The role of data in sustainable urban mobility policy

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THE ROLE OF DATA IN SUSTAINABLE URBAN MOBILITY POLICY

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Chapter I

Introduction

Sustainable urban mobility is one of the main challenges facing cities in the EU and a matter of concern for many EU citizens (ECA, 2020). Mobility plays a role in most economic and social activities, and, accordingly, enables economic growth and societal and human development. At the same time, however, urban areas are burdened with negative impacts from transport activities, such as congestion, harmful emissions, traffic accidents, and noise. Transport is a major source of greenhouse gas (GHG) emissions, and one of the few sectors in Europe where emissions did not decrease between 1990 and 2017 (EEA, 2019). Modelling of abatement options has shown that new, cleaner propulsion technologies (e.g. electric vehicles) will not reduce CO_2 emissions of transport sufficiently to achieve the European climate goals (EC, 2021). Various ways to address these issues have been proposed. Car trips should be replaced by public transportation and, at shorter distances, by 'active travel' (i.e. walking, cycling, e-biking) (Brand et al., 2021). Avoiding the need to travel in the first place (for instance through online working) is another possible strategy.

Generally, the sustainable urban mobility transition refers to a reconfiguration process of the urban mobility system resulting in a significant reduction of the share of car mobility being the most unsustainable form of mobility (Banister, 2008, Cairns et al., 2014), whilst ensuring a high and socially equal level of accessibility. Given the tremendous scale of the sustainable urban mobility transition challenge, it is crucial that policies to achieve this are designed and implemented soon.

This chapter introduces the focus of my PhD thesis. It first explores the background of the sustainable urban mobility challenge (1.1). It then describes the overall research questions (1.2), which is followed by an overview of the research approach and the methods (1.3).

1.1 Background and challenges

1.1.1 The future is urban

Although only 3% of global land is occupied by cities, 56% of the world population currently lives in cities, a number that will increase to 70% by 2050 (IBRD, 2022)[1]. In automobile-dependent cities, 35-50% of the land is used for road and parking lots (Rodrigue, 2020), which gives an indication of the spatial impact of car mobility.

Cities are facing an increasing amount of challenges due to urbanization and climate change. More than 60% of greenhouse gas (GHG) emissions are caused by cities while cities are also responsible for 78% of the global energy consumption (Finck et al., 2020b). Concerning urban mobility, more than 33% of GHG emissions are caused by all different modes of transport globally (OECD, 2020). In the European context, 77% of all EU transport GHG emissions are caused by road transport, constituting the highest proportion of all transport emissions (see Figure 1.1).

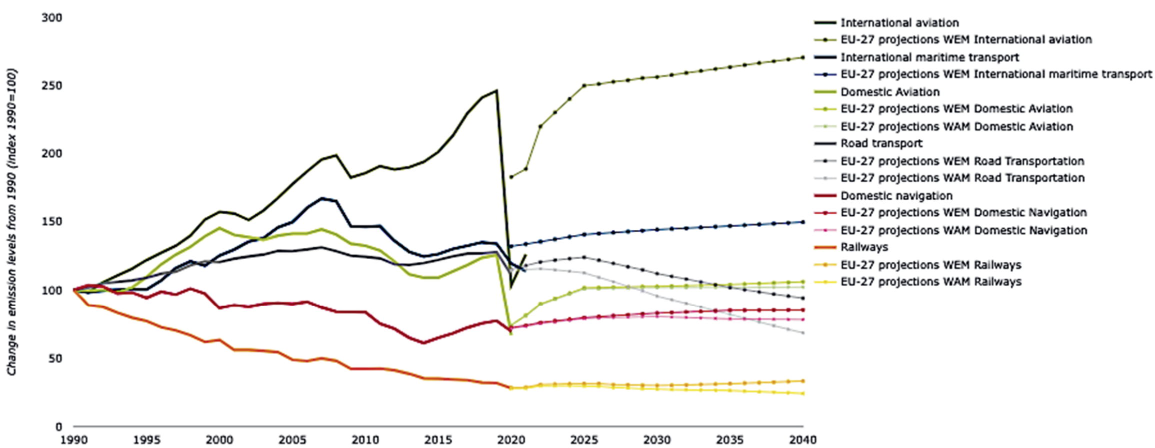

Figure 1.1. Greenhouse gas emissions from transport in the EU, by transport mode and scenario (EEA, 2022)

However, as cities account for a large share of pollution and emissions of greenhouse gases, they can also provide opportunities to solve this problem due to their high density and small share in global land use. Compact urban areas with high densities of citizens and activities offer conditions to reduce per capita energy consumption, road trips, and CO_2 emissions (Seto et al., 2011). In addition, city governments could address these issues in case national governments fail to do so (Barber, 2013). Thus, the city level seems critical to effectively

[1] This thesis uses the term urban area and city as synonymous, referring to them as places characterized by 'a population of at least 50,000 inhabitants in contiguous dense grid cells (>1,500 inhabitants per square kilometer)' UN 2020. National Sample of Cities. *In:* HABITAT, U. (ed.). https://unhabitat.org/sites/default/files/2020/06/national_sample_of_cities_english.pdf.. The functional urban area consists of a city and its commuting zone.

mitigate environmental degradation and reduce emissions, whilst retaining accessibility and livability (Gabrielli et al., 2014).

1.1.2 The emergence of the Sustainable Mobility concept

In the 1990s, awareness that urban mobility as it was developing was not sustainable became more mainstream among local governments in Europe (ECA, 1992). The term 'unsustainable' in those days was associated with the impact of car mobility, especially congestion, harmful emissions (particulate matter, nitrogen oxides), traffic accidents and noise. The need for a different approach was seen, which included a much higher priority of public transportation. Besides the promotion of public transport, technology was also introduced to manage mobility demand, in particular to use existing infrastructure more optimally (e.g. traffic control systems, parking indicator systems, traffic free central areas etc.).

Although local governments have the most specific executive policy power concerning urban mobility through the subsidiarity principle, it was the EU that started to voice increasing ambitions and plans (Halpern, 2014). The concept of 'sustainable mobility' first appeared in the 1992 EU Green Paper on the Impact of Transport on the Environment (ECA, 1992). Figure 1.2 shows the European directives and policy instruments introduced to support the development of sustainable mobility. In this thesis, 'policy' is defined as a course of action or plan formulated by a public authority, including the selection of goals and the means of achieving them, to address specific problems that affect societies directly and indirectly, across various time scales and geographical spaces (Estrada, 2011).

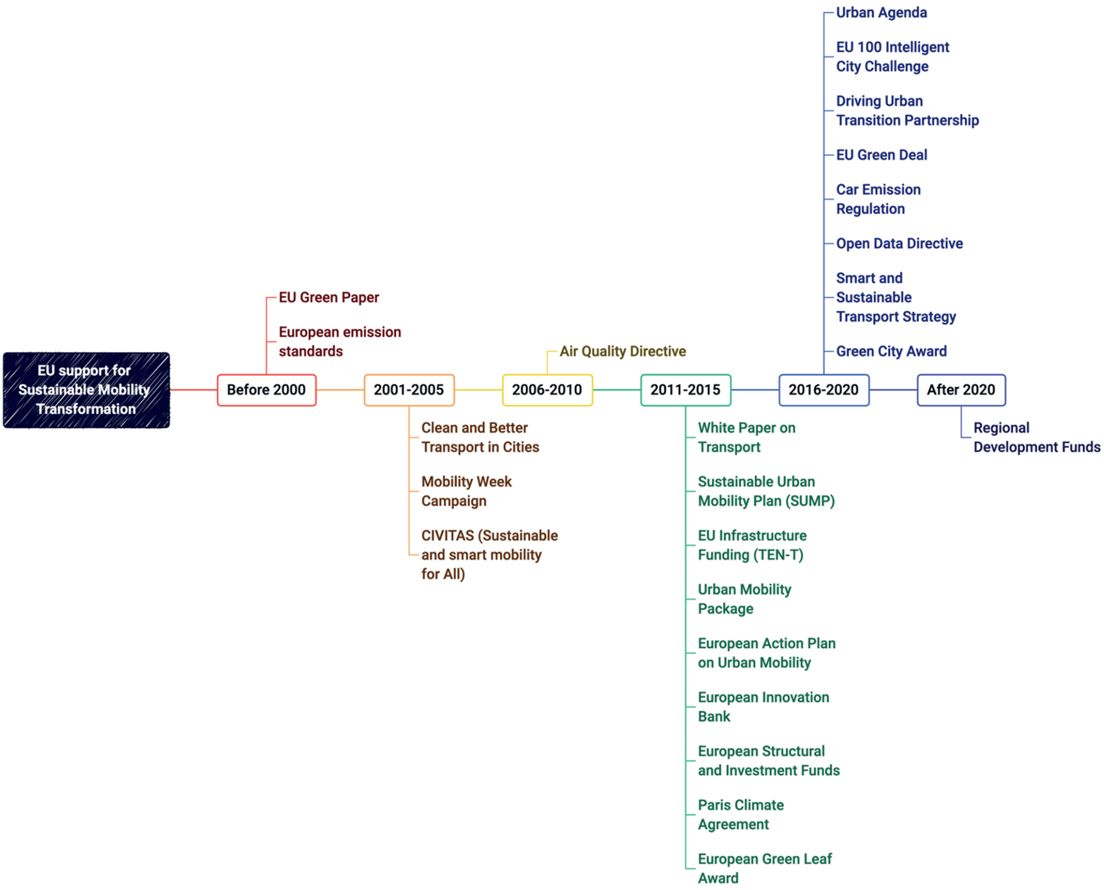

Figure 1.2. EU policy instruments to support Sustainable (urban) Mobility Transformation

However, urban policymakers continued to struggle to find a good compromise concerning constraining and enabling car use (Curtis and Low, 2012). Although many cities developed visions of reduced shares of car mobility, they did not yet fully abandon the car-enabling logic of 'predict-and-provide', i.e. predicting where (car road) congestion issues may arise in the future, and adding infrastructural (road) capacity to mitigate it.

The measures that policymakers introduced to constrain car use can be grouped into two broad categories: 'push' and 'pull' measures (Batty et al., 2015b, Curtis, 2015). 'Pull' measures aim to increase the supply of high-quality car alternatives, i.e. low carbon transport modes such as public transport and active mobility (walking, cycling), and to increase the supporting infrastructure for these modes (Buehler et al., 2017b, Strompen et al., 2012). 'Push' measures, on the other hand, aim to discourage car use, e.g. by making it more expensive or less convenient, for instance by implementing road pricing and congestion charges, or traffic calming measures (Buehler et al., 2017b, Strompen et al., 2012, Curtis, 2015). To encourage a modal shift most effectively, it is generally accepted that both 'push' and 'pull' types of measures are needed (Black and Schreffler, 2010, IEA, 2009a, Strompen et al., 2012), although in practice this was hardly done, seemingly due to "a lack of societal and political acceptance for such restrictions" (Schippl and Arnold, 2020).

In 2011 an EU White Paper claimed that 'still, the transport system is not sustainable' (EC, 2011), and placed the emphasis on developing a common strategy for decarbonization (so adding CO_2 emissions as an key element of unsustainability). Since then, the EU policy instruments such as the Sustainable Urban Mobility Plan (SUMP), Urban Mobility Package, and Trans-European Transport Network projects (TEN-T) were all shaped by the 2011 White Paper's ambition to facilitate sustainable urban mobility and target all (i.e. national, regional, and local) governance levels. A subsequent step was the publication of the EU Urban Agenda in 2016 (EU, 2016). It introduced a new multi-level working method promoting cooperation among Member States, cities, the European Commission and other stakeholders in order to stimulate growth, livability and innovation in the cities of Europe and to identify and successfully tackle social challenges. The *Partnership for Urban Mobility* action plan (EC, 2018), proposes solutions to improve the sustainability and framework conditions for European urban mobility development. It aims to stimulate the transition to sustainable urban mobility not only by upgrading infrastructures and promoting public transport, but also by integrating social aspects, such as green space and public health.

1.1.3 Increasing ambitions after 2018

After 2018 the impact of the Paris Agreement (2015) became more apparent in mobility policy. On December 11th 2019, the European Commission issued the European Green Deal to announce the EU target of climate-neutrality by 2050, which requires the transport sector reducing 90% emissions (EU, 2019b). "Accelerating the shift to sustainable and smart mobility" is one of the eight main objectives in the European Commission's Communication and puts emphasis on:

- automated and connected multimodal mobility;
- increased production and deployment of alternative transport fuels, specifically zero- and low-emission vehicles;
- transport becoming "drastically" less polluting "especially in cities", including more stringent air pollutant emissions standards and CO_2 emission standards for vehicles (EU, 2019b).

