Pathways toward the reduction of private car use from a psychological perspective

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Statement for a publication-based dissertation

In accordance with §8 (1) of the doctorate regulations of the School of Science of Dresden University of Technology, this dissertation has been prepared as a self-contained work. Chapter 1 provides an introduction to the theoretical background, and concludes with the aim and research questions. Chapters 2-5 present four studies addressing different aspects of the aim, each of which has been published in or is under review at a peer-reviewed journal. Three of the four studies have also been presented at international conferences. While the papers remain otherwise unchanged, the chapters, research questions, tables, figures, references, and appendices were given a unitary format and consecutive numeration to ensure consistency. The four studies have not been used and are currently not intended to be used in other dissertations. The doctoral candidate's contribution to each study is outlined below according to Elsevier's Credit system. Chapter 6 provides a conjoint discussion and conclusion.

Study I, chapter 2.

- **Publication:** Hauslbauer, A. L., Schade, J., & Petzoldt, T. (2022). The identification of mobility types on a national level. *Transport Policy, 125*, 289-298.
- **Presentation:** Hauslbauer, A. L. (2022, January 11). *The identification of mobility types on a national level* [Poster session]. TRB - Transportation Research Board Annual Meeting, Washington, DC, United States.
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Study II, chapter 3.

- **Publication:** Hauslbauer, A. L., Verse, B., Guenther, E., & Petzoldt, T. (2024). Access over ownership: barriers toward the use of MaaS from the perspective of users and non-users. *Transportation Research Interdisciplinary Perspectives*, *23*, 101005.
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Study III, chapter 4.

- **Publication:** Hauslbauer, A. L., Schade, J., Drexler, C. E., & Petzoldt, T. (2022). Extending the theory of planned behavior to predict and nudge toward the subscription to a public transport ticket. *European Transport Research Review, 14*(1), 1-14.
- **Presentation:** Hauslbauer, A. L. (2022, August 23). *Nudging employees to commute sustainably* [Paper presentation]. ICTTP - 7th International Conference On Traffic And Transport Psychology, Göteborg, Sweden.
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Study IV, chapter 5.

- **Publication:** Hauslbauer, A. L., Malik, J., Iogansen, X., Circella, G., & Petzoldt, T. (2023). Telecommuters vs. physical commuters during the Covid-19 pandemic: the change in mobility-related attitudes and the future intention to telecommute. Under review at *Transportation Research Record.*
- **Presentation:** Hauslbauer, A. L. (2022, December 14). *Change in mobility-related attitudes during the Covid-19 pandemic among teleworkers vs. physical commuters* [Paper presentation]. IATBR Conference - 16th International Conference on Travel Behaviors Research, Santiago, Chile.
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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
App	Smartphone application
AT	Attitude
AVE	Average variance extracted
BVG	Berliner Verkehrsbetriebe
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CO_2	Carbon dioxide
Condition DSN	Condition default-social norm
Condition D	Condition default
Condition SN	Condition social norm
Covid-19	Coronavirus disease 2019
DF	Degrees of freedom
DV	Dependent variable
EC	Environmental concern
EFA	Exploratory factor analysis
EV	Electric vehicle
Gen X	Generation X (born 1965-1980)
GFI	Goodness-of-fit index
ICTs	Information and communication technologies
IV	Independent variable
KMO	Kaiser-Meyer-Olkin measure
M	Mean
MANOVA	Multivariate analysis of variance

MAXQDA	MAXQDA software for the analysis of qualitative and mixed data
N	Sample size
NFI	Norm fit index
PBC	Perceived behavioral control
PCA	Principal component analysis
RMSEA	Root mean square error of approximation
RQ	Research question
SPSS	IBM SPSS (Statistical Package for the Social Sciences) Software
SEM	Structural equation modelling
SD	Standard deviation
SN	Subjective norm
TAM	Technology acceptance model
TLI	Tucker-Lewis-Index
TPB	Theory of planned behavior

SYNOPSIS

Travel not only serves the purpose of engaging in spatially separated activities but also fulfills fundamental human needs for self-actualization, independence, and a sense of connection with the world. Unfortunately, the transportation sector faces significant challenges related to environmental, economic, and social issues, largely attributed to privately owned cars. Cars contribute to environmental problems through, e.g., emissions, resource depletion, and noise pollution, while also imposing economic burdens and exacerbating social inequalities. Despite these challenges, private car ownership and usage remain dominant.

Addressing these issues calls for a transition to a sustainable and equitable mobility system. Currently, the predominant approach is the *efficiency strategy*, which focuses on technological advancements to reduce resource consumption. However, this strategy alone falls short, as the success of technological innovations ultimately depends on human behavior. Adaptations in behavior may offset efficiency gains, and improved technologies may not fully consider the true motivations, habits, and needs of mobility users. Consequently, the *sufficiency strategy* becomes indispensable, centering on human decision-making, lifestyles, behaviors, and consumption patterns.

This dissertation aims to contribute to the development of a sustainable transportation system by identifying and laying the groundwork for effective, psychology-based approaches. Four individual studies delve into different aspects of the sufficiency strategy.

Study 1. First, it is important to recognize that individuals exhibit a wide array of diverse needs, physical abilities, attitudes, and available mobility options. This study embarked on the task of identifying distinct mobility types prevalent among the German population. Drawing data from a representative national survey on everyday mobility behavior, socio-demographic, behavioral, geographic, and psychographic information was used to cluster individuals into eight stable mobility profiles by means of exploratory factor and cluster analysis. The results provide a foundation for the development of customized interventions aimed at reducing private car use and fostering sustainable transportation choices that accommodate diverse needs and preferences.

Study 2. In the realm of novel mobility solutions tailored to address these needs, a qualitative, focus-group based study was conducted in Berlin, Germany, to explore the potential of Mobility as a Service (MaaS) in redirecting users away from private cars and enhancing access to diverse transportation options. Data from 12 focus group sessions was analyzed using qualitative content analysis. Results revealed that while MaaS effectively

addresses nearly all instrumental motives of private car use, it falls short in tackling the symbolic and affective motives associated with car ownership. However, MaaS may contribute to a more sustainable mobility system by emphasizing its unique symbolic and affective motives as well as highlighting its potential to alleviate the burdens of car ownership.

Study 3. As a readily applicable intervention, this study comprised an experiment to assess the effectiveness of *nudges* in encouraging commuters to shift toward transit options, employing the theory of planned behavior as a theoretical foundation. Participants were randomly assigned to different *nudging* groups or a control group, and data was analyzed using structural equation modeling and logistic regressions. While the theory demonstrated a good prediction of individuals' decisions, none of the *nudges* achieved statistically significant effectiveness. This exploration of *nudging* interventions in the transportation sector provides insights into the limitations of strategies aimed at changing habituated commuting behavior.

Study 4. The Covid-19 pandemic presented an unprecedented disruption to commuting habits, offering a unique opportunity to examine the impact of telecommuting on mobility-related attitudes. Through factor analysis and multivariate analyses of variance on longitudinal data from the California panel study of emerging transportation, the development of mobility-related attitudes of telecommuters and physical commuters was compared. Further, individuals' intentions to telecommute in the future were modeled using external job related and attitudinal predictors. Results showed that fundamental attitudes toward mobility remained largely stable despite the variations in commuting behavior and the pandemic's progression. The main determinants of intentions to telecommute in the future were not job related but internal, including attitudes and tech-savviness. The model further suggests a prevalence of hybrid working beyond the pandemic, potentially opening up opportunities to prioritize sustainable transportation options due to a reduced demand for daily commuting.

In addition to examining these four research projects individually, findings and their broader implications that span across the studies are discussed. These include the increasingly important role of tech-savviness, the integration of attitudinal constructs in interdisciplinary transportation research, the questionable impact of environmental concern on behavior, and the ambiguous effects of *nudging* interventions in the transportation sector.

By delving into various psychological aspects of individuals' mobility behavior, this dissertation highlights the potential and, at times, the shortcomings of a diverse range of measures aimed at addressing the challenges of the transportation sector in the pursuit of sustainability and equity.

"And of course, she had studied the civilization that had immediately preceded her own - the civilization that had mistaken the functions of the system, and had used it for bringing people to things, instead of for bringing things to people. Those funny old days, when men went for change of air instead of changing the air in their rooms!"
— E. M. Forster (1909), "The Machine Stops"

1 THE TROUBLE WITH INDIVIDUAL MOBILITY AND WHAT TO DO ABOUT IT

1.1 WHY WE MOVE

In the science fiction novella *The Machine Stops* (Forster, 1909), travel has become obsolete and unpopular as a consequence of an omnipresent, omnipotent technology that meets all needs. In our world, quickly accelerating technological advancements already provide increased from-home access to resources and opportunities, such as employment, education, and healthcare. This trend was recently propelled further by the Covid-19 pandemic and ensuing lockdowns (Ebner et al., 2020; Shakeel et al., 2022; Sneader & Singhal, 2021). Following the notion that travel is solely instrumental and demand oriented, which has been the predominant view in transportation research for a long time (Mokhtarian et al., 2015), an ongoing advance of technology would make travel truly obsolete in the future.

Yet, we do not only travel because the activities we engage in are spatially separated. Individual mobility allows us to fulfill basic human needs, such as *esteem* and *self-actualization* of Maslow's (1943) pyramid of needs, and is considered an essential emotional experience, a means to participate in the world, and to express independence and autonomy (Kaufmann & Widmer, 2006; Mollenkopf et al., 2011, Mokhtarian et al., 2015; Steg, 2005). The concept of a stable travel time budget (Zahavi & Ryan, 1980), proposing that we dedicate about an hour per day to traveling, suggests that time spent traveling persists, regardless of technological advancements (Ahmed & Stopher, 2014). Accordingly, *The Machine Stops* alleges that without individual mobility, people may become limited in their experiences, leading to a narrower worldview and to a society devoid of genuine human connection and personal exploration.

Despite advances in technology, individual travel will likely persist. But on a planet with finite resources, the means and methods of transportation have a significant impact on the world. Unfortunately, our current transportation system is not sufficiently sustainable and equitable.

1.2 CHALLENGES BROUGHT ABOUT BY THE TRANSPORTATION SECTOR

We did a bad job. We, that includes stakeholders of the traffic and transportation universe: politicians and policymakers, the automobile industry, transportation planners and economists, researchers, and users. Why, because transportation is responsible for grave environmental issues, economic issues, and social issues (Litman & Burwell, 2006). With respect to individual mobility behavior, the central culprit for this predicament is the privately owned car. To embark on the challenging, winding journey of resolving these issues, we first need to contemplate the private car's contribution.

1.2.1 Environmental issues and the private car

To manufacture cars, generate fuels, and build roads, non-renewable resources get depleted. Once the car's lifetime has passed, disposing of the used material poses another environmental challenge (Litman & Burwell, 2006). While the car is on the road, it emits exhaust gases, particulate matter (e.g., smog), heat, and noise, which harm biodiversity and endanger habitat preservation (HEI, 2010; Litman & Burwell, 2006; Nieuwenhuijsen, 2016; Petralli et al., 2014).

Perhaps the most pressing issue is the acceleration of global warming through greenhouse gas emissions (CO_2 and others), to which the transportation sector significantly contributes (BMWK, 2022; HEI, 2010). According to the German Federal Ministry for Economic Affairs and Climate Action, in 2021, the transportation sector caused 19% of all greenhouse gas emissions in Germany. With this percentage, it accomplished a spot on the unfavorable podium, coming in third after the energy and the industry sector. Whereas the latter two have successfully reduced their emissions since 1990 by up to 47%, the transportation sector has only recently, on account of the Covid-19 pandemic, managed a small reduction of 9% (BMWK, 2022). Spotlighting the sources of emissions within the German transportation sector, the ministry found that motorized on-road travel is responsible for colossal 96.8% of emissions, dwarfing domestic air, ship, and rail traffic. The car specifically is responsible for 59.2% of emissions (BMWK, 2022).

1.2.2 Economic issues and the private car

Despite being discussed less than environmental concerns, the challenges that the transportation sector poses regarding economic issues are not to be underestimated. Especially in the case of perceived or actual car dependence, economic impacts on individual households, i.e. the portion of household expenditures devoted to transportation, can be immense, and lead to further implications for accessibility to job opportunities and commercial services (Chevallier et al., 2018; Curl et al., 2018; Litman & Burwell, 2006; Mattioli et al., 2018).

Furthermore, car owners typically underestimate the true private cost of owning a car, and immensely underestimate the true environmental and social cost of car ownership (and concerningly, so do politicians and policymakers) (Gössling et al., 2022).

But the economic cost of cars is not only borne by the car owners. The expansion and maintenance of bridges, highways, and other roads is a burden for every tax payer (Litman & Burwell, 2006).

1.2.3 Social issues and the private car

Social issues, which impact a large number of individuals at once and include topics such as public health, safety, and equity, overlap with environmental and economic concerns (Rubington & Weinberg, 2010). Car based emissions not only harm the environment, but also burden public health and community livability. Specifically in urban areas, noise pollution and particulate matter are a strain on (and economic cost for) public health (Hickmann & Banister, 2014). Furthermore, on-road transportation is inherently dangerous and a burden on the healthcare system. In Germany in 2021, a total of 2,314,938 on-road accidents were registered, in which 232,129 individuals were harmed and 2,562 individuals were killed (Destatis, 2022a).

Equity concerns, such as affordability and access, constitute another social issue. Those that cannot drive a car, due to economic disadvantages, physical constraints, old age, or other limitations, are faced with barriers to participate in public life outside of their home if no suitable alternative transportation options are available (Haustein & Siren, 2015; Remillard et al., 2022).

Those who do drive a car are typically familiar with being stuck in traffic. Beyond environmental and economic issues due to increased emissions and fuel consumption (Barth & Boriboonsomsin, 2009), congestion has implications for physical and mental health: drivers sitting in traffic are directly exposed to increased tailpipe emissions (Levy et al., 2010), and experience higher levels of stress; if experienced during commuting this can even spill over into the workplace and weaken performance (Chatterjee et al., 2020).

Last, the quality of the local environment is compromised by roads and road traffic taking up space that could otherwise be dedicated to walking and biking lanes or green spaces. In inner cities, car lanes and parking spots occupy 70-80% of public space, while cars are typically parked for 23 hours of the day (Apel, 2012; Nobis & Kuhnimof, 2018; Notz, 2017; Stößenreuther, 2014).

Even though we have known and discussed these overlapping, interconnected issues for years, the private car still accounts for 78.4% of all traveled kilometers (in 2019 in

Germany; BMDV, 2022), and the 70.1 million adults living in Germany jointly own 48.5 million cars (Destatis, 2023; KBA, 2022). The dominance of private car based automobility is rampant, and so are the issues this causes. To have any chance at successfully changing this, strategies need to target antecedents of car use and ownership. Therefore, we need to understand *why* the car is so popular (Steg, 2007).

1.3 ROOTS OF MOBILITY BEHAVIOR

While the previous paragraph summarized issues caused by *transportation*, it is important to distinguish this from the concept of *mobility*. Whereas transportation (Latin: *trans* = across, *port* = carry) refers to the intentional act of moving people or goods from one place to another, the term mobility (Latin: *mobilitas* = the capacity for movement) focuses on the ability to freely move (Cambridge dictionary, 2023), or, as political and social scientist Prof. Dr. Andreas Knie puts it, "mobility […] happens in the head"[1] (Die Mediation, 2019).

1.3.1 Mobility decisions on three levels

In order to understand the car's popularity and to develop effective measures to alter mobility behavior, it is necessary to properly comprehend how mobility choices are made. This is not straightforward, because mobility choices are not made independently, but are interwoven and mutually impact or even constrain each other. To allow for a better understanding, it may be helpful to structure mobility choices from larger, long-term decisions to smaller, short-term behaviors. An overarching framework that does so is Schlag and Schade's (2007) categorization in three interconnected levels. On the macro level, decisions are only indirectly related to mobility, but build the foundation for options available on lower levels and imply long-term consequences. Examples are decisions about residential and work location (which have implications for, e.g., commuting), or about mobility equipment such as if to buy a car or not. On the meso level, decisions concern the planning process of participating in daily mobility. This includes, for example, mode choice, though the available choice set is determined by decisions made on the macro level (e.g., if a car is available, if a transit stop is nearby). Vice versa, experience with available modes may prompt individuals to change decisions on the macro level (e.g., to purchase a car because transit is perceived as unsatisfactory). On the micro level, short term decisions are made, such as the style of driving (e.g., driving at a steady speed as opposed to accelerating aggressively).

[1] Translated from German: "Mobilität […] findet im Kopf statt."

1.3.2 How the private car came to and stays in power

In the past, economists and engineers predominantly explained mobility behavior (such as mode choice: car) on the meso level, as a function of travel time and cost, implying that the individual makes a rational choice. Today, these disciplines have recognized that mobility behavior (like most human behavior) is not the choice of an economically rational *homo economicus* (it may, however, be rational to the individual himself with all their biases and subjective opinions), and that psychological factors need to be considered (Schlag & Schade, 2007; Steg, 2005). Examples for psychological models that conceptualize the relationship between specific mobility behaviors such as mode choice and psychological factors are the norm-activation model (Schwartz, 1977) and the theory of planned behavior (Ajzen, 1991). The norm-activation model has been used to extract personal norm as a predictor for mode choice, based on the idea of individual assumption of responsibility as the main motivator. Based on the idea of individual advantages as main motivators, the theory of planned behavior has been used extensively to predict mode choice using attitudes, subjective norm, and perceived behavioral control (Hunecke, 2015).

Beyond explaining mode choice, to thoroughly understand the rise and stability of private car dominance, interdisciplinary approaches are needed, because mobility choices are not made in a vacuum, but within a complex web of (infra)structural and spatial, economic, social, and psychological (e.g., social norms, habits, emotions) interconnected factors and constraints (Aarts & Dijksterhuis, 2000; Bamberg, 2010; Hunecke, 2015; Steg, 2005). For example, on the macro level, the steadily expanding infrastructure of highways, roads, and petrol stations has invited more driving, the growing economy producing higher income has increased affordability of private cars, and the social trend to suburbanize has increased the need to travel (Newman & Kenworthy, 2007). Furthermore, on the meso level, car use is largely habituated, meaning that the car is chosen repeatedly without a conscious decision being made about it (Verplanken et al., 1998). Steg (2005) has found that affective and symbolic motives for car ownership can outweigh its instrumental functions. Accordingly, less than half of the value associated with car ownership is attributed to its instrumentality, even in the US (Haustein, 2021; Moody et al., 2021). The recent trend of cars growing in size, weight, and horsepower (which may allow for more “exciting” driving styles on the micro level) has been attributed to emerging *aspirational* car ownership, meaning that drivers perceive *car careers* and aspire to move up this career-ladder by purchasing bigger cars (Humpe et al., 2022).

These and numerous other developments on all levels have contributed to car use being this dominant, attractive, and partly even inevitable (Steg, 2007). How, then, can the issues caused by transportation, especially by the private car, be effectively addressed?

1.4 CHANGING FOR THE BETTER: THE MOBILITY TRANSITION

To address the challenges caused by transportation, the term "mobility transition" (German: "Verkehrs-/Mobilitätswende") has been used extensively. This term suggests that mobility changes from one state to another, but opinions on what the goal state may be and how to achieve it vary (Drexler et al., 2022). In their communication on the subject, stakeholders of transportation intentionally or unintentionally create a certain narrative of what the mobility transition may entail by highlighting specific aspects of it while omitting others. This process is called framing (Kahneman & Tversky, 1984). Understanding how stakeholders frame a subject is crucial, because this has a strong impact on how the subject is perceived, evaluated, and which actions are pursued as a consequence (Entman, 1993; Kahneman & Tversky, 1984). To examine such frames, Entman (1993) proposes to identify how actors define the problem and its cause, what moral evaluation they attribute to it, and what actions they suggest to remedy the problem.

To analyze how stakeholders of transportation in Germany use the term "mobility transition" in their public communication, Drexler et al. (2022) used Entman's (1993) framing elements. They found that for politics and the media, the understanding of a "mobility transition" is as broad as the political spectrum itself. There is disagreement with respect to the underlying problem: descriptions reach from an active denial of environmental issues and instead an identified lack of highways, to climate change as the most urgent issue of our time. Similarly, proposed approaches to solve problems within the mobility transition reach from the necessity of building more roads to a prohibition of cars altogether. One particularly insightful finding is that the perspective that was most repeated and focused on is the perspective of the automobile industry. According to the industry, the problem is almost purely of an environmental nature, is caused by outdated fuel technologies, and the solution is a change in fuel technologies toward e-mobility and synthetic fuels (Drexler et al., 2022). In other words, in public communication, the most reported frame in which the term "mobility transition" is presented fits within the so-called efficiency strategy.

1.4.1 The efficiency strategy

The term efficiency strategy represents the idea that objectives may be achieved by means of an improvement of technologies, processes, and products. By increasing the efficiency of the use of (raw) materials and energy, resource consumption can be reduced. Put simply, the "input-output-ratio" can be improved (Behrendt et al., 2018).

While this is a necessary approach, to address the challenges posed by transportation, the efficiency strategy alone will not be sufficient. Because for the efficiency strategy to be successful, human behavior needs to be considered as well (Schlag & Schade, 2007).

For one, although innovations can retain the technological potential to increase sustainability, they may pose certain new behavioral requirements, which need to be considered and incentivized or regulated. For example, while EVs do not directly emit greenhouse gases when in use like a combustion engine, the production of electricity to charge them may. Here, individuals need to be convinced to perform certain behaviors, such as smart charging, so that CO_2 emissions caused by electricity production may stay low (Kramer & Petzoldt, 2022).

Likewise, efficiency gains might be offset by adaptations in human behavior, a phenomenon called rebound effect. For example, car drivers might increase the use of their energy-efficient cars because they perceive them as sustainable and because propellants are cheaper (Berkhout et al., 2000; Binswanger, 2001; Schlag & Schade, 2007; Steg, 2007).

Furthermore, even if behavioral adaptations are considered, the efficiency strategy alone cannot address all environmental, economic, and social issues caused by transportation (Behrendt et al., 2018; OECD, 1990):

With regard to the environment, issues that are not addressed or are even amplified by new technologies like EVs include non-exhaust particulate matter (such as tire abrasion, which is increased through EVs due to their increased weight; Timmers & Achten, 2016), or the disposal of used materials (in the case of EVs, this includes potentially hazardous battery waste, which needs to be carefully recycled; Deshwal et al., 2022).

With regard to economic issues, technological innovations may increase the problem of affordability. For example, the combined costs that occur during an EVs lifespan (at least for the lower segments of small city cars and medium cars) tend to exceed the costs of a conventional vehicle (Lebeau et al., 2013), while the expansion and maintenance of road infrastructure remains a tax burden.

With regard to social issues, barely any existing concerns are solved. For example, public health is still impacted by non-exhaust particulate matter and on-road accidents, and land use issues (e.g., public space blocked by parked cars) are not addressed. Furthermore,

improved technologies might not fully consider the true motivations and needs of mobility users.

Nonetheless, the efficiency strategy plays an essential role in achieving a sustainable mobility transition. But this approach alone is not sufficient to achieve a sustainable and equitable mobility system. To have any chance at success, human behavior and decision making needs to be considered as well. This is done within the so-called sufficiency strategy.

1.4.2 The sufficiency strategy

The term sufficiency strategy represents the idea that objectives may be achieved through a change in lifestyle and consumption patterns (Heyen et al., 2013). In the transportation context, this encompasses measures and strategies that reduce the use of resources through changing travelers' behavior (Behrendt et al., 2018).

In contrast to the efficiency strategy, which is more favorable toward economic gains, the sufficiency strategy rather relates to economic restrictions. This is perhaps the reason why the industry proposes the efficiency strategy so dominantly and tends to overlook the sufficiency strategy.

In the recent decade, an approach within the sufficiency strategy called nudging has garnered extensive recognition within academia and in the broader scope of popular culture, leading to calls for the application of nudging interventions within the transportation sector (Avineri, 2009). Nudges aim to steer choices and decisions by making use of human heuristics and biases, while retaining freedom of choice (Thaler & Sunstein, 2009). As such, a diverse array of interventions may be called a nudge, such as setting defaults or stressing social norms. Despite the considerable attention it has received, so far, nudging does lack a cohesive theoretical model (Ölander, & Thøgersen, 2014).

In contrast, a widely recognized theoretical model that has been used to conceptualize the process of individual (traveler) behavior change is the stage model of self-regulated behavior change (Bamberg, 2013a; Bamberg, 2013b; Olsson et al., 2018; Pan et al., 2021; Sunio et al., 2018). Bamberg (2013a) differentiates four action phases: pre-decisional, pre-actional, actional, and post-actional. The segmentation into these phases allows for derivation of specific interventions, depending on which phase an individual is in. Then, goal, behavioral, or implementation intentions can be actively supported with the right interventions at the right time (Hunecke, 2015).

Banister (2008) names three goals that such interventions toward a more sustainable transportation system within the sufficiency strategy may target: modal choice, reduction of

trip number, and reduction of trip length. Interventions with regard to modal choice involve moving away from the private car toward more desirable modes (e.g., transit or active modes such as walking). Trip number can be reduced by, for example, combining trips (as in fulfilling several trips in one go), sharing trips with others who would otherwise drive individually, or making certain car trips obsolete altogether (e.g., by working from home instead of commuting). Reducing trip length could be achieved by choosing different destinations or routes, or on the macro level, by changing job or home location to reduce travel distances (Steg, 2007).

While the German Federal Ministry for Economic Affairs and Climate Action names the expansion of e-mobility as the main intervention in the car sector, they also consider the sufficiency strategy and mention, specifically, CO_2 emission pricing, the strengthening of transit, and the expansion of bike lanes (BMWK, 2022). CO_2 pricing is one of many measures within the category of "push measures", whereas increasing the attractiveness of transit and biking can be seen as "pull measures". A frame through which sufficiency-based strategies can be viewed is this categorization in push and pull measures, or, to speak figuratively: carrot-and-stick approaches.

1.4.2.1 Push measures

Push measures (penalties, i.e. the 'stick' in carrot-and-stick) are designed to make car driving more unattractive (Steg, 2007). Examples are the introduction of parking restrictions, car-free zones, or congestion pricing (see, e.g., Fürst & Dieplinger, 2014; Langbroek et al., 2016; N. Wang, 2017). Because of their restrictive nature, push measures tend to be associated with negative emotions, may cause reactance, and are generally less accepted by the public (Geller, 2002; Steg, 2007).

For example, as early as 1997, Schlag and Teubel found that while the technical feasibility of transportation pricing schemes has been explored, the perceived lack of public acceptability keeps authorities from enforcing them. Acceptability depends on information, perceived effectiveness and efficiency, individual claims (e.g., privacy concerns), equity, and transparency of revenue allocation (Schlag & Schade, 2000). This is evidence that where push measures are concerned, traffic users must be involved in transportation planning, because behavioral change can only follow if the rationale behind measures such as policy changes are understood and accepted (Banister, 2008; Schade & Schlag, 2003).

Since car use typically is habituated and not solely determined by cost considerations, push measures such as transportation pricing may be more effective if feasible, attractive

alternatives are available (Steg, 2007). In other words, the penalty stick is necessary, but we also need a carrot.

1.4.2.2 Pull measures

Pull measures (incentives, i.e. the 'carrot' in carrot-and-stick) enlarge behavior options by making sustainable alternatives more attractive (but not by making car use less attractive per se) (Steg, 2007). Examples here are an expansion of transit and safer biking and walking infrastructure. A more psychological oriented example is emphasizing the sustainability of environmentally friendly transport modes. Individuals who are aware of environmental issues and are willing to contribute to their solution, i.e. those with certain level of environmental concern (Dunlap & Jones, 2002), may then be more likely to use those modes. Since predominantly associated with positive emotions, pull measures are typically more accepted by the public. For example, Schlag and Schade (2000) found that improvements in transit and the implementation of a park and ride system were universally accepted in their study. However, pull measures are less effective in reducing car use than push measures (Steg, 2007).

A pull measure that has recently and rapidly drawn attention is the idea of 'servicing mobility'. Mobility as a Service (MaaS) advocates argue that a single replacement mode for the car is not sufficient, because mobility needs are diverse and dynamic (Matyas, 2020). MaaS schemes aim at providing access to numerous, integrated mobility options (e.g., transit, ride hailing, sharing vehicles) through a single interface (a mobile phone application) that offers trip planning, booking, payment, and mobility packages (Jittrapirom et al., 2017; Spickermann et al., 2014).

Using push and pull measures in an integrated manner, for example introducing transportation pricing in urban areas and simultaneously offering MaaS as an attractive alternative seems, in theory, to be one promising approach toward a more sustainable transportation system. But for an intervention to "sound good in theory" is not good enough.

1.5 AIM AND RESEARCH QUESTIONS

1.5.1 Aim: identifying effective strategies to achieve a sustainable transportation system

Interventions to support a sustainable transportation system need to be rigorously tested for their effectiveness and, if unsuccessful, refined or replaced (Steg, 2007). Geller's (2002) "DO IT" process provides a framework for this: the targeted behavior needs to be *defined*, the conditions that uphold the unsustainable behavior (or suppress the sustainable behavior) need

to be *observed*, so that *interventions* can be designed and implemented and finally, *tested* for their effectiveness.

In this introduction so far, we have *defined* car use as a harmful behavior causing numerous environmental, economic, and social issues (Chapter 1.1) and we have *observed* antecedents and upholding factors for car use (Chapter 1.2). Chapter 1.3 gave a broad overview of the different strategies for *interventions*, detailing the efficiency strategy and its shortcomings, the importance of the sufficiency strategy and push and pull measures within it. Now, it is time to *test*.

The following chapters (2-5) illustrate different strategies based on the insights above that have been trialed with the hopes to contribute to a more sustainable mobility system by reduction of private car use. Ultimately, the aim of this dissertation is to give advice on specific measures within the sufficiency strategy: are they worth pursuing, or do they need to be refined or replaced?

1.5.2 Research questions: trialed strategies

First, it is important to recognize that the playing field is not level. Individuals are diverse, they have differing mobility options, needs, physical abilities, and attitudes. Chapter 2 deals with the identification of mobility profiles to precisely address the respective needs as well as environmental and equity issues for each group.

> ***RQ 1:*** *Can the German population be meaningfully segmented into distinct mobility types, which are able to provide a basis for the development of tailored interventions to promote a sustainable and equitable mobility system?*

Second, for a pull measure, chapter 3 consists of a case study investigating perceived enabling factors and barriers for a recently introduced MaaS scheme, and specifically, to what extent individuals would reduce the use of their private car because of it.

> ***RQ 2.1****: What are the relevant enabling factors and barriers for MaaS users and non-users, within the application (e.g., nudging) and external (e.g., policy measures)?*
>
> ***RQ 2.2:*** *Under which (psychological) circumstances would individuals be willing to reduce their use of or discard the private car on account of MaaS?*

Both chapter 2 and 3 have identified commuting as a frequent and thus impactful trip type. Based on an extended version of the theory of planned behavior, as a softly designed measure somewhere between a pull and a push, chapter 4 details an experiment that tested the effectiveness of nudging commuters toward a transit ticket, with the intention to replace the car commute with transit.

RQ 3.1: *Can the theory of planned behavior extended by environmental concern predict the decision to subscribe to a transit ticket?*

RQ 3.2: *Are nudges (a default and a social nudge) aimed at enticing employees to purchase a transit ticket able to increase transit subscription numbers effectively?*

RQ 3.3: *Can nudges be integrated into the theory of planned behavior?*

In the wake of the Covid-19 pandemic, a 'cosmic' push measure struck the globe. The pandemic and related policies forced many commuters to work from home (temporarily), whereas others continued to commute. Chapter 5 investigates how mobility-related attitudes developed for telecommuters in comparison with physical commuters, and how these attitudes impact plans to reduce (car based) commuting trips by working from home in the future.

RQ 4.1: *How do mobility-related psychological factors, such as attitudes, differ between those who continued to commute physically during the pandemic vs. those who started to telecommute?*

RQ 4.2: *Which attitudinal (and external) factors predict (in 2020 vs. 2021) if individuals intend to telecommute in the future?*

Conclusions on the effectiveness of the trialed strategies are drawn individually at the end of each chapter, and holistically as the final chapter in this dissertation.

2 STUDY I. THE IDENTIFICATION OF MOBILITY TYPES ON A NATIONAL LEVEL

Abstract

Current transportation systems are not sufficiently sustainable and equitable, making the development of effective interventions indispensable. An intervention's effectiveness increases when tailored to a specific target group. To facilitate this, mobility types available in a population need to be identified.

To date, no segmentation study has profiled a nation's mobility behavior both geographically (household location), psychologically, and socio-demographically. The present study aims to fill this gap by using a uniquely vast data set to segment a representative sample of the German population into distinct mobility types.

The data (N = 86,498) was derived from MiD, a national survey on citizens' everyday mobility behavior commissioned by the German Federal Ministry of Transport and Digital Infrastructure. It includes a broad array of variables, among them information on general mobility behavior and equipment in conjunction with mobility behavior on a reference date, socio-demographic data, as well as psychographic data such as satisfaction with transportation modes or tech-savviness. The latter has increased in importance as technology-based mobility options such as sharing services have emerged in the recent years.

By means of an exploratory procedure incorporating principal component analysis followed by K-means cluster analysis, eight distinct, stable mobility profiles were extracted. The results partly overlap with previous research but substantially extend the body of knowledge existing in the field.

The description of the profiles and allocated interventions offer recommendations for the development of effective, nation-wide interventions and policies to enable the establishment of a sustainable and equitable mobility system.

2.1 INTRODUCTION

2.1.1 The rationale of profiling traffic users

To achieve a sustainable and equitable mobility transition, regulators and policy-makers aim to change travelers' behaviors through the implementation of measures and interventions. However, populations are diverse in terms of needs and requirements, and thus it is difficult to employ one-size-fits-all interventions successfully (Anable, 2005). Implementing general interventions follows the strategy of maximizing average effects, which is not sensitive to correlations between variables in specific subgroups (Hunecke et al., 2010). Hence, the effectivity of interventions can be increased if these interventions are accurately tailored to specific user groups, allowing for an understanding of a group's specific needs and requirements (Haustein et al., 2018), and consequently gaining a higher degree of accuracy.

