key lever in the transformation of PT systems. Real-time information, multimodal mobility platforms, adaptive on-demand services and digitally enhanced mobility hubs offer substantial potential to improve functional performance and reduce access barriers. Moreover, the integration of

AI and automated vehicles opens up prospects for addressing the foreseeable shortage of skilled labour in the transport sector, particularly in regions with low and fluctuating demand. At the same time, the extent to which such technological innovations can be socially accepted and institutionally stabilised over the long term remains an open question.

The findings clearly indicate that issues of societal acceptance constitute a critical challenge, especially with regard to autonomous mobility solutions. Perceived risks related to job security, safety and the erosion of social interaction significantly shape public attitudes towards automation. These concerns call for differentiated and participatory communication strategies that go beyond technological optimism. A socially embedded implementation pathway appears essential—one that aligns technological innovation with principles of inclusivity, transparency and accessibility.

With regard to future research, several avenues for further investigation emerge. First, more in-depth analyses of regional heterogeneity are required, as mobility decisions are strongly context-dependent and embedded in local socio-spatial structures. Second, longitudinal research designs would be particularly valuable in assessing whether observed behavioural changes represent transient reactions or more durable shifts, and how learning and appropriation processes evolve over time in line with Kaufmann's concept of motility. Third, greater attention should be paid to specific user groups, such as people with limited mobility, in order to refine the requirements for inclusive and automated transport solutions. Fourth, expanding the scope of research through international comparative studies would allow for the systematic identification of structural commonalities and differences, thereby supporting the development of transferable policy strategies.

Overall, the results suggest that sustainable mobility transitions can only be realised through the interaction of pricing policies, service quality, technological innovation and societal acceptance. The key challenge for future mobility policy lies less in optimising individual instruments than in developing systemic, context-

sensitive strategies that understand mobility as a socio-technical and infrastructural whole. From this perspective, sustainable mobility does not emerge from singular interventions, but from a long-term transformation process whose success depends on structural coherence, institutional cooperation and societal embeddedness.

9 References

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