Also, the Directorate-General for Mobility and Transport (DG MOVE) published an 'EU strategy for Sustainable and Smart Mobility' (MOVE, 2020). It mentioned that "overall, we must shift the existing paradigm of incremental change to fundamental transformation". It paid more attention to cities, specifying that "cities are and should therefore remain at the forefront of the transition towards greater sustainability" and that the European Commission will help Member States and cities to accelerate the transition by issuing and implementing different policy instruments (MOVE, 2020). .

Despite these efforts at various governance layers, progress towards sustainable urban mobility remained weak. Although a few larger European cities have successfully reduced private car use to some extent, in others it has grown (ECA, 2020). The capacity for sustainable mobility planning approaches in smaller cities and towns is weak, especially in countries outside Western and Northern Europe (Dragutescu et al., 2020). How the recent EU policies work out in cities, and whether they work in coherence or in conflict with national ones remains unclear. A key question remains how sustainable urban mobility can be promoted more effectively (Abdullah and Robles, 2021).

1.1.4 New opportunities of Data

As mentioned in 1.1.3, the European Commission launched the European Green Deal, which consists of a series of policies targeted to reach a climate-neutral Europe in 2050 (EU, 2019b). For cities, the objectives have been elaborated in the New European Urban Mobility Framework (EU, 2021). This policy framework mentions the importance of modeling "to support mobility decision-making in an integrated matter". It also emphasizes the use of urban mobility data to support sustainable urban mobility planning for which it could bring new opportunities. For instance, better monitoring data can help to 'manage' the modal shift more effectively. This requires data of the usage levels of the various modalities (bus, tram, shared bike, shared car, etc.), but also data about 'why' travelers choose the various modalities. Another example concerns data about the CO_2 gains of the modal shift, which are highly relevant with respect to the EU climate targets. The following quotation (from an interview with the director of EU Mobility and Transport Directorate-General) illustrates the increasingly important role of data in the mobility policy-making process.

'The other thing we haven't talked about is data, which is central. If you don't measure it, you can't manage it. If you don't have data, you just have an opinion' —Director of EU Mobility and Transport Directorate-General, 2021

In this thesis the term of 'data' is generally defined as a collection of discrete or continuous values that convey information about quantity and quality, to help decision makers address the substantive aspects of the problem at hand (Radin, 2013).

Data have played a role in urban mobility policymaking for decades, especially in forecasting demand, but much less in policy evaluations and assessments. Since the increasing availability and openness of (big) data, interest has grown in the new opportunities data could provide for evidence-based mobility policy-making (OECD, 2016, Urbanek, 2018). Big data are commonly defined as data with high volume (information), velocity (frequency of observation) and variety (diversity of data), such as 'track & trace' data, mobile phone traced data, and social media data. Many researchers have shown how to advance data use to improve understanding of transport policy effects, but there is hardly insight in how this is adopted in policy practice. Big data could play a role to improve the effectiveness of policies, since more evidence-based policymaking requires more data to monitor and evaluate the effect of policy measures (Howlett and Giest, 2012, Ronzhyn and Wimmer, 2021, Chalikias et al., 2020).

A number of studies have explored the role and potential of data for mobility policy. De Gennaro et al. (2016) developed a platform with five modules based on GPS and Geographic Information System (GIS) data to enhance data use in mobility policy assessments (De Gennaro et al., 2016). Their approach shows some of the possibilities of big data for policy assessment from a data-supply perspective, but does not engage with potential users or policymakers. They also mention the technical challenges of 'data-for-policy' platforms, such as definition of the data input format, the implementation and customization of data processing algorithms, the generalization and profiling of these algorithms and their interface with visualization and post-processing tools. Chalikias et al. (2020) specifically focused on parking policy in one city and created a dashboard built on open-source data and a spatial analysis platform. It enabled local mobility policymakers to explore parking planning options. Their case study shows that most of the users (policymakers, data analysts, etc.) regarded it as supporting their decision-making significantly as it gave more information from different dimensions (i.e. environmental, social and economic). Ronzhyn and Wimmer (2021) identified current and future research directions in policy modelling for data-driven policymaking. For urban mobility policy they identify as key future research directions: tapping real-time data opportunities, user involvement (to improve usability), improving data literacy, breaking silos, engaging private sector, and including data ownership in public procurement. Papyshev and Yarime (2021) discussed the use of city digital twins (CDTs) in simulating mobility policy interventions. They argued that CDTs could provide information about realistic behavioral responses to hypothetical policy interventions without breaching any legal or privacy concerns. The authors propose and show ways to generate computer-generated mobility data that could be used as an alternative source in supporting sustainable mobility policymaking. During the Covid-19 pandemic, big data, especially mobile phone data, have been applied to track mobility and to check whether governmental interventions led to mobility reductions (Jansen et al., 2021, Calabrese et al., 2021, Milusheva et al., 2021). For instance, Calabrese et al (2021) developed a solution to anonymously monitor the daily movements of Vodafone SIMs in Italy, at aggregate level, at different spatial and temporal granularity, to provide insights into the movements of Italians. Jansen et al. (2021) discuss how to maintain public trust when using mobile operator data in policy. They present five governance principles that can act as a checklist for implementing organizations: necessity and proportionality, professional independence, privacy protection, commitment to quality, and international comparability. Additionally, Nochta et al. (2021) studied the role of data in Cambridge's evidence-based urban planning. They argue that data-driven knowledge should be considered as one part of a multifaceted evidence-base to inform policy decisions. With the tendency of data-driven knowledge to claim monopoly over knowing and understanding the city, incorporating other forms of knowledge, for example, diverse 'analogue' community knowledge, requires a concerted effort from city administrators, practitioners, and researchers.

Despite an increasing number of studies on the potential of data for mobility policy, it is unclear whether and how this is adopted in policy practice. It is not known what the needs and priorities of urban mobility planners are in this respect (Isaksson et al., 2017). This means that there is a risk that the development of data-driven tools for urban mobility planning will be mainly driven by technical possibilities and potential data availability rather than by the needs of the prospective users (in particular policymakers) and actual data availability. Earlier research suggests that urban mobility policymakers often do not have enough capacity and knowledge to deal with data to support evidence-based policymaking (Chinellato, 2018). Limited financial and staff resources and gaps in technical knowledge and experience, strongly constrain the retrieval, collection, processing and interpretation of data, hence the process of monitoring and evaluation (Gühnemann, 2016). The question is how the new data potential can be used most effectively in data-driven tools that are most worthwhile for urban policymakers to support sustainable mobility.

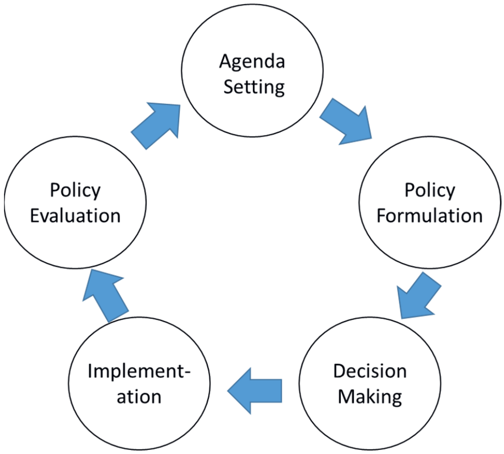

Figure 1.3. Policymaking cycle (Howlett et al., 2009)

Where new data types offer the best opportunities may also differ across the policy cycle (see Figure 1.3) (Shaxson, 2005). Which types of data are most suitable for which steps of mobility policymaking cycle? Although big data seems to bring new opportunities for mobility policymaking to better map travelers' behavior, survey data still give more insights about why commuters display certain travel patterns (Bamberg et al., 2003, McGuckin et al., 2005, Long and Thill, 2015). Are big data increasingly employed and found more useful and powerful than traditional survey data? These are questions that still need to be answered.

1.2 Research questions, research approach and thesis outline

Aim, objectives and research questions

The challenges cities are facing in practice to achieve sustainable urban mobility transformation, the new potential of data, and the limitations of the current academic literature concerning this, are the starting point of this research. It aims to explore how data can better support sustainable urban mobility transformations. The more specific objectives are to investigate the current role of data in urban mobility policy practice and to investigate how data can support urban policymakers more effectively in the sustainable mobility transformation. To achieve this aim and the objectives, the following research questions are addressed in this thesis:

1. What is the policy context of sustainable urban mobility in European cities?
2. What is the state-of-the-art in data use for sustainability assessment of urban mobility policies?
3. How is data use currently embedded in urban mobility policymaking practice?
4. What is the current use of data-driven tools in urban mobility planning practice in Europe, and what are the needs and future potential for such tools?

In order to answer the research questions, four studies were conducted, which are presented as four chapters in this thesis. In the final chapter, the outcomes of the four studies are discussed and synthesized to address the overall aim and objectives of the thesis (see figure 1.4).

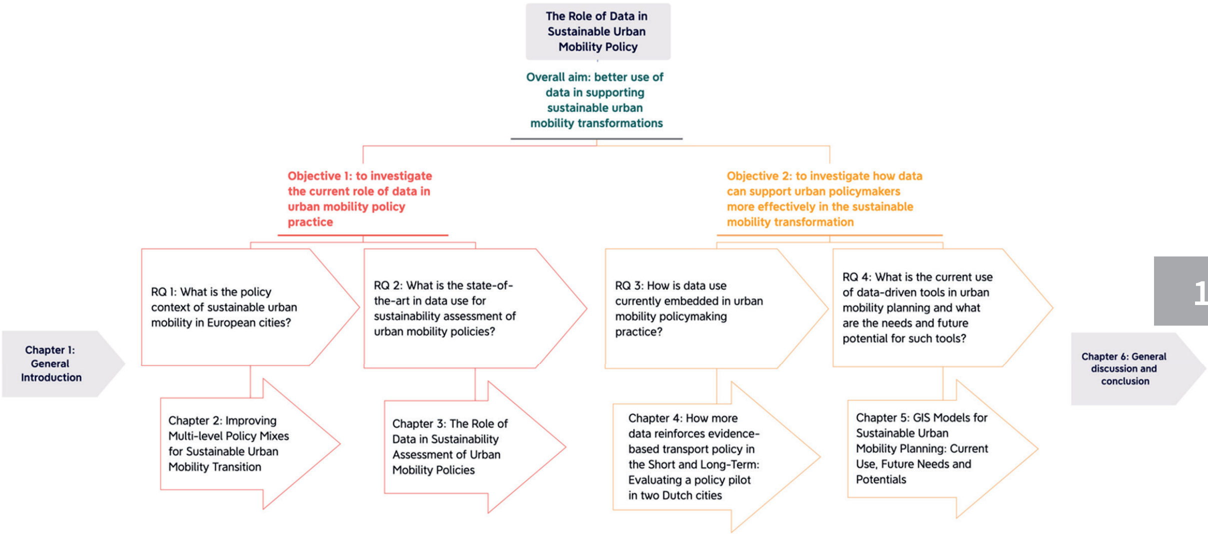

Figure 1.4. Outline of the thesis

Research approach
Policymaking is a techno-political process among social actors, entailing both the search for an optimal relationship between goals and means (i.e. technical), and search for agreement and support concerning the problem and/or solution (i.e. political) (Howlett et al., 2018). In this thesis existing policymaking processes are analyzed in the light of significant sustainability challenges in order to recommend how these can be better addressed. Accordingly, this study is primarily (societal) challenge-driven, but employing theory for sound analysis. There are various theoretic traditions for the analysis of policymaking, broadly ranging from more rational approaches to more interpretative approaches. The goal-rational approaches assume that policymaking is 'neat and rational' and that sound analysis based on good data can support policymakers in finding 'optimal' solutions. Interpretive approaches assume that policymaking is 'chaotic and messy' and that analysis can give insight in different perspectives and interests, and how power dynamics lead to particular solutions. As a challenge-driven study that seeks to understand the new potential of data for policymaking, this thesis adopts primarily a rational approach to policymaking, because it is more suitable to understand the instrumental role of data in the mix of policy aims, instruments and processes. However, I also acknowledge the limitations of this approach, and therefore the analysis does touch upon some of the various problem frames and roles of stakeholders in the analysis. Chapter 6 reflects on the strengths and limitations of this approach.

Concerning methods, a mixed-method approach is taken, combining qualitative and semi-quantitative methods. A mixed-method approach is most appropriate for this thesis because to understand the role of data in policy processes includes subtleties which can easily be missed by a single method or only quantitative methods. Both detailed information regarding data use in urban mobility policy practices and the relations between policies and processes at higher governance levels are needed.

A total of 42 semi-structured interviews and 51 completed surveys were the main data source for the thesis, and in addition, to understand the context of the responses better, 93 relevant documents were also analysed. The interviewees came from different governance layers and organizations, including municipalities (17), regional governments (6), national governments (7), European Commission (10), and NGOs (2). Through interviews with policymakers and data analysts at the urban level, as well as policymakers at higher levels, their different knowledge, experiences and perspectives concerning the role of data in policy could be tapped, jointly providing a balanced insight in the most influential factors and (in)coherencies concerning sustainable urban mobility development. In order to understand the current use of traffic models in sustainable urban mobility planning and to guide modelers developing transport models suiting policymakers' needs, a survey was conducted. A survey is instrumental to probe more general expertise and opinions of a larger set of respondents across Europe concerning matters that could be caught into a limited set of multiple-choice question and some open questions for concise answers (Harris and Brown, 2010). In the end, 51 valid replies were received from staff members of urban mobility departments, covering 42 cities in 21 European countries.