Additionally, as a population is not homogenous, policy-makers and regulators need to properly estimate how interventions will impact different parts of the population. For example, national policies such as carbon or gasoline taxes entail regressive distribution effects, implying that low-income households are disproportionately disadvantaged whereas high income households remain largely unaffected (Andersson & Atkinson, 2020). To avoid or control for such effects, policy-makers require insight into the diverging contexts and circumstances of different parts of the population.

Unearthing these differing needs, requirements, and behaviors by statistically segmenting a population into meaningful, homogenous sub-groups thus provides a basis for the customized development of interventions, measures, policies, and advertising campaigns (Semanjski & Gautama, 2016).

Undoubtedly, effective interventions within the mobility transition are a needed and pressing matter: First, equity concerns in the transportation sector in terms of accessibility, safety, health, or affordability arise (Van Wee & Mouter, 2020). Second, motor car use continues to increase and generates environmental and health related problems (Steg, 2005).

In the foundational work of Banister (2008), four main interventions for a sustainable mobility approach include substitution, i.e. reducing the need to travel to reduce the overall number of trips; modal shift, i.e. encouraging a shift toward sustainable transportation modes; distance reduction, i.e. reducing trip lengths; and technological innovations. The latter evoke human behavioral adaptations, which can offset efficiency gains or even reverse the reduction of resources by increased or intensified use (Binswanger, 2001). Therefore, altering human

behavior to support trip substitution, distance reduction, and a modal shift is of equal, if not higher importance.

2.1.2 Previous segmentation studies and research gap

Earlier segmentation studies typically segmented samples into mobility types using demographic data, behavioral data, psychographic data such as attitudes, access, and equipment data, or a combination of the above. For example, studies include variables covering attitudes toward modes, demographics, and neighborhood attributes (Lee et al., 2020) or travel behavior in the form of frequency of mode use (Krueger et al., 2018). To derive input variables, models rooted in psychology have been used, such as the goal framing theory (Bösehans & Walker, 2020), an extended theory of planned behavior (Anable, 2005), or a combination of socio-psychological and lifestyle-oriented models (Krueger et al., 2018).

In those cases, assumptions regarding the structure of the input variables were made before data collection, therefore, analysis approaches mostly incorporated a confirmative factor analysis followed by exploratory cluster analysis (e.g., Bartz, 2015).

Regarding the sample populations used to segment into mobility types, the focus is predominantly on specific demographic groups whose household is located within particular geographic areas: Lee et al. (2020) found that millennial and Gen X commuters in California can be grouped into *monomodal drivers, carpoolers, active travelers* and *transit riders.* Kastenholz et al. (2018) segmented tourists in a Portuguese village into *little concerned tourists, active preservers of nature and culture*, and *local nature, culture, and community seekers.* Mendiate et al. (2020) divided commuting cyclists in the city of Quelimane (Mozambique) into *informal workers with children, short-distance students*, and *occasional cyclists*.

The latter study is exemplary for the array of studies that center on single transportation modes. Apart from cyclists (Francke et al., 2019), there are segmentation studies focusing on car drivers (Brambilla et al., 2017; Sodenkamp et al., 2019), transit users (Grisé & El-Geneidy, 2018; Machado et al., 2018), and new mobility services such as carsharing (Baumgarte et al., 2021; Burghard & Dütschke, 2019) or e-scooter sharing (Kubicek & Hadasik, 2020).

These studies provide valuable recommendations fitted to individuals residing in the respective areas, socio-demographic groups, or transportation modes, which are suitable for advising regional or mode-specific interventions and policies. Yet, a policy that might be suitable for one region or for a certain mode could have unforeseen and unwanted effects in other geographic areas or for other traffic participants. Moreover, as travel behavior is a

multiplex process, “structural or behavioral measures will need to address all traveler types’ needs simultaneously” (Bösehans & Walker, 2020, p. 266), implying that many policies, regulations, and interventions have to be implemented on a national basis (e.g., carbon or gasoline price tax), which highlights the need of a nationally representative mobility typology. To our knowledge, a large-scale segmentation that is representative for a whole country, both by spatial type (i.e. a household location’s degree on a rural-urban scale) and socio-demographically, and covering multiple transportation modes, is not yet available.

We addressed this gap by using a large sample ($N > 86{,}000$) that enables a nationwide (Germany) generalization of results. Based on earlier studies, we selected a variety of variables covering socio-demographic variables, general mode choice, and mobility behavior on a reference date, information on access to mobility, mobility equipment, and psychological factors. Tailored to the mobility types resulting from a principal component and cluster analysis, we provide up-to-date recommendations to improve sustainability and equity, derived from another literature analysis, structured along Banister’s criteria (2008), and implementable on a national level**.**

2.2 METHOD

2.2.1 Data set “Mobilität in Deutschland”

To address the issue, we used the 2018 edition of *Mobilität in Deutschland* (MiD) (Nobis & Kuhnimhof, 2018). MiD is a survey spanning the federal republic of Germany and is repeated every 4 to 5 years. Data on everyday mobility behavior is collected on order of the Federal Ministry of Transport and Digital Infrastructure and forms the basis for traffic and transportation planning, traffic modeling, and policy decisions of the German federal government. It representatively covers the nation both geographically and socio-demographically (except for children younger than 14). The variables included in this study are described in the sections below, and to provide an overview, more details on the data are listed in tabular form in Appendix 2-A.

316,362 interviewees participated in a multistage procedure consisting of pen-and-paper surveys, telephone calls, or online surveys, and were assigned one specific reference date. The individual recorded details of all trips they made on that date. These reference dates were set at about two weeks after a person’s household interview, between June 13, 2016 and September 12, 2017. To gain insight into both weekday and weekend mobility, as well as into seasonal differences, the reference dates were placed to cover all months and days of the week (save for Christian holidays and New Year’s Day). This means that for every individual,

information for only one specific day was collected. While it can be assumed that in most cases, the reference date fell on a typical day, for some individuals, the reference date certainly might have included some unusual or atypical activities. When investigating smaller numbers of individuals, the specifics of the selected reference days are certainly essential; however, averaged in big numbers, they give a general overview. To control for outliers due to atypical reference dates in our analysis, we also include several items recording typical mobility behavior in the analysis.

MiD includes a base sample and additional regional samples as well as differing modules. The data is categorized in several, partly overlapping data sets. Detailed information on MiD is publicly available at www.mobilitaet-in-deutschland.de[2].

2.2.2 Data preparation and sample

The present paper uses the MiD data sets *trips, persons*, and *households*, which in combination contain roughly 400 variables. 42 variables were selected for further analysis, as described below (see Appendix 2-A for additional information), and combined into one single data set. Categorical data were, when possible, restructured to binary or ordinal scales and recoded to range from least/lowest/worst to most/highest/best, in order to simplify interpretation of the results. "No answer" was coded as missing. Variables not fit for cluster analysis, such as age and gender or categorical variables, were used to further analyze the typologies after the main analysis (Lee et al., 2020). Participants with missing values > 30% were excluded, resulting in $N = 86{,}498$. Age ranged from 14 to 99 years ($M = 53.53$, $SD = 16.09$) and 47.50% were female. Since this exclusion of cases incorporates the danger of skewing the representativeness of the dataset, basic demographic variables were compared using the original and the reduced sample used for this study (see Appendix 2-B). It was concluded that there are no significant differences in these basic socio-demographic data, thus we assume that the claim of representativeness holds.

2.2.3 Choice of data

2.2.3.1 Socio-demographic information

Apart from age and gender (which are typically used post-hoc to describe clusters), participants' education level, economic status, extent of occupation, and size of household were

[2] last accessed on March 07, 2022

chosen along with the number of children under the age of 14 to allow for a closer look at family constellations.

2.2.3.2 Psychographic information

Addressing psychographic information within a segmentation of mobility profiles has been described repeatedly as being essential (Haustein & Hunecke, 2013). This includes, for example, mode-specific attitudes or an individual's satisfaction with different mobility options (Bösehans & Walker, 2020). Another psychological construct, which is increasingly relevant with regards to the development of new mobility technologies, is tech-savviness (Ozbilen et al., 2021). We thus included the complete psychographic module of MiD into the analysis, namely attitudes toward different modes of transportation and satisfaction with different mobility options. Additionally, tech-savviness was assessed by including the use of portable devices for different mobility purposes together with an item assessing the frequency of use of e-commerce.

2.2.3.3 Geographic information

Transportation infrastructure and accessibility differs considerably between urban and rural areas (Hunecke et al., 2010). Based on address information, *MiD* researchers geocoded households and subsequently rated them on a scale ranging from very rural to highly urban spaces (Nobis & Köhler, 2018). We refined this information by including two items which assessed the quality of the local transit (density of stations and location of stations), as well as the quality of local amenities (assessed via the distances to amenities such as pharmacies, supermarkets, postal services, etc.).

2.2.3.4 Behavior

Assessing travel behavior is key to many traveler segmentation studies. We included general information of a subject's mobility on the reference date by transponding the respective variables from the data set *trips*: the time en route, traveled mileage, average speed, percentage of trips that were intermodal, and number of trips. For the latter, the coding ranged from 0 to "10 or more trips" and included a person's first 10 trips in a single day.

Though very specific, recorded mobility behavior of a single day can differ greatly from a person's general behavior (Lee et al., 2020). To reduce possible bias, we included items assessing the typical use of transportation modes: private car, (e-)bike, walking, local transit, long-distance trains and buses, and the newer mobility options carsharing and bikesharing.

2.2.3.5 Access to mobility and equipment

We included the variables that assess access to cars and bikes/e-bikes as well as the number of cars, bikes/e-bikes, and motorbikes in the household (as in, e.g., Krueger et al., 2018; Anable, 2005; Redmond, 2000). To develop an understanding of further variables that moderate access, we included information on the person's driver's license (Lee et al., 2020), carsharing membership (Baumgarte et al., 2021), and the type of transit ticket that is typically used, if any (ranging from single trip ticket to subscription).

2.2.4 Analysis

To allow the data to speak for itself, we chose a common two-step method of principal component analysis followed by cluster analysis (Vos et al., 2019; Grisé & El-Geneidy, 2018). Principal component analysis (PCA) is an exploratory procedure used to identify latent variables reflected in a data set. Since the present data set includes a large number of variables, we use principal component analysis to reduce the dimensionality of the data and reduce it to the most important features (i.e. components) which still capture maximum information about the dataset. For a detailed explanation on principal component analysis, please refer to literature such as Backhaus et al., (1994), Bartz (2015), Field (2013), or Schendera (2011). The resulting components will serve as input variables for the subsequent K-means cluster analysis. Cluster analysis is a strategy used to "group respondents with similar profiles", and the analysis of the resulting groups allows for generating knowledge regarding "differences between clusters in terms of demographic traits, travel behavior, and other characteristics" (Redmond, 2000, p. 50) without making a-priori assumptions about the data (Anable, 2005). An alternative to K-means cluster analysis is hierarchical cluster analysis, but due to the large sample size, K-means cluster analysis was preferred (Bacher, 2001). Again, for further details on cluster analysis, refer to literature such as Bacher et al., (2010), Bartz (2015), or Schendera (2011).

2.3 RESULTS

2.3.1 Principal component analysis

After an initial principal component analysis conducted on the 42 variables using direct oblimin oblique rotation, the variable *number of trips* formed its own component, which is far below the recommendation of retaining at least three items per component (Costello & Osborne, 2005; Fabrigar et al., 1999), and another component (consisting of the items *long-distance train rides*, *long-distance bus rides,* and *use of sharing bikes*) did not meet the reliability criterion (Cronbach's $\alpha > .50$) (Cronbach, 1951). These items were not used in the further principal

component and cluster analysis, but to retain the information that these items hold, they were used for post-hoc description of the clusters. Again, the principal component analysis was run with 38 variables using direct oblimin oblique rotation. The Kaiser-Meyer-Olkin (Kaiser, 1970) measure verified good sampling adequacy for the analysis (KMO = .71), and all individual KMO values for items were greater than the acceptable limit of .50 (Field, 2013). The result of Bartlett's (1954) test of sphericity was significant ($p < .01$), and the determinant (.00007) was greater than the acceptable minimum of .00001.

12 components (Table 2-1) were extracted with eigenvalues larger than Kaiser's (1974) criterion of 1 and in combination explained 60.12% of the variance. A reliability analysis revealed that all components met the minimum reliability criterion and were transformed into z-standardized variables for further analysis using the Anderson-Rubin method.

Table 2-1

Reliability (Cronbach's α), variables, and loadings for the 12 components (named after interpretation) derived from PCA

Type of information	Component	Variable	Loading	α
Behavioral, psychographic	Transit affinity	Use of local transit	.84	.74
		Transit ticket	.82	
		Attitude toward transit	.65	
		Percent of intermodal trips	.51	
Psychographic	Mobility-related tech-savviness	Use of smartphone/tablet for…		.71
		… schedule/delay information	.81	
		… route planning/navigation	.78	
		… ticket purchase	.69	
		Use of e-commerce	.64	
Behavioral, psychographic	Cycling affinity	Use of bike	.86	.81
		Attitude toward biking	.79	
		Availability of bikes	.77	
Socio-demographic, mobility equipment	Size of household	Size of household	.88	.77
		Number of children aged < 14 in household	.85	
		Number of bikes in household	.70	
Behavioral	Mobility on reference date	Mileage	.93	.73
		Time en route	.80	
		Average speed	.65	
Behavioral, access to mobility	Carsharing affinity	Carsharing membership	.94	.88
		Use of carsharing	.94	
Psychographic	Satisfaction with traffic situation for the resp. mode	Satisfaction Bike	.77	.56
		Satisfaction Walk	.66	
		Satisfaction Car	.62	
		Satisfaction Transit	.50	

Type of information	Component	Variable	Loading	α
Socio-demographic	Socio-economic status	Education	.72	.53
		Economic status	.66	
		Extent of occupation	.60	
Geographic	Locality	Quality of local transit	.79	.58
		Quality of local amenities	.67	
		Spatial typology	.58	
Behavioral, psychographic	Walking affinity	Attitude toward walking	.76	.61
		Amount of walking	.73	
Mobility equipment, behavioral	Motorization of household	Number of cars in household	.78	.55
		Sum of annual mileage of cars in household	.64	
		Number of motorbikes in household	.60	
Behavioral, psychographic, access to mobility	Car affinity	Use of private car	.78	.54
		Availability of car (driver/passenger)	.68	
		Attitude toward car driving	.59	
		Driver's license	.48	

2.3.2 Cluster analysis

The input variables for the cluster analysis were the 12 z-standardized components, extracted from the PCA detailed in section 2.5.1 and in *Table 2-1*. Due to the large sample size (N = 86,498), the usually preferred method, hierarchical cluster analysis, was not suited for the present data set (Schendera, 2011). In this case, the K-means cluster analysis is preferable (Bacher, 2001). This analysis entails the drawback of not providing a best-solution number of clusters; rather, the number of clusters has to be specified in advance. Hence, this analysis was repeated nine times, once each for a pre-specified solution resulting in 2 to 10 clusters. This allows for comparison of the quality of the nine different solutions. Subsequently, the solutions were compared using the criteria Eta², Pre-coefficient, and F-max (Bacher, 2001), followed by interpretability.

To interpret Eta² and the Pre-coefficient, the values per cluster solution were graphed to visualize upward "elbows," which were marked in circles (Figure 2-1). Eta² suggests the best cluster solution at either 5 or 8 clusters, and the Pre-coefficient suggests the best cluster solution at either 4 or 8 clusters. For F-max, a higher value suggests a better cluster number. The F-max value reaches a plateau from 4 to 8 clusters, peaking at 5 (Figure 2-2). The only solution that can be derived from all three test statistics simultaneously is the 8 clusters solution. A screening of the 8 clusters confirmed that it offers appropriate interpretability and higher granularity than the 4 or 5 clusters solutions.

Figure 2-1

Test statistic Eta² and Pre-coefficient for 2 to 10 clusters solutions

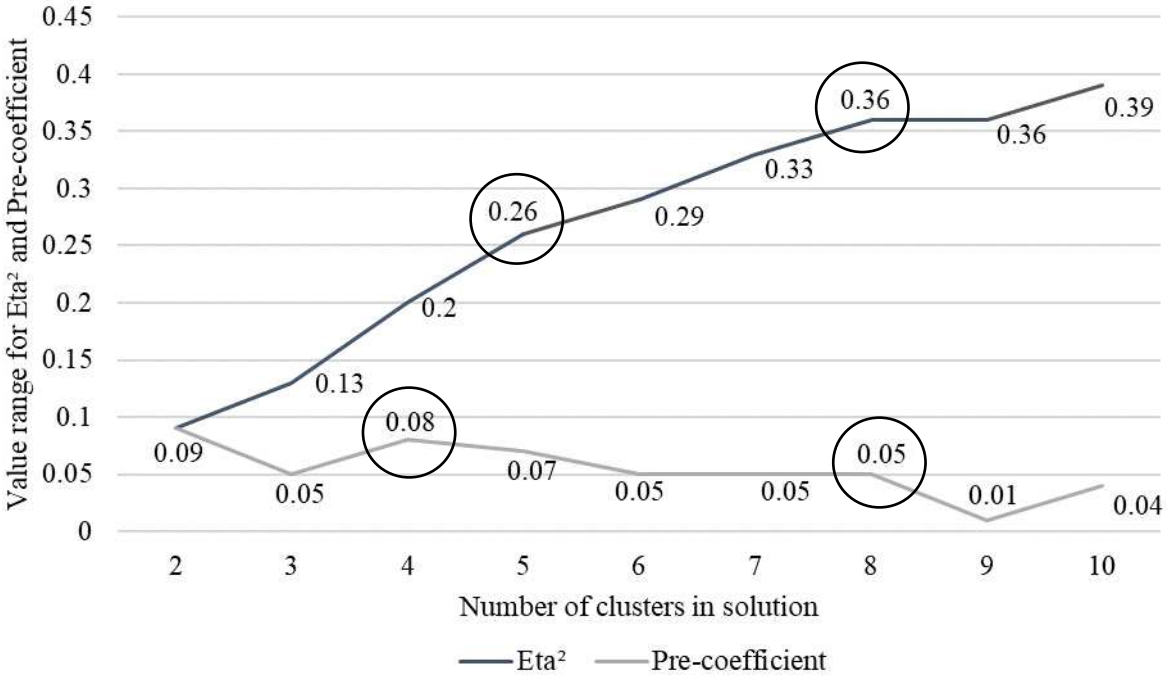
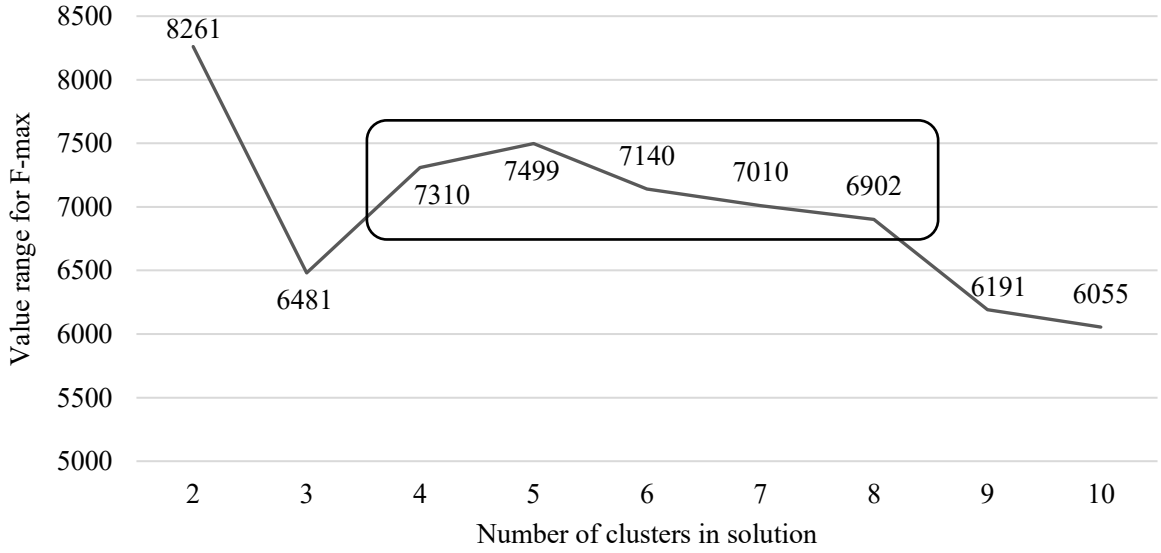


Figure 2-2

F-max test statistic for 2 to 10 clusters solutions



To ensure that the solution is stable, a stability test was implemented (Bartz, 2015; Cannon, 1992). Using randomization, 50% of the sample was selected. A K-means cluster analysis was run, asking for 8 clusters. For 72.05% of participants in this half of the sample, the clustering

matches that of the complete sample. This exceeds 68% (Cannon, 1992), thus, the cluster solution is regarded as stable.

Means of each cluster and standard deviations of the 12 components are depicted in Table 2-2. Additionally, the variables that had to be excluded as well as age and gender were analyzed post-hoc regarding their distribution across the clusters. To demonstrate if components differ statistically significantly across clusters, results of a one-way ANOVA (IV = cluster, DVs = components/variables) with Bonferroni post-hoc analysis are included in the table.

Table 2-2

Z-standardized cluster centers and standard deviations for the 12 components and additional variables across the 8 clusters

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
N (86,498)	2244	21892	16314	5416	8992	4001	10425	17214
%N	2.59	25.31	18.86	6.26	10.40	4.63	12.05	19.90
Components								
Transit affinity	.68** (1.02)	-.37** (.66)	.81** (1.01)	.96** (1.14)	-.23[a] (.84)	-.03** (.91)	-.24[a] (.90)	-.42** (.72)
Mobility-related tech-savviness	.61** (1.11)	-.42** (.91)	.34** (.96)	-.02** (.97)	.29** (.95)	.19[a] (.99)	-.37** (1.02)	.17[a] (.88)
Cycling affinity	.39[a] (.83)	.40[a] (.56)	.49** (.69)	-.04[b] (1.10)	.23** (.77)	.07** (.88)	-1.82** (.60)	-.05[b] (.71)
Size of household	.07* (1.05)	-.51[a] (.42)	-0,31** (.59)	.20** (.91)	2.10** (.84)	-.07** (.87)	-.53[a] (.52)	.12* (.65)
Mobility on reference date	.04* (1.15)	-.29[a] (.54)	-.24[b] (.60)	-.31[a] (.63)	-.05** (.65)	3.25** (1.45)	-.23[b] (.61)	.10* (.63)
Carsharing affinity	5.75** (1.93)	-.16[a] (.12)	-.11** (.08)	-.15[a] (.16)	-.15[a] (.22)	-.13[a] (.30)	-.16[a] (.12)	-.19** (.18)
Satisfaction with traffic situation	-.06[a] (.94)	.18[b] (.88)	-.08[a] (.96)	.20[b] (.99)	.12** (.94)	-.02[a] (.99)	-.17[c] (1.13)	-.17[c] (1.08)
Socio-economic status	.66** (.70)	-.57** (.74)	.58** (.75)	-1.16** (1.27)	.40[a] (.82)	.22** (.89)	-.33** (.89)	.39[a] (.82)
Locality	.71[a] (.96)	-.16** (.86)	0,66[a] (.86)	.26** (.96)	-.07** (.90)	.07[b] (1.00)	.05[b] (.96)	-.61** (.92)
Walking affinity	.07[a] (.92)	.32** (.82)	.21** (.87)	-.10** (1.01)	.10[a] (.89)	.00[a] (.98)	-.19** (1.16)	-.52** (1.05)

	1	2	3	4	5	6	7	8
Motorization of household	-.18[a] (.84)	-.38** (.56)	-.34** (.63)	.36** (1.13)	-.23[a] (.77)	.12** (.96)	-.46** (.64)	1.08** (1.14)
Car affinity	-.19* (.95)	.24[a] (.59)	-.13* (.80)	-2.61** (1.23)	.19* (.71)	.13** (.72)	.23[a] (.68)	.41** (.50)
Additional variables								
% female	32.84[a]	46.70[b]	46.03[b]	59.03**	51.41[c]	34.14[a]	52.59[c]	46.18[b]
Age in years	42.68[a] (11.98)	63.24** (12.53)	52.04[b] (15.07)	39.63** (22.26)	42.62[a] (8.08)	52.25[b] (13.59)	61.53** (15.78)	49.56** (12.99)
Use of sharing bike	1.08** (2.46)	-.10[a] (.64)	.10[b] (1.22)	.06[b] (1.27)	-.03[c] (.84)	.05[b] (1.16)	-.10[a] (.72)	-.07[ac] (.75)
Use of train > 100km	.70** (1.22)	-.17[a] (.86)	.37** (1.06)	.20[b] (1.17)	-.03** (.96)	.21[b] (1.23)	-.24** (.86)	-.18[a] (.89)
Use of bus > 100km	.27** (1.32)	-.07[a] (.87)	.10** (1.12)	.41** (1.57)	-.07[a] (.84)	.02** (1.06)	-.07[a] (.89)	-.09[a] (.83)
# of trips on reference date	4.26* (2.71)	4.03[a] (2.50)	4.06[a] (2.35)	3.47** (2.00)	4.59** (3.01)	5.25** (5.74)	3.77** (2.61)	3.99[a] (2.75)

Note. Standard deviations written in parentheses. Items in superscript indicate which means are statistically significant from each other (ANOVA with Bonferroni post-hoc test): **stat. significantly different from all other clusters at .01 level; *stat. significantly different from all other clusters at .05 level; [abc]stat. significantly different from all other clusters at .05 level except the cluster(s) with the same superscript letter in the row.

2.4 INTERPRETATION AND DISCUSSION

The aim of this paper was to provide a basis for the development of tailored interventions and targeted measures to promote a sustainable and equitable mobility system. A data set representative for Germany both geographically and demographically (N = 86,498) was used to cluster the population into distinct traffic user types. General travel behavior, specific behavior on a reference date, mobility equipment, psychographic data, socio-demographic, and geographic data were analyzed in an exploratory manner by means of a principal component analysis followed by a K-means cluster analysis. The 8 clusters solution was chosen due to test statistics and interpretability.

In the following section, these clusters are interpreted based on the mathematical definition of clusters (Table 2-2) and demographic data. Since the data was standardized, cluster descriptions are based on the comparison with the remaining clusters. Exemplary recommendations for action are derived from another literature analysis and systematized, if

applicable, following Banister's (2008) four criteria for sustainable transportation: [1] reducing trips, [2] reducing distance, [3] modal shift, and [4] efficient technological innovations. Next, the results are integrated with findings of previous studies by pointing out congruities and extensions of the literature. Finally, limitations are discussed and followed by a conclusion to this paper.

2.4.1 Cluster interpretations and recommendations

2.4.1.1 Cluster 1: The multi-optional urbanist (2.59 %)

Interpretation. The data for cluster 1 produces a clear picture: in comparison to the sample's average, this small cluster is younger, mostly male, displays a higher socio-economic status, is more tech-savvy and a fan of sharing options such as carsharing or bikesharing, as well as of transit. In contrast, car affinity and motorization are lower. The individuals in this cluster live in urban spaces, which provide numerous mobility options. The combination of these characteristics led to the labeling of this cluster as *the multi-optional urbanist*. Presumably, this cluster is mostly comprised of *innovators* in the *diffusion of innovations* theory (Rogers, 2003), which make up 2.5% of the population (similar to the *multi-optional urbanist*).

Recommendations. The *multi-optional urbanist* seems receptive to emerging mobility technologies. It is thus crucial that new mobility technologies [4] be sufficiently sustainable. This is of special importance when considering that the highly tech-savvy Generation Alpha will soon come of age. Therefore, more research is needed to help obviate possible rebound effects regarding number of trips and distances traveled [1, 2].

2.4.1.2 Cluster 2: The active older adult (25.31%)

Interpretation. Cluster 2 is the oldest and largest cluster. This reflects the aging society of Germany and highlights the importance of considering elder generations in transportation research. Accordingly, this type lives in smaller households and displays a lower socio-economic status than the sample's mean. This cluster is not tech-savvy, not fond of transit, and owns fewer cars than the average household, but affinities toward cycling and especially toward walking are higher. It was thus coined the *active older adult*.

Recommendations. Recommendations for this cluster are less concerned with sustainability issues, but rather with assuring that this cluster can move around freely, autonomously, safely, and comfortably. Concerning this cluster's most used modes, walking and cycling, many urban areas are not safe and/or barrier-free. To ensure that these individuals can maintain (or even increase) active mobility, ideas encompass improvements such as broader sidewalks, slip-

resistant surfaces, or adapting traffic lights to pedestrians. On a structural level, research on the topic is overshadowed by (car) driving research, and walking is often not taken seriously by decision makers (Bauer et al., 2018).

For situations in which active travel is not possible but sustainability should prevail, this cluster's low affinity toward transit needs to be addressed. Proposals on designing an accessible transit system that allows for seamless intermodality including walking and cycling, with a focus on the user's general well-being (Friman et al., 2019), include outlines for waiting facilities, cleanliness, and ease of wayfinding. As *the active older adult* is not tech-savvy, possible educational campaigns could be implemented but, importantly, individuals who do not have and are not able to obtain technological competencies need to be accommodated nonetheless.

2.4.1.3 Cluster 3: The pragmatic urbanist (18.86%)

Interpretation. Compared to the other clusters, this cluster is not fond of private cars and clearly prefers transit, biking, and walking. All these options are available because they live in an urban area and display a high socio-economic status. Though sufficiently tech-savvy, this cluster is less interested in new mobility technologies than the *multi-optional urbanist*. This type was named the *pragmatic urbanist*.

Recommendations. No issues arise from either a sustainability or an equity perspective. Improvements of transit and of walking and biking routes might be necessary to keep this cluster satisfied in the future. To discourage the use and ownership of private cars, enforced regulations (such as car bans in inner cities) are an option as this cluster can easily use alternatives.

2.4.1.4 Cluster 4: The transit captive (6.26%)

Interpretation. The small cluster 4 contains more females than average, is the youngest cluster, and displays the highest affinity toward transit observed in the sample. This attribute was decisive for labeling it the *transit captive*, as using transit might be the only option for this cluster due to their lower income level (lowest socio-economic status in the sample). The *transit captive* shows slightly above-average motorization, yet affinity toward private cars is strikingly low. For individuals younger than 18, of which the majority (69.06%) are categorized into cluster 4, a car could be found in the household but the individual is not yet able to drive it. According to self-perception theory (Bem, 1972), low car affinity could be due to the lack

of affordability; however, this attitude could change once a car was available. In general, cluster 4 is less mobile than other clusters.

Recommendations. Since this cluster uses more transit than private cars, sustainability issues do not arise. However, from an equity perspective, it is not clear if they would prefer to be more mobile but simply cannot – i.e. if their circumstances allow these individuals the public and social participation that they desire. A combination of improvement of the transit system and introducing the individuals of age in this cluster to carsharing or neighborhood sharing (Westskog et al., 2020) could be a possibility to fulfill this small cluster's needs without owning a car.

2.4.1.5 Cluster 5: The family member (with children) (10.40%)

Interpretation. The increased size of the household ($M = 4.3$) and number of younger children ($M = 1.8$) imply that individuals of this household live in a family setting. This cluster was labeled *the family member (with children)*, displays a relatively high socio-economic status, and the household is equipped with, on average, 1.8 private cars. Though very mobile on the reference date, individuals of this cluster display neutral tendencies toward transportation modes, but transit affinity is low and it can be assumed that this mode, if available, might not be convenient to transport children and shopping. On the other hand, affinities for private cars (but not carsharing), biking, and walking are slightly above average.

Recommendations. Reducing the number of trips [1] could be difficult due to the children in the household who need accompanying. A modal shift [3] is often difficult if cars are needed to chauffeur family members. A decoupling of families and private-car based mobility could be achieved by introducing electric bikes, cargo bikes, or (neighborhood) carsharing (Dowling & Maalsen, 2020; Westskog et al., 2020). Furthermore, infrastructure needs to be safe for children so that parents consider active modes as an alternative. Finally, efficient technological innovations [4] such as cars fueled by green electricity or hydrogen could provide relief.

2.4.1.6 Cluster 6: The vastly mobile (4.63%)

Interpretation. The small cluster 6 only has one very distinct attribute, apart from being predominantly male: out of all clusters, this type was the most mobile on the reference date, and a post-hoc look into the complete MiD data set shows that most trips were work or business related. Thus, this cluster was coined the *vastly mobile*. The *vastly mobile* is well educated and has a higher income than average. Motorization of the household is higher, and though neutral toward transportation modes, the car is slightly preferred. Higher than average use of long-

distance trains was also recorded. This smaller cluster seems to encompass intensive commuters and workers with frequent business trips, so recommendations for action focus on these sorts of trips.

Recommendations. The data used in this study was collected before the Covid-19 pandemic. Assumedly, this cluster's mobility was reduced during the pandemic to some extent (amongst others) due to the introduction of home office regulations. In a recent survey, a quarter of participants indicated that they would continue to practice mobility-related behavioral changes brought about by Covid-19, even as restrictions begin to be lifted (Anke et al., 2021). US-based survey data (Salon et al., 2021) suggests that workers with a higher education and income (i.e., a higher socio-economic status, which is true for the *vastly mobile*) are twice as likely to expect to telecommute at least a few times a week post-pandemic. The many advantages of working from home and online conferences for both businesses and employees incited a national (German) discussion of a right to certain telecommuting days (Lott et al., 2021).

Apart from reducing trips [1] by offering employees the option of working from home, the possibility to induce modal shifts [3] for the *vastly mobile* is one goal of corporate mobility management. Corporate mobility management can increase an employee's sustainable commute, encourage active travel, and can even alter relevant attitudes (Saake et al., 2021).

2.4.1.7 Cluster 7: The inactive older adult (12.05%)

Interpretation. This cluster is comprised of people older (M = 62 years) than the sample's average and living in smaller households with a lower socio-economic status and lower tech-savviness. In contrast to *the active older adult*, as the label of this cluster suggests, striking differences in mobility affinity emerged. The *inactive older adult* displays low affinity for walking, cycling, and transit. More often than not, there are no cars in the household. Accordingly, this cluster made among the least trips and was less mobile than the average individual. Also, this cluster is among the most unsatisfied with mobility options in general. A look into the complete *MiD* data set confirmed the suspicion of handicaps: 13.39% of this cluster indicated "yes" when asked about mobility-related physical limitations, which is thrice as many as in other clusters (M = 4.48%). Thus, access is likely an issue and equity concerns surface.