Outline

The first research question is addressed in chapter 2, with a study that seeks to better understand the context in which urban mobility planners operate, which has a multi-level character concerning policy and governance (chapter 2). Although local governments have the most specific executive policy power concerning urban mobility through the subsidiarity principle, sustainable urban mobility transition is clearly shaped by the regional, national and supranational levels too. The different policy instruments at different governance levels jointly affect urban mobility and also affect each other (i.e. form a 'policy mix'). There are hardly studies focusing on how these policies actually work in synergy or in conflict with each other in practice, and how they could be adapted to strengthen cohesion and to avoid contradiction. Do the different governance levels actually have similar policy aims and definitions of sustainable urban mobility? What are the key conflicts and synergies in the urban sustainable mobility transition between different governance levels? How to use the synergies to overcome the contradictions? These questions are addressed in this analysis that includes the EU level, and the Netherlands national, regional, and local levels.

The second research question is addressed in chapter 3, with a systematic review of the academic literature concerning how different types of data are employed in urban mobility policy assessments, focusing on 74 papers in more detail (chapter 3). Data use has become a hot topic in recent years, especially since the emergence of big data. What is the state-of-the art on this? Are some types of data found more useful than others, and more applied in mobility policymaking? Are big data (e.g. mobile phone data, social media data, GPS data, etc.) increasingly employed and found more useful than traditional survey data? This case study on data use in mobility policy includes comparisons between the role of big data and traditional survey data in urban mobility policymaking, as well as the different roles of data types in the various stages of the policy cycle.

The third research question is addressed in chapter 4, with a study that zooms in on data use in urban mobility policymaking in two Dutch cities - Maastricht and Groningen. These cities have trialed a more data-driven policymaking approach, funded through a national programme (BeterBenutten). Ten semi-structured interviews with the people working in the mobility departments and document analysis of twenty-one policy reports were conducted to understand how data is currently embedded in urban mobility policy- and decision-making and what the advantages and limitations of more data use are in these processes. This study on data use in urban mobility policy practice distinguishes different roles of big data and survey data in short- and long-term policy cycles and discusses better ways to embed data into practical mobility policymaking.

The fourth research question finally, is addressed in chapter 5, with a study that explores the needs and priorities for and potentials of data-driven support-tools for sustainable urban mobility planning, with a focus on GIS models (chapter 5). For cities, these models are the most important tools to help them understand, analyze, and assess different policy options. However, there is little insight in the needs and priorities of mobility policymakers concerning the further development of these models, and even the use and usefulness of the currently available GIS models among European urban mobility planners is unclear. How are the current GIS-based traffic models used in mobility policymaking practices within cities? What are the urban mobility policymakers' requirements and difficulties in GIS-based model use for policymaking? What are the potentials to advance GIS-based models for future mobility planning? This study on GIS models in urban mobility planning investigates these questions among European cities. The different requirements of different regions are also discussed.

2

Chapter 2

Improving Multi-level Policy Mixes for Sustainable Urban Mobility Transition

Liu, X., Dijk, M., & Colombo, C.
Improving Multi-Level Policy Instrument Mixes for Sustainable Urban Mobility Transition. Environmental Innovation and Societal Transitions, *under review.*

Abstract:

Transitioning to sustainable urban mobility, which entails, amongst others, a significant reduction of the share of car mobility, is one of the main challenges EU cities are facing nowadays. Such transition requires a complex mix of policies across multiple layers of governance. Yet, existing literature on transport policy has mostly focused on less complex policy design, i.e. concerning one modality or one governance level. Combining literatures on multilevel governance and mobility policy-mixes, in this article we explain the relationships, in terms of synergies and conflicts, of policies developed across multiple governance levels to enable a transition to sustainable urban mobility. Based on 32 interviews, focused on cities in the Netherlands, this paper first highlights two key conflicts hampering the transition to urban sustainability mobility: (1) national transport funding being biased to ‘solving bottlenecks through infrastructure’, and (2) the national level having significant influence on the local level, whilst itself being hardly influenceable by the other levels. We discuss how (a) transforming the national funding focus from infrastructure to broader mobility focus and (b) institutionalizing multi-level co-development of policies, are ways to overcome these conflicts.

Keywords:
Policy mixes, Urban mobility transition, Sustainability transition, Multi-level governance

2.1 Introduction

To achieve the goal of climate neutrality by 2050, the EU has recently raised the level of ambition in the transport sector, setting a target of 90 percent reduction in CO2 emissions (EU, 2019a). Modelling of abatement options has however shown that new, cleaner propulsion technologies (e.g. electric vehicles) will not suffice to reduce current transport emissions to the required level (EC, 2021). Car trips need to be replaced by public transportation, and, for shorter distances, investment and promotion of 'active travel', i.e. walking, cycling, e-biking, are necessary (Brand et al., 2021)[2]. Given the tremendous scale of this challenge, the level of policy ambition among European cities to develop a sustainable urban mobility transition is growing, in particular in the Netherlands (te Boveldt et al., 2022, GA, 2019, GDH, 2022). We define sustainable urban mobility transition as a reconfiguration process of the urban mobility system (Laakso et al., 2021), resulting in a significant reduction of the share of car mobility (Banister, 2008, Cairns et al., 2014), whilst ensuring a high and socially equal level of accessibility.

In the last decades, various approaches or policies to promote or facilitate alternatives to urban private car mobility have been implemented by policy makers from the urban, to the regional, national and European levels. All in all, this has led to a mix of policies affecting urban transport, including policies on car transport, public transport, and non-motorized transport, at various levels of governance. Yet, effects have been so far limited and scattered. Although private car use have been successfully reduced in a few larger European cities, in many others it has grown (ECA, 2020). At the same time, the adoption of sustainable mobility planning capacities in smaller cities and towns are weak (Dragutescu et al., 2020).

Research on sustainable transitions (Köhler et al., 2019, Kivimaa and Kern, 2016, Reichardt et al., 2016, Schmidt and Sewerin, 2019, Zepa and Hoffmann, 2023) has recently argued that attention to policy mixes, as well as the ways in which policy goals, instruments and processes therein interact, is critically important for understanding the degree to which policy facilitates (or hinders) transitions. However, studies developed so far have focused mainly on national and supranational energy issues, whilst the overall (in)coherence and (in)effectiveness of the urban mobility policy mix has remained underexposed (Howlett et al., 2017, Dijk et al., 2018)[3].

At the same time, most of the existing literature on urban transport policy tools has to date focused on the effects of single instrument choices and less complex design, i.e. often

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[2] Avoiding the need to travel in the first place (for instance through the 15-minute-city concept) is another possible strategy.

[3] The study of Zepa & Hoffmann (2023) is a positive exception in this regard, studying how policy mixes concerning sustainable energy in Latvia unfold across vertical scales of governance (i.e. local, national, European). They consider consistency, coherence, comprehensiveness and credibility of the vertical policy mix. They find that the frequently changing policy strategies and instruments at state and local levels in Latvia offset the ambitious sustainability agenda at EU level, reinforcing the status quo over substantial political and economic change.

concerning one transport modality and one governance level[4]. While many studies have noted these issues and the need for a more integrated approach to policy-making in areas such as mobility (Jordan and Lenschow, 2008, Jordan and Lenschow, 2010, Briassoulis, 2010), how exactly policies are to be better integrated, avoiding contradictory effects, remains unclear (Candel and Biesbroek, 2016, Howlett et al., 2017). In this paper we assume three possible relations between policies, building on Del Rio (2007) (del Río González, 2007) and Givoni et al (2013)[5]: (1) synergetic linkages: when policies reinforce or complement one another in achieving changes towards sustainable mobility; (2) contradictory or conflicting linkages, when two or more countervailing policy measures undermine the functional capacity of both or either to support sustainable mobility; and (3) 'neutral' relationships in case none of the above was applicable or the effect was mixed or unclear. In our definition a policy mix is more coherent when it has more synergetic linkages and less contradictory linkages between policies.

This paper seeks to develop a sharper understanding of the main conflicts of policies between the various layers of governance concerning sustainable urban mobility and start exploring how these may be overcome. More specifically, we address two questions: what are the key conflicting policies for urban sustainability mobility transition in its multi-level governance context? And how to overcome these in order to improve policy outputs and outcomes? Empirically, our study is based on 32 interviews with policymakers at four governance levels. It is focused on the case of the cities in the Netherlands, to learn about what they see as most relevant instruments concerning sustainable urban mobility transition, their effects and interference.

By answering these questions, our study seeks to contribute to academic as well as professional audiences interested in urban sustainability transitions. First, we contribute to academic research on sustainable transition and on urban mobility policy. We do so by pioneering a novel connection between two debates on (multilevel) policy mixes and urban transitions, which previous research work has urged on this topic (Hodson and Marvin, 2010). Second, we offer practical insights and recommendations for professionals to improve the vertical policy mix for sustainable urban mobility in Europe.

The paper is structured as follows. Section 2 develops a conceptual frame for our analysis, building on previous research. Section 3 describes our methodology. In Section 4, we present the findings, while Section 5 discusses the main implications for policy practitioners and research and section 6 concludes.

2.2 Towards a multi-level understanding of urban sustainable mobility transition policy mixes

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[4] There are a few studies that analyze (or offer concepts for analysis of) more complex transport policy mixes, however, only at the urban level: Curtis and Low 2012; Givoni et al 2013; Givoni 2014; Buehler et al. 2017; Dijk et al 2018.

[5] In addition to synergetic and contradictory relations, Givoni et al 2013 distinguish pre-condition relations, corresponding to a situation whereby the successful implementation of one policy measure remains wholly contingent upon the prior successful implementation of another. We take this as a special case of synergetic linkages, and, for our purpose, prefer this more general category (including all cases in which the functional capacity of a policy measure is enhanced by the presence of another measure), while the specific form of synergy will become clear in the analysis.

2.2.1 Urban transition

Our definition of sustainable urban mobility (see Introduction) is in line with a more general framing of urban transition by Hodson et al. (Hodson et al., 2017). According to these authors, urban transitions are not about (the impact of) technological or social innovation per se, but about how multiple innovations (including those in policy & planning) shape patterns or forms of reconfiguration (which entail 'the new' and 'the established'). Attention for urban transitions has grown in the past decade in the context of debates between scholars in socio-technical transitions and urban geography. Key themes in this dialogue were (1) spatial context, (2) scales and (3) urban experiments. Firstly, while the first generation of transition studies (roughly before 2012) focused largely on the national level, neglecting *spatial context*, a number of later studies have sought to better involve spatial aspects into transition studies. In this context, some focused on local energy issues (Späth and Rohracher, 2012), while others on local climate initiatives (Bulkeley and Castán Broto, 2013).

Secondly, when it comes to scales, scholars stressed that urban transitions are shaped by developments at *multiple scales* beyond the local one (Coenen et al., 2012). This implies that, to analyze urban transitions, an account of the distribution of activities in a particular space (i.e., a particular urban area) is not enough. Rather, according to this scholarship, there is a need to examine the interconnections with other places (Bridge et al., 2013), as well as with territorially unspecific factors, such as national and international institutions and networks of interests (Hodson et al., 2013).

Thirdly, an increasing range of studies looked at urban *experimentation* in relation to urban transitions, drawing various observations therefrom (Evans and Karvonen, 2014). Some have stressed the ability (or potential) of experiments to create highly context-sensitive and locally-relevant knowledge (Karvonen and Van Heur, 2014). The definition of experiments in this regard has been rather loose and the analysis of impact involving a rather unspecific notion of 'change' (ibid.). Various scientific strands engage with the study of urban experiments, especially sustainability transition literature (see e.g. (Torrens et al., 2019, Huang and Broto, 2018, Frantzeskaki et al., 2017), or urban geography and governance literature (see e.g. (Bulkeley et al., 2011); (Scholl and De Kraker, 2021). As Hodson et al (Hodson et al., 2017) state, for experiments to contribute to urban transitions, focus must go beyond the experimental practices and also involve pre-existing infrastructures and institutions, including those at multiple levels of governance[6].

As far as empirical studies on urban transition are concerned, hardly any research has taken such a 'whole system reconfiguration' approach (McMeekin et al., 2019), but primarily studies focusing on a single urban experiment concerning some radical technology or social innovation with a limited share of practitioners in a city-wide perspective. Exceptions are often historical transition cases, such as Switzer et al. (2015), and Dijk et al (2021), the latter

[6] Ehnert et al (2018) and Servou et al (2022) are the only studies that put urban experiments (or initiatives) in a multi-level governance context. The former explores the difference between federal and unitary political systems in providing opportunities and obstacles for urban sustainability transition, while the latter studies how governance cultures in multiple governance levels affect the co-creation of experiments and their impact. Both analyses do, however, not address (multi-level) policy mixes.

also highlighting the role of the policies in sustainability transitions. The ways in which mixes of policy goals, instruments and processes interact, seem of crucial importance for the degree to which policy facilitates (or hinders) urban transitions (Switzer et al., 2015, Dijk et al., 2021). We zoom in on this now.

2.2.2 Policy for sustainable mobility

Policies across multiple governance levels

As noted in Section 1, the EU has a system with multiple levels of governance, with European, national and sub-national policy arenas embedded in each other (Kern and Bulkeley, 2009, Bache and Flinders, 2004). The notion of multi-level governance can be conceived in a narrow and a broader sense (Kern and Bulkeley, 2009). In narrow sense, it refers to the distributed regulatory competences between local, national and supranational governmental institutions. In a broader sense, it encompasses also other sorts of formal and informal interactions across actors from different levels of governance, including public-private partnerships, etc (Stephenson, 2013, Beisheim et al., 2010). In this paper, we will follow the broader definition. In the past decades, public authority in Europe has not just simply shifted upwards to European institutions, but also downwards, among multiple territorial levels and a variety of private and public actors (Kern and Bulkeley, 2009, Rosamond, 2007). This includes the transfer of public authority of national to sub-national levels (i.e. regions, provinces or municipalities), due to processes of decentralization. This has resulted in a rather complex situation of somewhat indistinct boundaries between the different governance spheres, with some policy actors (e.g. NGO's, lobby or branch organizations) being active across various levels at the same time. Governance levels affect not only their underlying or parent layer (e.g. EU and national level dynamics), but there are also direct relations between EU institutions and local authorities (Marshall, 2005). Accordingly, there is a mix of policies across levels that reconfigure urban transport in a more or less sustainable direction, and these policies interfere (see Figure 2.1).

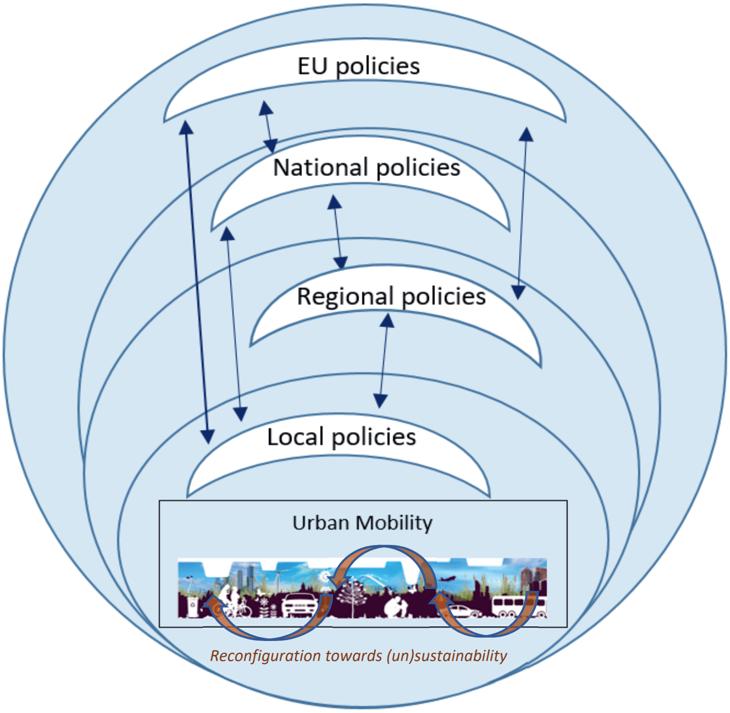

Figure 2.1. Reconfiguration of urban mobility amid multi-level policy interaction

In this rather complex policymaking context, Bemelmans-Videc and Vedung (Bemelmans-Videc and Vedung, 1998) distinguish three different forms of policy packaging for policymakers: 'vertical packaging', representing the implementation of policy measures that also considers policies at other levels of governance to achieve common policy aims; 'chronological packaging', referring to implementation of policy measure deliberately in sequence, thus following a particular order in time; and 'horizontal packaging', meaning the implementation of measures whilst considering other policy measures adopted at the same time within the same level of government. To keep the analysis manageable, our analysis will focus on vertical packaging. The question is how policy coherence of policy mixes in this rather complex, multi-level governance context can be enhanced to promote sustainable urban mobility transition.

Mobility policy mixes

Early transport policy literature suggests two options for reducing transport emissions: a shift to cleaner technology or behavioural change (i.e. modal shift) (Chapman, 2007). In practice, technological solutions tend to dominate policy for transport and climate change (ibid.). Later work suggested that at least some level of behavioural change is required if carbon emissions from transport are to be reduced significantly (Banister, 2008, Anable et al., 2012). Accordingly, they argue to move beyond a focus on one or a few instruments (e.g., information provision or reduced fares) and transcend the hard/soft and behaviour/technology dualisms (Schwanen et al., 2012). The most relevant mobility policy studies in this regard are those that address 'modal shift', which refer to a (significant) reduction of the share of private car mobility. Traditionally, there are two broad strategies that policy can take to encourage modal shift: ‘push’ and ‘pull’ measures (Batty et al., 2015a, Curtis, 2018). ‘Pull’ strategies aim to increase the supply of high-quality, low carbon transport modes such as public transport, active mobility (walking, cycling) and increase the supportive infrastructure available for these modes (Buehler et al., 2017a, Strompen et al., 2017). By contrast, ‘push’ strategies aim to discourage unsustainable behaviors (i.e. high car use) by making these forms of transport less convenient, for example by implementing road pricing and congestion charges, or traffic calming measures (Buehler et al., 2017a, Strompen et al., 2017, Curtis, 2018). To encourage a modal shift most effectively, it is generally accepted that both ‘push’ and ‘pull’ types of measures are needed (IEA, 2009b, Black and Schreffler, 2010 , Strompen et al., 2017). However, the majority of the transport literature addresses either one in isolation: strategies to encourage active mobility (i.e. walking & cycling), or strategies to encourage public transportation, or strategies to constrain car use.

Transition scholars have traditionally argued that in order to initiate a sustainability transition, policy mixes should combine policies aiming for the creation of ‘the new’ and for destabilizing or constraining ‘the old’ (Kemp et al., 1998, Kivimaa and Kern, 2016). This corresponds with transport policy literature that attributes most effective modal shift strategies to combinations of push and pull measures. A successful example of such strategies is reported by Buehler et al., who found that, in all five European cities under assessment, modal shift was successfully encouraged through “a coordinated package of mutually reinforcing transport and land-use policies that, in combination, have made car use slower, less convenient, and more costly, while increasing the safety, convenience, and feasibility of walking, cycling, and public transport” (Buehler et al., 2017a). Yet, despite these successes, Curtis and Low (2013) find generally that in many cities policymakers struggle with a (contradictory) compromise concerning constraining and enabling car use (Curtis and Low, 2012). Although they have developed visions of reduced shares of car mobility, they have not yet fully dropped the car-enabling logic of ‘predict-and-provide’, i.e. predicting where (car road) congestion issues may arise in the future, and adding infrastructural (road) capacity to mitigate it. A study on sustainable urban mobility in Stuttgart also finds that there is a dilemma between the measures that are needed and those that are feasible for policy-makers (Schippl and Arnold, 2020).

Due to the limited number of studies that combine push and pull measures, and the fact that they address the local governance level only, the overall (in)coherence and (in)effectiveness of the multi-level urban mobility policy mix, has remained underexposed (Howlett et al., 2017, Dijk et al., 2018). Therefore, in this paper we analyze urban mobility transition through a conceptual frame that connects synergies and conflicts in multi-level policy mixes with shifts towards sustainability mobility modalities (i.e. public transport, cycling, walking, etc.). The final aims are to develop a sharper understanding in the main conflicts of policies supporting a transition towards sustainable urban mobility among the various levels of governance and develop initial lessons on how these conflicts may be overcome.

2.3 Method and Data

We chose a qualitative research method, interviewing, to answer the research question because this method is sensitive to the subtleties of policy effects and interactions between different governance levels, more than quantitative methods (Kivimaa et al., 2017). Semi-structured interviews with the people from different governance levels and departments taps into the different knowledge, experiences and perspectives at the levels of governance concerning policy impacts, jointly providing a balanced insight in the most influential factors and (in)coherencies of the policy mix concerning sustainable urban mobility development.

2.3.1 Interviews

We started to contact the governance levels that had issued the most explicit urban mobility policy plan or visions, which were the urban and European level. To avoid too much heterogeneity in terms of governance context, we chose to focus on one country for the urban, regional and national area. We chose to focus on The Netherlands, because, albeit considered relatively advanced in terms of integrative governance approaches, Dutch cities still suffer from pressing mobility problems, like most other EU cities. We started to contact one governmental and one non-governmental organization at each level: DG MOVE and POLIS at the European level, and Municipality Maastricht and Maastricht Bereikbaar at the urban level. Combing suggestions of these interviewees (‘snowballing’) with our analysis of stakeholders in associated policy reports (positional approach), we selected further interviewees. Snow-balling assumes that people working for the same field in a group are interconnected, they know each other personally or by reputation, so they will know when you ask who is relevant in this field (Myers and Newman, 2007). Through this process, we also got in touch with interviewees at regional and national level. We stopped contacting more interviewees at each level when an interview had delivered hardly any new insights, concluding we had reached data saturation by then. Finally, we conducted 32 semi-structured interviews with policymakers, program managers, international organizations, and non-governmental organizations from the EU (10), national (8), regional (6), and local (7) levels during 2020-2021, see Table 2.1 (and see Appendix 8.2.1 for more details about interviewees). The semi-structured interviews lasted between 40 and 100 minutes and were transcribed. Semi-structured interview gives the person who is being interviewed a certain degree of freedom to decide what, how much and how to respond to questions (Drever, 1995, Fink, 2002a). As the interview structure shows in Appendix 8.2.2, we started to ask interviews with how sustainable urban mobility is defined at their department or organization. Subsequently, we asked what policies or instruments at their level as well as on other governance levels they see as having the most significant impact (on urban mobility), and finally how they see the relationships between those policies at the various governance levels. As noted in the questions, we initially did not regard regions as a specific governance level, but included it after interviewees referred to it.

To understand the context of the responses better, we also checked policy reports concerning the mentioned policies that were mentioned by interviewees (see list in Appendix 8.2.4). These reports were in some cases explicitly mentioned by them, sometimes we searched for them pro-actively.

Table 2.1. List of the interviewees

Level	#	Organization	Duration (minutes)

EU (10)	1	Local Governments for Sustainability (ICLEI)	98
	2	European Cyclists' Federation	46
	3	European Commission	64
	4	Eurocities	93
	5	The Directorate-General for Mobility and Transport (DG MOVE)	41
	6	DG MOVE	71
	7	The Directorate-General for Regional and Urban Policy (DG REGIO)	94
	8	Directorate-General for Environment (DG ENV)	86
	9	Cities and Regions for Transport Innovation (POLIS)	70
	10	European Institute of Innovation and Technology (EIT) Urban Mobility	71
National (9)	11	Milieudefensie (Friends of the Earth Netherlands)	57
	12	Natuur & Milleu (Nature & Environment)	89
	13	Urban Mobility at German Institute of Urban Affairs	49
	14	Planbureau voor de Leefomgeving (Netherlands Environment Assessment Agency)	77
	15	Ministry of Infrastructure and Water Management	51
	16	Ministry of Infrastructure and Water Management	69
	17a&b	a. Ministry of the Interior and Kingdom Relations	85
		b. Ministry of the Interior and Kingdom Relations	85
	18	Ministry of the Interior and Kingdom Relations	71
Regional (6)	19	Rotterdam–The Hague metropolitan area	76
	20	Province Zuid Holland	66
	21	Province Limburg	68
	22	Province Gelderland	86
	23	Arnhem Nijmegen Region	92
	24	Arnhem Nijmegen Region	84
Local (7)	25	Maastricht Bereikbaar	72
	26	Rotterdam City	85
	27	Rotterdam City	82
	28	Rotterdam City	80
	29	Maastricht City	89
	30	Maastricht City	74
	31	Nijmegen City	95

2.3.2 Interview analysis

All interviews were recorded and transcribed, and software-tool Atlas.ti was applied to code the interviews systematically and efficiently (Konopásek, 2007). Each of the three authors started with coding two interviews respectively, taking the topics in the interview format as potential codes (i.e. definitions, policies, relations, patterns, actors, challenges, and solutions). This was followed by a meeting to compare and align the coding. Based on the discussion, we agreed on three main coding categories: Definition of Sustainable Urban Mobility, Policies, and Relations between Different Levels.