Recommendations. As with the *active older adult*, recommendations regarding safe and comfortable pedestrian traffic and biking also apply here. However, even more consideration needs to be given to physical ability, e.g., hand rails, toilets, or sitting opportunities like

benches. Cirella et al. (2019) outline transportation innovations for the elderly with special consideration of mobility-impaired people. These include (but are not limited to) vehicle innovations to support better entry and exit (by altering doorframes or seats) or smart vehicles to compensate for the driver's decreased functionality, infrastructural innovations, and organizational innovations (e.g., self-developed service providers catered via local community efforts). A transit system tailored to the elderly and their travel needs is of particular importance when considering sustainability (Friman et al., 2019) because many people in that age group cannot or do not want to use active modes.

2.4.1.8 Cluster 8: The rural (19.90%)

Interpretation. This larger cluster was named according to its geographic situation, rather than its higher affinity for cars, motorization, or higher socio-economic status. Affinities toward walking and transit are lower than the sample's average, which is probably due to the fact that distances to destinations are too large for walking, and transit exists only sparsely. This type seems to be defined by the limited mobility options in rural areas and resulting car dependence.

Recommendations. It is the task of scientists, policy-makers, and companies to develop and implement transit and other options to make means of sustainable transportation available. After all, this cluster makes up a fifth of the sample. Recent literature dealing with improving sustainable mobility options in the countryside suggest interventions [3] such as ride-pooling in the form of flexible demand responsive transportation (Sörensen et al., 2021), new information and communication technology and autonomous vehicles (Pettersson & Khan, 2020), or neighborhood sharing (Westskog et al., 2020). However, solutions like these are complex and might take time to implement successfully. Thus, efficient technological innovations [4], e.g., hydrogen fueled cars or electric vehicles, seem to be the most immediate solution to reduce on-site emissions. Rural areas hold the advantage of higher distributed generation potential and lower population densities, which allows for a simplified offset of overloading effects of EV charging as opposed to in urban areas (Haider & Schegner, 2021). Additionally, as with the *vastly mobile* cluster, lesser trips [1] due to the increased possibility of home office could bring relief.

2.4.2 Integration with previous findings

Cluster 1, the *multi-optional urbanist*, appears in different studies with slightly altered profiles, e.g., the *young intended mobile* (Bartz, 2015), *car-less crusaders* (Anable, 2005), or *mode-mixers* (Bösehans & Walker, 2020).

To our knowledge, a differentiation of two groups of elderly travelers in a holistic traveler segmentation, as in the present paper (clusters 2 and 7, the *active* and *inactive older adult*), has not been found in previous research. On a more detailed level, Haustein and Siren (2015) systematically compared segmentations of the older population, and find that (in Europe), not two but four segments of older people can be distinguished. Differentiating among older people is crucial, as they are not homogenous in terms of health, travel needs, and mode preference (Cirella et al., 2019): the elderly can be active and fit as well as suffering from poor health and decreased mobility, which is directly reflected in the results of this paper.

Clusters 3 and 4, the *pragmatic urbanist* and the *transit captive*, are intermittently merged, e.g., in the *public-transit-oriented class* (Krueger et al., 2018), whereas the present cluster 4 is distinct in its low socio-economic status, displaying a dependence on transit, as opposed to cluster 3 with its high socio-economic status. The present study allows for differentiating car-oriented classes (e.g., Krueger et al., 2018; Lee et al., 2020) by splitting those into *the family member (with children)*, *the rural*, and *the vastly mobile*.

2.4.3 Limitations

Two main themes of limitations for this study can be distinguished. First, the study was limited by the content of the *MiD* data set. The data set did not include new mobility services beyond carsharing and bikesharing, but including technologies such as MaaS apps, ride hailing, and pooling would be valuable. The psychological module included attitudes toward and satisfaction with transportation modes, which is sparse compared to other studies. Possibly, an individual's mobility behavior on his or her reference date was atypical (an individual could have been on holiday, not have typical modes of transportation available, etc.). We tried to control for this by including numerous items assessing "typical mobility behavior" which participants provided via self-report. Additionally, we believe that our large sample size protects from a strong distortion of results. Nonetheless, it is a drawback of our approach that should be kept in mind. As the data set is representative for Germany, it is unclear if the results can be transferred to other nations. Assumedly, similar results would emerge for neighboring (both locally and culturally) countries, while differences might emerge in comparison to countries such as the USA or China (Bartz, 2015). With regard to the representativeness of the German population, we want to draw attention to the fact that the original data set had a non-negligible amount of missing data, and respective cases were excluded from our analysis. While basic descriptive analysis (Appendix 2-B) showed that the demographic means of the

reduced sample do not substantially differ from the original *MiD* sample, this fact should still be kept in mind.

Second, the analysis approach introduces limitations: Principal component analysis entails the drawback of decreasing granularity. Differences among components such as "I like transit but it is not available in my area" become difficult to demarcate within the component "transit affinity". Even though principal component and cluster analysis are a great tool for exploratory purposes, they will produce a result regardless of the propriety of data input. Though the self-imposed statistical quality criteria were met, the results highly depend on the choice of variables and number of selected clusters (Bösehans & Walker, 2020). The selection of variables is based on previous literature, however, subjectivity is inevitably involved. Ultimately, the cluster solution is an approach meant to organize reality rather than to provide perfect descriptions of individuals. When interpreting the cluster solution, it is further important to remember that a cluster's definition is based on the comparison with the other remaining clusters.

2.5 Conclusion

While earlier studies segmented specific demographic or geographic groups, this study suggests that it is possible to meaningfully segment a whole nation into relevant, distinct mobility types. The results contain important implications for policies on a national level: first, the eight clusters provide a basis to develop and apply tailored measures and interventions, and second, they allow for an estimation of the impacts of policies to be applied nation-wide.

Recommendations to increase sustainability and equity are given, though a careful evaluation of trade-offs is necessary as, for some clusters, an increase in equity can lead to a decrease in sustainability and vice-versa. For two out of three clusters with a "problematic" mobility behavior regarding sustainability (*the family member (with children)* and *the rural*), other feasible options are not available, and infrastructural as well as technological improvements are needed.

Yet, the role of the individual cannot be underestimated. Banister (2008) emphasizes that traffic users must be involved in transportation planning: only if the rationale behind policy changes is understood and publicly accepted can behavioral change follow (Schade & Schlag, 2003). The decision on trips and modes must be liberated and incentivized, so that people are comfortably able to and willing to *choose* sustainable transportation.

3 Study II. Access over ownership: barriers for adopting Mobility as a Service (MaaS) from the perspective of users and non-users

Abstract

Mobility as a Service (MaaS) can potentially create positive impacts for sustainability and social equity: MaaS could steer user choices away from the private car, and increase access to transportation options for all social groups. Though MaaS is not an entirely new concept anymore, in terms of user numbers, it remains a niche phenomenon.

We aimed to extract the relevant enabling factors and barriers for MaaS use by zooming in on the individual user's and non-user's perspective against the backdrop of their personal situation, preferences, and needs. Specifically, we investigated under which circumstances MaaS can convince individuals to reduce the use of or discard their private car, using the theory of material possessions which asserts that the motives for (car) ownership are not only of an instrumental nature, but can also be symbolic and affective. We employed a qualitative research approach, focusing on the MaaS case in Berlin, Germany. Data was collected in 12 focus group sessions of 3-5 users and non-users, following a semi-structured guideline. The sessions were recorded, transcribed and analyzed using qualitative content analysis.

Results show that for MaaS use, socio-economic factors play a smaller role than expected, and use cases center around non-habituated trips. The added value of MaaS compared to regular transit apps was often difficult to discern or irrelevant. Even if MaaS provided perfect service and functionality, certain groups of car users would still not consider it, due to the vehement symbolic and affective motives associated with the private car. However, we found that individuals can associate symbolic and affective motives with MaaS as well. The most prominent lever for MaaS to contribute to a more sustainable mobility system seems to be emphasizing these MaaS related motives as well as the car as a burden, a burden which can be lifted by using MaaS.

3.1 INTRODUCTION

The negative effects caused by increasing private car ownership and usage have been widely discussed in academia and politics. Reducing the need of and demand for private car use and ownership is considered a main lever to achieve a sustainable mobility system, particularly in highly urbanized areas. To replace the private car, a single alternative transport mode, such as transit, is not sufficient to serve urbanists' diverse and dynamic transport needs (Matyas, 2020). With multimodality in mind, the concept of 'servicing mobility' has emerged, aiming at providing functionality and access to diverse mobility options and thus reducing the need for actual ownership of transport means (Spickermann et al., 2014).

Installed as an application on a mobile device, Mobility as a Service (MaaS) schemes facilitate individual transport paths by combining different transport modes and presenting them to users in a convenient, integrated manner. To qualify as a MaaS scheme, the application needs to be able to perform trip planning, booking, and payments through one single interface, including a registration requirement and tariff options (Jittrapirom et al., 2017). Even when these definition criteria are met, the design of the application and additional available functions can differ.

MaaS schemes are typically available in larger cities, usually developed and offered in cooperation with local authorities and transit companies. Traditional forms of transit are integrated with additional services such as carsharing, bikesharing, e-moped, or e-scooter sharing, among others. So far, "MaaS may be more of a niche product than a 'game changer' in urban mobility" (Reck et al., 2021, p. 2), because MaaS schemes register a relatively small user base and constitute a minor share in the overall modal split.

Although the future impact of MaaS is unclear, it gives rise to hopes regarding the facilitation of important political objectives, namely equity and sustainability (Schikofsky et al., 2020). Regarding equity, the convenience for the user is central: everyday travel with MaaS is supposed to be easy, flexible, reliable, user centered, easy to plan, price-worthy, and seamless during the trip. This is supposed to be achieved by an integration of all transport means and systems, by using real-time data, and by responding to a broad range of individual user priorities (Giesecke et al., 2016). Thus, MaaS schemes could simplify and increase access to more transport options for disadvantaged groups of society, thereby fostering more transport equity (F. Wang et al., 2019). Regarding sustainability, hopes that MaaS schemes could steer user choices toward more sustainable transport modes, leading to greater resource and modal efficiency, have been voiced (e.g., Arias-Molinares & García-Palomares, 2020; Mattioli & Heinen, 2020). Shifting the current ownership-based transport system into a functionality-

based system and fostering a thinking in functional results instead of car ownership is a commonly named goal of MaaS.

For MaaS to be successful and to achieve these aims, an understanding of barriers and enabling factors, both within the application and resulting from the surrounding policy and infrastructural conditions, is needed. Further, the circumstances that would potentially allow MaaS to reduce private car use and ownership are unclear. While research on these topics has expanded in the past years, studies focusing on user behavior and the shift away from private cars are still surprisingly scarce in the MaaS context (Matyas, 2020). Predominantly, studies focus on the behavior of those individuals that already use MaaS, who are a minority (e.g., Reck et al., 2020; Smith et al., 2022). Of course, it is vital to understand MaaS users and their use cases. But as long as non-users are not considered, conclusions on the barriers for a broad public to use MaaS cannot be drawn.

Thus, including MaaS users and non-users, the aim of this paper is to discern the relevant enabling factors and barriers regarding the use of MaaS, and to identify under which (external and psychological) circumstances individuals would be willing to reduce their use of the private car, or discard it altogether on account of MaaS.

3.2 THEORETICAL BACKGROUND

3.2.1 User's perspective on MaaS

Since the concept of MaaS emerged, numerous studies have generated specific knowledge around MaaS use, such as potential user's willingness to pay, the difficulties in combining different economic stakeholders, or the effectiveness of mobility bundle designs (e.g., Ho et al., 2018; Reck et al., 2020; Schippl & Arnold, 2020). Taking a holistic perspective, Karlsson et al. (2020) identified barriers and enabling factors for MaaS from the perspective of the providers, and found impacting factors on three levels: from the macro to the micro level, they identified policy and public administration, business models and collaboration among stakeholders, and individual's habits and attitudes. Numerous, important studies deal with policy and public administration, business models, and stakeholder collaboration (e.g., Esztergár-Kiss & Kerényi, 2020; Ho et al., 2018; Schippl & Arnold, 2020). However, concerning the individual user, "little is known about the motivational and psychological determinants that affect users' intention to adopt MaaS offerings - but especially for MaaS with its inherent user need orientation, those insights are of utmost importance" (Schikofsky et al., 2020, p. 297). User attitude and acceptance is essential for a successful implementation of MaaS (X. Zhao et al., 2020).

With the aim of increased equity in mind, it is important to consider which improvements or additions would help making MaaS accessible to all sorts of users (Mattioli & Heinen, 2020). With the aim of increased sustainability in mind, nudging could be a promising strategy to incentivize sustainable consumption choices among end-users and has already been employed in other sectors and consumption settings (Thaler & Sunstein, 2009). Nudges are interventions that incentivize certain behaviors by changing the information set that individuals are presented with when taking a decision. Thus, nudges exploit the fact that human behavior is subject to limited cognitive resources and bounded rationality, whilst still retaining freedom of choice (Avineri, 2009; Byerly et al., 2018). Examples include default settings with opt-out options or accentuating a group norm (Hauslbauer et al., 2022a). For routing apps, nudging ideas that have been investigated are, e.g., eco-filters (presenting sustainable transport modes more saliently) or green routing (indicating the sustainability of proposed routes) (e.g., Bothos et al., 2013; Bothos et al., 2014; Zhu et al., 2017). However, if and how internal nudges within MaaS can shift users' choices toward public, sharing, and pooled transport means is unclear.

The attitude toward and use of MaaS is dependent on local infrastructural and policy-related characteristics, which need to be considered to enable a successful implementation of MaaS (Butler et al., 2021). It is well known that the surrounding external transport and infrastructure conditions impact individual mobility behavior and decision-making (Schlag & Schade, 2007). An attractive transit system and suitable infrastructure for active mobility, for example, are a necessity for MaaS to be practicable (pull measures). Regulatory measures like the enforcement of car parking rules, car-free zones, parking tariffs, or congestion pricing tend to increase the likeliness for individuals to give up their car and be open to offers such as MaaS. Sometimes, such measures are used deliberately by municipalities to achieve behavioral change (push measures) (e.g., Fürst & Dieplinger, 2014; Langbroek et al., 2016; N. Wang et al., 2017).

3.2.2 The move away from the private car

One goal of MaaS providers is to convince private car users of sustainable alternatives. Alyavina et al. (2020) found five factors that influence the use of MaaS, one of which is private car dependence, and claim that the success of MaaS is dependent on, among other factors, a change of attitude toward the private car. Indeed, the individual's strong reliance on the private car has been described as the biggest social barrier for a successful implementation of MaaS (Polydoropoulou et al., 2018).

While it has been stated repeatedly that "multimodal options are needed to service the unique travel requirements of each individual" (Matyas, 2020), we believe that it is not sufficient for MaaS to fulfil instrumental mobility needs. In other words, for MaaS to provide a fully functional, convenient alternative way of achieving one's mobility goals is not sufficient. The traffic psychology literature has long established that the functionality of car use and ownership is only a part of the private car's appeal. Next to these instrumental motives (e.g., the [in]convenience caused by car use like speed or flexibility, to get from A to B), possessions, such as the car, are highly associated with symbolic (e.g., expressing one's social position) and affective motives (e.g., feeling at home in the car; feeling excited at high speeds) (Dittmar, 1994; Steg, 2005).

We conclude that moving from car ownership to access-based mobility necessitates a detachment from all motives of ownership, not just a car's functionality (instrumental motive). It remains unclear if MaaS could serve affective and symbolic motives in a different form (e.g., offering flexibility and independence). To understand how possession motives influence the use of MaaS, we integrated this theory into the present study.

3.2.3 Research aim and questions

The first aim of this paper is to discern the relevant enabling factors and barriers regarding the use of MaaS, both within the app (e.g., nudging) and external (e.g., policy measures). The second aim of this paper is to uncover under which psychological circumstances individuals are willing to reduce their use of or discard the private car on account of MaaS, using possession theory as a theoretical underpinning. Taking a qualitative approach, we address these research questions:

RQ 2.1 *MaaS from the perspective of users and non-users*

a. Users and use cases: who are the users (and non-users) of MaaS, which situations are suitable to use it and which are not?
b. Advantages and barriers: what are perceived advantages and barriers regarding the use of MaaS?
c. Improvements and additions: are there improvements or additions needed within the application to potentially overcome the mentioned barriers?
d. Internal sustainability nudging: to what extent can environmental nudges within the app convince MaaS users to choose sustainable travel?
e. External context: how does the infrastructural and political context influence the use of MaaS?

RQ 2.2 *Psychological motives for car possession and MaaS use*

a. Instrumental motives: can MaaS offer the same instrumental needs as the private car?
b. Symbolic motives: which symbolic motives do individuals associate with MaaS, and can these offer a counterpoint to those associated with the private car?
c. Affective motives: which affective motives do individuals associate with MaaS, and can these offer a counterpoint to those associated with the private car?

3.3 METHOD

3.3.1 Case study: MaaS in Berlin

To answer our research questions, we selected a real world MaaS case ("Jelbi"[3] in Berlin). The urban area of Berlin, the capital and biggest city of Germany, has a population of roughly 4.5 million and a well-developed transit system. Since, June 2019, the application "Jelbi", offered by the main transit provider in Berlin (BVG[4]), is available to inhabitants.

The platform qualifies as a Mobility as a Service application according to our definition criteria inspired by Jittrapirom et al. (2017). It offers access to numerous transit and sharing options, including the underground, busses, trams, ride hailing, or sharing services such as e-mopeds, e-scooters, bikes, and cars. While the availability of these is much higher within the city core, there are "hubs" throughout the city where different modes can be found (though the density of the offer decreases toward suburban areas). After a single registration (including verification of ID and, for certain sharing services, verification of a driver's license), journey planning, booking, and payment are available through the application. Possible routes and modes are compared by duration and price, using real-time traffic information.

According to the provider, the goal of the MaaS service available in Berlin is to trial a multimodal and intermodal mobility platform. To do so, BVG cooperates with numerous mobility providers. The service was developed in cooperation with Trafi Ltd.[5], who also built MaaS solutions for Munich, Basel, Bern, Zurich, and Vilnius.

3.3.2 Qualitative approach: focus groups

To address our research questions, we chose a qualitative research approach, which allows for the collection of data in a partly exploratory fashion. To understand the subjective relevance of

[3] https://www.jelbi.de/, last accessed on February 25, 2023
[4] https://www.bvg.de/, last accessed on August 08, 2023
[5] https://www.trafi.com/, last accessed on June 20, 2022

factors that lie below observable mobility behavior, qualitative methods have been described as particularly suitable (Gebhardt, 2021).

The focus group method was deemed appropriate because it is especially suited for fields of research that are characterized by the relative novelty of their subject, and as such it allows in-depth understanding of new phenomena and free exploration of a topic (Polydoropoulou et al., 2018). Morgan (1996) defined three basic components of focus groups: they are a research method devoted to data collection, they pinpoint group interaction as the source of the data, and the researcher occupies an active role in creating the group discussion. Focus groups are usually recorded or taped to subsequently allow for the analysis of the reactions displayed by the participants.

In a thematic analysis, Guest et al. (2017) showed that six focus groups typically suffice to capture 90% of themes on a topic. However, it is more difficult to capture themes with increased sample heterogeneity and increased complexity of the topic. To sufficiently saturate all themes that may emerge, we doubled the recommendation of six focus groups and employed twelve.

The focus groups were conducted online, a format which holds several advantages over traditional formats, such as lower cost, easy recording, an informal characteristic which allows participants to be more open than face-to-face, and draws a richer participation in general (Stewart & Shamdasani, 2017).

3.3.3 Sampling strategy

To recruit and select participants, a theoretical sampling strategy was chosen. The idea of theoretical sampling is to increase the overall heterogeneity and diversity of perceptions and views (Glaser & Strauss, 2006) across the focus group discussions. The theoretical sampling strategy was based on the selection of participants to include MaaS users and non-users, and to cover each of the following mobility types: car individualists, pragmatic transit users, environmentally aware type, multioptional type, bike affinity type, and forced mobile type (adapted from Schäfer & Quitta, 2016). For a tabular overview and details on each type's mode use, attitudes, mode availability, routes and distances, please see Appendix 3-A.

It should be emphasized, however, that the goal of this sampling approach was not to later compare mobility types (which would require representative sampling and quantitative analysis), but, in line with the idea of theoretical sampling, to ensure that the entirety of perceptions, attitudes, and reasonings are included (Glaser & Strauss, 2006).

3.3.4 Recruitment

Initially, participants were recruited via social media. A link led individuals to a website hosted by Dresden University of Technology, which asked for demographic information, mobility related information, and contact details. Afterwards, the researchers called these individuals and, if necessary, collected more information on the mobility behavior to identify their mobility type and to verify that the participant is in a fact resident of Berlin. After a time and date for the focus group was confirmed, participants received an e-mail with the focus group information and link to the web-conference platform *Zoom*. If necessary, the researchers aided the participants in downloading *Zoom* and practicing its use. After participation, each participant was compensated with a gift voucher (wunschgutschein.de) of 50€ sponsored by Trafi Ltd.

Through this self-selecting sampling strategy, both users and non-users of all mobility types except for car individualists were recruited. To compensate for this, the professional recruitment platform TestingTime [6] was hired, sponsored by Trafi Ltd. Three screening questions were used to select suitable applicants: applicants had to indicate that they live in Berlin, had to own a car that they used for more than 50% of their daily travel, and indicate among a number of statements that they associate their car with prestige and/or with a status symbol and/or agree to affective statements, such as "my car is my baby that I take care of". TestingTime reimbursed these participants according to their own rates.

3.3.5 Participants and groups

Twelve focus groups were conducted online via *Zoom*. Each focus group consisted of three to five participants and two moderators, resulting in a total of $N = 46$ participants. Participants ranged from age 18 to 70, averaged 39.9 years of age ($SD = 16.7$), and 58.7% were female. An overview of participants, including basic demographic data, residential area (inner or outer city[7]), car access, awareness of the MaaS service and the mobility type is provided in Appendix 3-B. The mobility types were represented as follows: pragmatic transit users (26%), multioptional type (37%), car individualists (24%), forced mobile type (9%), bike affinity type (2%), and environmentally aware type (2%).

[6] https://www.testingtime.com/en/, last accessed on June 27, 2022

[7] Inner and outer city were divided by the Berlin "S-Bahn Ring", a closed-loop circle railway surrounding Berlin's inner city

3.3.6 Procedure

Participants were informed that the meeting was recorded for the purpose of later analysis, but that all data was anonymized upon transcription. The researchers introduced the concept of MaaS (using the example of the application available in Berlin) with a short video (introduction to the app available in Berlin) and PowerPoint slides, and answered questions should the participants have any. For the actual focus group discussion, the researchers followed a semi-structured discussion guideline that covered the topics as described in the introduction (Table 3-1), while leaving room for additional topics.

Table 3-1

Focus group content blocks (arranged and numbered to follow the order of research questions)

Block	Content
RQ 2.1	**MaaS from the perspective of users and non-users**
a.	Users and use cases
b.	Advantages and barriers
c.	Improvements and additions
d.	Internal sustainability nudging
e.	External context: policy and infrastructure
RQ 2.2	**Psychological motives for car possession and MaaS use**
a.	Instrumental motives
b.	Symbolic motives
c.	Affective motives

For block 2.1 d, two proposals for nudges were shown to participants as illustrative mock-ups on the MaaS app screen: an “eco-filter”, which filters and presents sustainable transport modes before the booking, and a carbon footprint (“green route”), indicating the sustainability of the proposed routes, which was associated with a bonus or premium for the users once they book the route. Though details of such nudges would need to be worked out precisely, the general attitudes of participants regarding these additional information features were of interest.

3.3.7 Analysis

The twelve resulting recordings were transcribed word by word, including unambiguous nonverbal gestures such as fervent nodding or thumbs up or down. The transcripts were fed into the software MAXQDA, in which the qualitative content analysis was performed.

Qualitative content analysis is a widely used technique to derive meaning from textual data. Words or expressions are not merely counted, but themes are coded into explicit categories. Resulting patterns can then be analyzed and interpreted to better understand the phenomenon in question (Hsieh & Shannon, 2005).

This is achieved in seven well established steps (Kaid & Wadsworth, 1989), the first three of which ([1] the formulation of research questions, [2] the sample selection, and [3] the definition of applied categories) we described in the introduction and method sections.

The next step of qualitative content analysis is [4] the definition of the coding process and coder training. For this step, two researchers underwent coder training and jointly defined the coding process. The directed approach was combined with the conventional approach, meaning that initial codes were directed by the pre-defined topics of the guideline used in the focus groups (see Table 3-1) and additional themes were coded as they appeared in the text (Hsieh & Shannon, 2005).

Last, qualitative content analysis requires [5] carrying out the coding process, [6] a determination of trustworthiness, and [7] the analysis of results. Both researchers coded the emerging themes in a complementary manner to ensure trustworthiness. The analysis of the resulting thematic codes is described in the next section.

3.4 Results

The following table (Table 3-2) displays an overview of the coded result categories following the order of our research questions. The text below summarizes the results and features selected quotes from participants. This section is meant to give a pragmatic, comprehensive overview of the results. In the discussion section, we derive meaning and implications from these findings, integrate them with previous research, and draw conclusions.

Table 3-2

Result categories per focus group content block

Block	Content	Codes
2.1	**MaaS from the perspective of users and non-users**	
a.	Users	Age, income, employment status, multimodal habits, residential location, car-less, tourists
	Use cases	Uncommon trips (unknown routes, moving people/goods, transit failure) downtown, leisure trips (joy, excursions, nighttime)
	Uses for which MaaS is unsuitable	Habituated trips, daily commute
b.	Advantages	Simplicity, pragmatism, integration of mobility providers, flexibility, overview
	Barriers	Missing added value, unattractiveness of transit/sharing modes, distrust in functionality of app, insufficient service area and vehicle availability, data security
	Prerequisites	Convincing design, reliable information, pricing
c.	Improvements and additions	More real-time information, filter, additional routing information, increased sharing options, assisted parking, increased MaaS service, further “nice-to-have” functions
d.	Internal sustain-ability nudging	Question of effectiveness, of methodological reliability, of use cases, of business integrity
e.	External context (pull measures)	Improvement of cycling/pedestrian/transit infrastructure, subsidized mobility budgets
	External context (push measures)	Congestion pricing, car-free zones
2.2	**Psychological motives for car possession and MaaS use**	
a.	Instrumental motives	Instrumental functionality
b.	Symbolic motives (+)	“Zeitgeist”, modern, prestige due to access, innovative, smartness
	Symbolic motives (-)	Not comparable to car symbolism, invisible to outside
c.	Affective motives (+)	Curiosity, fun in trying new modes, connection to city
	Affective motives (-)	Difficulty in finding affective connections to MaaS
	Ownership as burden	Relief from parking and associated fees, tax and mechanic costs, and of worry about break-ins

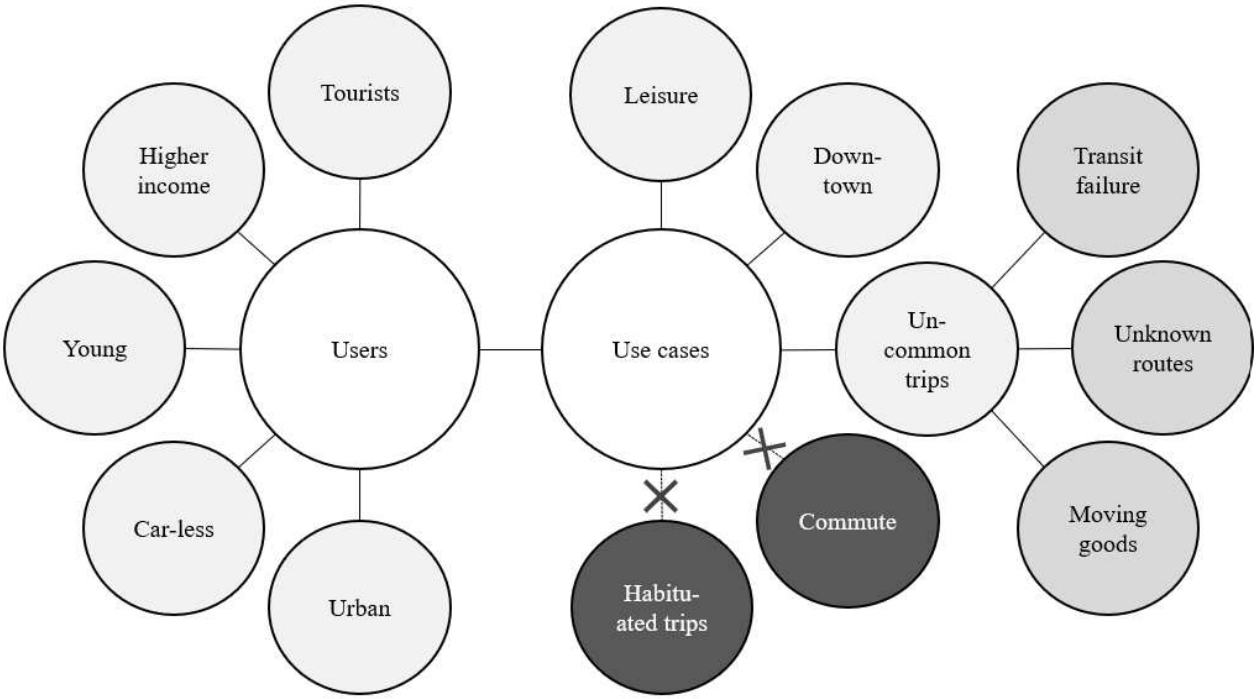
During the focus groups, we aimed to generate knowledge in the frame of the integrated, multimodal MaaS service. However, participants sometimes discussed only partial aspects of the MaaS system, for example the specifics of different transport modes, losing sight of encompassing the MaaS scheme as a whole. It seemed difficult for participants to stick to the meta-level of the MaaS scheme: facilitating transport paths by combining modes and presenting them in an integrated manner.

3.4.1 MaaS from the perspective of users and non-users

3.4.1.1 Users and use case situations

Figure 3-1

Visualized results for content block 2.1a.: Users and use cases



Participants deemed younger individuals the primary target group, assuming that digital natives would be enticed by MaaS. In contrast, some older focus group participants claimed that as long as tech-savviness suffices and the modal offer is broad, MaaS use could be age-independent.

> *"When I'm 75, I'm not going to pick a pedal scooter (...), and maybe I won't be able to ride a bike anymore. But the [modal] range is wide, so I think there'll be the right thing for me."*

When discussing the role of income and employment status, participants focused on the affordability of sharing vehicles. MaaS was seen as a solution for those who have a lower

income to access a car when needed, whilst avoiding the general high cost of car ownership. In their view, MaaS was developed for those who do not currently own a car (this does not reflect the reality of why MaaS was developed), instead of being an alternative to the car.

"If you already own a car, you don't need that, it would just be additional costs."

As a consequence of low income, some participants excluded students from the MaaS user group, and shifted the focus to young professionals with a higher income. Using sharing vehicles, especially e-mopeds and e-scooters, was regarded as high-end and a leisure activity.

"Only when you have an income do you use many of these services. I've noticed this (...): [people] cheerfully take an e-moped or a scooter just to get somewhere faster."

Participants deemed individuals who already display multimodal habits as a suitable user group. Consequently, MaaS was perceived as useful for residents of the inner city, where multimodal service is offered extensively. On the outskirts, where vehicle pick up and return hubs are sparse and the distance toward these is potentially far, using MaaS was not perceived as an ideal solution.

Regarding use cases, unknown routes were mentioned for which the easy access to different modes via MaaS would be helpful. In line with his, participants voiced that multimodality offered by MaaS would be especially suitable for tourists, who do not know the city and would profit from simple access to a diversity of mobility services and flexible switching between modes.

"I could imagine that [tourists] are a good target group. Especially for people who are in Berlin for (...) a week and don't want to deal with what kind of transport services are available here. They'll get the app and say, 'Cool, today we're taking the bike! But now we're taking the bus! And tomorrow we'll take the S-Bahn!'"

The flexibility of MaaS was recognized as useful for special occasions: For example, when spacious vehicles are needed to move large objects such as furniture, or when a group of relatives or friends needs to be transported. Transit disruptions due to construction work, or unexpected train or bus cancellations were also mentioned in this context.

"...if somehow the train breaks down (...), then I'm at the station and don't know what I should do, should I take a bus, or substitute transport, and then such an app would perhaps be quite cool, if you could find alternatives quickly."

MaaS was perceived as a "savior" solution for trips during the night, for purposes such as clubbing or bar-hopping, when the operation of vehicles is not an option due to intoxication and waiting times for transit are extended. In such cases, easy access to ridehailing or ridepooling was appreciated.

During the summer, different options for using bikes, e-mopeds or e-scooters were considered for hedonistic reasons within the city, and for excursions and leisure trips beyond the city borders.

> *"Just into the countryside. There are destinations and small lakes where you just can't get to with [transit], only to a certain end point."*

In the other direction, trips to downtown were named as use cases, where driving the private car is perceived as high-end but inconvenient due to e.g., parking issues, which could be solved by using a sharing car of the MaaS scheme.

> *"It's also a question of what kind of appointment you have. I find it totally relaxing to drive into the city center using carsharing, then just park the car there, not having to pay anything for parking fees, and arrive relaxed."*

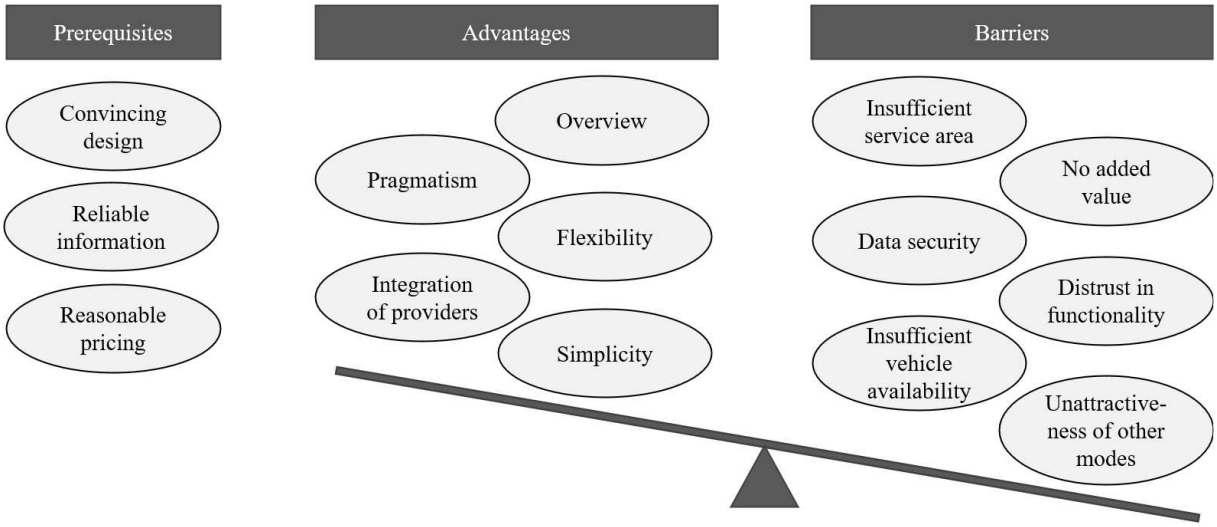
MaaS was not seen as useful for the daily commute to and from the workplace, or generally for well-known routes. However, if existing transit subscription tickets could be integrated, transit could be accessed through MaaS, whereas sharing options were not seen as useful for the commute.

> *"So I would not use the app for my commute but rather for leisure trips, especially if you are in places you do not know well."*

3.4.1.2 Advantages and barriers

Figure 3-2

Visualized results for content block 2.1b: Advantages and barriers



Before discussing advantages and barriers, participants outlined what prerequisites had to be met for them to consider using the app. Among those are a convincing design and reliable

information. Additionally, the services need to be budget friendly and the cost comparable to those of individual provider applications.

The main advantages were the general simplicity and pragmatism of using different mobility services and transit, facilitated by the integration of mobility providers into a single interface. Hence, MaaS was deemed capable of increasing individual flexibility. The benefit of an extensive overview in terms of route, transport means, and price comparison was highlighted.

Numerous potential barriers and disadvantages that complicate the use of MaaS were described. On a meta-level, many individuals had trouble identifying the added value of MaaS compared to either their private bike or car, or compared to other transit or routing apps. The value of having all mobility applications and services integrated into one application was not convincing or necessary to most, and only after the moderators' repeated mention of possible tariff options and integration of payments was the service part of MaaS acknowledged.

> *"If anything, I use Google maps (...) because I just do not need more features. I haven't used e-scooters and rental cars for a long time, I do not have these apps anymore and I do not need to switch to those."*

Especially car individualists categorized MaaS as inferior to their own car, and found no convincing reason to consider using MaaS instead. The rationale for this was manifold, including e.g., the speed and convenience of the private car, flexibility in the case that goods need to be transported spontaneously, that the car is known and familiar, or for other purely symbolic and affective reasons (as discussed later).

> *"To go shopping, you can't easily carry those goods, you need a car."*

Compared to the private car, some services available within MaaS were rated as especially unattractive by some, and thus rendered MaaS itself unattractive. Especially during the Covid-19 pandemic, some participants disliked being close to strangers in crowded transit, and voiced concerns about the quality and hygienic state of sharing vehicles. Additionally, sharing vehicles such as e-mopeds, e-scooters, and bikes were perceived as littering sidewalks and bike lanes.

One major concern was that MaaS is not sufficiently available in suburban areas. For example, sharing vehicles cannot be parked or rented in walking distance from a person's home. Taking the private car or bike to reach a MaaS station wasn't seen as sensible. Within some parts of the service area, a lack of offer availability was noted. In this case, using MaaS was seen as complicated and stress inducing instead of relieving. The insufficiency of included services was commented on, since popular services such as *Uber* (ridesharing) or *Lime* (e-scooter sharing) had to be accessed using a different, specific app anyway.

Another barrier was the lack of trust in and reliability of the application. Especially those participants who had made negative experiences with transit applications before worried that the app would provide incoherent or wrong information. Some were also concerned about a potential higher cost due to using various mobility services through a second provider.

> *"My fear is that the app somehow doesn't work. For example, BVG isn't even able to read the barcode correctly when I'm at a stop, which is simply unreliable."*

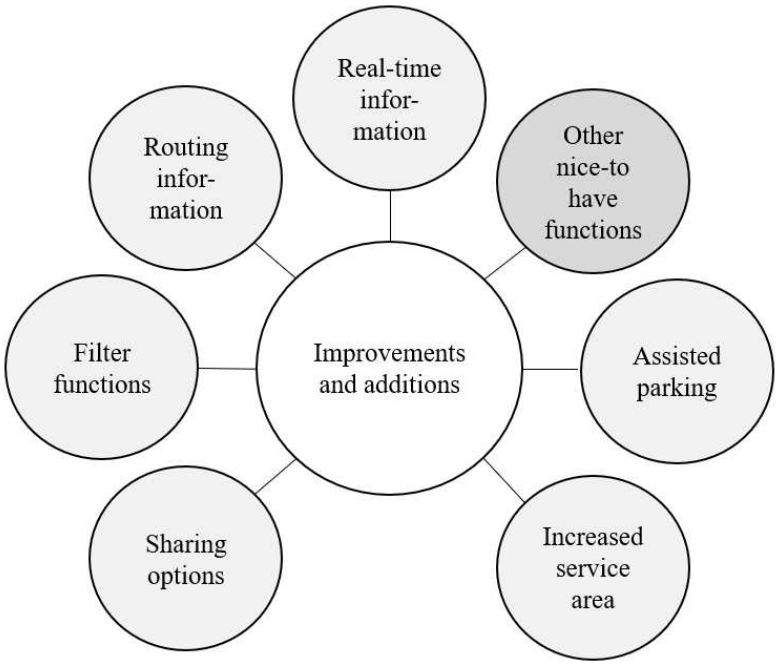
Connected to the design of the MaaS application, a few participants voiced concerns regarding data privacy and security, and were surprised that data protection was not addressed in the semi-structured guiding questions. They worried about (real-time) tracking and processing of personal mobility data by the transit company and other integrated mobility operators.

> *"What I miss is the data protection aspect. It's not really clear: What happens to the data? What is it used for? Are movement profiles created? Will the data be sold?"*

3.4.1.3 Improvements and additions

Figure 3-3

Visualized results for content block 2.1c: Improvements and additions



Next, improvements and additions were discussed. Naturally, these are specific to the implementation of the application "Jelbi" in Berlin, yet, results could give valuable pointers toward other MaaS applications.

Regarding transit, real-time information metrics on transit capacity via the MaaS application was wished for, in order to avoid crowded buses, trams, or subways, along with

information of delays or cancellations. In general, a filter for mobility options – e.g., the exclusion of e-scooters – and advanced personalization options would be appreciated. For rental and sharing vehicles, participants would enjoy the rental of several vehicles with a single MaaS account to enable trips with friends or visitors. An increase of the service area and more MaaS mobility stations to make MaaS attractive for the outer city residents was a theme, though some participants voiced concerns about the economic feasibility of such an endeavor. Further, the integration of additional, if not all, mobility services available in Berlin was wished for, such as ride hailing services like *Uber*. Transit fans mentioned that MaaS would be more attractive if they could integrate their subscription tickets (e.g., student semester tickets) and allocated discounts in the app.

Similar to *Google maps*, participants wished for additional information on the surrounding area, to simplify finding e.g., drug stores or pharmacies. The display of certain types of routes was requested, especially safe routes for bikers.

Participants wished for support in finding parking spots for carsharing vehicles: MaaS could act as a platform to organize the parking space for sharing vehicles by indicating virtual stations, in which they may be deposited.

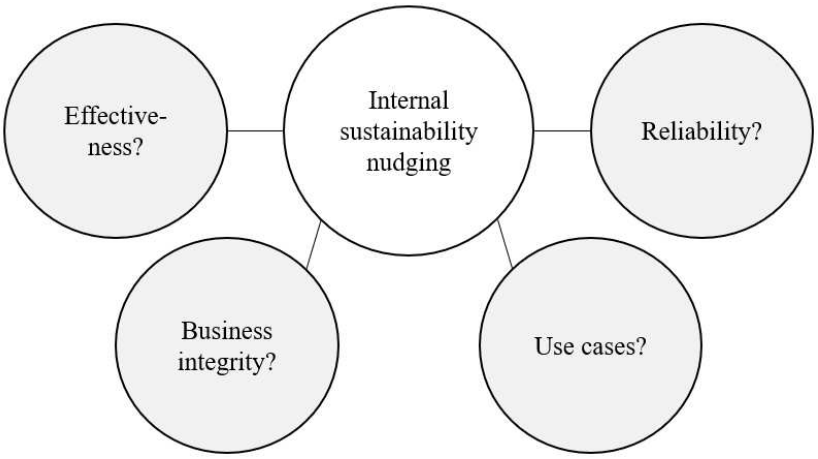
> *"This could be solved through Jelbi, exactly! (...) if someone thinks he has to leave a bike or scooter somewhere where it doesn't belong, then it just costs. Then the clock keeps running. That would already be some form of organization (...)."*

In general, participants' brainstorming was very fruitful. Remaining themes that came up but were not discussed further are the addition of a calorie counter within the app (which tracks the calories burnt when walking or using sharing bikes), special offers and gift vouchers, a prepaid system (which allows charging one's account, instead of deducting from bank accounts), and CO_2 information of the different mobility options (as discussed below).

3.4.1.4 Internal sustainability nudging

Figure 3-4

Visualized results for content block 2.1d: Internal sustainability nudging



Participants were asked about their opinion of an "eco-filter" nudge (filtering sustainable transport modes) and a "carbon footprint" nudge (indicating the sustainability of a route). Views on the matter diverged. Some deemed these nudges useful and interesting.

> *"I find this appeal or invitation to think again for a moment very helpful."*
>
> *"I think it's actually important that you can filter according to the shortest, fastest and, for my sake, also the most CO_2-neutral route. In fact, I expect that [from an app] when so many means of transport are offered."*

Other participants questioned the underlying assessment method and true purpose by which certain transport means and routes are described as more sustainable than others. The results seemed obvious to many, e.g., that using a bicycle was more sustainable than using a car.

> *"Somehow I've become so ingrained with skepticism when it comes to these things, because the greenwashing light is flashing again."*

The general effectiveness of such nudges onto the actual mobility behavior remained questionable. Some participants indicated that such information would play a role in their decision-making. However, they would only rely on those in certain circumstances, for example concerning trips for leisure purposes, after considering the trade-off with cost and time. Others highlighted that they would choose actual routes and transport mode combinations based on cost and time only.

> *"I don't believe that anyone walks for 30, 40 minutes and uses the app. I want to get from A to B as fast, cheap, and easy as possible!"*

Some focus group participants also questioned if such nudges can be viable and feasible from the provider's standpoint. Even though the MaaS provider, a public service-oriented company,

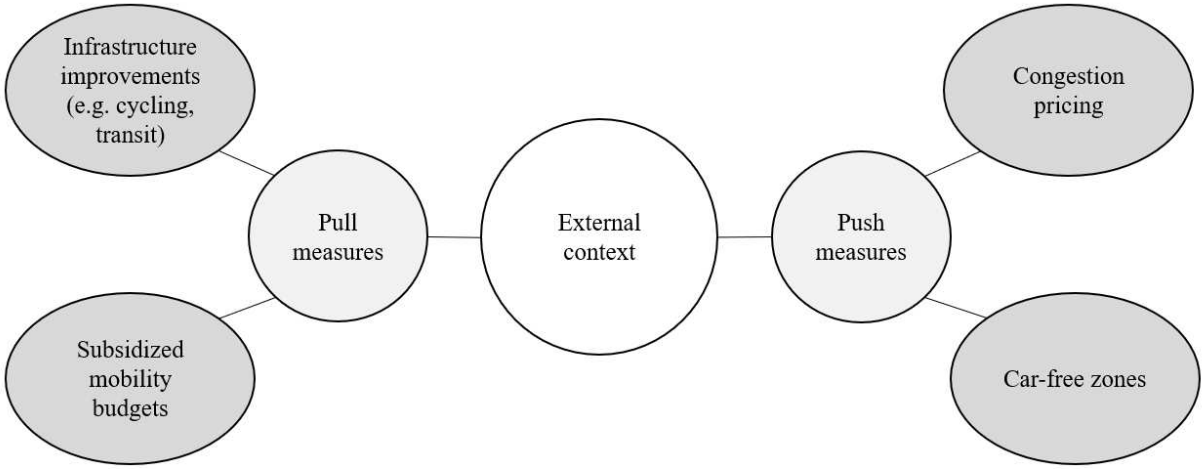
could nudge its users toward transit, participants speculated about a conflict of interests among the various mobility providers and the risk of business cannibalization.

> *"Would Jelbi suggest that you take the subway or the bike, and then they would give you Eco-Points if you took the bike? That would be more of a promotion from the bike rental company, wouldn't it? Or isn't that contradictory for the companies that participate there? If Jelbi decides, 'we send the customers there and there?'"*

3.4.1.5 External transport policy conditions and scenarios

Figure 3-5

Visualized results for content block 2.1e.: External transport policy conditions and scenarios



Suiting external conditions were seen as a necessity for many services to be attractive (e.g., sharing, transit). Here, participants often dived into describing what made individual modes attractive, dismissing the MaaS scheme as a whole. But, as these individual modes are a major part of the MaaS service, the external conditions are essential for MaaS to ever be successful.

Regarding pull measures, participants highlighted the need to improve the infrastructure for cyclists and pedestrians, which at the moment encourages dependence on and use of private cars. Further, the frequency and service area of subway, bus, and tram lines needs to be improved, particularly in the outer districts. Some participants also highlighted the insufficient and chaotic parking situation and infrastructure for sharing cars, bikes, e-mopeds, and e-scooters. MaaS's attractiveness would improve if sharing vehicles could use separate parking spots.

> *"Regarding parking spaces, it should be the case that, if I use the cars of carsharing companies, that I can park for free and that there are more parking spaces available."*

Another discussed pull measure was the introduction of subsidized mobility budgets (i.e., financial support for using transport modes via the MaaS application) to be offered to MaaS

customers. The overall social fairness of such subsidies was controversial, since mainly inner-city residents who have good access to transit and new mobility services would profit. If mobility budgets were introduced, MaaS may increase the divide between inner and outer districts.

Regarding push measures, a major theme was the introduction of congestion pricing in the inner city. In view of the (at the time of the focus groups) upcoming Berlin federal elections, several participants were aware of this controversial policy proposal, and regarded the MaaS concept as a response by the Senate to disincentivize private car use. Support for or opposition against a congestion pricing policy was discussed among participants and may be traced back to the different multimodal mobility types and their dependence on private car use. Proposals such as car-free zones in the inner city were less frequently mentioned. A potential introduction of road pricing schemes was identified as a window of opportunity to increase MaaS adoption. In general, several participants doubted the public's acceptance for push measures.

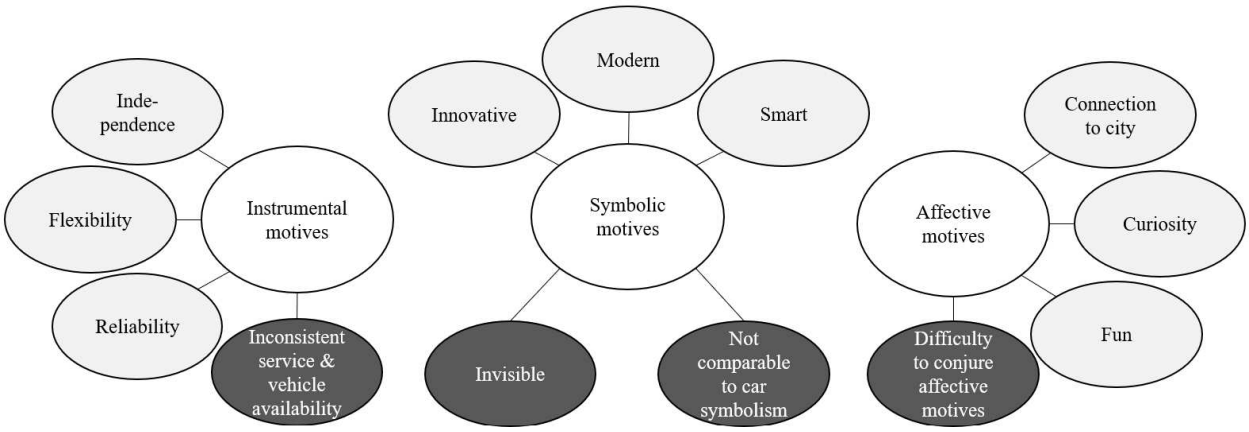
> *"If a city toll is implemented, and driving becomes more expensive, you gain a completely different group of people: those who have always traveled by car and never used transit. And they have not really thought about how to get around in the city center using public or sharing transport before. Then this app becomes interesting […]."*

3.4.2 Psychological motives for car possession and MaaS use

Our second research aim centered on the psychological motives for car possession (Steg, 2005), and how MaaS could potentially compensate for these. Specifically, we raised the question if MaaS can serve the same instrumental needs as the private car, and further, which symbolic and affective motives individuals associate with MaaS, and if these can offer a counterweight to those associated with the private car.

Figure 3-6

Visualized results for content block 2.2: Psychological motives for MaaS use



3.4.2.1 Instrumental motives

Participants explained that they appreciated the instrumental function of MaaS, as long as it was available near an individual's frequently visited locations, predominantly close to home. It was agreed upon that MaaS could potentially offer everything that is needed in terms of mobility. Reliability, flexibility, and independence were mentioned.

> *"It's practical and it meets the need to be mobile and to be independent of certain modes of transportation because it allows you to use a wide variety of modes."*

3.4.2.2 Symbolic motives

Participants mentioned numerous symbolic motives that MaaS could potentially fulfill: going with the "Zeitgeist", being modern and innovative, prestige due to the access to different, expensive cars, and a symbol of smartness and cleverness.

> *"I'm one of the people of tomorrow (...), even I get that."*

However, many participants mentioned that those who take pleasure in the symbolism of their private car could hardly be convinced to see positive status symbols in using MaaS, as it is invisible to the outside world. Using MaaS has symbolic value – painting the user as a fresh, tech-savvy, independent, and progressive person – but this symbol is perceived entirely differently from car ownership, which was mostly connected to a contrasting value system, and judged by most participants (but not by car individualists) as snobbish, gaudy, and conservative.

> *"I have the feeling with the app that it's a great solution, but that's not something that I show to the outside. Like my house, my boat, my car, and my trophy wife."*

3.4.2.3 Affective motives

Regarding affective motives for MaaS use, participants mentioned curiosity (i.e., trying something new) and fun connected to riding different scooters on sunny days. In contrast to the private car, MaaS may offer a better possibility to emotionally connect to and experience the city (similar as to why participants judged MaaS as a good option for tourists).

"...leave this personal shelter [car] and see what makes Berlin tick."

"...beneficial, practically, but that doesn't trigger any emotions."

In the discussions, participants – including car individualists – mentioned with considerable emphasis that they despise the burdens of car ownership, such as cost (mechanics, taxes, insurance, fuel, parking), expenditure of time for finding parking and getting to mechanics, or being stressed that the car is broken into or stolen. "Use it and leave it", was seen as a relief, connected to the feeling of freedom (from this burden).

"...because possession also burdens you, and does not necessarily give you freedom. You have to take care of a car."

3.5 DISCUSSION

In this paper, we aimed to discern the relevant enabling factors and barriers regarding the use of MaaS (considering internal as well as external factors), and to uncover under which psychological circumstances individuals are willing to reduce the use of the private car (or discard it altogether) on account of MaaS.

Beyond the individual themes described below, an overarching finding is a lack of clarity regarding the service aspect of MaaS. MaaS was often perceived as "just another" transit ticketing and routing application. The fact that the application is provided by the local transit company increased this perception. For many individuals, the idea of servicing mobility was hard to conceptualize. Thus, the use of individual mobility services and circumstances was predominantly discussed, less so the concept of servicing mobility itself.

3.5.1 MaaS from the perspective of users and non-users

3.5.1.1 Users and use cases

Our content analysis revealed age as a proxy for tech-savviness and openness for new experience, rendering age a correlating and not a causal factor for MaaS use. Identifying tech-savviness as the true causal factor, we assume that age as a constricting factor will decrease in importance in the following decades, given that today's middle-aged population is already significantly more tech-savvy than their parent generation. Our findings further suggest that

MaaS may be a solution for all income groups, noting that it can provide lower income groups access to a car when required. The urbanity of a potential user's residential area (as a proxy for service density) was also identified as a predictor for MaaS use. Additionally, individuals with preexisting multimodal habits were described as a potential user group. These habits have been shown to partly correlate with urbanity and younger age (Nobis & Kuhnimof, 2018). While previous research summarizes attributes of the proposed MaaS user base as younger, higher income, tech-savvy, and without a car (Loubser et al., 2021), we argue that there is a case for MaaS to be used by all age groups (if tech-savviness suffices) and for all income groups.

The classification of tourists as a target group stems from the perception that MaaS is rarely an option for habituated trips. In our data, business-related travel or the commute were predominantly ruled out as relevant trip purposes. The main perceived use cases for MaaS were uncommon trips and situations in which regular transit service is not available or disrupted. This finding conflicts with previous theoretical considerations, asserting that work-related trips are a major use case (Jittrapirom et al., 2017). The impact of this finding is considerable, since work-related trips make up about 42% of miles traveled in Germany (Nobis & Kuhnimof, 2018), and work is the main trip purpose for individuals that travel extensively (Hauslbauer at al., 2022b). If acquiring commuters as a user group and work-related trips as a use case for MaaS is the goal, extra effort needs to be dedicated to this end. This could be done, for example, by providing mobility bundles or packages that target commuters specifically, and more research in this direction may be helpful (as shown by, e.g., Kim et al., 2021).

3.5.1.2 Advantages and barriers

Seamless functionality was identified as a prerequisite for MaaS to be considered as an option. This underlines the importance of technical effort and design considerations for the application. The main identified advantages of the service were ease of use and simple access to modes, pragmatism, and flexibility. However, residents of the outer districts voiced regret that due to the lack of access to these services, they would not benefit from these advantages.

While the advantages of simplified access and flexibility appear repeatedly in MaaS studies across countries and cities (e.g., Schikofsky et al., 2020; Alyavina et al., 2020), we found a fundamental constraint regarding their persuasiveness: even though these advantages were perceived independently of the mobility type, they are subject to the limitation that car individualists found MaaS a good idea – *for others*, not for themselves. They categorized their own car as superior, and found no convincing reason to consider using MaaS instead, despite

acknowledging its advantages. This points toward the issue of symbolic and affective motives, indicating that functionality alone does not suffice to make MaaS successful.

App-specific distrust in the functionality, insufficient service areas, and vehicle availability (especially in the suburban areas) were identified as relevant barriers. Data security concerns and transparency was discussed seldomly, but if so, a strong emphasis was placed on it. Remaining issues concerned external infrastructural factors, such as the unattractiveness of transit or sharing modes, which are outside the reach of MaaS provider platforms. This indicates that, unsurprisingly, MaaS cannot operate in its own bubble, it is dependent on external factors, as discussed below.

3.5.1.3 Improvements and additions

A plethora of ideas was produced when discussing possible improvements and additions. These included real-time information, increased sharing options, assisted parking, and more. However, the resulting list does not serve as direct advice to providers, because participants were not asked to consider and were likely unaware of usability factors, such as that cluttering of functions can easily decrease attractiveness of services. More detailed ideas were predominantly voiced by those participants that already used MaaS, as they already had extended knowledge about the app (e.g., calorie counters), whereas non-users described more basic features (e.g., real-time information). This substantiates the importance of including both users and non-users in the data collection when the aim is to achieve a holistic view. Importantly, none of these potential additions convinced the car individualists of our sample to reconsider MaaS use. Again, the lure of the private car is unbeatable, untouched by whatever alternative options may be available.

3.5.1.4 Internal sustainability nudging

The positive impact of environmental nudges within MaaS was questioned repeatedly, due to distrust in the accuracy of information about the sustainability of options, and due to the importance of cost and time. It is beyond the scope of this article to report on the effectiveness of nudging in this context, but the doubts voiced by participants do curtail hopes in that regard. This, however, corresponds to recent findings indicating that nudging in the transportation sector has proven difficult (e.g., Hauslbauer et al., 2022a), and that the usefulness of nudging in general is questionable (e.g., Maier et al., 2022). Bieler and Maas (2018) propose that beyond nudging, adding game design elements may be constructive, and benefits from gamification approaches in the transportation sector have been noted (e.g., by Yen et al., 2019).

3.5.1.5 External transport policy conditions and scenarios

Our results suggest that, unsurprisingly, the surrounding transport and infrastructure conditions are extremely important, and should therefore be taken into account. The main take-away is that pull measures and a perfect MaaS service alone would not be sufficient to convince all car users to switch. Only if using the car was maximally inconvenient, certain individuals may consider looking into alternatives. Thus, targeted push measures to reduce the desirability of the private car are essential.

3.5.2 Psychological motives for car possession and MaaS use

The discussion on psychological motives further supports the introduction of push measures: results show that MaaS can cover almost all instrumental functions of the private car. But, according to the theory of material possessions (Dittmar, 1992; Steg, 2005), car ownership does not only fulfill instrumental functions (e.g., the (in)convenience caused by car use like speed or flexibility), but also symbolic functions (e.g., expressing one's social position) and affective functions (e.g., feeling at home in the car; feeling excited at high speeds).

Predominantly the car individualists argued fervently that no matter how excellent the MaaS service, they would never give up their private car. Reasons for this can be attributed to private car-specific symbolic (e.g., pride to be able to afford it) and affective motives (e.g., feeling independent [from transit], identification with the car/group of car drivers, "by nature, I am a passionate car driver").

In that regard, our study is the first to demonstrate that analogous to car ownership, MaaS can cover specific symbolic and affective motives. Symbolic motives predominantly center around showing one's innovative spirit and cleverness, but are as diverse as the MaaS offer itself. A striking unique example here was the need to arrive elegantly for a job interview, using an extravagant sharing car. Affective motives may be activated by MaaS with regards to hedonism or fostering an emotional connection to the city by making different modes like open-air sharing modes or overground transit available. However, these MaaS related motives are less obvious and not as readily accessible than those associated with car ownership.

Additionally, many discussions steered to the inconvenience and burdens connected to car ownership (e.g., anxiety regarding break-ins, stress about managing reparations, frustration due to parking difficulties, concern for insurance cost, etc.), which could be intensified using push measures such as road pricing or parking restrictions.

3.5.3 Limitations

While these qualitative findings depict the MaaS scenario in Berlin, they may not directly apply to diverse cultures and cities. In fact, Butler et al. (2021) found that a universal MaaS solution is unattainable because local characteristics are critical. For example, in a city like Kochi, India, where MaaS includes water ferry, auto-rickshaw, bus, and rail (Singh, 2020), results are bound to differ. Therefore, the present study and similar research should be viewed as complementary, and in combination may reveal context-dependent and context-independent aspects of MaaS.

In the semi-guided focus group sessions, not all potential aspects connected to MaaS were included. For example, topics such as MaaS bundle design or mobility packages did not appear within the focus groups, but offers like these might have an impact on individual's attitude and use intention toward MaaS.

The online format and online recruiting strategy could have caused our sample to be more tech-savvy than the average individual. Further, our sample did not include children, who were recently described as a key group of MaaS users (Casadó et al., 2020), and who might have brought additional or diverging views into the discussion.

3.5.4 Conclusion and implications

Partly, our findings overlap with related studies on MaaS in different countries or cultures. For example, similar advantages of MaaS (e. g. simple access to modes) and prerequisites for MaaS use (e. g. sufficient tech-savviness) were found across studies. This indicates that some factors are relatively context independent.

However, some findings contradict previous research. Specifically, age has been used as a predictor for MaaS use, and while it may technically function as a predictor, our findings suggest that age is a correlating, but not a causal factor. Due to the availability of numerous mobility options, physical or age induced limitations were not seen as a general barrier for MaaS use. Senior citizens may as well use MaaS if they can overcome the bottleneck of tech-savviness. Education offers for older individuals with lower tech-savviness may be a step to increase access. Therefore, the hope for MaaS to increase transport equity by making cars and other modes accessible to everyone seems rational, as MaaS is a potential option for individuals of every age and education level, provided that the service is extensively available and individual tech-savviness is sufficient.

Another contradicting finding is the use case of commuting. In the present study, habituated trips such as the commute were clearly ruled out as a use case. Research efforts need to be dedicated to integrating those trips as a use case as well. Measures such as the introduction

of mobility packages and bundles, or opportunities to integrate existing subscriptions (such as for transit) may be effective.

A novel finding, to our knowledge, is the perceived lack of any added value. To combat this, MaaS providers may need to put extra effort into distancing their product from mere routing apps, accentuating the added value and service aspect of MaaS.

Perhaps the most poignant finding results from investigating the psychological motives for car ownership and comparing them to MaaS use. At least partly due to strong car-specific symbolic (e.g., prestige) and affective (e.g., private space) motives, even a perfect fulfillment of instrumental mobility functions through MaaS will not suffice to convince vehement car users to switch modes. To overcome this predicament, we propose two roads forward. To begin with, increasing the burdens for car ownership using push measures may be able to overrule the strong symbolic and affective motives for car use, so that individuals may switch to more convenient modes (using MaaS, for example). Furthermore, this study showed for the first time that MaaS, too, can be associated with symbolic (e.g., modern, innovative) and affective (e.g., fun, connection to city) motives. For now, providers predominantly stress the functionality of MaaS. Emphasizing these motives, beyond instrumentality, and simultaneously stressing (and increasing) the burdens of car ownership, may be MaaS's biggest lever to pull individuals out of the private car.

Our findings are a testament to the importance of considering traffic psychology in transportation: ignoring the impact of psychological motives associated with car ownership and only offering a convenient alternative service is simply not sufficient to induce behavior change.

4 Study III. Extending the theory of planned behavior to predict and nudge toward the subscription to a public transport ticket

Abstract

To reduce pollution from motorized private cars, a modal shift toward more sustainable modes, such as transit, is desired. A first step to achieving this is the subscription to a transit ticket. It was investigated if an extended version of the *theory of planned behavior* is suited to predict subscription to a transit ticket, and if *environmental concern* – the channel through which many sustainable transportation modes are advertised – plays a significant role. It was further examined if nudging serves as an effective measure in convincing employees to subscribe to the offered ticket. *Nudges* encourage desired behaviors by changing the information set that individuals face when taking decisions; in this paper, this includes favorable *defaults* and the manipulation of the *social norm*. Since nudges lack a coherent theory, it was tested if these nudges can be integrated into the aforementioned theory.

By means of an online experiment, participants (N = 373) were randomly assigned to different nudging conditions or a control condition. The questionnaire mimicked a working contract, including the decision for or against a subscription to the ticket.

Results of structural equation modeling revealed that the theory predicted the purchase decision well, yet the impact of *environmental concern* was low. Most tickets were purchased in the default condition, but no nudge reached statistical significance. The limitations of nudging in the transportation sector are discussed, along with the effectiveness of advertising transit through an environmental lens.

4.1 INTRODUCTION

4.1.1 The need to change mobility behavior

Motor car use in urban areas is connected to numerous ramifications for the environment and public health, including greenhouse gas emissions, fine-particle and noise pollution. Cars stuck in traffic, e.g., during rush hours, emit even more of these damaging substances, and simultaneously decrease the viability of transit (Vlek & Steg, 2007). One approach to overcoming these issues is achieving a modal shift, i.e., convincing private car users to switch to more sustainable means of transport, such as transit or bicycles (Lind et al., 2015). Strategies aimed at achieving this modal shift typically follow the push-and-pull approach: They either try to increase the attractiveness of more sustainable travel or decrease the attractiveness of car use (Stradling et al., 2000; Thorpe et al., 2000). As sustainability concerns are on the rise, advertising for environmentally friendly travel is increasingly becoming part of transportation marketing strategies as well. But, within the frame of a liberal society, changing behavior, especially habituated behavior like car use, is an ambitious and difficult task (Bamberg, 2010).

4.1.2 New approaches to changing mobility behavior

To be able to change behavior, it is important to understand what drives said behavior. One of the most widely used and accepted models to explain behavior is the theory of planned behavior (TPB) (Ajzen, 1991), which uses attitudes, subjective norm, and perceived behavioral control as predictors. A previously unexplored attempt to achieving a behavioral change, i.e., the decision to switch from private car to transit, is addressing the predictors of this theory using nudges (Thaler & Sunstein, 2009). The concept of *nudging* (Thaler & Sunstein, 2009), developed in the field of behavioral economics, has proven effective in incentivizing voluntary behavior change across numerous fields. Nudges are interventions that direct the choices that people make (e.g., healthy, sustainable, etc.) without restricting freedom of choice. Nudging is an umbrella term for numerous interventions, and as such, its definition suffers from lower levels of granularity, and a coherent "nudging theory" still needs to be developed (Ölander & Thøgersen, 2014). A step toward resolving this could be the integration of nudges into the theory of planned behavior.

To test nudging, a mobility context is required in which a modal shift could provide a considerable impact. Thus, the commute to the workplace was chosen: for the working population, work-related travel accounts for more than half of their weekly distance traveled (Nobis & Kuhnimhof, 2018, p. 103). Many employers in Germany incentivize the use of transit for the commute by offering subscription tickets to transit at a reduced price, frequently called

Job ticket. Even though owning such a ticket is not equivalent to using transit instead of the private car, it can be assumed that subscriptions are the first critical step to increasing the use of transit. Thus, the decision to subscribe to the Job ticket is the behavior central to this study.

4.1.3 Aim of the study

First, this study investigates if the theory of planned behavior extended by environmental concern is able to predict the decision to subscribe to a transit ticket (RQ 3.1). Second, this study aims to test if two nudges (a default and a social nudge) aimed at enticing employees to purchase a transit ticket could increase subscription numbers (RQ 3.2). Finally, this study analyses if the nudges can be integrated into the theory of planned behavior (RQ 3.3).