The next step was to code the transcriptions regarding each of the three categories: differentiating the types of definitions, identifying the policies as well as detecting the relationships between (policies at) different levels that affect sustainable urban mobility. In the next step, each author initially coded four interviews (i.e. from each of the four levels) and then met to present and explain the codes defined in every category to each other. This helped to align the coding process of three authors, although it did not change the three main code categories. However, it did result in the agreement on sub-categories. For coding category 'Policies', we coded according to the four governance levels discussed in section 2: (a) European policies, (b) Dutch national policies, (c) Dutch regional policies, and (d) Dutch local policies. By counting the number of times, a policy was mentioned by interviewees, we ranked policies affecting urban mobility. For coding category 'Relations between different levels', we coded according to two types of relationships as discussed in Section 1: (a) synergies, and (b) conflicts. By counting the number of interviewees that flagged a conflict or synergy, we scored the degree of significance of it. Concerning the third coding category, 'Definition of Sustainable Urban Mobility', we coded two types: (a) broader definitions, and (b) more narrow definitions. This reflects the fact that there is no universally agreed definition of it, neither among experts and academics, nor among practitioners (Gudmundsson and Regmi, 2017, Marsden et al., 2010), but in the range of definitions in the academic literature, there are generally two groups that can be distinguished (Kayal et al., 2014). In the broader definition, sustainable urban mobility is regarded as an alternative concept of the conventional transport planning (i.e. accommodating travel demand at low cost), which balances travel demand (i.e. 'accessibility') with the quality of the urban space and equity for residents (i.e. 'liveability'), entailing prioritization of active and public mobility above car mobility (Banister, 2008). The narrow definition refers to the 'greening' of transport, focusing on reducing emissions, especially through low- or zero emission vehicles (i.e. electrification or hydrogen vehicles), but also low-emission zones, etc. With these codes, the 32 interview transcriptions were coded.

2.4 Results

This section presents the main results on definitions of sustainable urban mobility, the policies affecting sustainable urban mobility, and lastly, the reported conflicts and synergies among different policies at various levels.

2.4.1 The definition of Sustainable Urban Mobility

Concerning the definition of sustainable mobility, we aimed to analyze similarities and differences among and also within the four governance levels (supranational, national, regional, local), highlighting any (in)consistencies in terms of the definition of sustainable urban mobility or goals they keep.

Consistencies

At the Dutch national, regional, and local levels, interviewees showed high consistencies in defining sustainable urban mobility in a broader way, i.e. as modal shift with less car mobility. They mentioned that increasingly the most common concern for cities is CO_2 reduction. This is triggered both by the European 'Green Deal' and the 'Dutch Climate Agreement' (NCA, 2019). In addition, liveability is getting increasing attention, including the aspects of safe and heathy cities, which drives the regional and local governments working together to promote sustainable urban mobility.

Interviewees from two European NGOs both stressed that climate change is a strong motivation to promote sustainable urban mobility, which they broadly defined as facilitating modal shift to public transport, walking, cycling, with attention for safety, accessibility, and affordability (interview #9 & 10). They also noted that urban mobility should be integrated in the whole societal-related policymaking domains rather than only limited to the field of transport and traffic regulation. One specific issue highlighted by the representative of POLIS is that many higher-level (supranational and national) policymakers tend to neglect the complexity at the local level, referring to the effects caused by the tradeoffs of different measures and policies, which needs a better approach to evaluate the impacts of a mix of policies (interview #9).

Inconsistencies

At the European level, some disparities existed in different departments and organizations. A participant working on urban environmental policy (from Directorate-General for Environment, DG ENV, Interview #8) comprehended sustainable urban mobility narrowly as reducing air pollution by replacing fossil fuel-driven vehicles with clean vehicles. He specified that most of the current cars were designed for long distance and high-speed travels but the type of vehicle that we should drive around in cities is something between a car and an electric bicycle, for which there is currently no legislative space. Another interviewee from The Directorate-General for Mobility and Transport of European Commission (DG MOVE, Interview #5) stated that sustainable urban mobility is about how to find usable, affordable, sustainable, and alternative vehicles to replace traditional fossil fuels cars. By contrast, the other participant from the same department (Interview #6) defined it broader as urban transitions toward mobility with less impact on nature while meeting the needs of people and increasing quality of life.

2.4.2 Policies

When asking interviewees which policies mainly affect sustainable urban mobility, a broad range of programmes, instruments and measures was mentioned: seventy-two in total (see Table 2). In order to create some overview, we distinguish them not only across the four governance layers, but also (1) policy directives and plans that give direction to lower level governments or departments (Nordholm, 2016); (2) Car mobility policy measures, so policy actions that are typically targeted at (altering) car mobility, such as the creation of zero emission zones or low speed zones, building new roads and tunnels, or extending parking area, etc. (Dijk et al., 2018); (3) Public transport policies, for instance measures extending bus or tram lines, introducing zero emission buses, and creating fast bus lines, etc.; (4) Non-motorized transport policies, so policy measures affecting walking and cycling (and e-steps etc.); and (5) Informative policies, which are laws and regulations etc. concerning information creation, processing, flows, access, and use (Braman, 2011), such as the creation of expert groups to support policymaking. Not all mentioned policies fit perfectly in one group (for instance some are primarily affecting car mobility, but also partly other modalities), but that is not critical here for the analysis, and still helps to attain some overview of the measures. Table 2.2 also shows the primary effect of the policy on sustainable urban mobility that was mentioned by the interviewee or in the associated policy reports (i.e. whether it generally reduces the share of car mobility, with '+' as yes, likely, '-' as no, unlikely or and '+/-' as indeterminate). Finally, the Table shows, between brackets, how often a policy was mentioned.

Table 2.2. Different types of policies related to sustainable urban mobility development mentioned by the interviewees

Types of policy	EU (24)	National (16)	Regional (13)	Local (19)
Mobility Development Directive & Plan	EU Green Deal^{+} (11)[a]	Klimaatakkord^{+} (Climate Agreement) (14)	POVI (provincial spatial vision)$^{+}$ (1)	City Climate Agreement^{+} (1)
	EU Climate Agreement^{+} (4)	Omgevingswet Agenda^{+} (1)	BDU$^{\pm}$ (traffic and transport act) Funding (1)	Sustainable Procurement Policy^{+} (1)
	Sustainable Urban Mobility Plan (SUMP)$^{+}$ (11)	Program Mobility as A Service^{+} (1)	Smart Ways^{+} (1)	GOVI^{+} (local spatial vision) (1)

	Clean and Better Transport in Cities^{+} (CIVITAS) (4) EU Air Quality Directive^{+} (10) EU White Paper on Transport^{+} (1) Urban Mobility Package^{+} (5) Urban Agenda^{+} (5) Smart and Sustainable Transport Strategy^{+} (1) Regional Development Funds$^{\pm}$ (1)	Multiyear Fund Infrastructure, Space, and Transport Program (MIRT)$^{\pm}$ (11) New Urbanization Strategy^{+} (1) NOVI^{+} (national spatial vision) (2) Program MoVe^{+} (2) Smart Mobility^{+} (2)	Smart and Clean Mobility^{+} (1)	Stedelijk Verkeersplan^{+} (Urban Traffic Plan) (1)
Car Transport Policy	EU Car Emission Regulation^{+} (2) EU Emission Norms^{+} (1) EU Infrastructure Funding (TEN-T)$^{\pm}$ (6) EU Alternative Fuel Infrastructure^{+} (1)	Logistical Laws^{+} (1) Car Taxation^{+} (5) National Truck Charging Plan^{+} (1) Charging Infrastructure^{+} (3)	Parking Norms^{+} (1) Car Sharing^{+} (1) Concession for Electric Vehicles^{+} (1) E-hubs^{+} (1) A50 Road Construction^{-} (1) A2 Tunnel Construction^{-} (1)	Zero Emission Logistics Agreement^{+} (15) Low Emission Zone^{+} (5) Speed Limitation Zones^{+} (1) Congestion Charges^{+} (1) Parking Permit^{+} (1) Parking Taxation^{+} (1) P&R^{+} (Park and Ride) (1) E-hubs^{+} (1) Local Freight Hubs^{+} (1) Evs Charging Infrastructure^{+} (1) Narrowing Roads^{+} (2) Intelligent Traffic Lights^{+} (1)
Public Transport Policy	Public Service Obligations^{+} (1)	National Zero Emission Bus^{+} (1)	Tendering process public transport operator^{+} (7)	
Non-motorized Transport Policy	EU 100 Intelligent City Challenge^{+} (1) EU Driving Urban Transition Partnership^{+} (1) Green City Award^{+} (1) Mobility Week Campaign^{+} (1)	Beter Benutten Program^{+} (4)	South Limburg Bereikbaar^{+} (1) Fast Bike Lane^{+} (1)	Cycling Ambassador^{+} (1) Urban Labs^{+} (3) Investment in Cycling Infrastructure^{+} (3)
Informative Policy	EU Inter Service Consultation Groups^{+} (1) Open Data Directive^{+} (1) Shared Management Approach^{+} (1) Expert Group on Urban Mobility^{+} (1) European Innovation Bank^{+} (1)	Urban Logistics Expert^{+} (1) Pool Collaboration Project^{+} (1)		

$^{\pm}$: To some extent support/hinder SUMT (sustainable urban mobility transition); $^{+}$: Support SUMT; $^{-}$: Hinder SUMT; a: The number indicates how many times this policy was mentioned by the interviewees.

Main policies

The most mentioned policies at EU level was the European Green Deal, Sustainable Urban Mobility Plan (SUMP) programme, the Air Quality Directive and the Trans-European Transport Network (TEN-T) funding. Table 2.3 shortly presents how interviewees described these policies, including their primary effect[7]. The Table also includes the main instruments mentioned for the national level (National Climate Agreement, the Multiyear Fund Infrastructure, Space, and Transport Program [MIRT], car taxation), for the regional level (Tendering process public transport operator), and for the local level (Emission Zones and local traffic and land use policies).

Table 2.3. Descriptions of main mentioned policies

Main EU Policies	The European Green Deal is *'a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas'* (EU, 2019a), which plays the role in deriving projects and policy measures to promote sustainability (interviewee #1, 3, 8). One interviewee from DG MOVE argues that the European Green Deal is a '*bigger game changer than the Paris Agreement as the Paris Agreement was not legally binding'* (interviewee #6). Though the Green Deal leads the member states do a lot of work in terms of reaching the CO_2 reduction goal, it has not trickled some of the ministries that kept doing what they always do, such as prioritizing on economic growth and subsidizing gas vehicles (interviewee #14).
	SUMPs (Sustainable Urban Mobility Plan) issued by the European commission have been designed to solve mobility-related problems in city regions more efficiently. It guides and encourages cities to develop sustainable urban mobility plans, share best practices, and showcase a series of successful projects (interviewee #5). Most of the interviewees who mentioned it and rated it as a successful policy in integrating sustainability into the long-term mobility plans are from EU (interviewee #4, 5, 6, 7, 8, 10). The key reason pointed by the project coordinator of Eurocities is: *'it sets the example for other smaller cities around these cities that made these plans, like Amsterdam…If they make these steps to more sustainable development of the city, then it helps set the example for the other cities. That helps it to go top-down from Europe'* (interviewee #4). Whereas the mobility expert from South-Limburg alluded that the SUMPs did not stimulate them to do much in corresponding with the SUMT (interviewee #25). Moreover, a small group of cities, especially the small size cities, were not satisfied with this measure since they cannot get the specific information for their type of context. But the EU does not have enough capacity to tackle such complaints, specified by the coordinator of SUMPs (interviewee #1).
	DG ENV introduced a European Commission directive aimed at improving local air quality in 2008, the EU Air Quality Directive. Although EU norms for particulate matter had gone into force in 2005 already, they had resulted in little action in EU member states (interviewee #5, 8). Since the issue of the Air Quality Directive, the Netherlands acted immediately with a national plan to improve air quality in 2009, including the promotion of e-mobility (Ministry of Infrastructure and the Environment, 2009). Both the interviewees from DG REGIO and DG ENV rated the Air Quality Directive as the most powerful EU instrument in promoting SUMT: *'I think the most powerful driver has been the air quality legislation. Because I mean, if people get taken to court, because they are, again, not meeting the thresholds. I think this has been a strong driver' (interviewee #7, E[8]).* '*I would say the air quality legislation in relation to, is probably one of the most the biggest impacts on urban mobility that we have. Because the SUMP is not compulsory. I think cities are supposed to have they're maybe supposed to, if they don't, they're not going to be taken to court over it' (interviewee #8, E).*

[7] It is logical that instruments at EU and national level are mentioned more often, because all interviewees share national and EU level, but there are participants from three regions and cities with, at least partly, different instruments.

[8] In the quotes in this section we use E is the abbreviation of European level, N for national level, R for regional level, and L for local level.