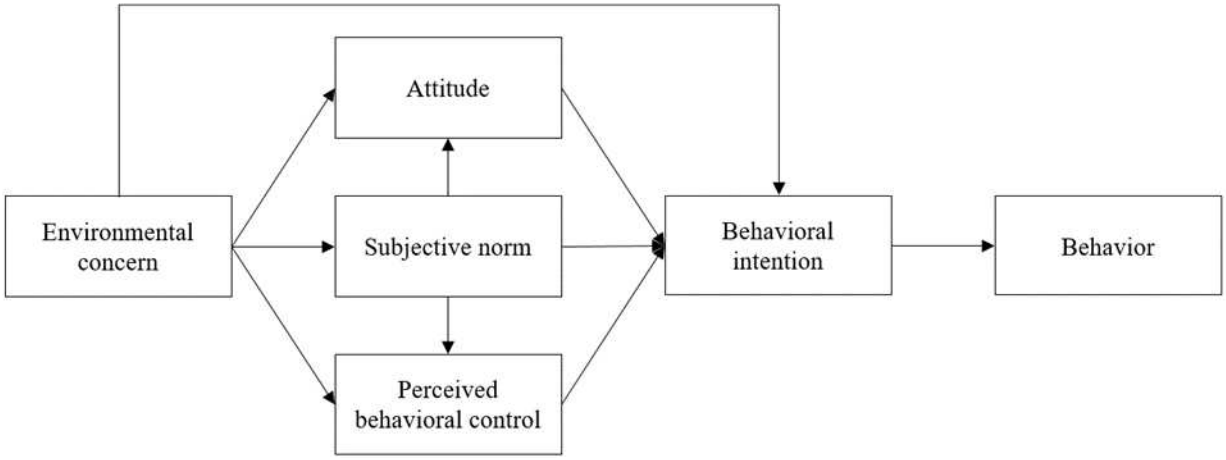
4.2 Literature review

4.2.1 The theory of planned behavior extended by environmental concern

The theory of planned behavior (TPB) by Ajzen (1991) is one of the most widely used models to predict behavior. Studies found that the predictors of the TPB affect the intention of car use as well as the decision to use transit or other modes instead of the car (e.g., Bamberg et al., 2003; Bamberg & Hunecke, 2007; Gardner & Abraham, 2010; Harland et al., 1999). Donald et al. (2014) argue that the prediction of mode choice can be enhanced by environmental concern, and found that it has an indirect effect on car use. In an extended version of the TPB (Paul et al., 2016), environmental concern (Dunlap & Jones, 2002) functions as a predictor of behavioral intention as well as of its other predictors (Figure 4-1).

Figure 4-1

Extended version of the theory of planned behavior



Note. Adapted from Paul et al., 2016.

Attitude (AT) is defined as the extent to which a person has a favorable or unfavorable evaluation of the behavior. Subjective norm (SN) is defined as the perceived social pressure to perform or refrain from the behavior. Two kinds of subjective norms can be differentiated (Ajzen, 2002): injunctive norms refer to what others (dis)approve of, while descriptive norms refer to the actual behavior of others. Perceived behavioral control (PBC) is defined as the perceived ease or difficulty of performing the behavior.

Environmental concern (EC) scales the awareness of environmental issues and the personal effort to contribute to their solution (Dunlap & Jones, 2002). It is targeted specifically at current environmental issues regarding the transportation sector, based on the assumption that "attitudes toward specific environmental topics are ultimately reflections of a single, broad environmental attitude - what is sometimes referred to as environmental concern" (Cruz & Manata, 2020, p. 2; Dunlap & Jones, 2002). Donald et al. (2014) argue that the prediction of mode choice can be enhanced by environmental concern, as it provides these additional beliefs beyond the three classic TPB constructs, and they indeed found that EC has an indirect effect on car use. We thus adapted the model from Paul et al. (2016), who too, found environmental concern to be of predictive value (regarding green consumption), and included environmental concern in the model used in this study. However, there is an ongoing discussion on the proper measurement of environmental attitudes in the literature. Harland et al. (1999), for example, use items that are phrased similarly to our conceptualization of environmental concern (e.g., "I am worried about the condition of the environment"), for their measurement of environmental involvement. This topic will be resumed in the discussion of this paper.

4.2.2 Nudging within the transportation sector

Nudges (Thaler & Sunstein, 2009) are interventions that direct the choices that people make (e.g., healthy, sustainable, etc.) without restricting freedom of choice. Examples include design interventions (like spatial arrangements that place healthy food in cafeterias or supermarkets at eye-level) or default settings with opt-out options (like being an organ donor by default vs. having to sign up as an organ donor) (e.g., Rozin et al., 2011; Johnson & Goldstein, 2003).

The relevance of nudges with regard to sustainable transportation derives from travelers not being a rational *homo economicus:* cost-benefit calculations alone do not determine which transportation mode travelers choose because their behavior is subject to limited cognitive resources and bounded rationality. Nudging travelers can "help them to make better decisions for themselves, to improve the performance of the overall transportation system, and to reduce some of the external costs (economic, environmental, societal) associated with choices made

by individual travelers" (Avineri, 2009, p. 2). Among the most promising nudges are default settings and social nudges. While often addressed on a theoretical basis, according to Byerly et al. (2018), both have been used rarely as interventions to change mobility behavior.

4.2.2.1 Default nudges

The default is defined as what happens when a person does not act. Defaults are thus unavoidable (Brown & Krishna, 2004) and among the most utilized approaches in the nudging literature. The "decision" not to act can be explained by several psychological phenomena: inertia, the status quo bias, or the path of least resistance (Ölander & Thøgersen, 2014; Tversky & Kahneman, 1974), which can be loosely summarized as the tendency to stay put if not compelled to change. Related explanations are cognitive processing limitations (Brown & Krishna, 2004), e.g., being overwhelmed by the number and complexity of available choices, and cognitive misperceptions (Samuelson & Zeckhauser, 1988), e.g., the assumption that a default was set for a certain reason.

In an online experiment, Momsen and Stoerk (2014) found that in the context of choosing an energy contract for the household (conventional energy vs. renewable energy at a higher cost) a default setting was effective. They informed the subjects that the contract entailing renewable energy was the default in their region, and that making no active choice would set them up with this default contract. This simple nudge increased the share of subjects who choose the renewable energy contract by 44.6% compared to a control condition. Similar results were found in an experiment regarding the default transfer of a percentage of an employee's wage to a pension scheme with an opt-out option. The number of people saving for old age was significantly higher (50-67% increase) than in a previous opt-in system (Choi et al., 2001).

Within the context of the extended theory of planned behavior, defaults seem to be connected to perceived behavioral control, as a default setting increases the ease of performing said behavior drastically: no action needs to be taken.

4.2.2.2 Social nudges

Social pressure has long been known to be an effective mechanism to push others toward performing or abstaining from a certain behavior. This is included in Ajzen's (1991) theory of planned behavior as the predictor subjective norm. People tend to conform to group norms, e.g., in the form of opinions and actions, because non-conformity induces fear or shame of not belonging to the group (Akerlof & Kranton, 2000).

Brandon et al. (2019) tested social nudges for their effectiveness in decreasing household energy consumption during peak load events. Enabling social comparisons regarding energy consumption with other households decreased energy consumption by up to 6.8% compared to a control condition. According to Ajzen's (2002) differentiation of subjective norms, this can be called a descriptive social nudge, as participants were informed about what others did (as opposed to what they think).

A classic example for injunctive social nudges are Asch's (1951) conformity experiments, revealing that participants will verbalize a clearly wrong assessment of displayed line lengths in the attempt to comply with the social norm exhibited by other (fake) participants. As described, social nudges can be closely linked to both descriptive and injunctive subjective norms of the theory of planned behavior.

4.2.3 Combining the theory of planned behavior and nudging

The effectiveness of some nudges is explained with generic theories, e.g., with dual process theory (Kahneman & Frederick, 2002) or the reflective-impulsive model (Strack & Deutsch, 2004), but a coherent "nudging theory" still needs to be developed (Ölander & Thøgersen, 2014). This paper tries to connect the two nudges mentioned above to the theory of planned behavior, thus hoping to contribute to the development of a more coherent nudging theory. This derives from the assumption that setting a default is expected to simplify the perceived ability to perform the behavior, and that adding information of the social norm acts as a manipulation of the predictor subjective norm in the extended TPB.

The nudging concentrates on the purchasing process of a transit ticket, consequently, the model targets the decision for the ticket, and not the intention to use it. To be consistent, we include the PBC predictor for the purchase decision, but we recognize that PBC is, perhaps even more than other predictors, also strongly related to the *use* of transit.

This paper focuses on the specific case of the Job ticket offered in Dresden, Germany (ca. 550,000 inhabitants) by the local transportation association in collaboration with the local university (ca. 8,000 employees). The Job ticket is a price-reduced monthly subscription to the local transit and offers several advantages over a comparable monthly subscription ticket, e.g., by being 20% cheaper and usable as a family ticket. In 2018, only 16% of university employees used the Job ticket to ride transit (Wittwer et al., 2019). There is room for improvement, defined as higher subscription rates.

4.3 METHOD

4.3.1 Participants

The target population contained any adult either working at the university or potentially may soon start working there (i.e., Master students). An invitation to the experiment's web link appeared in student newsletters and was emailed via the administrative board. Participants were unaware of the aim of the study and were led to believe that it focused on the feasibility of digital working contracts. 373 people participated in the study (58.1% female; age $M = 34.47$, $SD = 10.10$), out of which 161 participants indicated that they already owned the Job ticket or a similar subscription ticket. To be able to identify the effectiveness of the nudges on those that did not yet possess such a ticket, we separately analyzed this subsample of $N = 212$ (51.9% female; age $M = 38.01$, $SD = 9.64$).

4.3.2 Design

Participants were randomly and unknowingly assigned to one of four between-subject conditions. Following the data security information, they were asked to imagine that they had just received their working contract and to click through it as if they are just about to start working at the main campus (which offers relatively good transit connections). After a few unrelated standard contract paragraphs to increase realism, participants encountered the Job ticket paragraph. The ticket information was identical to the actual Job ticket arrangements. Depending on the condition, this page either contained both the default and social nudge (condition DSN), only the default (condition D), only the social nudge (condition SN), or no nudge at all (control).

In conditions in which the default nudge was active, the information about the Job ticket came with the notice that the participant, as a future employee, was automatically subscribed to it. If they wished to unsubscribe, they had to un-check the preselected "Yes, I want to subscribe to the Job ticket" and instead select the "No, I do not want to subscribe". In conditions in which the default was not active, this information stated that, if the participant wished, they could subscribe to the Job ticket by checking the respective button. In conditions in which the social norm nudge was active, a yellow banner at the top-right corner of the webpage informed the participant that 76% of future colleagues had already subscribed to the Job ticket. In conditions in which no social norm nudge was active, this information was missing. The investigated behavior was the subscription decision regarding the Job ticket at the bottom of the page. The layout of the webpage with the example condition DSN can be found in Appendix 4-A.

After clicking through this Job ticket paragraph, the mock-up contract ended and participants encountered a questionnaire. The questionnaire items provided information on participants' demographic data, their mobility-related behavior, and on the extended TPB.

4.3.3 Demographic data and descriptive statistics

Demographic, geographic, and mobility-related descriptive data (adapted from *MiD*; Nobis & Kuhnimhof, 2018) is presented for the complete sample ($N = 373$) and for the subsample of participants (who reported that they already possess transit subscription ticket, $N = 212$) in Table 4-1. After scanning this data, no substantial differences between the four experimental conditions (DSN, D, SN, Control) were discernable in the complete sample, nor in the subsample. This impression was supported by test statistics (see Appendix 4-B).

Table 4-1

*Descriptive statistics for the complete sample (*N = *373) and subsample (*N = *212)*

Complete sample	**DSN**	**D**	**SN**	**Control**	**Total**
N	87	113	92	81	373
Age in years	33.93 (9.90)	35.05 (9.90)	33.01 (10.07)	35.90 (10.57)	34.47 (10.10)
Female	60.70%	63.60%	48.30%	58.40%	58.10%
Education: University degree	70.20%	74.50%	77.0%	63.60%	71.80%
Economic status of household. *Scale 1-5 (very low-very high)*	3.32 (1.20)	3.08 (1.13)	2.95 (1.21)	3.34 (1.05)	3.16 (1.15)
Car availability: anytime	47.60%	60.00%	56.50%	68.80%	58.10%
Residing within the city (vs. outside the city)	79.76%	87.27%	88.51%	80.52%	84.36%
Satisfaction with transit connection at home *Scale 1-6 (very low-very high)*	4.68 (1.15)	4.64 (1.16)	4.90 (.89)	4.66 (1.22)	4.72 (1.11)
Attitude toward using transit *Scale 1-4 (neg-pos)*	2.80 (.93)	2.74 (1.0)	2.76 (.95)	2.97 (.97)	2.81 (.98)

Subsample	DSN	D	SN	Control	Total
N	48	66	52	46	212
Age in years	38.98 (9.68)	39.03 (9.28)	36.10 (10.00)	37.67 (9.72)	38.01 (9.64)
Female	56.30%	54.50%	42.30%	54.30%	51.90%
Education: University degree	68.90%	74.60%	77.60%	61.90%	71.40%
Economic status of household *Scale 1-5 (very low-very high)*	3.68 (0.94)	3.41 (1.02)	3.41 (1.00)	3.38 (1.05)	3.46 (1.01)
Car availability: anytime	57.80%	71.40%	71.20%	71.40%	68.30%
Residing within the city (vs. outside the city)	73.33%	85.71%	83.67%	78.57%	80.90%
Satisfaction with transit connection at home *Scale 1-6 (very low-very high)*	4.60 (1.18)	4.56 (1.13)	4.96 (.89)	4.38 (1.34)	4.63 (1.14)
Attitude toward using transit *Scale 1-4 (neg-pos)*	2.53 (.99)	2.35 (.94)	2.46 (.98)	2.55 (.99)	2.46 (.97)

Note. Data (other than percentages) formatted *M* (*SD*). Economic household status was calculated as suggested in *Mobilität in Deutschland* (Nobis & Kuhnimhof, 2018) to reduce bias for families with children.

4.3.4 Questionnaire

The questionnaire's design followed Ajzen's (2002) recommendations and included adapted items from Paul et al. (2016), who established the extended TPB. The questionnaire measured attitude and injunctive as well as descriptive norm toward the purchase of transit tickets, perceived behavioral control of purchasing a transit ticket, and environmental concern with a focus on the environmental issues caused by motor car use, with 5 to 7 items on a 7-point Likert scale each (see Appendix 4-C). Items regarding purchase intention were omitted, as our experiment was designed to record purchase behavior within the scenario directly.

Scale reliability was ensured through computation of Cronbach's (1951) α using SPSS 26. Two items (PBC5 and EC6) did not meet the threshold value of .50 (Clark & Watson, 1995) in the corrected item-total correlation and were thus removed from further analysis. After exclusion of these two variables, Cronbach's α of all constructs was greater than the optimal .80 (Streiner, 2003) (Table 4-2).

Table 4-2

Scale reliability for constructs of the extended theory of planned behavior

Construct	Item	Corrected item-total correlation	Cronbach's α
Attitude	AT1	.77	.92
	AT2	.84	
	AT3	.83	
	AT4	.78	
	AT5	.81	
Subjective norm	SN1	.83	.92
	SN2	.83	
	SN3	.84	
	SN4	.55	
	SN5	.72	
	SN6	.83	
	SN7	.60	
Perceived behavioral control	PBC1	.81	.91
	PBC2	.75	
	PBC3	.84	
	PBC4	.79	
	PBC5[a]	*.25*	
Environmental concern	EC1	.77	.87
	EC2	.67	
	EC3	.66	
	EC4	.68	
	EC5	.70	
	EC6[a]	*.49*	

Note. [a] Deleted due to low item-total correlation. Cronbach's α reported without these.

4.4 ANALYSIS AND RESULTS

To check if purchase behavior could be predicted with the extended version of the theory of planned behavior, a two-step analysis comprised of a confirmatory factor analysis (CFA) followed by structural equation modeling (SEM) using maximum likelihood estimation was performed. CFA was used to determine if the questionnaire adequately measured the four latent constructs, and therefore to assess the reliability and validity of the measurement model. SEM was used to determine the causal relationships between these constructs and the outcome variable, and therefore to assess the validity of the structural model.

To evaluate the goodness-of-fit of the measurement model as well as the structural model, a range of recommended indicators was used. A good model fit was considered when χ^2/df was between 2 and 3; when goodness-of-fit indicators GFI (goodness-of-fit index), CFI

(comparative fit index), and TLI (Tucker-Lewis-Index) > .90; and when RMSEA < .07 (Hair et al., 2010; Hooper et al., 2008).

4.4.1 Test of measurement model

On a range from 1 (lowest) to 7 (highest), four constructs were assessed: attitude, consisting of 5 items (M = 5.64, SD = 1.42); subjective norm, consisting of 7 items (M = 3.93, SD = 1.64); perceived behavioral control, consisting of 4 items (M = 5.93, SD = 1.10); and environmental concern, consisting of 5 items (M = 5.38, SD = 1.49).

CFA assumes normality of distribution and linearity among constructs. Visual screening of Q-Q plots for all items suggested no deviation from the normality assumption and the skewness and kurtosis values deviated from 0 no further than +/- 2 and +/- 4, respectively (Kline, 2011). The relationships among constructs were linear, as depicted in Table 4-3.

Table 4-3

Pearson correlations for constructs of the extended theory of planned behavior

Construct	AT	SN	PBC	EC
Attitude	1.00			
Subjective norm	.66**	1.00		
Perceived behavioral control	.48**	.34**	1.00	
Environmental concern	.40**	.28**	.28**	1.00

Note. ** p < .01 (2-tailed).

The goodness-of-fit statistics of the confirmatory factor analysis were nearing acceptable thresholds (χ^2 = 748.17; df = 183; p < .001; $\chi2$/df = 4.09; GFI = .82; TLI = .89; CFI = .91; RMSEA = .09). To improve these statistics, minor modification steps were taken based on Hair et al. (2010). Items with standardized factor loadings λ < .70 were considered as low and thus deleted (SN4 [.52], SN5 [.64], and SN7 [.52]). Based on modification indices >10.0, paths for indicated error covariance within constructs were made available. These steps produced a very good fit of the measurement model ($\chi2$ = 289.63; df = 124; p < .001; χ^2/df = 2.33; GFI = .92; TLI = .96; CFI = .97; RMSEA = .06).

Construct validity was assessed by following the guidelines of Hair et al.'s (2010) rules of thumb. First, standardized loading estimates are > .70; and second, convergent validity was confirmed through average variance extracted (AVE) >.50 and composite reliability > .70 (Table 4-4). Third, discriminant validity was confirmed through AVE estimates exceeding the square of the correlation between factors (Table 4-5).

Table 4-4

Convergent validity for constructs of the extended theory of planned behavior

Construct	Item	λ	AVE	Composite reliability
Attitude	AT1	.81	.72	.93
	AT2	.88		
	AT3	.87		
	AT4	.82		
	AT5	.85		
Subjective norm	SN1	.93	.79	.94
	SN2	.91		
	SN3	.93		
	SN4[a]	-		
	SN5[a]	-		
	SN6	.79		
	SN7[a]	-		
Perceived behavioral control	PBC1	.87	.72	.91
	PBC2	.79		
	PBC3	.90		
	PBC4	.82		
Environmental concern	EC1	.85	.56	.86
	EC2	.72		
	EC3	.65		
	EC4	.72		
	EC5	.79		

Note. [a] excluded due to factor loadings < .70. AVE = average variance extracted.

Table 4-5

Discriminant validity for constructs of the extended theory of planned behavior

Construct	AT	SN	PBC	EC
Attitude	**.72**			
Subjective norm	.44	**.79**		
Perceived behavioral control	.23	.12	**.72**	
Environmental concern	.16	.08	.08	**.56**

Note. Numbers indicating squared correlations of constructs; average variance extracted in bold.

4.4.2 Test of structural model

A good fit of the measurement model was recognized and, therefore, it served as a reliable basis to test the structural model (Figure 4-2). Using SEM, a very good model fit ($\chi^2(142) = 382.4$, $p < .001$; $\chi^2/df = 2.69$, GFI = .90; TLI = .95; CFI = .96; RMSEA = .07) (Table 4-6) was

obtained. Perceived behavioral control did not statistically significantly predict the decision, and environmental concern did so only indirectly by affecting the other predictors. Apart from that, all expected *β*-coefficients were statistically significant ($p < .001$). Overall, the decision to purchase the ticket was well predicted by applying the extended TPB. The coefficient of determination (R^2) of .44 describes moderate explanatory power (Henseler et al., 2009).

Table 4-6

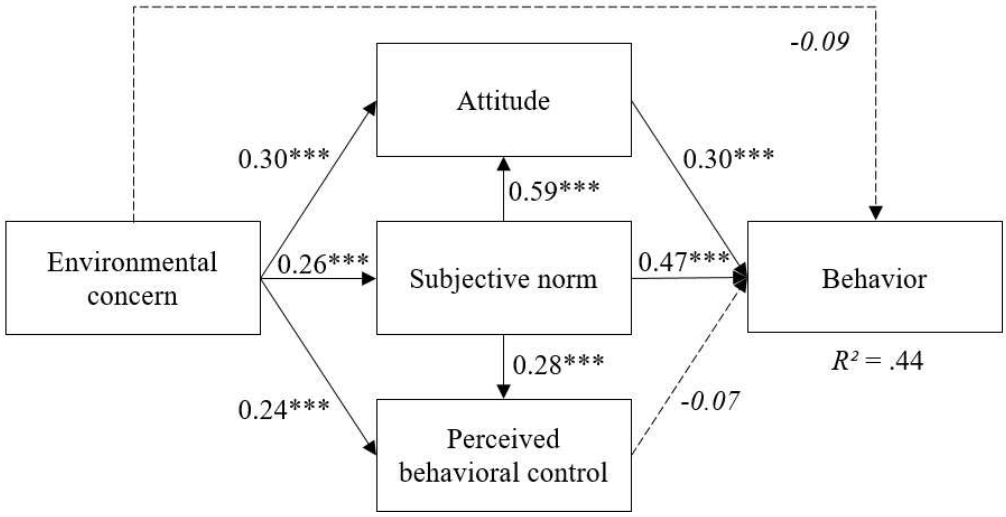
*Standardized and unstandardized β-coefficients and significance levels for the structural extended TPB model (*N = *374)*

Parameter estimated	Unstandardized *β*	Standardized *β*	*p*
EC → SN	.31 (.07)	.26	***
EC → Attitude	.27 (.04)	.30	***
EC → PBC	.16 (.04)	.24	***
SN → Attitude	.45 (.04)	.59	***
SN → PBC	.17 (.03)	.28	***
Attitude → Decision	.10 (.02)	.30	***
SN → Decision	.12 (.02)	.47	***
PBC → Decision	-.03 (.02)	-.07	.149
EC → Decision	-.03 (.02)	-.09	.076

Note. Errors in parentheses. ***= $p < .001$. $\chi^2(142) = 382.4$, $p < .001$; $\chi^2/df = 2.69$, GFI = .90; TLI = .95; CFI = .96; RMSEA = .07

Figure 4-2

Structural model for the extended theory of planned behavior



Note. ***$p < .001$. $\chi^2(142) = 382.4$, $p < .001$; $\chi^2/df = 2.69$, GFI = .90; TLI = .95; CFI = .96; RMSEA = .07

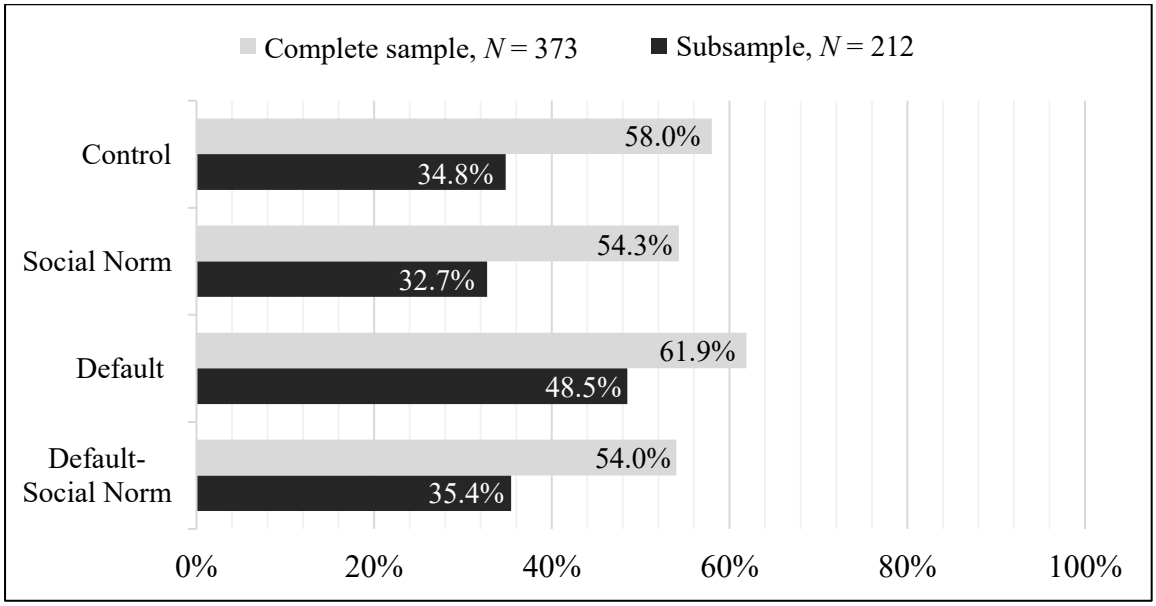
4.4.3 Effectiveness of nudges

To check if the nudges affected the purchase behavior, a binomial logistic regression with dummy variables was performed for the complete sample ($N = 373$). The raw choice data per condition is displayed in Figure 4-3. The least tickets were purchased in the conditions in which the social nudge was active (54.0% and 54.3%). The most tickets were purchased in the default condition (61.9%). In the control condition, 58.0% of people purchased the ticket.

To gain insight into the effect of the nudge on those that had not previously purchased a Job ticket or a comparable transit subscription ticket (and were thus the main target for this study), the participants who indicated they already owned such a ticket were excluded. With the resulting subsample of $N = 212$, the analysis was performed again. In these results, the trend visible for the complete sample intensified (Figure 4-3).

Figure 4-3

Raw choice data: percentage of participants per condition who decided for the ticket



To see if there are any statistically significant differences, a logistic regression with dummies for each variable (the control condition being omitted) was performed for both the complete sample and the subsample. Results are reported in Table 4-7. No condition had a significant effect on purchasing behavior. The model explained .06% (Nagelkerke R^2; Nagelkerke, 1991) of the variance in purchasing behavior and correctly classified 57.4% of cases in the complete sample. In the subsample, too, no condition had a significant effect on purchasing behavior. Here, the model explained 2.5% (Nagelkerke R^2) of the variance in purchasing behavior and correctly classified 61.3% of cases.

Table 4-7

*Effect of the experimental condition on the purchasing decision for the complete sample (*N = *373) and the subsample (*N = *212)*

Condition	*β*-coefficient (s.e.)	*p*-value	*t*-statistic	Odds ratio
Complete sample				
Default-Social norm	-.16 (.31)	.60	-0.52	0.85
Default	.16 (.30)	.58	0.55	1.18
Social norm	-.15 (.31)	.63	-0.49	0.86
Subsample				
Default-Social norm	.03 (.43)	.95	0.07	1.03
Default	.57 (.40)	.15	1.43	1.77
Social norm	-.09 (.43)	.83	-0.22	0.91

4.5 DISCUSSION

The goal of this study was to nudge commuters toward a transit subscription ticket and thus to make commuting more sustainable on a voluntary basis. It was first investigated if the theory of planned behavior, extended by environmental concern, could predict the subscription decision regarding the ticket (RQ 3.1). Second, a default nudge and a social nudge were tested to determine their effectiveness regarding increasing subscription numbers (RQ 3.2), with these nudges ultimately being integrated into the aforementioned model (RQ 3.3). An experiment with four nudge conditions and a questionnaire revealed that the theory is well suited to predict the decision, but environmental concern did not add direct predictive value.

Interestingly, more than half of the participants (57.4%) purchased the Job ticket, which is significantly more than the true number of tickets purchased (16% of employees purchased a ticket in 2018). Even in the subsample, which excluded those who had not previously owned such a ticket, purchase numbers were quite high (38.7 %). This effect could be partly explained by the "nudge" of confronting everyone with the ticket, even in the control condition.

4.5.1 Extended theory of planned behavior

The extended theory of planned behavior (Paul et al., 2016) predicted the purchasing decision well. It did, however, not prove to be of higher utility than the original theory of planned behavior by Ajzen (1991). Commonly, subjective norm is described as the weakest predictor of behavior (Ajzen, 2002; Saeri et al., 2014). In this experiment, however, subjective norm was the strongest predictor of the subscription decision. If a participant believed others appreciated the ticket (injunctive) and would purchase it as well (descriptive), they were likely to purchase the ticket, too. As expected, attitude toward purchasing a ticket predicted the subscription

decision as well. Perceived behavioral control, however, had no statistically significant influence on the purchasing decision. This is likely due to the questionnaire items revealing slight skewness and kurtosis, meaning that most participants found it similarly easy to purchase the ticket in this study. After all, it took only a simple mouse click to decide for or against the ticket. Undoubtedly, perceived behavioral control still plays a significant role when it comes to *using* transit, as shown in several studies (e.g., Donald et al., 2014; Heath & Gifford, 2002), however, this was not investigated in the present study.

Last, environmental concern had an indirect effect on behavior by affecting each of the other predictors of the TPB, but had no direct effect on the subscription decision. On the one hand, this finding is in line with Heimlich and Ardoin (2008), who summarize that pro-environmental attitudes rarely lead to actual behavioral changes. In the traffic sector (and numerous others), behavior change is often induced by marketing/advertising of the environmental benefit or sustainability of a transportation mode. However, according to our results, sustainability concerns did not drive the decision to buy the ticket on its own, so it might be worthwhile to interlock environmentally-focused marketing with subjective norms. On the other hand, the lack of a direct effect on behavior could, in part, be explained by the use of environmental concern as opposed to other constructs measuring environmental attitudes. For example, the personal (environmental) norm of Schwartz's (1977) norm-activation theory targets self-expectations based on internalized values and may have yielded different results.

4.5.2 Effectiveness of nudges

We investigated whether the effectiveness of nudges stretches to the transportation sector. While trends were observed, statistically significant results were not obtained, which highlights the limits of the effectiveness of nudges in this context.

The results presented here fall in line with the summarized findings of Byerly et al. (2018), i.e., that in changing the environmentally relevant behavior of transportation choice, defaults and norms (as well as education) have no effect – even though it was established with the structural equation modelling, that subjective norms do have a strong effect on the purchase decision. It seems, thus, that it is difficult for nudging interventions to influence this predictor. Still, it is claimed that "the nudging of travelers could be one of the most promising approaches to deal with the need for a radical and urgent behavioral change" (Avineri, 2009, p. 15). If this is the case, social nudges and defaults, as designed in the presented experiment, do not seem to be the appropriate choice.

Even though subjective norm was the strongest predictor in the model, the social nudge was not at all effective, producing even less subscriptions than the control condition. There has previously been evidence that people display reactance to social nudges (Arad & Rubinstein, 2018). Considering that the social nudge used was relatively obvious (a yellow banner), and mentioned a high number of purchased tickets compared to the real numbers (73% vs. 16%), reactance might be an explanation. Social nudges do work, on the contrary, in the sector of waste reduction (e.g., Hamann et al., 2015) and water use (e.g., Brent et al., 2015). These studies focused on refraining from "bad" behavior (reducing paper waste, using less water), while this experiment focused on incentivizing "good" behavior (buying a ticket, using transit). The social nudge used in this paper further targeted habituated behavior and involved monetary cost.

The involvement of habituated behavior and monetary cost might also explain the results of the default nudge. Even though there was a trend following our expectations, the result was not robust. Commuters have traveled this route countless times and changing the mode or route is thus connected to possibly uncomfortable alterations and mental workload. The targeted behavior in successful nudging studies using the default (e.g., choosing an energy contract; Momsen & Stoerk, 2014) is typically not routine behavior.

Further, the monetary cost could have led to bigger resistance toward purchasing the ticket. Losses weigh higher than gains (Tversky & Kahneman, 1974), which might have activated conscious thinking (system 1 of the dual process theory), whereas nudges are believed to attack system 2 (i.e., unconscious processing). Additionally, the effort to *not* subscribe was kept very low (compared to e.g., the opt-out of organ donation, which involves a considerable amount of paperwork). This can be seen clearly in the results of the perceived behavioral control items: participants of all conditions found it similarly easy to purchase the ticket. Defaults might need to connect the undesired behavior with more hurdles than the design of this study provided.

As previous studies found, nudges can be effective. In this experiment, where there was monetary cost involved, switching the default was simple, the social nudge was quite obvious, and the targeted behavior was habituated, nudging was not effective.

Since the nudges themselves were not effective, they could not be tied to the predictors of the model. We therefore urge that connecting nudges to model predictors should be retested with effective nudges to facilitate the establishment for a comprehensive framework regarding nudging theory. However, in light of these results, it is debatable if there is a good enough

reason to keep using the general term of nudging or if it is more promising for future research to revert back to considering interventions and their mechanisms individually.

4.5.3 Limitations

When interpreting the above-mentioned results of the structural equation model, it is important to remember that the questionnaire was targeted at the purchase of the ticket, in line with Paul et al. (2016), who targeted the purchase of green products. However, the purchasing decision of a transit ticket would naturally be influenced by attitude, subjective norm, and self-efficacy toward *using* transit, as well.

Another suggestion for future studies is taking the experiment out "on the road". Participants were asked to imagine the scenario and to act accordingly. While this procedure offers great feasibility and is fairly common, it can obviously not be guaranteed that it would produce the same results as a field study.

While promoting transit seems like a good idea to increase sustainability, it entails an important drawback: instead of attracting car drivers, promotions tend to entice walkers and bikers, who are already moving sustainably. In the City of Hasselt (Belgium), 16% of transit users stated that they had left a car at home, while 21% would have walked or biked instead (Van Goeverden et al., 2006). To avoid this, ways to target such strategies at car drivers directly need to be found.

4.5.4 Conclusion

While the theory of planned behavior predicted the purchasing decision toward the transit ticket well, environmental concern did not directly affect it. This is an important finding regarding the advertisement of sustainable transportation while also implying considerations regarding the measurement of environmental attitudes. The lack of effectivity of the nudges provides insights into the limitations of nudging theory for the transportation sector. Here, nudging is different to – and apparently more difficult than in – the fields of behavioral economics, in which the concept initially boomed. Rather than a single or once in a lifetime decision, transportation mode choice is habituated behavior, enforced daily, and monetary costs are involved. For policy makers, it is important to consider that social nudges could potentially trigger reactance in people, and that softly designed nudges might only have very slight effects in the transportation sector, which needs to be weighed against the (typically low) cost of implementing them.

5 Study IV. Telecommuters vs. physical commuters during the Covid-19 pandemic: the change in mobility-related attitudes and the future intention to telecommute

Abstract

Factors that shape mobility behaviors include individual's subjective, mobility-related attitudes. A better understanding of attitudinal factors could help identify effective levers to change mobility behavior of individuals, which has proven difficult, because mobility behavior is often habituated. Among other subjective factors, habits seem to especially dominate the daily commute. Key events, such as the Covid-19 pandemic, that alter entire contexts might serve as important windows of opportunity, in which habits can be partly inactivated. One particularly consistent finding is that a large part of the population that previously commuted shifted to working from home, while others continued to commute.

While studies found behavioral and attitudinal changes directly after the onset of the pandemic, it is unclear if these changes were just an initial reaction, or if they remain stable over the course of the pandemic. Further, it is unclear if those that started to telecommute intend to keep doing so in the future, and how different attitudes contribute to this intention.

In this study, we use longitudinal, individual-level survey data from the California panel study of emerging transportation to compare two groups (those that started working from home vs. those who continued to physically commute to their workplace; $N = 981$) at two points in time: early in the pandemic (2020) and later in the pandemic (2021). We employ exploratory factor analysis to extract the respective latent attitudinal constructs, followed by confirmatory factor analysis to describe the future intention to telecommute for each year.

Results show that some attitudes (e.g., environmental concern) are independent of group and time, whereas others (e.g., concern for pathogens) depend both on group and stage of the pandemic. The future intention to telecommute remains high, and depends less on Covid-related or demographic factors than on psychological factors, e.g., on the attitude toward telecommuting or on individual tech-savviness. Conclusions on the impact of a forced disruption of habituated commuting behavior regarding individual attitudes and the intention to telecommute are drawn.

5.1 INTRODUCTION

US workers spend an average of 55.2 minutes commuting per day, and in large metropolitan areas in California (e.g., Los Angeles or San Francisco), the average commuting time even exceeds one hour (Burd et al., 2021). This not only consumes significant time but also has implications for land use, sustainability, and well-being. Among US commuters, 75.9% drive alone in motorized cars (Burd et al., 2021), occupying valuable space that could be used for pedestrians, bikes, or urban landscaping. Commuting is a major cause of greenhouse gas emissions (Kissinger & Reznik, 2019) due to the dependence on car travel, the frequency of commuting trips, and the intensity of travel during peak hours, often generating massive congestion levels on the road network. Additionally, commuting can cause negative emotions such as stress and frustration, which can spill over into the workplace and impact mood and performance (Chatterjee et al., 2020). Efforts to reclaim land from parked cars[8] and to promote sustainable commuting practices (e.g., Hauslbauer et al., 2022a) are on the rise, as the negative impacts of commuting by car are increasingly recognized.

In early 2020, society experienced a forceful disturbance of commuting behaviors as one of many disruptions brought about by the outbreak of the Covid-19 pandemic (Marsden et al., 2020). While the long term effect of the impact of Covid-19 on commuting behavior is still unclear, a large body of research has dealt with the immediate changes in mobility behavior that the pandemic has led to (e.g., Anke et al., 2021; Borkowski et al., 2021; Engle et al., 2020; Matson et al., 2021; Warren & Skillman, 2020). These studies focused on, for example, the adaptations in activity patterns, mode choice, or destination choice. One particularly consistent finding is that a large part of the population that previously commuted shifted to working from home. Another part of the population continued to commute either by choice or because the nature of their work demanded physical presence (Iogansen et al., 2022).

It is unclear how this disruption in commuting habits in the context of Covid-19 has influenced psychological factors, such as perceptions of or preferences for certain modes. Investigating psychological factors in transportation is essential, because they impact mobility choices and behavior (Schlag & Schade, 2007). For example, one crucial factor that influences mobility choices such as commuting is an individual's attitude, which refers to their learned tendency to judge certain objects or behaviors as favorable or unfavorable (Rose & Brown, 2021), and to adjust their behavior accordingly (Moody & J. Zhao, 2020; Steg, 2005). The

[8] see, e.g. San Francisco Smart City Challenge, 2016 (http://smartcitysf.com/); Copenhagenize Design Co., 2023 (https://copenhagenize.eu/)

theory of planned behavior (Ajzen, 1991) posits that beliefs about the outcome of a behavior result in an attitude toward it, which predicts an individual's intention to perform that behavior. For instance, attitudes toward transport modes such as toward the car or bike predict mode use (Moody & J. Zhao, 2020; Steg, 2005), and the consequentially sought out experiences create a feedback loop back to the behavioral beliefs, reinforcing or reshaping them. Thus, attitudes and behavior can be conceptualized in a bidirectional relationship. A bidirectional relation of attitudes and behavior in the mobility context, specifically, has been supported using the theory of planned behavior and the theory of cognitive dissonance (Kroesen et al., 2017).

Understanding psychological factors such as attitudes is key to identifying approaches to adjust behaviors within the mobility system, including daily commuting. However, despite an abundance of research on altering mobility behavior, effecting lasting change is difficult. One reason for this is that mobility behavior is often mediated by habits (Aarts & Dijksterhuis, 2000), particularly the daily commute, due to the unchanging cue to “go to work” (Zarabi et al., 2019). Merely a discontinuation of exposure to cues typically fails to produce lasting behavior changes (Gardner, 2015). Instead, key life events that alter an individual's context offer important opportunities for habit inactivation (Brette et al., 2014).

The Covid-19 pandemic has disrupted commuting habits on an unprecedented scale, particularly for those who shifted to telecommuting. We are presented with a unique opportunity to investigate the impact of this shift to telecommuting on mobility-related psychological factors such as attitudes, in comparison with individuals who have continued to commute physically, as they can serve as somewhat of a control group.

Therefore, we aim to provide insights into the effects of the pandemic-induced habit break by exploring the differences in psychological factors between individuals who shifted to telecommuting and those who continued to commute physically at different stages of the pandemic, and to develop a model that considers these psychographic factors, in order to assess how prevalent full or partial telecommuting (i.e. hybrid work) will become beyond the pandemic and how attitudes may drive this trend.

To achieve these objectives, we derived hypotheses from the theoretical background below, compared a California sample of telecommuters to physical commuters, and built a model to predict individuals’ intention to telecommute in the future.

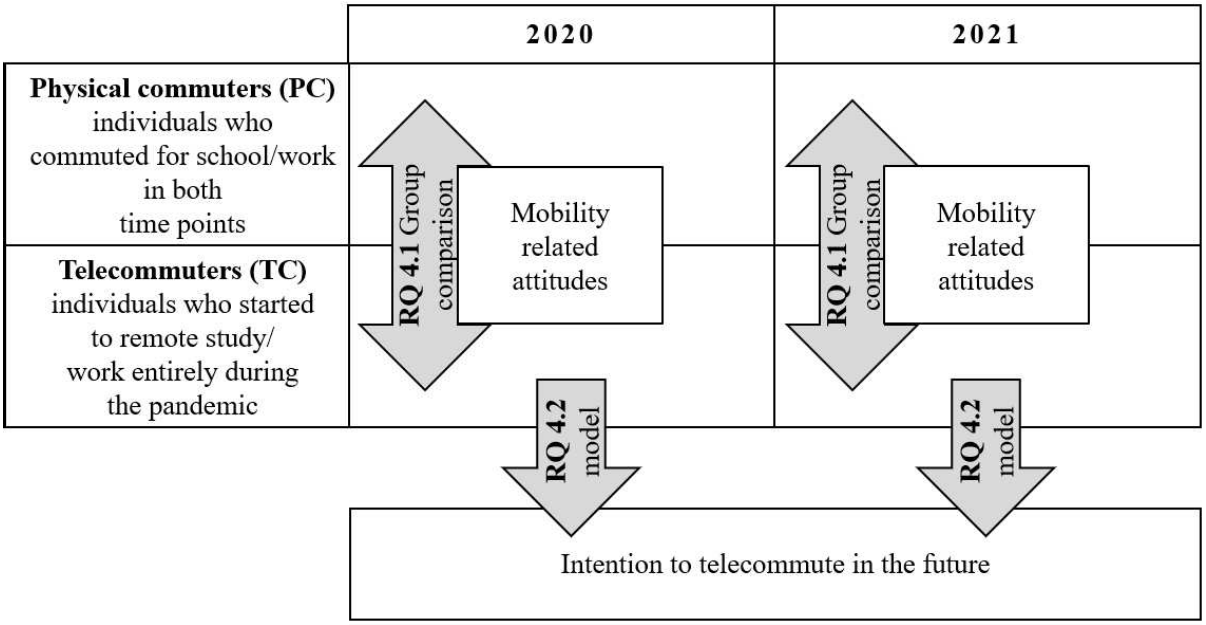
5.2 CONCEPTUAL FRAMEWORK AND HYPOTHESES

For this study, the above-mentioned research aims were formalized as research questions and arranged within the conceptual framework visualized in Figure 5-1. In the paragraphs below, we describe how the reviewed literature led to our hypotheses.

> ***RQ 4.1:*** *How do mobility-related psychological factors, such as attitudes, differ between those who continued to commute physically during the pandemic vs. those who started to telecommute?*
>
> ***RQ 4.2:*** *Which attitudinal (and external) factors predict (in 2020 vs. 2021) if individuals intend to telecommute in the future?*

Figure 5-1

Conceptual framework for chapter 5



5.2.1 Socio-demographic differences

The literature has revealed a clear distinction in socio-economic status between those who have transitioned to telecommuting and those who continued to commute physically, both in North America and Europe (e.g., Budnitz et al., 2020; López Soler et al., 2021; Su et al., 2021; Yasenov, 2020). Typically, (partial) telecommuters exhibit higher levels of household income and education, and are overrepresented in professional and managerial positions, indicating a divide between white and blue-collar workers. It is worth noting that telecommuting may not be a feasible option for blue-collar workers, for whom on-site presence is often required. Additionally, studies have found that men are more likely to telecommute than women.

However, in 1997, Mokhtarian and Salomon proposed that socio-economic and demographic characteristics alone cannot explain individual preferences for telecommuting, as they can have different effects on different individuals, depending on attitudes.

5.2.2 Differences in various psychological factors

5.2.2.1 Active lifestyle

Research suggests that active mobility and round trips, such as walking and biking tours, have gained popularity amidst the pandemic (De Haas et al., 2020). To fill their travel time budget (Ahmed & Stopher, 2014), individuals who have transitioned to telecommuting likely have utilized this newfound time to engage in other activities. Thus, we hypothesize that telecommuting has lifted people's attitude toward an active lifestyle.

RQ 4.1 **H1** *From 2020 to 2021, the telecommuters developed a more positive attitude toward an active lifestyle than physical commuters*

5.2.2.2 Concern about pathogens

Multiple studies have examined the public's perception of risk associated with transit or shared vehicles since the onset of the pandemic, revealing that these concerns were particularly high during the initial stages of the pandemic (e.g., Przybylowski et al., 2021; Scorrano & Danielis, 2021). Nevertheless, only weeks after the outbreak of the pandemic, a phenomenon known as "quarantine fatigue" was observed in the US, indicating a gradual return to previous behaviors among the populace (J. Zhao et al., 2020). The fear of contracting pathogens may have influenced people's decision to switch to telecommuting during the pandemic, with those who expressed higher levels of concern being more inclined to opt for telework. Furthermore, these individuals may also be more likely to continue telecommuting in the future.

RQ 4.1 **H2** *The telecommuters report a higher concern about pathogens than the physical commuters*

RQ 4.2 **H3** *Concern about pathogens is positively associated with attitude toward telecommuting and the group (telecommuters)*

5.2.2.3 Attitudes toward telecommuting.

The research conducted by Chai et al. (2022) identified that attitudes toward telecommuting itself emerged as the most significant predictor for an individual's intention to telecommute during the pandemic. However, the items of their study also include the infection aspect, which

leans toward what we called a concern about pathogens[9]. To predict an individual's intention to telecommute beyond the pandemic, it seems crucial to extract their attitude toward telecommuting using a definition which aligns with the theory of planned behavior (Ajzen, 1991): in terms of belief of a favorable or unfavorable outcome. This includes examining beliefs about the practicality, efficiency, and overall work performance associated with telecommuting. Furthermore, the theory of cognitive dissonance (Festinger, 1962) suggests that individuals who were initially compelled to telecommute may have adjusted their attitude toward telecommuting to alleviate any cognitive dissonance.

RQ 4.1 **H4** *The telecommuters report a more positive attitude toward telecommuting than the physical commuters*

RQ 4.2 **H5** *Attitude toward telecommuting is positively associated with intention to telecommute in the future and group (telecommuters)*

5.2.2.4 Tech-savviness.

In order for an individual to successfully engage in telecommuting, they must be able to effectively use relevant information and communication technologies (ICTs), such as cloud solutions and video conference systems. The degree to which one can comfortably and competently operate ICTs has been termed "tech-savviness" among other labels. In their research, Chai et al. (2022) have effectively utilized the perceived ease of use and usefulness of technology as predictors for an individual's attitude toward telecommuting and, indirectly, for their intention to continue telecommuting. Tech-savvy individuals are presumed to be more comfortable with utilizing ICTs at home and require less support from colleagues. Therefore, measuring an individual's interest and comfort with technology may represent a valuable predictor for their intention to telecommute in the future.

RQ 4.2 **H6** *Tech-savviness is positively associated with intention to telecommute in the future and attitude toward telecommuting*

5.2.2.5 External factors for telecommuting

To create an accurate prediction model, it is important to also consider external factors that may affect the decision to telecommute, because the option to work remotely is not always unconstrained. For instance, the extent to which the job allows teleworking is a crucial external factor (Rose & Brown, 2021). Additionally, individuals who were initially required to work

[9] Exemplary items are "security measures, such as telecommuting, is a good idea during the Covid-19 outbreak", "Taking telecommuting to protect myself is important during the Covid-19 outbreak".

remotely during the pandemic may be more likely to continue doing so in the post-pandemic period (Rose & Brown, 2021). Thus, the commute status during the pandemic could potentially serve as a predictor of intention to telecommute in the future.

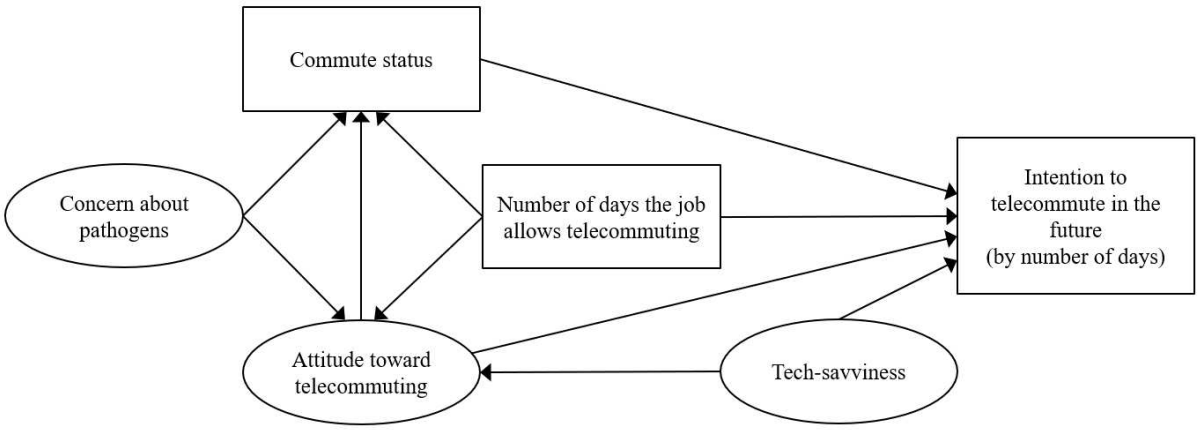
RQ 4.2 **H7** *The number of days the job allows telecommuting during the pandemic is positively associated with the intention to telecommute in the future, the group (telecommuters), and the attitude toward telecommuting*

RQ 4.2 **H8** *The telecommuters show a stronger intention to telecommute in the future than the physical commuters*

Summarizing the hypotheses of RQ 4.2, we derive the following model (Figure 5-2), which will be tested for both the data of the year 2020 and 2021.

Figure 5-2

Hypothesized model to predict the intention to telecommute in the future



5.3 DATA AND METHOD

5.3.1 Data collection and sample

For this study, longitudinal survey data collected by researchers in the Institute of Transportation Studies at the University of California, Davis, was used. As part of a larger research effort on increasing the understanding of mobility behavior during the Covid-19 pandemic among other objectives, multiple waves of surveys were administered in the US and Canada, with the analyses presented in this paper focusing specifically on the California sub-sample. To collect data, mixed sampling methods were used, including the recruitment of participants through an online opinion panel using quota sampling, convenience sampling recruiting participants through professional listservs and social media, and the recall of

previous survey respondents that participated in surveys administered by the research team before the Covid-19 pandemic. The survey was administered on the online survey platform Qualtrics, and was available in both English and Spanish, with completion taking an average of 30-40 minutes.

Information was collected on various aspects of participants' lives, including socio-demographics, household formation, lifestyle, use of technology, attitudes and preferences, response to the Covid-19 pandemic, and current travel patterns, such as commuting behavior and home and work location. Data from the fall 2020 and fall 2021 survey waves was used to investigate the developments of attitudes during the initial outbreak of the Covid-19 pandemic. Notably, by fall 2021, fewer pandemic related restrictions were in place and vaccines had become largely available in California.

For the present analysis, the sample was divided into groups based on a previous cluster analysis conducted by Iogansen et al. (2022), which compared individual's adaptations in trip generation and mode-use patterns before the pandemic (fall 2019) and during the pandemic (fall 2020). Of the resulting clusters, two groups are relevant for the present study: group 1 (physical commuters) consisted of individuals "who had ever commuted for school/work in both time points", while group 2 (telecommuters) comprised individuals "who started remote study/work entirely during the pandemic". The remaining individuals were not relevant to the research questions as they were neither student nor employees during both time points. After the longitudinal cases were extracted and data cleaning was conducted, the sample size was $N = 981$ individuals.

5.3.2 Data description

Socio-demographic information pertaining to individuals' age, gender, income, educational background, household size, presence of children in the household, and job telecommuting eligibility, among others, was collected from the participants.

Psychographic data was collected by presenting a battery of statements to participants, where they were asked to indicate their level of agreement on a Likert-type scale ranging from "Strongly Disagree" to "Strongly Agree". A total of 41 statements were selected for the analysis, based on the theoretical framework and hypotheses. The analysis section outlines how these statements were used to generate latent attitudinal constructs.

Regarding the model, the dependent variable was the participant's "intention to telecommute in the future", which captured telecommuting exclusively as well as partial telecommuting (hybrid work). This variable was derived from the survey item "What day(s) of

the week would you like to telework once the pandemic is over?" Participants could select any day(s) of the week, "will not/do not want to telework," or "flex/variable schedule." For the analysis, the indicated days were counted, "will not/do not want to telework" was coded as 0, and if "flex/variable schedule" was the only response, the sample mean of selected days of the week (2.08) was imputed. The survey items pertinent to the model are provided in Appendix 5-A.

5.3.3 Analysis

5.3.3.1 Socio-demographic data

In addition to descriptive statistics, the socio-demographic data was analyzed for differences between the physical commuter and telecommuter group. To accommodate for non-parametric, continuous or near-continuous variables, Mann-Whitney U tests were used (Field, 2013).

5.3.3.2 Latent psychographic constructs

In order to derive latent constructs, exploratory factor analysis (EFA) was employed on the 41 extracted items for both the 2020 and 2021 dataset. EFA is an exploratory technique used to identify underlying variables in a dataset by reducing the dimensionality of the data to the most significant features (known as factors) that still capture the maximum information about the dataset (for more details, see e.g., Backhaus et al., 1994; Bartz, 2015; Field, 2013; Schendera, 2011).

In the EFA, direct oblimin oblique rotation was used to allow for correlation among constructs. Variables with factor loadings that rounded to < .50 in at least one solution (2020 or 2021 data) were removed for both datasets to facilitate comparability of the final solution across both years. The choice for this rather conservative cutoff was made since the constructs contained a relatively small number of items (2-5), which means that each item contributed considerably to the measured construct. Therefore, it was crucial that each item had a strong relationship with the underlying factor (Costello & Osbourne, 2005). Scale reliability was ensured using Cronbach's (1951) α, with values > .60 deemed acceptable to proceed (Nunnally, 1967; Streiner, 2003), and item-total-correlations > .40 (Streiner, 2003).

To evaluate the quality of the factor analysis, Field's (2013) recommendations were followed: sampling adequacy was considered acceptable with a Kaiser-Meyer-Olkin (KMO; Kaiser, 1970) value > .50, Bartlett's (1954) test of sphericity should be significant at the 5% level, and since the sample is rather large (> 250), extracting factors using Kaiser's (1974) criterion of > 1 for eigenvalues was deemed appropriate.

To address RQ 4.1, the resulting factor scores obtained through the regression method were saved to form the basis for group comparisons using multivariate analysis of variance (MANOVA).

5.3.3.3 Structural equation model

A confirmatory factor analysis (CFA) was performed to ensure that the hypothesized measurement model fit well. Subsequently, structural equation modeling (SEM) was carried out to develop the models for both the 2020 and the 2021 dataset.

To predict the intention to telecommute in the future, for each dataset, a two-step analysis including CFA and SEM using maximum likelihood estimation was performed. At this point, an additional step in the data cleaning process was deemed appropriate, as some participants who began telecommuting during the pandemic indicated that the (current) nature of their job did not allow them to telecommute at all. To ensure data accuracy, these participants were excluded, resulting in a final sample size of $N = 909$.

CFA assessed the validity of the measurement model by determining how adequately the factors are measured by individual items. Since CFA assumes normality of distribution, skewness and kurtosis values should deviate from zero no further than +/−2 and +/−4, respectively (Field, 2013). Construct validity was evaluated following the rules of thumb set forth by Hair et al. (2010), with standardized loading estimates > .70, average variance extracted (AVE) > .50, and composite reliability > .70 for convergent validity, and AVE estimates exceeding the square of the correlation of factors for discriminant validity.

SEM assessed the causal relationships between factors and the outcome variable to evaluate the validity of the structural model. The goodness-of-fit of the measurement and structural model was evaluated using a range of recommended indicators. A good model fit was considered by $\chi^2/df > 2$ and < 5, NFI (norm fit index), CFI (comparative fit index), and TLI (Tucker-Lewis-Index) > .90; and RMSEA < .07 (Burghard & Dütschke, 2019; Redmond, 2000).

5.4 RESULTS

5.4.1 Socio-demographics

Table 5-1 provides an overview of the demographic characteristics of the two groups, with Mann-Whitney U tests being used to identify statistically significant differences. Results indicate that age, gender, and household size were similar for both physical commuters (PC) and telecommuters (TC). However, telecommuters report significantly higher income and

education than physical commuters, indicating a higher socio-economic status. Moreover, compared to physical commuters, telecommuters had fewer children under the age of 18 living with them, reported that their job allowed them more days to telecommute, and expressed a greater likelihood of telecommuting in the future.

Table 5-1

Socio-demographic data of and differences between the physical commuters (PC) and telecommuters (TC)

	Group 1 (PC)	**Group 2 (TC)**	**Total**	**Mann-Whitney U**
N	523 (53.3%)	458 (46.7%)	981	/
Age in years	46.84 (12.54)	46.41 (13.41)	46.62 (12.95)	$U = 116721$, $p = .49$
Female	286 (55.00%)	270 (59.21%)	556 (56.7%)	$U = 114611$, $p = .18$
Household income *Scale 1-7 (low-high)*	3.99 (1.55)	4.41 (1.48)	4.19 (1.53)	$U = 83641$, $p < .001$
Educational background S*cale 1-6 (low-high)*	4.09 (0.98)	4.29 (0.87)	4.18 (0.93)	U = 104563, $p < .001$
Household size	2.72 (1.41)	2.59 (1.37)	2.66 (1.39)	U = 106813, $p = .13$
Children in household <18 years	0.62 (1.01)	0.50 (0.92)	0.56 (0.97)	U = 104973, $p = .02$
Max. frequency of job allowing tele-work (0 ‘never’ - 5 ‘5 or more/ week’)	1.75 (1.96)	3.52 (1.82)	2.57 (2.09)	$U = 62962$, $p < .001$
Days of intended future telework	2.13 (1.96)	3.57 (1.70)	2.80 (1.97)	$U = 70161$, $p < .001$

Note. If no percentage is given, the parentheses encompass standard deviations.

5.4.2 Generation of constructs

Following the initial exploratory factor analysis (EFA) conducted on the 41 attitudinal items using direct oblimin oblique rotation on both the 2020 and 2021 dataset, 13 items were removed due to low factor loadings. Additionally, one construct (consisting of two items) with a low Cronbach’s (1951) α, and one item with a low item-total correlation that also considerably reduced the reliability of its construct, were excluded from further analysis. The remaining 25 variables were subjected to factor analysis using direct oblimin rotation, for both the 2020 and 2021 dataset.

For both datasets, the Kaiser-Meyer-Olkin measure (Kaiser, 1970) indicated good sampling adequacy with the general KMO as well as KMO values for individual items > .50, and Bartlett's (1954) test of sphericity was significant ($p < .01$). Eight factors (constructs)[10] were extracted with eigenvalues over Kaiser's criterion of 1 and in combination explained 64.07% and 65.97% of the variance for the 2020 and 2021 datasets, respectively. The constructs were named after interpretation and are presented in Table 5-2, along with items, loadings, and reliability (Cronbach's α) for both datasets.

Table 5-2

Reliability (Cronbach's α), items, and loadings for the eight constructs (per year) derived from factor analysis

Construct	**#**	**Item** *strongly disagree (1)-strongly agree (5)*	**2020**		**2021**	
			Loading	*α*	*Loading*	*α*
Pro micro-mobility	AT33	If shared bikes and/or e-scooters were cheaper, I would use them more often.	.84	.79	.83	.81
	AT34	I am interested in monthly rentals of bikes and/or e-scooters that include maintenance and theft protection.	.88		.78	
	AT30	Using bikesharing/e-scooter sharing is fun.	.72		.75	
	AT23	If I felt protected from car traffic, I would ride a bicycle more often.	.68		.63	
	AT8	I like riding a bike.	.45[a]		.63	
Against telecom-muting	ATC9	Working from home is not practical for me (e.g., due to lack of office devices, distractions from family members).	.76	.74	.74	.77
	ATC3	Working from home makes me less disciplined/self-controlled.	.72		.72	
	ATC5	I experience substantial gains in efficiency when working from home. *(reversed)*	.71		.72	
	ATC1	I perform better when I interact with colleagues/co-workers in person (on site).	.70		.73	
	ATC8	The quality of interaction during online meetings is disappointing.	.61		.70	
Driving affinity	AT11	I prefer to be a driver rather than a passenger.	.88	.76	.90	.76
	AT7	I like driving a car.	.82		.83	

[10] Three of the 8 constructs consist only of two items. The discussion and analysis regarding their stability is detailed in Appendix 5-B.

Construct	#	Item *strongly disagree (1)-strongly agree (5)*	2020		2021	
			Loading	*α*	*Loading*	*α*
Concern about pathogens	AT27	I will feel uncomfortable sharing a ride with strangers (e.g., *UberPOOL, Lyft Share*) due to concerns about pathogens (e.g., Covid-19).	.79	.66	.77	.77
	AT28	I feel uncomfortable putting my hands on the handlebar of a shared e-bike, e-scooter, e-moped recently used by someone else.	.77		.85	
	AT24	I feel uncomfortable using public transportation due to concerns about pathogens (e.g., Covid-19 or other).	.75		.87	
Active lifestyle	AT5	Getting regular exercise is important to me.	.82	.68	.82	.68
	AT3	I like walking.	.81		.81	
Tech-savviness	AT18	I'll stretch my budget to buy something new and exciting.	-.75	.60	.74	.63
	AT14	I like to be among the first people to have the latest technology.	-.71		.76	
	AT16	Having Wi-Fi and/or good internet access on my mobile phone everywhere I go is essential to me.	-.70		.71	
Pro env. friendly transport	AT6	We should raise the cost of driving to reduce the negative impacts of transportation on the environment.	-.94	.77	.90	.74
	AT17	We should raise the cost of driving to provide funding for better public transportation.	-.92		.86	
	AT19	I always think about ways in which I can reduce my impact on the environment.	-.54		.56	
Car dependency	AT2	My schedule makes it hard or impossible for me to use public transportation.	.87	.67	.86	.68
	AT12	Most of the time, I have no reasonable alternative to driving.	.82		.80	

Note. [a]also loaded on construct *active lifestyle* with .47 in 2020; with .35 less so in 2021.

5.4.3 Differences in attitudinal constructs between groups and years

To address the first research question, the z-standardized, regression-based factor scores were compared across groups and years (Table 5-3). Spider charts were used to visualize these factor scores for both groups in 2020 and 2021 (Figure 5-3 and 5-4). MANOVA indicated a significant difference between the groups for the year 2020 ($F(8, 972) = 18.91$, $p < .001$) and for the year 2021 ($F(8, 972) = 21.038$, $p < .001$). For the detailed MANOVA results, please refer to Appendix 5-C. In the case of active lifestyle, the construct does not consist of the exact

same items in 2020 as in 2021. Since the interpretation of this factor would thus be biased, simple means of matching items were used instead. Remaining non-standardized means of constructs are available in Appendix 5-D.

Table 5-3

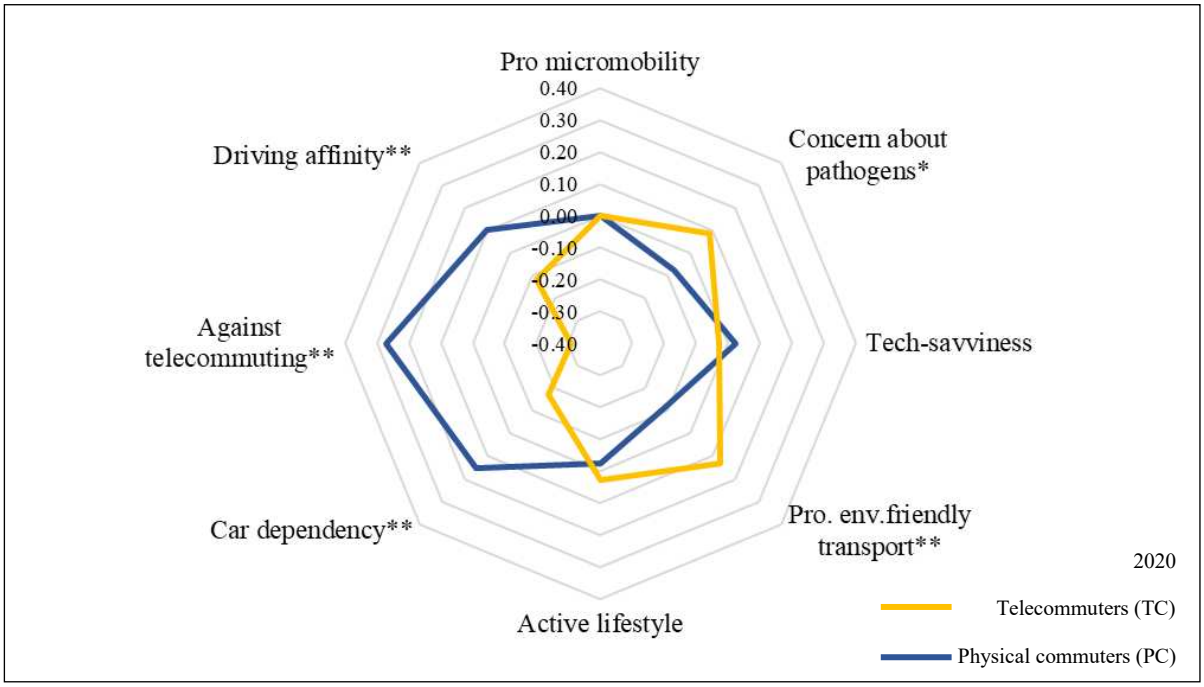
Factor scores of constructs for both years and groups (z-standardized, N = *981)*

	Year	**Physical commuters**		**Telecommuters**	
		Mean	*SD*	*Mean*	*SD*
Pro micromobility	2020	0.00	1.03	0.00	0.97
	2021	-0.01	1.04	0.02	0.96
Driving affinity	2020	0.10	0.95	-0.12	1.04
	2021	0.11	0.95	-0.13	1.04
Concern about pathogens	2020	-0.07	1.05	0.08	0.94
	2021	-0.01	1.01	0.02	0.99
Tech-savviness	2020	0.02	1.04	-0.03	0.96
	2021	-0.07	1.05	0.08	0.93
Pro env. friendly transport	2020	-0.12	1.01	0.13	0.97
	2021	-0.10	1.00	0.11	0.99
Active lifestyle	2020	-0.02	1.06	0.03	0.92
	2021	0.06	1.02	-0.07	0.97
Car dependence	2020	0.15	0.97	-0.17	1.01
	2021	0.11	1.01	-0.13	0.98
Against telecommuting[11]	2020	0.27	0.90	-0.31	1.02
	2021	0.32	0.93	-0.36	0.96

[11] The factor analysis produced a ‘negative’ construct for the attitude toward telecommuting, which we thus coined ‘attitude against telecommuting’ in the further text.