	Although the Air Quality Directive is a strong incentive for SUMT, some interviewees (#3, 8, 11, 23) pointed that cities are still far from the air quality standard set by WHO (World Health Organization), so the EU standard definitely needs to become stricter.
	Trans-European Transport Network (TEN-T) creates an integrated and intermodal long-distance, high-speed, trans-European transport network, mechanized by providing funding for infrastructure construction including all modalities (e.g. road, rail, water, air). TEN-T funding is granted under a system of centralized administration. That means that the Commission sets the rules. Sustainability is, currently not a criterion of importance in funding decisions. Infrastructure is developed based on the need for more capacity (usually due to congestion issues), not to support modal shift to more sustainable modalities (interviewee #5, 10). For instance, when funding new ring roads or road tunnels, induced demand of car mobility is not considered. The lack of sustainability consideration is also noted in a recent evaluation on the TEN-T framework (interviewee #3). Increasingly, however, there are calls to include sustainability requirements (such as the existence of a sustainable mobility plan), in order to receive TEN-T funding (interviewee #28, 31).
Main national policies	The Netherlands National Climate Agreement (NCA, 2019), involving over 100 parties (governments, the business community, social organizations), aims to reduce the greenhouse gas emissions by 49% in 2030 and 95% in 2050. For the mobility sector, the key measures include the shift to zero-emission cars, the introduction of low-emission zones in cities, a form of road pricing, and more attention for alternatives to the car.
	A key financial instrument of the Dutch national government is the Multi-Year Programme for Infrastructure, Spatial Planning, and Transport (MIRT), managed by the Ministry of Infrastructure and Water Management. This program earmarks large sums of money to address 'bottlenecks' (i.e. apparent infra capacity issues that lead to congestion) for the coming decades. In some way it is the national counterpart of the TEN-T. The MIRT is important for local and regional levels of governance because large investments are impossible without funding from MIRT (interviewee #17, 20). However, the emphasis on infrastructure also tends to bias policy strategies towards 'expanding infrastructure' (which is prone to lead to induced demand), as opposed to more demand management policies (interviewee #14). Local authorities (generally in need of money from supra-local level) are incentivized to reframe their policies into infra-driven policies. In the last five years, possibly under influence of climate ambitions, there are efforts to gradually reframe the fund from an 'infrastructure' into a 'mobility' fund (interviewee #12, 31).
	Taxation plays a strong role in speeding sustainable mobility transitions. Like most countries, Dutch car drivers were paying various types of taxes: a monthly road tax, fuel tax for every liter bought, VAT (Value Added Tax) when the vehicle was purchased, and, for lease drivers, an addition to their income tax ('bijtelling' in Dutch). These taxes on car mobility were slightly higher than average in Europe. For traditional fossil-fuel vehicles, VAT had been connected to energy labels since 2006, but this became combined with CO2 emissions in 2010, and fully based on CO_2 after 2013. After 2010, a 'feebate' system gave low-emission vehicles a tax discount (or even exemption), while high-emission vehicles were taxed extra, so they were taxed progressively according to their CO2 emissions. In addition, there was a generous tax exemption for full battery-electric vehicles. In the policy communities, one spoke of 'greening of the tax regime'. Still, since tax is not based on km's driven, there was little incentive to constrain total distance driving (interviewee #15).
Main regional policies	Dutch provincial governments have the authority to provide the concessions for public transport operators (bus, regional trains, trams, metro). The regulation of the regional public transport not only includes adjusting the amount of buses or the energy transitions for the busses, but also contains drawing new lines and amending the frequencies based on travelers' needs. For instance, the possibilities of more direct, more frequent and faster public transport, to make sure that there is always an alternative for the car use, which on the other hand smooths the mobility transitions (interviewee #22).
Main local policies	Local governments have the authority over the public space (i.e. incl. all road space) within the municipal boundaries, in line with the subsidiarity principle. Accordingly, local traffic and land use policies shape the mobility infrastructure, and have a strong influence on the space for car roads, bicycle paths, bus lanes, pedestrian spaces, parking spaces and tariffs. Clearly these

	decisions strongly shape the attractiveness of the various mobility practices (i.e. car mobility, cycling, public transportation, walking).
	Zero or Low Emission Zones have been introduced in 2010s by some Dutch cities based on local needs, which lead to a patchwork of different rules. The national government intervened and since 2019 with a national standard was set. Cities were not always happy with this (interviewee #11, 23, 26, 29, 30). Maastricht, for instance, close to the German border, had adopted a system adapted to Germans guests, but was now required to change to much more expense national one, which did not receive sufficient support in the council (interview #29). Concerning freight traffic, Dutch cities had been cautious for strict measures, fearing commercial competition from other cities. The participatory process around the Dutch climate agreement, however, resulted in an agreement between the largest 40 cities to achieve a zero-emission zone for freight by 2025, which is listed as a local policy instrument and has been mentioned the most in the local level.

It is observable that the most explicit urban mobility policies at EU level, such as SUMPs, CIVITAS program, urban agenda, are rather soft measures. Respondents describe them as useful to develop knowledge and skills and be inspired by other cities, but participation is voluntary. TEN-T funding is financially significant for large infrastructural projects, while its effect on sustainable mobility is slightly negative until now (due to ample investments in roads), or indeterminate at best. One of the main policies at the national level, the Klimaatakkoord, followed to meet the EU's commitment to the Paris agreement. The Dutch national government has adopted new strategies and targets, in correspondence with the EU Green Deal and EU Climate Agreement. A number of national instruments have significant impacts on regional and local mobility developments. Push policy measures (such as taxation, emission regulation), mainly from directives and car transport policies, show stronger impacts than pull policy measures (such as the zero-emission bus program). All measures in the Most regional policies had mild influence. The regional and local level both have the most specific policy measures on car transport and public space. This is understandable from their direct authority over a particular area. Hence, local governments have the most car transport policies to limit car use by regulating road space, parking areas, charging congestion fees, developing electric car sharing schemes (E-hubs), etc. Smaller experimental and pilots' projects are done there to learn for larger-scale policy measures (interviewee# 28).

2.4.3 Contradictions and synergies between levels

Interviewees came up with a number of general observations concerning the multi-level package of policies. First, there are a lot of people at various levels out there who 'do' urban policy, or affect it (interview #5). This means there is a lot of need for alignment and integration, to prevent the obvious, ample risk for misalignments and conflicting policies. Second, all levels have slightly different roles and responsibilities. Currently, the according policies are enacted rather independently. Although responses do not lead to a long list of contradictions between policy policies at the various levels, there is a lot of missed opportunities for alignments and synergies (interview #2). Overall, interviewees agreed that, urban mobility is primarily shaped and determined at the local level, through co-creation of urban politics with local stakeholders (interview #1, 31). The influence of EU level policies on urban mobility is limited, since it is mostly based on 'soft' instruments. However, in order to operate effectively, cities need to attract funding and knowledge and skills, hence need to make partnerships beyond their administrative borders (interview #4), and therefore a lot of coordination with national level (concerning funding) and European level (concerning knowledge & skills) is needed.

From the total set of 32 interview transcriptions, we now highlight the main (reported) conflicting and synergetic relations between policies at various levels (see Figure 2.2), i.e. the ones that we mentioned by at least three interviewees. We now shortly discuss these: four conflicts and nine synergies. Appendix 8.2.3 shows another 48 interactions, which were mentioned one or twice.[9] Hence, we take the number of interviewees that flagged a conflict or synergy as degree of significance of it.

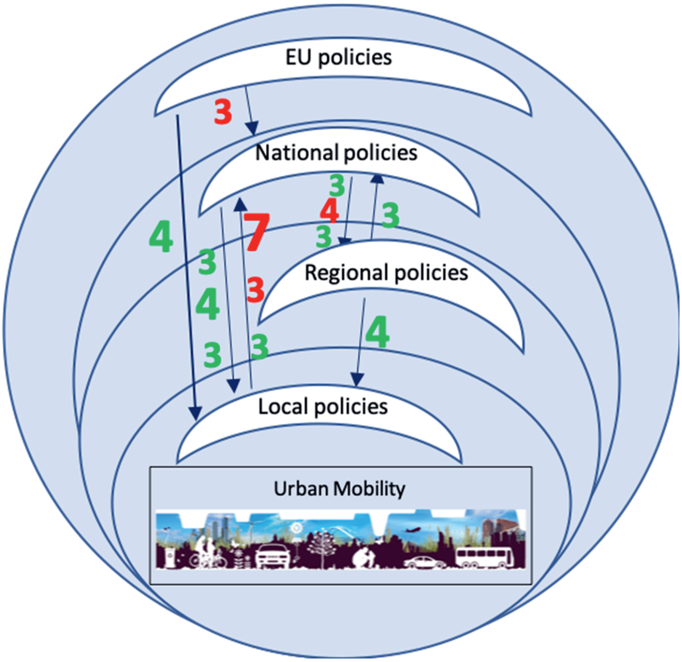

Figure 2.2. The main contradictions and synergies reported

Contradictions

The main conflict, which was flagged by seven policymakers at the national (1), regional (2), and local (4) levels, is that national funding does not really promote or is insufficient to promote urban sustainable mobility. Some interviewees argued that:

'The local authority really doesn't have the funding to fix this kind of thing ([i.e. transport infrastructures and emission reductions – authors]). So, you really have to look at the National and hopefully also the European level to help fund this. But it is really difficult to reach these (funding).' (interviewee #23, L).

'There's no monitoring ([i.e. of the implementation of Climate agreement – authors]) from the national level, there's no extra money, except for some subjects, such as charging

[9] Appendix C also shows that on a number of relations (i.e. 8) there are contested views on the nature of it: some find it synergetic, some conflicting. Apparently, there is 'interpretative flexibility' in those cases. For the thirteen-relationships discussed in the main text there was no contestation, except for one that is discussed below.

infrastructures. No extra money for reaching the (sustainable urban mobility) goals' (interviewee #28, L).

'The policy framework of the Ministry, for example, also excludes everything that's outside of their framework. So, even though some measure, some ideas, have a very positive contribution to, for example sustainability. There won't be any funding available' (interviewee #25, R).

Although funding is offered by the national government to the cities, in many cases this is only provided when projects suit the purpose of the national policies, which centers around 'solving congestion' and 'reducing vehicle emissions'. In some cases, the cities also have to compete with each other to earn the funding, as noted by the local mobility policymaker from Rotterdam (interviewee #26): '*When it comes to negotiating with the national government, and there is a lack of money and choices need to be made, then it's getting difficult, because of course, you get competition between Rotterdam, the Hague, etc. ... There can be differences in priorities.*'

Related to this conflict, one thing flagged by three regional policymakers is that funding that regions receive from the national government is also actually mostly for (road and housing-related) infrastructural projects (interviewee #20, 21, 22). For instance, the urban planner from Zuid Holland (interviewee #20) pointed that: *'we now get some funds from the Ministry of Internal Affairs, it's mainly for housing but not for mobility… the only link with mobility is that municipalities can hire also people to make sustainable mobility plans for new housing developments.'* Similar with this, the interviewee from the province Limburg (interviewee #21) brought this issue as well: *'we as a province, try to look at mobility as a whole and not specifically on an infrastructural basis. And the ministry does take our suggestions into consideration. So, they are trying to change ... But because now, the national government has this infrastructure fund, they still spend more to infrastructure than on broad mobility solutions.'*

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Another conflict that was flagged by European and national level interviewees is that the EU lacks the authority or influence to affect national policies. As the urban planner from the Netherlands Environmental Assessment Agency argued: *'In the field of transport, European policies, except the car transport policies, have very little influence on (national) policies concerning cities'* (interviewee #14). He further specified that regulations such as the EU vehicle emission norms played a strong role, but soft measures like SUMP hardly have impacts on the national governance level. Another example was given by the Interviewee from Eurocities (interviewee #4) as: *'you can see in Central and Eastern Europe, there's still a big interest in using money from the European Commission to invest in highways (…), which negatively affects mobility in the urban regions that these highways pass by, which traditionally have good public transport systems. (…) Member States still have a big say on how the EU money is spend'*. This shows that for some European countries, investing in road infrastructures instead of developing sustainable transport options still dominates the national mobility development, although this contradicts European level urban mobility strategies. European policymakers have little room to change this.

Similarly, local level representatives complained that they do not have enough power to make big decisions for which they are always dependent on the national government: *'I also noticed that, the big decisions are being made on a higher level. And in terms of financing, and the allocation of resources available it is on the provincial and national level where the* *big decisions are being made' (interviewee #30)*. On the other side, the European mobility innovator from DG MOVE (interviewee #6) noticed the same problem from other member states as well: *'the problem with going in a legal way to give more power to cities lies with member states ... Our interlocutors are basically Member States and the European Parliament but not cities. Therefore, every attempt by us to give more power to cities is normally met with strong opposition by Member States who basically want to control what is happening in their own territory and they don't want to share the power with cities'*.

Synergies
At the same time, many interviewees see synergies between the various governance layers. For three interrelations especially, a number of interviews (i.e. four) saw these. First, both the European level and local level interviewees see the EU funding well in line with and give support to local efforts. The team leader (interviewee #7) of DG-REGIO elaborated the function of the EU funding: *'The European budget like European Regional Development Fund … can help people (i.e. cities – authors) to get a little bit out of their own block to connect with other cities to try something'*. The EU sustainable mobility projects help cities to develop their own skills and tools. Another interviewee from Rotterdam (interviewee #28) illustrated: *'for example, with (our) big cities, we always check if we could have funding from the European Investment Bank, such as for the charging infrastructure'*.

Second, both national and local level representatives argue that national and local goals concerning urban mobility are currently increasingly in line (interviewee #12, 22, 29, 31). For instance, the national Beter Benutten program supported behavior changes, i.e. preventing car trips, instead of (road) infrastructural development. *'In 2012, the ministry implemented Beter Benutten, before the ministry every year spends billions of euros on infrastructure, but they came to the point that they said okay but maybe we shouldn't implement more infrastructure, but think about how to utilize the existing infrastructure better'* (interviewee #25), '*Beter Benutten…is more efficiency. …And now it's transforming a little bit more in sustainable mobility'* (interviewee #12).

Thirdly, regional and local level interviewees find that their goals are well in line too. A good example was provided by the interviewee from province Limburg (interviewee #21): *'If we take a look at the cooperation with cities for example in Limburg, we have our global vision on mobility… Together with these cities, we make local policies… we come up with projects and policies to contribute to this vision and the goals we set in these visions to achieve within a couple of years'*. Another action taken by Rotterdam in response to the province South Holland's climate agreement is: '*the provinces have real targets from the climate agreement ... And that is a new task of the provinces to organize vehicle charging in regions. Rotterdam ([i.e. had the same goal and took the lead to – authors]) organize it for them ([i.e. other cities – authors])' (interviewee #28)*.

There were some other synergies that interviewees flagged. Both national and local representatives see growing collaboration between the two levels (3 from both levels), hinting at joint urban development programs. Respondents mentioned a program ('MoVe') in which 3 governance jointly develop a new area, combining housing challenges (i.e. building many more houses) with mobility challenges ('accessibility'). *'Despite the different roles & responsibilities at the various governance levels [i.e. national, regional, local -*

authors], we are trying to act like one government. One team with representatives of all three levels.' (interviewee #17a, N)
And another:
'They ([i.e. the national government– authors]) have a national strategy for charging infrastructure, and they work together with the bigger regions in the Netherlands… And they make their regional charging strategy, they are helping cities to make their own strategies and implement it.' (interviewee #31, L).
Similarly, national and regional representatives both experiences growing collaboration between the two levels (3 from both levels).
'We have an agreement with the Ministry of infrastructure, that Noord Brabant pays 17 million. And we also pay 17 million for them, then all of us-national, regional and local work together for making more use of public transport, making more use of high velocity bike lines, … to make the role of sustainable mobility more clear.' (interviewee #22, R)

National policymakers also find that they share the same goals with regional policymakers.
'We are working together more with the Ministry of infrastructure. It is not only we get money and then say goodbye. We find it very important that we also have our targets on sustainable mobility and we make deals together.' (interviewee #22, R)

Finally, although lack of national financial support to promote sustainable mobility transition is flagged as the biggest conflict with the local level, there are still also some interviewees (#10, 18, 31) who find that the national level offers sufficient funding for sustainable mobility to local policymakers. For instance, Nijmegen received budget from the national government to build two new train stations (in 2013 and 2014), which stimulates people to travel more with trains (interviewee #31). Another view from the national level is: *'when they (cities) do the things in line with our national mobility policy Omgevingsvisie, they will get the money, that's part of those policies. And when they don't align with it, they don't of course.'* (interviewee #18). So, there is also some level of contestation concerning the main conflict.

2.5 Discussion

An important question for urban mobility in Europe is how conflicts in the multi-level mix of policies (concerning sustainable urban mobility transition) can be mitigated and how synergies can be promoted. Clearly, our empirics is primarily from the Dutch context, and we are aware that those findings do not necessarily represent the situation in other countries. Therefore, we will deal with this in a manner of 'if this … is the case, then …' In the following, we first discuss potential ways to anticipate on the various conflicts and synergies mentioned above in Section 2.3 (also following that order) and then we discuss the findings in a broader context of sustainability transition research.

Transforming the funding focus from infrastructure to broader mobility
In section 2.3, we found that the biggest policy conflict in multi-level governance of sustainable mobility transition are that, although cities depend on national funding for more significant initiatives towards sustainable mobility, the national funding did not really promote urban sustainable mobility. National funding was provided primarily to solve bottlenecks in the current dominant way of travelling, car mobility, i.e. road infrastructure

adaptations or extensions. Mobility policymakers complained that in many ways funding structures for mobility still expect or prematurely dictate policies in the context of constructing road infrastructures. How could this conflict be mitigated? In the Netherlands, a programme aimed at better utilization of the existing infrastructure (started in 2011) started a gradual (although slow) change in the funding structure, which, in publications by 2018 emphasized the need for broadening the focus of funding regulation approaches and funneling decision-making process (I&W, 2018). This suggests that expanding the focus of funding from funding the construction of infrastructures only (to solve bottlenecks) toward achieving a broader set of mobility objectives can bring more opportunities for the recipients to design measures promoting behavioral change, i.e. modal shift, at local levels. Also, this alternative 'broader' focus can serve to fund 'innovation projects', such as Urban Living Lab 'experiments', that can in turn serve to learn how to tailor mobility solutions to local circumstances (Wimbadi et al., 2021, Roebke et al., 2022)[10].

In all countries that struggle with the same conflict of funding being biased to 'solving bottlenecks through infra', such a shift to a broader mobility perspective seems worthwhile. Where necessary, a pilot programme can be used to learn how this can function (as 'Beter Benutten in the Netherlands). The EU is currently exploring this direction by making the development of a SUMP a requirement for receiving TEN-T funding. This may be effective, but clearly it needs careful monitoring to prevent improper or symbolic SUMP creation in order to 'tick a box'. Alternatively, TEN-T funding could also incorporate the requirement that projects cannot only improve car mobility, but needs to improve car alternatives at least to an equal extent.

Institutionalizing multi-level co-development

It is not only that national funding structures are not well in line with urban sustainable mobility strategies, but also that the national level has significant influence (to the local level), whilst itself being hardly influenceable by the other levels. This is a source of some frustration both at EU and at local levels, which partly have stronger sustainable mobility ambitions than the national level. How could this conflict be mitigated? The EU Green Deal (2019), which set the main policy direction for the European future development, seems to point to the need to give the EU more influence on the member states, including on sustainable urban mobility transition. However, a limitation is that the societal transformation it seeks to achieve is approached primarily in a financial-economic instrumental way, with less sensitivity to the national, regional and local circumstances (see also Foulds et al 2023 for similar critique). This may prevent the EU from overcoming strong national inertia, which is a source of some frustration at the local level in the field of urban mobility.

In order to improve the multi-level coordination between the national and the other levels, the Dutch national-local collaborative programme on urban development ('MoVe', mentioned above) may be an example, especially when the EU level joins this. The Urban Agenda has been set up in 2016 as a 'new multi-level working method promoting cooperation between Member States, cities, the European Commission and other stakeholders in order to stimulate growth, liveability and innovation in the cities of Europe

[10] In the Netherlands this also happened with a number of Mobility-as-a-Service experiments being funded by the MIRT in 2020.

and to identify and successfully tackle social challenges.' But this has remained an arena for dialogue and knowledge exchange, with especially national representativea becoming less interested over time, whereas it should be a platform to start joint urban (re)development projects, addressing specific areas . Cooperation among different levels can pull them into each other's circumstance and knowing more context of each other's level, which can act as a magnifier to see the subtle conflicts that they cannot easily detect at a distance.

Translating climate targets at all levels
Despite the conflict and misalignments noted above, our findings also suggest that climate change pressures create a trend that CO2 reduction is rising to the highest priority level (i.e. next to 'congestion reduction') at all levels of governance. In this sense, the policy aims at the various governance levels become better aligned. While before the Paris agreement congestion reduction (associated to the economic functioning of cities) was generally winning from the environmental and liveability arguments, respondents agreed that CO2 is now seen as equally important as accessibility. For member states where this is not yet the case, it may be helpful to require all levels of governance to explicitly translate the Paris agreement for their area and policies.

Contribution to the literature
Our analysis of urban mobility transition, using a conceptual frame that connects synergies and conflicts in multi-level policy mixes with shifts towards sustainability mobility modalities, contributes to the literature in two ways. First, whereas existing transport policy literature is focused on less complex policy design (i.e. concerning one modality and one governance level), our study offered insight in vertical relations of the policy mixes and discussed potential ways to improve the vertical policy mix for sustainable urban mobility in Europe. Complementary to the few (conceptual or empirical) studies that analyze policy mixes at the urban level (Buehler et al., 2017b, Dijk et al., 2018, Curtis and Low, 2012, Givoni et al., 2013, Givoni, 2014), our study brings in the much-needed insight in the vertical dimension. While the urban level studies highlighted the role of local politics, obduracy of infrastructure and departmental silo structures at local governments, our analysis showed how urban practices and practitioners can be constraining (as well as, in some cases, enabled) by policy goals, instruments and processes at higher levels of governance.

By doing so, our study offers a second contribution. It pioneers a novel connection between two debates in sustainability transitions literature: on (multi-level) policy mixes and on urban transitions. Ehnert et al. (2018) started to consider urban experiments (or initiatives, as they call them) in a multi-level governance context, but do not address policy mixes (Ehnert et al., 2018). Zepa & Hoffmann (2023) study how policy mixes across vertical scales of governance shape sustainable energy in Latvia, but do not address urban transition (Zepa and Hoffmann, 2023). We hope that our study triggers more work in this direction, as earlier work has noted its relevance for urban transition and called for more research (Hodson and Marvin, 2010, Hodson et al., 2017). Literature on transition policy mixes in general has focused mostly on national and supranational energy issues, but with a more extensive conceptual framework that distinguishes coherence from consistency (i.e. the former used with reference to policy processes and the latter with regard to strategy, instrument mix and between the two) (Rogge and Reichardt, 2016). Our study has been more empirics- and practice driven, calling a policy mix more coherent when it has more synergetic linkages and less contradictory linkages between policies (either aims or instruments or processes). In addition, we referred to consistency when discussing the definition of sustainable mobility across the governance layers. Our results brought up synergies and conflicts concerning policy goals, instruments, processes (including level of collaboration and power aspects), etc. For our purpose of creating insights into the multi-level, practical challenges of implementing mobility transitions, we believe our more general definition of coherence was instrumental to enable an integrative approach, with various aspects (of coherence) emerging in the empirics.

2.6 Conclusion

Sustainable urban mobility is one of the main challenges facing cities in the EU and requires a complex mix of policies across all levels of governance involved. To date, however, most of the existing literature on transport policy tools and goals has focused on the effects of single instruments choices and less complex design (i.e. concerning one modality or governance level). At the same time, the few studies that analyze or offer concepts for analysis of the more complex transport policy mixes has primarily addressed the urban level (Dijk et al., 2018, Legacy et al., 2012, Givoni et al., 2013, Givoni, 2014, Buehler et al., 2017a). Therefore, the effect of policies across multiple governance levels has remained neglected in the literature. This paper has attempted to fill this gap, by offering a clearer insight in the main conflicts and synergies of policies between the various layers of governance concerning sustainable urban mobility and exploring how these may be overcome.

We found that climate change ambitions are bringing more alignment concerning sustainable urban mobility at the various governance layers. At the same time, the key multi-level governance conflicts for urban sustainability mobility transition are (1) funding being biased to ‘solving bottlenecks through infra’, which does not help shift to sustainable mobility, and (2) the national level having significant influence to the local level, whilst itself being hardly influenceable by the other levels. We discussed how (1) transforming the funding focus from infrastructure to broader mobility*;* and (2) institutionalizing multi-level co-development, are ways to overcome these conflicts. This can help the improve policy outputs and outcomes, i.e. making more progress towards sustainable urban mobility, which is important for European citizens. Therefore, it is crucial that policies to achieve this are further explored, designed and implemented soon.

Limitations and future research
Our study has only started to explore the connection between (multi-level) policy mixes and urban transitions, and room for future research. First, as noted, a limitation of this study is that it mainly focused on the context of the Netherlands. Yet, all member states have their partly unique governance context and associated policy conflicts. Clearly, studying other countries will broaden and deepen the insights we gathered, and allow for more tailored recommendations for other countries. This is recommended for future research.

Second, in our current analysis we have only included conflicts and synergies that were mentioned by three or more respondent in our discussion. This means that we have also left out a range of observations that may contain valuable ones. Moreover, as noted above, there was also sometimes some level of contestation concerning the observed conflicts. We have tried to maximize transparency concerning our interpretation by providing many quotes and often one or more sentences long (as opposed to selecting just a few words). Although we do think our method did lead to highlighting the most important conflicts and synergies that were mentioned across the 32 interviewees, we do acknowledge that there has remained a level of interpretation from our side. We also acknowledge that a larger number of respondents would have made our approach to scoring the degree of significance more robust (i.e., considering, as the degree of significance of our study, the number of respondents who reported a conflict or synergy). However, we believe that the results still carry weight in highlighting the relative importance of these conflicts or synergies and that future research can further build on this.