Figure 5-3

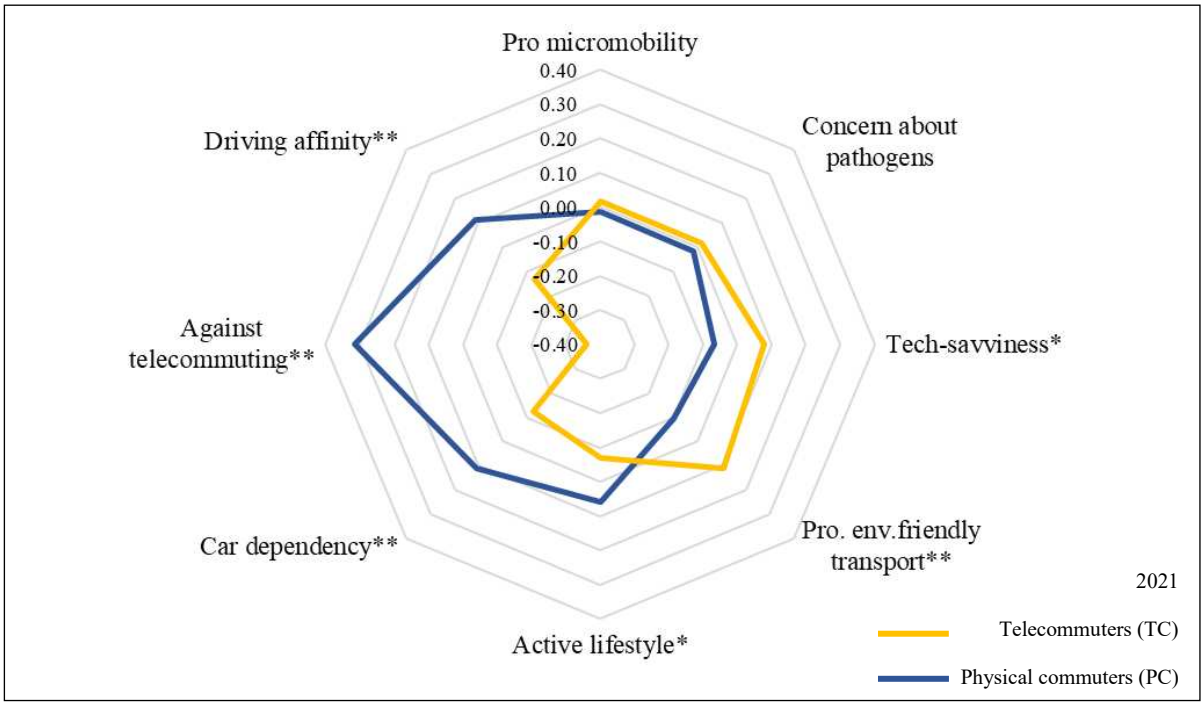
Factor scores (z-standardized) for both groups (PC, TC) in the year 2020



Note. *group difference (PC vs. TC) significant at .05 level; ** at .01 level

Figure 5-4

Factor scores (z-standardized) for both groups (PC, TC) in the year 2021



Note. *group difference (PC vs. TC) significant at .05 level; ** at .01 level

Some differences between the physical commuters and telecommuters in relation to car-related attitudes were stable over time. Specifically, the physical commuters demonstrated a greater affinity for driving and a higher level of car dependence, while the telecommuters displayed a more positive attitude toward environmentally friendly modes of transportation. Notably, the attitude toward micromobility (e.g., shared bikes and e-scooters) was consistently similar for both groups.

Regarding the remaining constructs, differences between the groups appeared and disappeared as the pandemic progressed. Regarding tech-savviness, while no significant difference was observed between the two groups in the year 2020, a marked contrast emerged in the year 2021, with telecommuters exhibiting a significantly higher level of tech-savviness.

Regarding concern about pathogens, the physical commuters exhibited less concern than the telecommuters in the year 2020. However, in the year 2021, the difference was not statistically significant anymore. A follow-up dependent sample t-test on the simple means of the whole sample revealed a general significant drop in concern about pathogens from 2020 to 2021: $t(980) = -15.170$, $p < .001$ (from 3.71 ± 0.98 to 3.17 ± 1.11, on a scale from 1 to 5).

Regarding active lifestyle, the difference in composition of the construct in 2020 vs. 2021 warrants additional analysis. As described in Table 5-2, the item “I like riding a bike” mostly loaded on the pro micromobility construct in 2020, but in 2021 was most associated with the active lifestyle construct. Therefore, analysis of the construct as depicted in the spider chart may be misleading, and a look at the simple means of the construct without the item in question “I like riding a bike” is warranted. One-tailed dependent-sample t-tests on the simple means of the remaining two items revealed that from 2020 to 2021, there was a statistically significant difference in active lifestyle for the telecommuters from $4.28 \pm .71$ to $4.32 \pm .71$ ($t(385) = -1.686$, $p = .046$). For the physical commuters, active lifestyle did not significantly change (from $4.23 \pm .83$ to $4.22 \pm .81$; $t(522) = .460$, $p = .323$). Therefore, the hypotheses can be answered as followed.

H1 (*From 2020 to 2021, the telecommuters developed a more positive attitude toward an active lifestyle than physical commuters)* was supported.

H2 (*The telecommuters report a higher concern about pathogens than the physical commuters)* was supported for the year 2020 only. In 2021, there was no difference, and overall concern dropped.

H4 (*The telecommuters report a more positive attitude toward telecommuting than the physical commuters)* was supported for both years.

5.4.4 Predictors of the intention to telecommute in the future

5.4.4.1 Test of measurement model

The model employed six variables, including three latent constructs that were measured on a scale ranging from 1 to 5. These constructs comprised "attitude toward telecommuting", which was measured using five items, "concern about pathogens", which was measured using three items, and "tech-savviness" which was measured using three items. Furthermore, one variable was binary, namely "commute status" in 2020. The remaining two variables comprised single items, namely "number of days per week that the job allows telecommuting" and "number of days per week that a person intends to telecommute in the future". An overview and descriptive statistics for these constructs and items, scale reliability of constructs, and the correlations among constructs is detailed in Tables 5-4, 5-5 and 5-6 respectively.

Table 5-4

Descriptive statistics for constructs (per year, not z-standardized) used in the models, N = *909*

Variable	***M***	***SD***	**Scale/Code**
Against telecommuting 2020	2.99	0.83	
Against telecommuting 2021	2.90	0.91	
Concern about pathogens 2020	3.70	0.98	Strongly disagree (1) –
Concern about pathogens 2021	3.17	1.11	Strongly agree (5)
Tech-savviness 2020	3.48	0.86	
Tech-savviness 2021	3.47	0.89	
Max. frequency of job allowing telework	2.78	2.04	0 – 5 or more days
# of days of intended future telework	2.51	1.94	0 – 7 days
Group (physical commuters)	57.5%		

Table 5-5

Scale reliability for constructs used as predictors of the intention to telecommute in the future, N = *909*

Construct	Item	Corrected item-total correlation	Cronbach's α
Against telecommuting 2020	ATC1	.50	.74
	ATC3	.55	
	ATC5	.47	
	ATC8	.42	
	ATC9	.56	
Against telecommuting 2021	ATC1	.54	.77
	ATC3	.54	
	ATC5	.53	
	ATC8	.50	
	ATC9	.56	
Concern about pathogens 2020	AT24	.46	.67
	AT27	.51	
	AT28	.48	
Concern about pathogens 2021	AT24	.66	.77
	AT27	.51	
	AT28	.63	
Tech-savviness 2020	AT14	.46	.61
	AT16	.37	
	AT18	.45	
Tech-savviness 2021	AT14	.53	.65
	AT16	.37	
	AT18	.48	

Table 5-6

Pearson correlations for constructs of Table 5-5, N = *909*

	Ag. tc 20	Ag tc 21	Con. p. 20	Con. p. 21	Tech 20	Tech 21	Job all. tc
Against telecommuting 2020	1.00						
Against telecommuting 2021	.66**	1.00					
Concern ab. pathogens 2020	-.07	-.08*	1.00				
Concern ab. pathogens 2021	-.08*	-.09**	.47**	1.00			
Tech-savviness 2020	.02	-.02	.06	.11*	1.00		
Tech-savviness 2021	.03	-.02	.03	.08*	.75**	1.00	
Max. frequ. job all. telecom.	-.28**	-.40**	.04	.02	.09**	.06	1.00
Group (1 = PC, 2 = TC)	-.31**	-.37**	.08*	.02	.00	-.05	.59**

Note. *significant at .05 level, **significant at .01 level (2-sided)

The data met the normality assumption, as evidenced by the skewness and kurtosis values deviating from zero no further than +/−2 and +/−4, respectively (Field, 2013). To assess construct validity, both convergent and discriminant validity were examined (Hair et al., 2010). While standardized loading estimates > .70, average variance extracted (AVE) > .50 and composite reliability > .70 were not consistently achieved for convergent validity (Table 5-7), the results were still deemed acceptable for the analysis to proceed as discriminant validity was consistently satisfactory (AVE estimates exceeding the square of the correlation between factors, Table 5-8).

The confirmatory factor analysis produced adequate goodness-of-fit statistics for the 2020 data ($\chi^2(61) = 287.11$; $p < .01$; $\chi^2/df = 4.71$; NFI = .88; TLI = 0.87; CFI = .90; RMSEA = 0.06) as well as for the 2021 data ($\chi^2(61) = 316.87$; $p < .01$; $\chi^2/df = 5.20$; NFI = .90; TLI = .89; CFI = .91; RMSEA = .07).

Table 5-7

Convergent validity for constructs used as predictors of the intention to telecommute in the future, N = *909*

Variable	Item	λ	AVE	Composite reliability
Against telecommuting 2020	ATC1	.59	.37	.74
	ATC3	.63		
	ATC8	.48		
	ATC9	.72		
	ATC5	.58		
Against telecommuting 2021	ATC1	.61	.28	.79
	ATC3	.57		
	ATC5	.64		
	ATC8	.54		
	ATC9	.75		
Concern about pathogens 2020	AT24	.60	.41	.67
	AT27	.69		
	AT28	.62		
Concern about pathogens 2021	AT24	.84	.54	.78
	AT27	.58		
	AT28	.77		
Tech-savviness 2020	AT14	.65	.36	.78
	AT16	.48		
	AT18	.65		
Tech-savviness 2021	AT14	.79	.40	.66
	AT16	.45		
	AT18	.62		

Table 5-8

Discriminant validity for constructs used as predictors of the intention to telecommute in the future, N = *909*

	Ag TC 20	**Ag TC 21**	**Con p 20**	**Con p 21**	**Tech 20**	**Tech 21**
Against tc 2020	**.37**					
Against tc 2021	/	**.28**				
Concern path. 2020	.01	/	**.41**			
Concern path. 2021	/	.01	/	**.54**		
Tech-savviness 2020	.00	/	.00	/	**.36**	
Tech-savviness 2021	/	.00	/	.01	/	**.40**
# days job allows tc	.08	.16	.00	.00	.01	.00
Group (1=PC, 2=TC)	.10	.14	.01	.00	.00	.00

Note. / excluded because the data of these different years are not in model together

5.4.4.2 Test of structural model

A good fit of the measurement model was recognized as basis to test the structural model. Using structural equation modeling, a good model fit was obtained for the 2020 model (χ^2 (67) = 278.81, $p < .01$; χ^2/df = 4.04, NFI = .90; TLI = .90; CFI = .92; RMSEA = .06, R^2 = .39) (Table 5-9), as well as for the 2021 model (χ^2 (67) = 302.28, $p < .01$; χ^2/df = 4.512, NFI = .91; TLI = .91; CFI = .93; RMSEA = .06; R^2 = .46) (Table 5-10). Both models are visualized in Figures 5-5 and 5-6, respectively.

Table 5-9

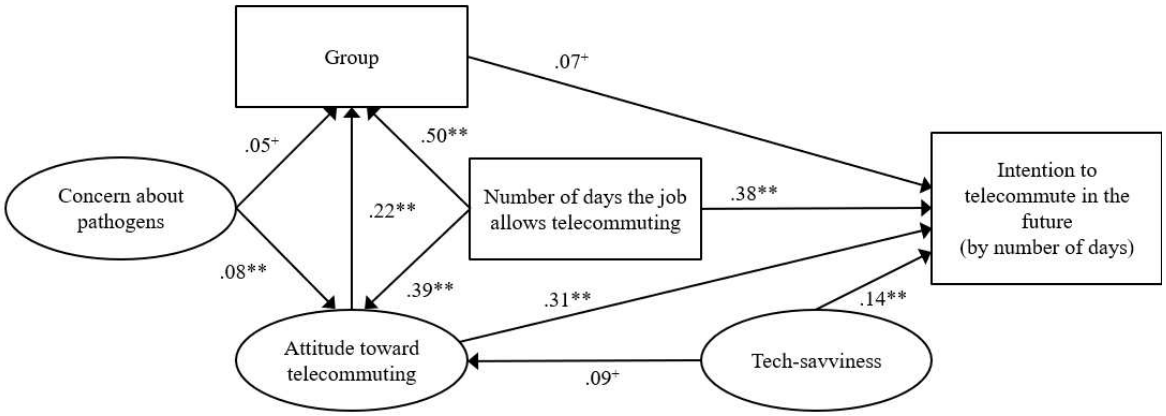
Standardized and unstandardized β-coefficients and significance levels for the 2020 structural model

Parameter estimated	**Unstandardized (error)**	**Standardized**	***p***
Concern about path. → Against tc	-.10 (.05)	-.08	**
Concern about path. → Group	.03 (.02)	.05	.10
Job allows tc → Against tc	-.19 (.02)	-.39	**
Job allows tc → Group	.12 (.01)	.50	**
Against tc → Group	-.11 (.02)	-.22	**
Tech-savviness → Against tc	.12 (.06)	.09	.06
Job allows t → Future intention tc	.36 (.03)	.38	**
Against tc → Future intention tc	-.58 (.08)	-.31	**
Group → Future intention tc	.26 (.14)	.07	.06
Tech-savviness → Future intent.tc	.37 (.09)	.14	**

Note. * significant at .05 level, ** significant at .01 level

Figure 5-5

2020 structural model to predict the intention to telecommute in the future



Note. +significant at .10 level, * significant at .05 level, ** significant at .01 level

Table 5-10

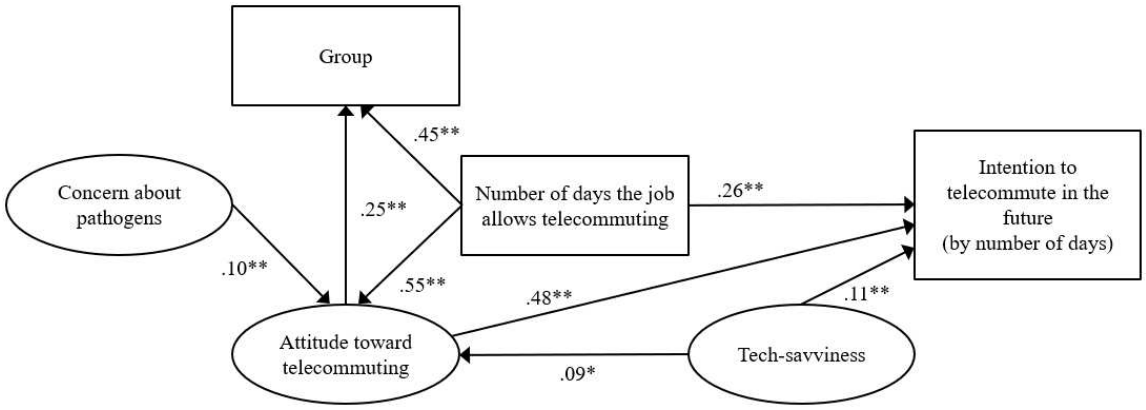
Standardized and unstandardized β-coefficients and significance levels for the 2021 structural model

Parameter estimated	**Unstandardized (error)**	**Standardized**	***p***
Concern pathogens → Against tc	-.16 (.02)	-.10	**
Concern pathogens → Group	-.01 (.02)	-.01	.71
Job allows tc → Against tc	-.31 (.02)	-.55	**
Job allows tc → Group	.11 (.01)	.45	**
Against tc → Group	-.11 (.02)	-.25	**
Tech-savviness → Against tc	.14 (.06)	.09	*
Job allows t → Future intent. tc	.24 (.04)	.26	**
Against tc → Future intention tc	-.78 (.08)	-.48	**
Group → Future intention tc	.12 (.13)	.03	.37
Tech-savviness → Future intent. tc	.28 (.08)	.11	**

Note. * significant at .05 level, ** significant at .01 level

Figure 5-6

2021 structural model to predict the intention to telecommute in the future



Note. +significant at .10 level, * significant at .05 level, ** significant at .01 level

5.5 DISCUSSION

With this study, we contribute to the growing body of literature on the effects of Covid-19 on the transportation sector, with a specific focus on attitudes and other psychological factors. We utilized individual-level survey data from a longitudinal sample in California, divided into two groups: those who shifted to telecommuting during the pandemic, and those who continued to commute physically. By examining these groups at two different points in time (2020 and 2021), we aimed to uncover differences in mobility-related attitudes between the two groups during different stages of the pandemic, and used various psychological and external factors to predict the intention of telecommuting in the future for both 2020 and 2021 data. In summary, our study explored the impact of the ongoing disruption of commuting behavior due to the pandemic on mobility-related attitudes and their influence on future commuting plans.

5.5.1 Socio-economic findings

The initial socio-economic differences observed between the two groups were largely consistent with previous research findings (e.g., Budnitz et al., 2020; De Abreu e Silva & Melo, 2018; López Soler et al., 2021; Su et al., 2021; Yasenov, 2020). Specifically, telecommuters exhibited higher levels of income and education, reflecting their prevalence in desk jobs and managerial positions, which typically allow for remote work. In contrast, physical commuters often require on-site presence for their work. This notion was corroborated by a significant difference in the reported number of days per week that each group's job allowed for telecommuting: physical commuters reported an average of 1.75 days, while telecommuters reported 3.52 days. Notably, gender differences were not observed between the groups in our

sample. Overall, these findings shed light on the socio-economic factors that may influence the ability and willingness to telecommute, and highlight the importance of understanding the demographic characteristics of each group in transportation research.

5.5.2 Psychographic differences

The socio-demographic disparities between the two groups undoubtedly contribute, to some extent, to the attitudinal differences that persisted between them over both years. These differences relate specifically to their attitude toward telecommuting, driving affinity, car dependence, and attitude toward environmentally friendly transport.

It comes as no surprise that telecommuters displayed a more favorable attitude toward telecommuting than physical commuters. After all, those who have a more positive view of it may engage in telecommuting more often (Chai et al., 2022). The theory of cognitive dissonance (Festinger, 1962) could also play a role in shaping these attitudes, particularly for individuals who were forced to either form of commuting during the pandemic. In some cases, attitudes may have been adjusted to reduce cognitive dissonance.

Car dependence is a multifaceted construct that encompasses both geography and transportation options, as well as subjective perceptions about the availability of alternative modes of transport (Saeidizand et al., 2022). Driving affinity, on the other hand, is more closely linked to one's affective and symbolic relationship with cars (Steg, 2005). Physical commuters reported consistently higher levels of car dependence and driving affinity, which is perhaps unsurprising given that they are more likely to rely on cars for commuting. However, telecommuters consistently displayed a more positive attitude toward environmentally friendly transport. This finding suggests that individuals who are more reliant on their cars are less likely to view other modes of transport in a positive light. It is possible that the reason for this difference in attitude is that alternative modes of transport are perceived as a threat to the preferential treatment of private cars, for example their right of way, space, and funding. Additionally, there is evidence suggesting that environmental concerns are more closely linked to personality traits (Hirsh, 2010), making them less likely to be influenced by external factors like a pandemic.

Several attitudinal differences between the two groups disappeared or changed between 2020 and 2021, which warrants further investigation. This is the case for concern about pathogens, tech-savviness, and active lifestyle. Notably, the level of concern about pathogens was initially higher among telecommuters but decreased to a level similar to physical commuters by 2021, and generally decreased for the entire sample, which may be attributed to

quarantine fatigue (J. Zhao et al., 2020) and the availability of vaccines. This finding calls into question previous literature that suggested a long-lasting impact of pathogen risk perception on mobility. Additionally, tech-savviness was similar between the two groups in 2020 but significantly higher among telecommuters in 2021. This discrepancy may be explained by the fact that telecommuting requires the use of technology, leading to increased familiarity and proficiency among telecommuters. Last, the findings for active lifestyle follow our hypotheses, though it is important to consider that the simple means of the respective construct were used instead of the EFA derived construct, since the latter were not composed of the same items in both years. The telecommuters reported a more active lifestyle, while the physical commuters remained unchanged in that regard. This aligns with our expectation that telecommuting may save time and reduce stress, giving individuals more time to engage in physical activity (De Haas et al., 2020).

5.5.3 Intentions to telecommute in the future

The 2020 dataset demonstrated the model's effectiveness, however, the 2021 model saw a decline in predictive power of two factors: concern about pathogens and commute status. In 2020, concern about pathogens was a reliable predictor of whether someone would be classified as a telecommuter or a physical commuter, yet this relationship did not hold in 2021. This aligns with the observation that concern about pathogens decreased over time as the pandemic progressed. Nevertheless, concern about pathogens still retained its indirect predictive power with regards to attitudes toward telecommuting, indicating that it remains a factor in determining the intention to telework, although its importance has waned as the pandemic has progressed.

Notably, in the 2021 model, group status was no longer a significant predictor of intention to telecommute in the future. While many individuals were compelled to telework at the outset of the pandemic, the widespread availability of vaccines and the implementation of remote-work policies may have rendered group status less salient as a predictor.

Our model instead identified workplace policy, namely the degree to which a job allows telecommuting, as a crucial predictor of teleworking intentions, paralleling the concept of perceived behavioral control in the theory of planned behavior (Ajzen, 1991). Perceived behavioral control refers to an individual's perceived ability to perform a behavior given available resources and constraints. In our model, the extent to which a job permits teleworking may serve as a proxy for perceived behavioral control over telecommuting. If a job allows teleworking, the individual enjoys greater control over their ability to telecommute, as they are

likely to have the necessary resources and support from their employer, thereby increasing their perceived ability to perform the behavior and intention to telecommute.

Importantly, our model highlights the profound impact of attitudes on future teleworking intentions, echoing another core tenet of the theory of planned behavior (Ajzen, 1991). Specifically, attitude toward telecommuting emerged as the most potent predictor of intention to telecommute in the future in our model, with a standardized beta coefficient surpassing that of the external impact of job flexibility on telecommuting. Mokhtarian and Salomon (1997) argue that job flexibility is a necessary, but insufficient precondition for telecommuting adoption. Therefore, if an increase in telecommuting is the goal, policy interventions should focus on addressing both structural and individual factors.

On a structural level, both corporate and government policies can play a crucial role in promoting job flexibility and facilitating telecommuting. Industries such as information technology services, administration and management of companies, consulting, as well as insurance and related sectors, are well-suited for implementing telecommuting options. However, in certain industries like healthcare, construction, and retail, the feasibility of telecommuting may be limited in the near future or may not be possible at all (Destatis, 2022b).

On an individual level, attitudes toward telecommuting are not as readily shaped or altered. However, going back to the definition of attitude as described in the introduction (as derived from beliefs about the favorable or unfavorable outcome of performing a behavior; Ajzen, 1991), this attitude can be addressed by improving individuals' beliefs about the favorable outcomes of telecommuting. Our model suggests that one strategy that might achieve this is to enhance individuals' tech-savviness.

Finally, we want to draw attention to the emergence of hybrid work, a combination of telecommuting and physical commuting. Wigert and Agrawal (2022) observed a shift in work trends, with hybrid work surpassing exclusive remote work among US remote-capable employees in 2022. Accordingly, in the present paper, we found that the telecommuter group (who exclusively worked from home at the outset of the pandemic) indicated their intention to telework an average of 3.57 days per week in the future. These findings emphasize that for most remote-capable individuals, the question is not *whether* they will engage in telework but rather *to what extent* they will incorporate it into their work routine. Research on current hybrid work arrangements may be needed to understand the most effective approaches that optimize both productivity and individual well-being (Hopkins & Bardoel, 2023).

For transportation research and policy, the evolving hybrid work landscape holds implications, too (Moglia et al., 2021). While our study contributes to understanding telework

frequency determinants, further research is necessary to discern the travel behavior of hybrid workers. This involves exploring their travel needs and preferences, alternative modes, flexible schedules, and reassessing transportation networks. With a reduced demand for daily commuting, there may be an opportunity to prioritize sustainable transportation options by promoting flexible mobility solutions and shared modes of transportation.

5.5.4 Limitations

First, this study employs a quasi-experimental design, which does not allow for drawing causal conclusions. This is particularly relevant when considering the impact of the socio-economic status. With respect to the prediction model, we controlled for this by including income and education as a predictor of intention to telecommute in the future. Our analysis revealed that these variables did not significantly impact the dependent variable, and the predictive value of the remaining variables remained largely unchanged. However, when interpreting the attitudinal differences in response to RQ 4.1, this drawback needs to be considered.

Second, some variables in our model are only barely ordinal and demanded specific decisions during recoding. For instance, the extent to which a participant's job allows for teleworking is coded on a scale from 0 to 5, which does not reflect the number of days per week a participant can telecommute but indicate scales from 0 “never” to 5 “5 or more times a week”. Additionally, the dependent variable includes an ambiguous response option labeled “flex/variable schedule”, which we imputed with the sample mean. It seemed likely that participants interpreted this option as “telecommuting some days, but unsure which days of the week”. However, it is possible that participants interpreted this option differently, which could have influenced our results. To control for this issue, we imputed this variable with 0 and found that the sample mean we originally used yielded better R^2 results, which supports our chosen procedure. Nevertheless, alternative coding decisions could have impacted the findings. However, our control analyses demonstrate that the results are likely not merely artifacts of our methods.

Additionally, we would like to draw attention to the construct of active lifestyle. Because the EFA with the 2020 data produced a different active lifestyle construct than that of 2021, direct comparison of these constructs was unfeasible. To address this issue, we utilized the simple mean of two items that did load on the construct in both years, while excluding the item that loaded on the construct in only one year (“I like riding my bike”). This follow-up analysis confirmed our hypothesis. However, it became apparent that a more precise description of active lifestyle, perhaps including other items such as affinity for biking, could have yielded

divergent findings. To arrive at a reliable conclusion, further research on the construct of active lifestyle is necessary.

5.5.5 Conclusions

This study illuminates the impact of the Covid-19 pandemic on individuals' attitudes and other psychological factors related to mobility, through the forced disruption of habitual commuting behavior. The analysis has explored the differences between telecommuters and physical commuters, highlighting the importance of individual attitudes in predicting the intention to telecommute in the future.

As the pandemic progressed, concern about pathogens has gradually lost its impact on commuting behavior. Consequently, research efforts may redirect their focus toward other factors that have gained prominence, such as tech-savviness. In fact, improving tech-savviness could be the key to increasing both intention and attitude toward telecommuting. Notably, attitude emerged as the main predictor of intention to telecommute, underscoring the importance of cultivating a positive mindset toward telecommuting.

While certain constraints on telecommuting, such as the nature of the job, persist, this paper demonstrates that telecommuting has emerged as a viable option for society, and that hybrid work will likely be the future of work. In addition to the options for transportation improvements this offers, such as greater freedom in mode selection, other positive societal benefits have become apparent. Specifically, individuals have developed a more positive attitude toward an active lifestyle, and those working from home have significantly enhanced their tech-savviness.

This study provides valuable insights into how we can leverage individual and external factors to promote telecommuting, which has the potential to benefit both individuals and society as a whole.

6 DISCUSSION

The aim of this dissertation was to contribute to the development of a sustainable transportation system by focusing on the psychological aspects of individuals' mobility behavior. This approach aligns with the so-called sufficiency strategy, which proposes that objectives may be achieved through understanding and changing travelers' behavior. Moreover, the needs of mobility users were considered, and economic and social issues were addressed. However, as this discussion highlights, achieving the mobility transition necessitates an interdisciplinary, multi-facetted approach. Therefore, while grounded in the field of psychology, the present research integrates ideas from economics and engineering disciplines. Although focused on individuals' general daily mobility behavior, a special emphasis was placed on commuting behavior. Following Geller's (2002) DO IT approach, the targeted behavior was *defined* as private car use, and the antecedents of car use that uphold the behavior were *observed* in chapter 1. Chapters 2-5 detailed the implementation of different *interventions* and *tested* their effectiveness. These include identifying various types of mobility users, investigating the impact of a new mobility service, testing a nudging intervention, and exploring the impact of the Covid-19 pandemic on mobility behavior. Each of these four chapters concluded with specific individual discussions, limitations, and conclusions.

The final discussion section follows a three-part structure. First, the most important findings and implications of the individual studies, in regard to the research questions and beyond, are reflected upon, and their relevance for achieving a sustainable mobility transition is addressed. Second, individual findings that play a role across studies are discussed. These include the increasingly important role of tech-savviness, the nudging approach, the impact of environmental concern on behavior, and the use of attitudinal constructs in interdisciplinary transportation research. Finally, general conclusions on how this dissertation may serve to pave a way forward within the mobility transition are drawn.

6.1 SUMMARY OF FINDINGS AND THEIR MEANING FOR THE MOBILITY TRANSITION

6.1.1 Chapter 2: Mobility types

The aim of this study was to identify the mobility types present in the German population, while taking into account their various needs, preferences, and circumstances. The derived results allowed an answer to the first research question of this dissertation (*RQ 1: Can the German population be meaningfully segmented into distinct mobility types, which are able to*

provide a basis for the development of tailored interventions to promote a sustainable and equitable mobility system?). Eight relevant clusters emerged, providing insight that can aid both in developing tailored measures and interventions as well as estimating potential policy impacts on different groups. For each cluster, recommendations to increase sustainability and equity were given.

From this study, it became apparent that a careful evaluation of trade-offs is necessary as, for some clusters, an increase in equity can lead to a decrease in sustainability and vice-versa. With regard to equity issues, particular attention is required for clusters consisting of older adults, which jointly comprise more than one third of the population and display the most mobility-related physical limitations, as well as lower tech-savviness, which can hinder their access to novel mobility options.

With regard to environmental issues, three clusters with less sustainable mobility behavior, characterized by increased car use, were identified. Among these clusters, two consist of parents with young children and individuals residing in rural areas. For these, convenient transportation options beyond the car are not readily available, rendering them car dependent. Mitigating car dependence is a complex process, which requires multi-facetted solutions (Hunter et al., 2021), encompassing adaptations in spatial context (Wiersma et al., 2017) and urban planning (Newman et al., 2016), as well as addressing psychological factors, such as car affinity or a lack of awareness of alternatives. Another clustering study (Anable, 2005) found that car dependents ("complacent car addicts") are more likely to switch to other modes (e.g., transit, bike), than those with high car affinity ("die hard drivers"), which affirms the proposition that psychological factors still need to be considered. Freeing mode choice is a critical step to achieving a sustainable mobility transition.

The remaining cluster that displayed increased car use is characterized by taking more than average, lengthy commuting and business-related trips, pointing to the need for targeted interventions aimed at altering their commuting behavior.

6.1.2 Chapter 3: MaaS

The two-part second research question targeted the concept of Mobility as a Service (*RQ 2.1: What are the relevant enabling factors and barriers for MaaS users and non-users, within the application and external? RQ 2.2: Under which psychological circumstances would individuals be willing to reduce their use of or discard the private car on account of MaaS?*). Mobility as a Service (MaaS) is a relatively novel concept, which can potentially generate positive impacts for sustainability and social equity by encouraging individuals to use modes

other than the private car and expand access to transport options for all social groups (Schikofsky et al., 2020). In this qualitative, focus-group based study, enabling factors and barriers for MaaS use, as well as circumstances under which MaaS could convince individuals to reduce their use of private cars, were identified.

Results revealed that, in theory, if individuals were adequately tech-savvy and service availability was sufficient, MaaS could meet all instrumental transportation needs. Therefore, the hope that MaaS could increase transport equity by providing accessible options for everyone seems rational, as MaaS is a potential option for individuals of all ages and education levels.

However, given the strong habituation of the daily trip to work, individuals found it unlikely that they would start using MaaS for their commute. Moreover, a poignant finding was that certain car-oriented users would not consider MaaS, despite the service's sufficient functionality, due to strong symbolic and affective motives associated with the private car (Steg, 2005). From this predicament, two implications can be drawn: first, findings suggest that increasing the burdens for car ownership using push measures may overcome the strong symbolic and affective motives for car use, so that individuals can switch to readily available, convenient modes within MaaS. Second, results revealed that MaaS itself can be associated with symbolic (e.g., modern, innovative) and affective (e.g., fun, connection to city) motives. To achieve a more sustainable mobility transition, it is suggested that MaaS providers start emphasizing these motives, beyond instrumentality, so that they become more prominent and perhaps counter the car-specific motives. While MaaS remains a niche concept (Reck et al., 2021), the present study raises hopes that MaaS may play an essential role in a future sustainable and equitable transportation system.

6.1.3 Chapter 4: Nudging

To address the issue of commuting, chapter 4 comprised a nudging experiment, which was designed to answer the three-part third research question (*RQ 3.1: Can the theory of planned behavior extended by environmental concern predict the decision to subscribe to a transit ticket? RQ 3.2: are nudges aimed at enticing employees to purchase a transit ticket able to increase transit subscription numbers effectively? RQ 3.3: Can nudges be integrated into the theory of planned behavior?).* A default nudge and a social norm nudge were tested for their effectiveness in encouraging employees to subscribe to a transit ticket. Additionally, an extended version of the theory of planned behavior (Ajzen, 1991) was utilized to predict the subscription decision. Although the prediction model performed well (save for the additional

predictor environmental concern), none of the nudges were found to be statistically significantly effective, could not be integrated into the theory, and the social norm nudge even caused a slight backfire effect. Unlike one-time decisions, the mode choice for commuting is a habituated behavior involving monetary cost, which makes successful nudging difficult. Despite a potential small effect, policymakers may feel compelled to use nudges due to their typically low implementation cost. However, following the publication of this study, meta-analyses on nudging have warned against its use due to potential backfire effects on the level of both consumers and policymakers (e.g., Maier et al., 2022). In chapter 6.2.2, the difficulties and risks of nudging within the transportation sector will be discussed further in the light of recent literature. It can be concluded that using nudges is unlikely to be an effective approach for achieving a sustainable mobility transition.

6.1.4 Chapter 5: Covid-19

Regarding the powerful influence of commuting habits, it appears that only a large-scale forceful disruption could yield significant behavior change. During the research conducted for this dissertation, we observed such an unlikely interference as one of many disruptions caused by the Covid-19 pandemic. In that context, a segment of the population that previously commuted shifted to working from home, while another continued to commute physically. Using these two groups and two data collection waves (2020 and 2021), the impact of this forced disruption of commuting behavior on mobility-related psychological constructs, as well as their impact on future intention to telecommute, was investigated to answer the two-part fourth research question (*RQ 4.1:* H*ow do mobility-related attitudes differ between those who continued to commute physically during the pandemic vs. those who started to telecommute? RQ 4.2:* W*hich attitudinal factors predict if individuals intend to telecommute in the future?*).

Results revealed that pathogen concern had a significant impact on mobility behavior at the beginning of the pandemic, but its importance has diminished over time and will likely play a smaller role in future transportation than initially anticipated. By 2021, the telecommuter group had become significantly more tech-savvy, while the physical commuters had not. Improving individuals' tech-savviness may indeed be the most effective lever to increase both the intention to telecommute and the attitude toward telecommuting. The latter was identified as the primary predictor of intention to telecommute in the future.

This study shows that despite a reduction of concern about pathogens, many individuals intend to continue telecommuting to some extent in the future, thereby making the physical commute partly obsolete. With regard to the mobility transition, efforts need to be directed

toward ensuring that these individuals fill the remainder of their daily mobility budget with environmentally friendly modes.

6.2 IMPACTFUL FINDINGS ACROSS STUDIES

6.2.1 Tech-savviness

A critical construct that surfaced throughout the studies is tech-savviness. In this dissertation, tech-savviness was defined as the level of proficiency in engaging in modern technology, including the aptitude in handling technical devices such as computers and smartphones, as well as intuitive knowledge of such systems (Apergis, 2019; Zaman et al., 2022). Put simply, tech-savviness describes the level of familiarity and affinity with technology (Asmussen et al., 2020).

The present studies demonstrated that tech-savviness is increasingly relevant for transportation. The use of MaaS (chapter 3), for example, was described as viable for everyone, but only if they possess sufficient tech-savviness. The mobility profiles (chapter 2) revealed that clusters which display lower tech-savviness are less satisfied with transport options in general. In the wake of the Covid-19 pandemic, for many individuals, physical commuting has been replaced by telecommuting, which also requires an adequate level of tech-savviness (chapter 5). Given the growing importance of tech-savviness, two main implications are derived from this research.

First, to my knowledge, there is no framework that jointly defines and models tech-savviness within the transportation literature. The development of a shared, comprehensive framework would be beneficial, because it could establish a conceptual foundation for future research and provide insight into how tech-savviness may be increased. It could also address the issue of the differing labels used in the transportation literature. For instance, what this dissertation and other transportation literature refers to as tech-savviness (e.g., Said et al., 2023) is elsewhere called *IT competency* (Mehmood, 2021), *technological literacy* (Vaičiūtė & Yatskiv, 2023), *computer literacy* (Circella & Mokhtarian, 2017; De Luca et al., 2021), or *technological self-efficacy* (Schreder et al., 2009). Although the technology acceptance model (TAM) (Davis et al., 1989) is a popular model that includes the seemingly related variables *perceived usefulness* and *perceived ease of use*, it focuses on the specific technology in question, whereas tech-savviness is used to describe an individual's affinity and skill. Some extended versions of the TAM include self-efficacy, which is defined as the perceived capability to handle technology successfully, but while focusing on the individual, it is not

concerned with an objective skill (Fathema et al., 2015). Yet, self-efficacy may be a suitable fit, as despite being conceptually distinct from tech-savviness, the latter is typically measured using self-reports, and thus naturally subjective. It may thus provide a starting point for a common framework for tech-savviness in the transportation literature.

Second, effort needs to be dedicated to developing strategies that increase transportation related tech-savviness, so that novel transportation technologies such as MaaS are accessible to everyone. Concurrently, these novel technologies may need to dedicate design efforts to enhance accessibility. The hope is that these mobility services become more appealing to currently less tech-savvy people, such as seniors or individuals with impairments, and provide them with access to mobility without the need to own or drive a car. The rise of and engagement with telecommuting, induced by the Covid-19 pandemic, served as an unexpected 'intervention' to increase tech-savviness (chapter 5). As Nair and Bhat (2021) and Asmussen et al. (2020) point out, efforts to increase tech-savviness must be tailored the technology in question and not be a generic approach. In conclusion, tech-savviness is a crucial factor in facilitating the mobility transition.

6.2.2 Nudging: utile or futile?

Nudging interventions have a strong appeal due to their simple and inexpensive nature, along with impressive examples of success in changing human behavior, such as the opt-in to opt-out strategy increasing enrollment in retirement savings plans and organ donations (Johnson & Goldstein, 2003; Thaler, 1994). However, exercising caution is crucial when extrapolating these findings to other domains, such as the transportation sector. In chapter 3, a large amount of skepticism and futility regarding the presented environmental nudges was recorded. As chapter 4 displayed, the trialed nudging intervention was not satisfyingly successful, and one nudging case even produced a slight backfiring effect.

Recent meta-analyses suggest that nudging may be less effective than initially proclaimed (Hummel & Maedche, 2019), and after adjusting for publication bias, there seems to be no evidence for nudging to be effective across domains (Maier et al., 2022). It is important to note that nudging is context dependent, which means that effects are heterogeneous across nudging types and domains. In the domain of mobility decisions, cost and habits often play a non-negligible role, and it is precisely those two factors that have been identified as the most likely reasons for the nudges in the present study not producing an effect. Nudges have proven effective in situations in which a one-time decision was made that otherwise remained 'invisible' in daily life, but even then, the impact on outcomes is often modest. In that regard,

Beshears and Kosowsky (2020) summarize that while automatic enrollment in retirement savings plans and personalized energy consumption reports did yield statistically significant effects, these are not sufficient to mitigate the risk of a household dropping in standard of living after retirement, or to reduce a notable amount of carbon emissions (Allcott, 2011; Munell et al., 2018).

With regard to achieving a more sustainable transportation system, a simple answer may be to dismiss nudging as an effective intervention. More concerningly, however, nudges have been found to backfire. Unsolicited, obvious nudging can cause reactance, or a backfiring effect, as was documented in chapter 4, perhaps leading individuals to pro-actively perform the undesired behavior. Additionally, small-scale, low-cost interventions such as nudges may convey a feeling of accomplishment, but truly stand in the way of larger scale structural change (Maier et al., 2022).

While nudges were initially thought to simply generate impactful changes in transportation (Avineri, 2009), results of chapters 3 and 4, conjoint with the other recent literature, paint a less hopeful picture. Much as identified in chapter 2, tailored nudges may be more effective than one-size-fits-all approaches, and recent research advocates that heterogeneous data is needed to allow for personalized nudges (Mills, 2022). However, this poses challenges for acquiring data and causes privacy concerns, and nudges may lose their great appeal of being quick and simple to implement. The transportation domain, in which behaviors are often habituated and costs are involved, may not be the right arena for nudges. Moving forward, policymakers and other nudgers need to carefully consider the potential harm before implementation, and reflect if the implementation of a nudge derails progress of other interventions. In conclusion, while nudges may have some efficacy, expecting progress within the mobility transition solely based on nudges seems doubtful.

6.2.3 Environmental concern

A construct that appeared across studies because it is presumably associated with travel behavior is environmental concern. Environmental concern was defined as the extent of awareness of current environmental issues (for this purpose, within the transportation sector) as well as the personal effort to contribute to their solution (Dunlap & Jones, 2002). However, the predictive value and impact of environmental concern is currently debated in the literature (Hsu et al., 2019). While some research suggests that the inclusion of environmental concern as a variable can enhance the prediction of mode choice and other travel behavior (e.g., Donald et al., 2014), other studies found that environmental concern rarely leads to changes in behavior

(Beirão & Cabral, 2008; Heimlich & Ardoin, 2008). For instance, studies on EV adoption (Mohamed et al., 2016; Ng et al., 2018), car use (Gardner & Abraham, 2010), or transit use, found that environmental concern is outweighed by other concerns such as for security or safety (Hsu et al., 2019), and that specific attitudes or beliefs are better predictors of travel behavior (Hunecke et al., 2010)

This dissertation contributes to this debate around the impact of environmental concern. The MaaS (chapter 3) and the nudging study (chapter 4) both found that, in the presence of other attitudinal and economic concerns, environmental concern had little to no direct influence on manifested mobility behavior. In the MaaS study, focus group results indicate that individuals do not expect that their concern about the environment would alter their own or other's mode choice. Similarly, in the nudging study, environmental concern was the only insignificant predictor for intention to subscribe to a transit ticket. In the longitudinal study (chapter 5), environmental concern did not change over time, suggesting that it is likely personality-related, and thus rather stable and harder to influence by external factors (Hirsh, 2010).

In summary, the results of the present studies support the notion that the effect of environmental concern on behavioral intention in transportation is low. Given that environmental concern is challenging to influence and does not have direct impact on mobility behavior, it may be wise to be cautious when dedicating efforts to interventions solely based on this factor.

6.2.4 The use of attitudinal constructs in transportation research

In the realm of interdisciplinary transportation literature, encompassing fields such as engineering and economics, there has been a growing recognition of the importance of attitudes that influence traveler's behavior (De Vos, 2022). The present work emphasizes the impact of attitudes on mobility behaviors. Specifically, the clustering study in chapter 2 revealed that attitudes toward modes are important in forming a joint affinity variable toward a particular mode. Furthermore, in the nudging study in chapter 4, attitude toward purchasing a transit ticket had strong predictive power. In the study on Covid-19 impacts in chapter 5, attitude toward teleworking was the strongest predictor for the intention to telework in the future.

In the literature, various models conceptualize attitudes, a prominent one being the theory of planned behavior (Ajzen, 1991). This theory served as a basis for the model in chapter 2 and for the item design in chapter 5. If attitudes are precisely defined, and related questionnaire items therefore follow a specific operationalization, they are known to achieve

good predictive value (Hunecke, 2015). In fact, attitudes toward transportation have been documented as having a bi-directional relationship with mobility behavior (Kroesen et al., 2017).

It is highly beneficial that attitudes have been recognized as a critical component in interdisciplinary transportation literature, because mobility choices are made within a complex web of infrastructural and spatial, economic, social, and psychological (e.g., social norms, habits, emotions) factors and constraints (Aarts & Dijksterhuis, 2000; Bamberg, 2010; Hunecke, 2015; Steg, 2005).

However, for interdisciplinary work to be fruitful, researchers of different disciplines need to speak the same language. Currently, there are discrepancies between the psychological transportation literature and the engineering/economics transportation literature regarding the term "attitude". Specifically, the latter seem to use "attitude" as an umbrella term to refer to various latent, subjective, potentially psychological constructs. For instance, researchers use items related to car dependence, perceived safety, travel minimizing, or environmental concern under the same, unspecific term "attitude" (e.g., Cao et al., 2007¸ Collins et al., 2022; Mitra & Nash, 2019). As a result, a single "attitude" construct may be used as a predictor for some choice or behavior, even though it consists of a combination of items concerning conceptually and practically different themes. For example, items regarding the 'effect of the Covid-19 pandemic on work and life' and items regarding the 'value of general travel' have been combined as an "attitude" predictor (Collins et al., 2022). This is not to say that authors do not fully understand attitudes, but that the term is used with different meanings. Despite a meticulous discussion of the concept and definition of attitudes in a study by Kroesen and Chorus (2018), it was later operationalized using items that address environmental concern, safety, health, or affective motives.

"Attitude" has become a catch-all for a multitude of psychological constructs. This is understandable, given that the standard English definition of attitude simply refers to "the way you think and feel about somebody or something" (Oxford dictionary, 2023), which potentially includes all of the statements above. This does not reflect the narrower psychological definition, and the lack of specificity poses several problems.

For one, if constructs are not labeled precisely, the comparison of results across studies, discourse on, and learning from results is inhibited. The construction of replicable models becomes more difficult. If different concepts are conflated into a single construct, the underlying factors contributing to the outcome cannot be distinguished, potentially distorting the implications for action. To illustrate, in chapter 2 of this work, the attitude toward modes

correlated strongly with its use, whereas the psychological construct of satisfaction formed its own, general satisfaction variable and had little relation to mode use. Were these two constructs not separated, this result would not have shown. Finally, if we do not speak the same language, this lack of consistency in terminology hinders interdisciplinary collaboration, which is essential for achieving a sustainable and equitable mobility transition.

Hence, transportation researchers need to recognize this issue, so that each discipline is aware of the other's use of vocabulary and that eventually, a consensus on using the term "attitude" can be reached. As the term originates from the field of psychology and because this definition is more precise, I, personally, suggest to use "attitude" only when using a specific definition, while labelling any other constructs by their own name. Certain studies in the engineering and economics domains already use "attitude" as one of several distinct psychological constructs (e.g., Paulssen et al., 2014; Shetty et al., 2020). If expertise to do so is lacking, an alternative approach could be to use "psychological factor" as an umbrella term for subjective, latent constructs.

6.3 CONCLUSIONS ON HOW TO MOVE FORWARD IN THE MOBILITY TRANSITION

These present findings allow to recommend measures that have proven useful, and to dissuade measures that seem futile in the pursuit of a sustainable and equitable mobility transition by targeting human behavior. However, this research presents only a few pieces of the puzzle toward achieving this goal. Solving the mobility transition is, of course, beyond the scope of this dissertation. This is an extremely difficult endeavor, and fulfills all characteristics of a complex problem: numerous variables are involved, they are interconnected and mutually dependent, the situation is dynamically changing, variables are partly untransparent, and goal states partly contradict each other (e.g., sustainability and equity) (Funke, 2012). In the introduction, it was demonstrated that even common awareness of the problem among stakeholders of transportation does not yet exist (Drexler et al., 2022), so undoubtedly, there is still a substantial amount of work to be carried out.

Evidently, no standalone intervention can singlehandedly solve the environmental, economic, and social issues posed by transportation. The results support the notion that a combination of push and pull measures is necessary: sustainable alternatives need to be made more appealing and accessible, while unsustainable alternatives such as cars need to be restricted or made inconvenient. Additionally, the findings highlight the significant role that psychological factors, such as attitudes and habits, play in individuals' mobility behavior.

Therefore, targeting these psychological factors is essential to support sustainable mobility choices.

Consequently, this dissertation emphasizes the importance of considering traffic psychology in transportation at several instances: Mobility users are not only diverse in their behaviors and access options, but also in their needs and preferences, and efforts to enhance equity and sustainability must be tailored to these specific preferences. While new concepts like Mobility as a Service may cater to functional aspects of mobility, they do not currently meet other psychological needs associated with car ownership, such as symbolic and affective motives, which renders them unattractive to certain individuals. Nevertheless, MaaS can fulfill its own affective and symbolic motives, which should be emphasized more prominently. The disruption of mobility habits brought about by the Covid-19 pandemic, specifically the increased prevalence of telecommuting, has not altered fundamental attitudes toward car use. Individuals' attitude toward telecommuting is the most influential factor in predicting their intention to engage in it in the future, thereby serving as a significant lever for increasing telecommuting rates. Finally, improving individuals' (subjective) tech-savviness is critical since access to mobility increasingly depends on it.

The present results also reinforce the assertion that only an interdisciplinary, multi-facetted approach, which includes psychological factors, but also technical innovations, and the broader social, economic, and political context, can fully grasp the complex causes and effects of mobility behavior. Such an approach may generate a basis from which interventions and policies can be derived. Therefore, the present findings do not only have implications for psychologists involved with travel behavior, but for transport planners, policymakers, service providers, and other stakeholders of the transportation universe.

Ultimately, in the future, instead of saying that *"Few travelled in these days, for, thanks to the advance of science…"* (Forster, *The Machine Stops*, 1909), we hope to find that everybody will travel as they wish, because thanks to the advance of science, sustainable travel is readily available to all.

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8 APPENDIX

8.1 APPENDIX FOR CHAPTER 2

Appendix 2-A

Table AP-1. *Phrasing and scales for the 42 variables selected for cluster segmentation*

Variable	Phrasing	Scale
Psychographic		
Satisfaction Car Satisfaction Bike Satisfaction Walk Satisfaction Transit	How do you rate your local traffic situation for the following modes of transport?	1 (inadequate) – 6 (very good)
Attitude Car Attitude Bike Attitude Walk Attitude Transit	In daily life, I enjoy using: [resp. transportation mode]	1 (do not agree) – 6 (fully agree)
Socio-demographic		
Education	What is your highest school/education degree?	0 (no degree yet) – 4 (university)
Extent of occupation	To what extent are you currently working?	0 (not working) – 3 (full time)
Economic status	*Calculated from household size and income (Nobis and Köhler, 2018)*	1 (very low) – 5 (very high)
Size of household	How many people live in your household?	#
Number of children younger than 14 in household	How many people younger than 14 live in your household?	#
Mobility behavior general		
Use of rental/sharing bikes in daily life Use of carsharing Use of private car Use of bikes Use of local transit Amount of walking Use of trains with a distance of min. 100 km Use of buses with a distance of min. 100 km	Please index how often you usually use the following modes of transport	1 ([almost] never) – 5 ([almost] daily)

Variable	Phrasing	Scale
Mobility behavior on reference date		
Sum of annual mileage of cars in the household	*not applicable*	kilometers
Time en route		minutes
Mileage		kilometers
Average speed in km/h		km/h
Percent of intermodal trips		%
Number of trips		#
Mobility equipment and access		
Availability of bikes	Do you have access to a functioning bike /ebike or pedelec?	0 (no) – 1 (yes, at least 1)
Availability of car (as driver or passenger)	How often do you have access to a car (incl. carsharing) as driver or passenger?	1 (never) – 3 (always)
Number of motorbikes in household Number of cars in household Number of bikes in household	How many of the following vehicles are there in your household?	#
Carsharing membership	Are you a member of a carsharing program?	0 (no) – 1 (at least with 1 provider)
Driver's license	Do you have a driver's license?	0 (no) – 1 (yes)
Transit ticket	What type of ticket do you usual use when riding local transit?	0 (never use pt) – 4 (abonnement)
Mobility-related tech-savviness		
Use of smartphone/tablet for …schedule/delay information …ticket purchase …route planning/navigation	Do you use portable internet-capable devices such as tablets or smartphones for the following purposes?	0 (no) – 1 (yes)
Use of e-commerce	How often do you shop on the internet?	0 (no internet access) – 6 ([almost] daily)
Geographic data		
Spatial typology	*Calculated using geographical data (Nobis & Kuhnimof, 2018; Nobis and Köhler, 2018)*	1 (rural) – 7 (metropole)
Quality of local transit		1 (very bad) – 4 (very good)
Quality of local amenities		

Appendix 2-B

Table AP-2. *Comparison of basic socio-demographic data between original MiD sample and reduced sample*

	Original sample Mean (SD)/%	**Reduced sample** Mean (SD)/%	**Change: original sample to reduced sample**
Gender (male)	49.56%	52,51%	2.95%
Age in years	53.05 (18.65)	53.53 (16.09)	0.90%
Education *0 (no degree yet) – 4 (university)*	2.74 (1.58)	2.75 (1.18)	0.36%
Economic status *1 (very low) – 5 (very high)*	3.40 (0.91)	3.49 (0.90)	2.65%

8.2 APPENDIX FOR CHAPTER 3

Appendix 3-A

Table AP-3. *Mobility types used for the MaaS study, adapted from Schäfer & Quitta (2016)*

Mobility type	**Routes**	**Mode use**	**Attitudes**	**Availability**
Car individualist	very mobile	mostly car	neg. toward bike/transit	increased car availability
Pragmatic transit user	rather fewer routes and shorter distances	mostly transit	no special affinities, pragmatic	low car av., transit ticket av.
Environment. aware type	shorter distances	mostly transit/ bike	neg. toward car	
Multioptional type	many routes, but shorter distances	multimodal, depending on purpose of route	no special affinities	varying
Bike affinity type	varying	bike/public transp. as useful	preference for bike	
Forced mobile type	many routes, long distances, forced destinations	mostly car	neg. toward all modes, incl. car	increased car availability

Appendix 3-B

Table AP-4. *Descriptive and socio-demographic information of focus group participants*

Group	ID	Inner city	Age	Gender	Access to car	Heard of MaaS	Mobility Type
1	T3_1811	outside	63	f	no	no	4
	T2_1811	outside	65	m	yes	yes	4
	T1_1811	outside	65	m	yes	no	4
	T4_1811	outside	57	f	no	no	4
2	T4_2511	inside	25	m	no	no	2
	T2_2511	inside	24	m	yes	no	2
	T3_2511	inside	31	m	no	yes	4
	T1_2511	inside	28	f	yes	yes	5
3	T2_0212	outside	26	m	yes	no	2
	T1_0212	inside	22	f	yes	no	4
	T4_0212	outside	23	m	yes	no	1
	T3_0212	outside	24	f	no	no	2
4	T3_0412	outside	43	f	no	no	2
	T1_0412	outside	45	f	yes	no	1
	T4_0412	outside	44	f	yes	no	2
	T2_0212	outside	46	f	yes	yes	2
5	T1_0912_1	inside	18	f	no	yes	4
	T3_0912_1	outside	22	f	no	no	2
	T2_0912_1	outside	22	m	no	no	4
6	T4_0912_2	outside	25	f	no	no	4
	T2_0912_2	inside	23	m	yes	no	6
	T3_0912_2	inside	25	f	no	yes	2
	T1_0912_2	outside	32	f	yes	no	6
7	T1_1012	outside	53	m	yes	yes	4
	T3_1012	outside	61	m	yes	yes	4
	T2_1012	inside	65	m	no	yes	3
8	T2_1512	inside	33	f	no	yes	4
	T3_1512	inside	30	m	no	yes	2
	T1_1512	outside	32	m	no	yes	4
	T4_1512	outside	54	f	no	no	2
9	T3_1612_1	outside	39	m	yes	yes	4
	T1_1612_1	outside	31	f	yes	no	2
	T2_1612_1	inside	35	f	yes	no	4
	T4_1612_1	inside	37	m	yes	no	4
	T5_1612_1	inside	19	f	no	no	4
10	T1_1612_2	outside	23	f	yes	no	6
	T2_1612_2	inside	19	f	yes	yes	1
	T3_1612_2	outside	23	f	yes	no	1
11	T2_2312	outside	58	m	yes	no	1
	T4_2312	outside	70	f	yes	yes	1
	T3_2312	outside	63	f	yes	no	6

Group	ID	Inner city	Age	Gender	Access to car	Heard of MaaS	Mobility Type
	T1_2312	outside	65	m	yes	no	1
12	T1_1301	outside	60	f	yes	no	1
	T2_1301	outside	57	m	yes	no	1
	T3_1301	outside	65	f	yes	no	1
	T4_1301	outside	45	f	yes	yes	1

Note. Mobility types coded as: 1 = car individualist, 2 = pragmatic transit fan, 3 = environ-mentally aware type, 4 = multioptional type, 5 = bike affinity type, 6 = forced mobile type.

8.3 APPENDIX FOR CHAPTER 4

Appendix 4-A

Figure AP-1. *Example condition Default-Social Norm (DSN)*

§ 5
Jobticket

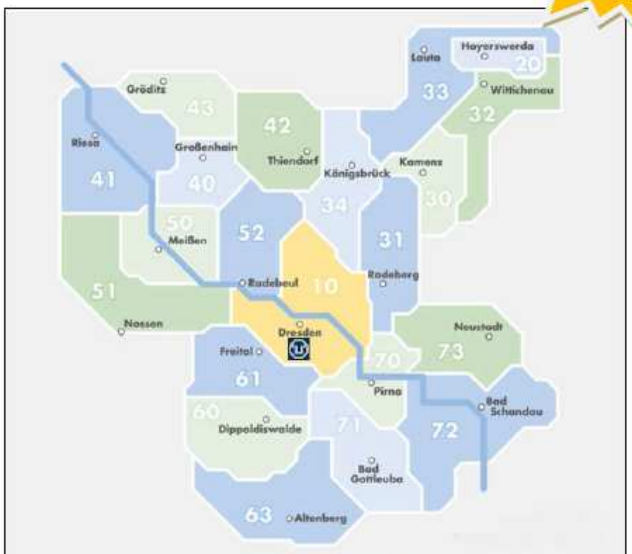
State employees automatically receive a job ticket based on their home address. You are free to unsubscribe from the job ticket at any time.

The job ticket is a monthly subscription ticket at a 20% discount for the local public transport and is offered as part of the environmental management of TU Dresden.

- Personal use from Mondays till Fridays from 6 am - 6 pm. During other times the ticket is transferable to any other person
- During weekends the Job ticket can be used as a family ticket
- Taking a bike is free at any time

73 % of TUD employees already use the job ticket!

Prices and fare zones



Territorial validity	Usual price for a monthly subscription ticket	Retail price monthly job ticket
Fare zone Dresden	€51,90	**€41,50**
Fare zone Dresden + 1 neighboring fare zone	€76,60	**€61,30**
Fare zone Dresden + adjacent fare zones	€114,20	**€91,40**
Whole operating area	€151,60	**€121,30**

- (●) Yes, I would like to purchase the job ticket.
- ( ) No, I would like to request the documents to unsubscribe from the job ticket.

Appendix 4-B

Group differences in the sample and subsample

The conclusion that there are no substantial differences between the four experimental conditions (DSN, D, SN, Control) in the complete sample or in the subsample was supported by test statistics: Kruskal-Wallis H tests on the complete sample (N = 373) (IV = condition), using the dependent variables education level ($\chi2(3) = 4.884$, $p = .18$), economic status ($\chi2(3) = 5.922$, $p = .12$), car availability ($\chi2(3) = 5.967$, $p = .11$), geographic living region (inside the city vs. surrounding villages; $\chi2(3) = 2.989$, $p = .34$), satisfaction with transit ($\chi2(3) = 1.552$, p = .67) and attitude toward transit ($\chi2(3) = 3.248$, $p = .36$) confirmed that there were no substantial group differences. The same was true for the subsample of N = 212 (IV = condition) and the same dependent variables: education level ($\chi2(3) = 2.674$, $p = .45$), economic status ($\chi2(3) = 2.207$, $p = .53$), car availability ($\chi2(3) = 3.182$, $p = .36$), geographic living region ($\chi2(3) = 4.036$, $p = .26$), satisfaction with transit ($\chi2(3) = 5.048$, $p = .17$) and attitude toward transit ($\chi2(3) = 1.335$, $p = .72$).

Appendix 4-C

Table AP-5. *Phrasing and scales for the items of the extended theory of planned behavior*

Item	Phrasing	Answer scale 1 - 7
Attitude		
AT1	My attitude toward purchasing the Job ticket is…	negative - positive
AT2	I find purchasing the Job ticket is…	a bad idea - a good idea
AT3	I find purchasing the Job ticket is…	disadvantageous - advantageous
AT5	I find purchasing the Job ticket is…	not desirable - desirable
AT4	I find purchasing the Job ticket is…	not reasonable - reasonable
Subjective norm		
SN1	Most people who are important to me would find it good if I purchased the Job ticket.	unlikely - likely
SN2	Most people who are important to me would want me to purchase the Job ticket.	
SN3	The people who are important to me would find it desirable that I purchase the Job ticket.	
SN4	My colleagues would support my decision to purchase the Job ticket.	
SN5	Most people in my situation purchase the Job ticket.	
SN6	The people who are important to me would purchase the Job ticket if they were in my place.	
SN7	Most of my future colleagues possess a Job ticket.	

Item	Phrasing	Answer scale 1 - 7
Perceived behavioral control		
PBC1	For me, purchasing the Job ticket is…	complicated - simple
PBC2	Buying the Job ticket is not very complex.	disagree - agree
PBC3	For me, purchasing the Job ticket is…	laborious - easy
PBC4	If I wanted to purchase the Job ticket, it would be easy for me to do so.	disagree - agree
PBC5	Whether I purchase the Job ticket or not is completely up to me.	disagree - agree
Environmental concern		
EC1	I am worried about CO^2 emissions caused by motor car use.	disagree - agree
EC2	I would be willing to use my car less if that helped the environment.	
EC3	Substantial political change is necessary to increase the sustainability of the traffic and transportation sector.	
EC4	Substantial social change is necessary to increase the sustainability of the traffic and transportation sector.	
EC5	Anti-emission laws should be implemented more strictly.	
EC6	If more employees would purchase the Job ticket, the environment would profit.	

8.4 APPENDIX FOR CHAPTER 5

Appendix 5-A

Table AP-6. *Additional items and scales from the 2021 questionnaire used in the model in chapter 5*

Job allows telework	*Assume there was no pandemic. Please answer the follow-ing questions regarding the possibility of teleworking at your job.* What is the maximum frequency that the nature of your job would allow you to telework?							
	never	less than once a month	1-3 times a month	1-2 times a week	3-4 times a week	5 or more times a week		
	0	1	2	3	4	5		
Future telework	*What day(s) of the week would you like to telework once the pandemic is over?*							
	Mon-day	Tues-day	Wed-nesday	Thurs-day	Friday	Satur-day	Sund-ay	Flex/ variable sched.	Will not/ don't want to telework
	1	2	3	4	5	6	7	8	0
	Coding: Number of days indicated (will not/do not want to telework: 0); if "Flex/variable schedule": sample mean of selected days of the week imputed (2.08)								
Commute status	*Binary variable adapted from Iogansen et al, 2022*								
	1, PC	Commuted for both timepoints							
	2, TC	Started remote study/work entirely during the pandemic							

Appendix 5-B

Constructs consisting of two items only

Three of the 8 constructs consisted of two items only. Two-item constructs run the risk of being unstable (Costello & Osborne, 2005), especially if they are conceptualized as multidimensional. But if a construct is narrowly defined, assessing it with as little as one item may be acceptable (Bergkvist & Rossiter 2007; Drolet & Morrison 2001; Wanous et al., 1997). In fact, a two-item construct can be considered reliable when the items correlate highly but remain relatively uncorrelated with other items (Worthington & Whittaker, 2006, p. 821). To assess if the three two-item constructs in the present analysis can be considered stable, the respective items were correlated with all remaining items. For the *car dependence*, the two items correlate acceptably with each other ($r = .51$), and little with all other items ($r < .30$). For the *active lifestyle*, the two items correlate acceptably with each other ($r = .51$), and little with all other items ($r < .32$). For the *driving affinity*, the two items correlate acceptably with each other ($r = .62$), and little with all other items ($r < .39$). We conclude that, while the assessment of these items may not be perfect using only two items, judging from these correlations and the construct reliability (Table 5-2), we can judge these items as stable.

Appendix 5-C

Table AP-7. *MANOVA results of attitudinal group differences (PC vs. TC) for 2020 and 2021*

Construct	**2020**		**2021**	
	F (df1, df2)	*p*	F (df1, df2)	*p*
Pro micromob.	F(1, 979) = .001	> .05	F(1, 979) = .230	> .05
Against TC	F(1, 979) = 89.44	**	F(1, 979) = 125,254	**
Driving affinity	F(1, 979) = 12,20	**	F(1, 979) = 14,800	**
Concern ab. path.	F(1, 979) = 6,21	*	F(1, 979) = .217	> .05
Active lifestyle	F(1, 979) = 0,588	> .05	F(1, 979) = 4,075	*
Tech-savviness	F(1, 979) = 0,620	> .05	F(1, 979) = 5,143	*
Pro.env.transport	F(1, 979) = 15,480	**	F(1, 979) = 10,626	**
Car dependence	F(1, 979) = 26,099	**	F(1, 979) = 13,653	**

Note. **significant at .01 level; *significant at .05 level

Appendix 5-D

Table AP-8. *Means and respective standard deviations of constructs (scale 1-5) for both years (2020, 2021) and groups (PC, TC)*

	Year	**PC (N=523)**		**TC (N=458)**		**Total (N=981)**	
		Mean	SD	Mean	SD	Mean	SD
Pro micro-mobility	2020	2,68	0,95	2,68	0,91	2,68	0,93
	2021	2,69	0,98	2,72	0,92	2,71	0,95
Driving affinity	2020	3,84	1,05	3,53	1,16	3,70	1,12
	2021	3,77	1,08	3,47	1,18	3,63	1,14
Concern ab. path.	2020	3,63	1,03	3,79	0,92	3,71	0,98
	2021	3,15	1,13	3,20	1,11	3,17	1,12
Tech-savviness	2020	3,48	0,86	3,46	0,83	3,47	0,85
	2021	3,51	0,90	3,41	0,85	3,47	0,88
Pro env. friendly transport	2020	2,96	1,09	3,22	1,05	3,08	1,08
	2021	3,00	1,01	3,22	1,00	3,1	1,01
Active lifestyle	2020	4,23	0,83	4,28	0,71	4,25	0,78
	2021	4,22	0,81	4,32	0,71	4,26	0,77
Car dependence	2020	3,37	1,17	3,01	1,22	3,2	1,21
	2021	3,45	1,18	3,15	1,19	3,31	1,19
Attitude against telecommuting	2020	3,21	0,76	2,72	0,85	2,98	0,84
	2021	3,19	0,89	2,56	0,87	2,90	0,92

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The AI chatbot ChatGPT by OpenAI was used to correct spelling and grammar, and to find synonymous expressions where necessary.

9.5 CHAPTERS 1 AND 6

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Thank you.

CONFIRMATION IN ACC. WITH § 5 OF THE REGULATIONS FOR OBTAINING A DOCTORAL DEGREE

I herewith declare that I have produced this dissertation without the unauthorized assistance of third parties and without using any resources other than those specified; assistance from third parties was only obtained to an extent that is scientifically justifiable and permissible under examination regulations, and notions taken over directly or indirectly from other sources have been identified as such. There have been no unauthorized monetary transactions, either directly or indirectly, related to the content of this dissertation to third parties.

No previous doctorate proceedings have been undertaken, and this dissertation has not previously been presented in identical or similar form to any other German or foreign examination board.

This dissertation was prepared between 03/2019 and 08/2023 at the Institute of Transportation Planning and Road Traffic at Dresden University of Technology, at the Boysen-TU Dresden-Research Training Group, and at the Institute of Transportation Studies at the University of California, Davis.

It was supervised by Prof. Dr. rer. nat. habil., Tibor Petzoldt (TU Dresden). Individual chapters have additionally been advised by Dr. rer. nat. Jens Schade (TU Dresden), Prof. Dr. rer. pol. Edeltraud Günther (UNU Flores), and Prof. Dr. Giovanni Circella (UC Davis).

I herewith recognize the Regulations for Obtaining a Doctoral Degree of the School of Science at Dresden University of Technology in the version dated February 23, 2011, last amendment May 23, 2018.

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