Lastly, our analysis of vertical relation needs to be combined with analysis of horizontal relation (i.e. conflicts and synergies within level of governance), because, ultimately, it is the combination of the two that shapes the reconfiguration of urban mobility.

Author Contributions
Conceptualization, X.L. and M.D.; methodology, X.L.; software, X.L.; validation, X.L. and M.D.; formal analysis, X.L. and M.D.; resources, M.D., C.C., and X.L.; data curation, X.L.; writing—original draft preparation, X.L. and M.D.; writing—review and editing, X.L., M.D. and C.C.; visualization, X.L. and M.D.; supervision, M.D. All authors have read and agreed to the published version of the manuscript.

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Chapter 3

The Role of Data in Sustainability Assessment of Urban Mobility Policies

Liu, X., & Dijk, M. (2022).
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Abstract:

Data has played a role in urban mobility policy planning for decades, especially in forecasting demand, but much less in policy evaluations and assessments. The surge in availability and openness of (big) data in the last decade seems to provide new opportunities to meet demand for evidence-based policy-making. This paper reviews how different types of data are employed in assessments published in academic journals by analyzing seventy-four cases. Our review finds that (1) academic literature has currently provided limited insight in new data developments in policy practice; (2) research shows that the new types of big data provide new opportunities for evidence-based policy-making; however, (3) they cannot replace traditional data usage (surveys, statistics). Instead, combining big data with survey and GIS data in ex-ante assessments, as well as in developing decision support tools, is found to be the most effective. This could help policymakers not only to get much more insight from policy assessments, but also to help avoid the limitations of one certain type of data. Finally, current research projects are rather data supply-driven. Future research should engage with policy practitioners to reveal best practices, constraints and potential of more demand-driven data use in mobility policy assessments in practice.

Keywords:
Data; Urban mobility; Policy; Sustainability Assessment

3.1 Introduction

Cities around the globe struggle to create better and more equitable access to important destinations and services, all the while reducing the energy consumption and environmental impacts of mobility (Schiller and Kenworthy, 2017). Urban mobility issues are crucial problems in many regions because of rapid urbanization in the last several decades, which puts significant pressure on environmental quality, economic structure and public health in urban areas, and challenges mobility policies (Fedra, 2004). It is now almost three decades since the concept of 'sustainable mobility' first appeared in the 1992 EU Green Paper on the Impact of Transport on the Environment. Nevertheless, the transport sector still consumes approximately one-third of our final energy and probably causes more environmental and social problems than any other sector (Holden et al., 2019). Although much progress in understanding its 'unsustainabilities' has been made (Gwilliam et al., 2004, Cepeda et al., 2017, Forehead and Huynh, 2018), this has not yet led to the implementation of corresponding policies in practice, leaving urban mobility systems still far from sustainable (EC, 2021).

In order to improve the effectiveness of policies, there is need for more evidence-based policymaking (Howlett and Giest, 2012). Evidence-based policymaking requires ex-ante assessment of policies, based on data and sound methods. Typical challenges for the effective monitoring and evaluation in urban policymaking practice are: limited financial and staff resources; gaps in technical knowledge and experience with regard to defining performance indicators, the retrieval, collection, preparation and interpretation of data (Gühnemann, 2016). One of the challenges the EU's regulatory scrutiny board has highlighted in the 5th international conference Data for Policy 2020 is the problem of a lack of data: the necessary data in order to evaluate the impact of the policy. Moreover, earlier studies also found that a lack of data and a poor culture of conducting monitoring and evaluation activities in urban governments are limitations in policymaking practice (Chinellato, 2018, Awasthi et al., 2018). From interviews with cities that are relatively advanced with sustainable mobility planning, it emerged that for many relevant indicators data availability and use is restricted – data is either not available at all, its use is restricted, or there is a fee for doing so (Chinellato, 2018). Additionally, many cities do not have experience with conceptualizing and conducting evaluations and selecting the most appropriate indicators (ibid.).

At the same time, developments in the last decade regarding the availability and openness of (big) data seem to provide new opportunities for evidence-based policy-making. Open data is touted as having the potential to transform science and fast-track the development of new knowledge (Dietrich et al., 2009). Urban data centers are emerging (CBS, 2020), while the UN has organized the first UN World Data Forum. The improved access to both traditional and new types of data have the potential to improve evidence-based evaluations of policies regarding sustainability. But how this new potential can be tapped in policy practice is an emerging problem faced by the urban mobility policymakers (OECD, 2016).

Although data may not necessarily be a blessing for policy evaluations, big data is increasingly employed and found more useful and powerful than traditional survey data. Still, it is yet unclear how the new type of data can be applied best in mobility policy

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practices, for instance in which part of practical policy cycles. This paper seeks to answer such questions, which helps urban mobility policymakers to get more insights in how to better use data in the policymaking process and also provides new opportunities for policymakers towards evidence-based policy-making. It reviews the state of the art of data use in sustainability assessment of urban mobility policy in academic literature. Based on the review, this research gives insights in how different types of data are used in urban mobility policy assessment and provides recommendations about how to tap potential for evidence-based policymaking.

The paper is structured as follows. After describing the policy domain of study, urban mobility policymaking and sustainability assessment are explained in more detail in 3.2. After that, we describe our research method in 3.3. Then, we classify the various types of data used in sustainability assessments of urban mobility policies and transportation management (3.4). In 3.5, we describe a review of seventy-four case studies to show how these types of data are employed in different (academic) urban mobility evaluations and discuss the advantages and disadvantages of them. Based on an analysis of these cases, we discuss how to improve data use in sustainability assessment of urban mobility policies. Finally, 3.7 concludes.

3.2 Urban Mobility and Sustainable Assessment

3.2.1 Urban Mobility

Urban mobility refers to the ‘way people move in urban areas’, considering all transportation modes (De Oliveira Cavalcanti et al., 2017). As noted, urban planners are challenged to keep urban areas accessible in an equitable and resource efficient way amidst the challenges regarding rapid urbanization, climate change and others. Under such pressure, traditional urban mobility planning is struggling to give weight to sustainability in policymaking and project implementing, and to adapt to the continually changing social circumstances. Most of the traditional transportation modes consume considerable amounts of energy and resources, which mainly focus on efficiency and convenience for travellers but are highly depended on unrecycled materials and cause serious environmental pollution with negative effects on human health (Schiller and Kenworthy, 2017).

It is now almost three decades since the concept of ‘sustainable mobility’ first appeared in the 1992 EU Green Paper on the Impact of Transport on the Environment (ECA, 1992). In 1990, the belief that urban mobility was not sustainable as it was developing became more mainstream among local governments in Europe (ECA, 1992). The need for a different approach was seen that included much more priority on public transportation. Nevertheless, cars were still given great freedom, although somewhat restrained by parking limitations and charges, sometimes justified by environmental reasons (Holden et al., 2019). This approach was seen to be more ‘balanced’ as the case was made that the car had to adapt to the city and that the city could no longer cope with the congestion that resulted from the continued growth in car use (Ibid.). Next to the promotion of public transport, technology was introduced to manage demand to use existing infrastructure most optimally (e.g. traffic control systems, parking indicator systems, traffic free central areas etc.).

At the beginning of the century, urban mobility had still not become more sustainable (Ibid.). Although much had been learned about the nature of the problem in a technical sense including possible solutions, the barriers to implement changes in practice had not been overcome (Costa et al., 2017, Schrank et al., 2019). This sheds light on the societal complexity of the problem: the idea that solutions can be implemented top-down is incorrect, but solutions need to be co-created with multiple actors, transport and parking operators, citizens, businesses, NGOs, along with the municipality.

The 2011 White Paper acknowledged that 'still, the transport system is not sustainable' (EC, 2011), and stated that 'curbing mobility is not an option' (Ibid p.5). Instead, the White Paper called for a common strategy of de-carbonization.

Since the adoption of the European Commission's Urban Mobility Package in 2013, the Sustainable Urban Mobility Plan (SUMP) concept has been promoted as a strategic planning instrument for local authorities. It has been proposed as a framework to foster the balanced development and integration of all transport modes and create a harmonized transport offer, whilst also encouraging a shift towards more sustainable modes and improving transport accessibility for all.

An 'Urban Agenda' for the EU was launched in May 2016. It represents a new multi-level working method promoting cooperation between Member States, cities, the European Commission and other stakeholders in order to stimulate growth, livability and innovation in the cities of Europe and to identify and successfully tackle social challenges. It includes a section on urban mobility, Partnership for Urban Mobility (EC, 2018), which proposes solutions to improve the framework conditions for urban mobility for cities across the EU. This covers issues relevant to technological advancements, encouraging the use of active modes of transport, improving public transport and promoting multi-level governance measures.

Based on a survey across 328 cities in Europe in 2017, 44% said they are already conducting integrated sustainability transport planning, including 37% which said they have a plan that qualifies as a SUMP (as defined above). In addition, 16% of cities surveyed declared they were currently developing a SUMP, whilst 19% were eager to do so. There is a clear growth of cities with well-established SUMP's from seven in 2011 to nineteen in 2017 (Chinellato et al., 2017). The study also states that simply making SUMPs obligatory in itself does not guarantee the adoption of good quality SUMPs (ibid. p17). Hence, it is 'the way in which' the SUMP is developed and implemented that makes it effective or not. If the local political will and majority for transformation towards low-carbon mobilities is not present, a SUMP plan is unlikely to have much effect.

In summary, after 2010 attention for more structural changes in urban mobility is growing (e.g. modal shift from car mobility to other modes, associated to more attention for public health and livability), and the Paris Agreement has given further thrust to this trend. The question is to which extent these more structural changes are occurring. At first glance, it seems that despite much attention for 'sustainable mobility', both at EU, national and local level, the modal share of car mobility in urban areas is not decreasing significantly. In various urban areas the concept of ‘sustainable mobility’ is reduced to promoting electric mobility and cleaner fuel, but not car alternatives (Bi et al., 2016, Calise et al., 2019).

3.2.2 Sustainability Assessment

According to the research of Intelligent Energy Europe, an EU Programme, there are four key policy (making) challenges for sustainable urban mobility: participation, cooperation, measure selection, and monitoring and evaluation (Susanne, 2016). Monitoring and evaluation is a key process to decide if the policies and plans could be implemented in further steps and which measures or approaches should be improved according to the results of evaluations (Chandrakumar and McLaren, 2018). Measure selection should be based on ex-ante assessment of options.

Sustainability Assessment (SA) is an important tool to do such ex-ante policy evaluations in an integrated way. SA has been regarded as a ‘marriage’ between environmental assessment and sustainable development (Dijk et al., 2017). It refers to the systematic and integrated frameworks to assess and identify the effects of alternative undertakings and find the best way for progress towards sustainability (Pope et al., 2004, Gibson et al., 2013). It has been widely used in the sustainability evaluation of urban mobility policies (Lima et al., 2014, De Oliveira Cavalcanti et al., 2017).

Sustainability Assessment, like policy assessment and formulation, generally consists of four steps (De Ridder et al., 2007): (I) problem analysis, (II) finding options, (III) assessment of options and (IV) follow-up. Ideally, the problem analysis involves data-based evaluation, as Jordan and Turnpenny (Jordan and Turnpenny, 2015) note:

> “Having established the existence of a policy problem (or problems) through some form of data collection, the various policy-relevant dimensions of the problem are then evaluated to determine their causes and extent, chiefly as a basis for identifying potential policy solutions. (…) While the point is often made that causation tends to be difficult to precisely establish, Wolman observes that ‘the better the understanding is of the causal process . . . the more likely . . . we will be able to devise public policy to deal with it successfully’ (Wolman, 1981). Understanding causation, as Wolman puts it, is also reliant on the generation of adequate theoretical propositions in addition to relevant data on which to support them.”

Clearly, data is a vital element of both ex-ante assessment of measures and also of monitoring and evaluation in order to understand the current urban mobility status, including the role of implemented policy (Keseru et al., 2019). In practice in Europe however, as noted in Section 1, policy evaluation is generally rather limited and a lack of data and a poor culture of conducting monitoring and evaluation activities exists in urban governments (Chinellato et al., 2017). The rest of this paper seeks to review academic literature to sketch the state-of-the-art on the role of data in sustainability assessment of urban mobility policy.

3.3 Materials and Methods

In order to understand the current state-of-the-art data use in urban mobility policies assessments and further to explore the potentials of different types of data applied in this process, we used systematic and critical review as a method to search the relevant published academic books, journal papers, governmental documents that reported on them, available in academic databases. The whole process is depicted in figure 3.1, followed the guidelines of Liberati et al. (Liberati et al. 2009).

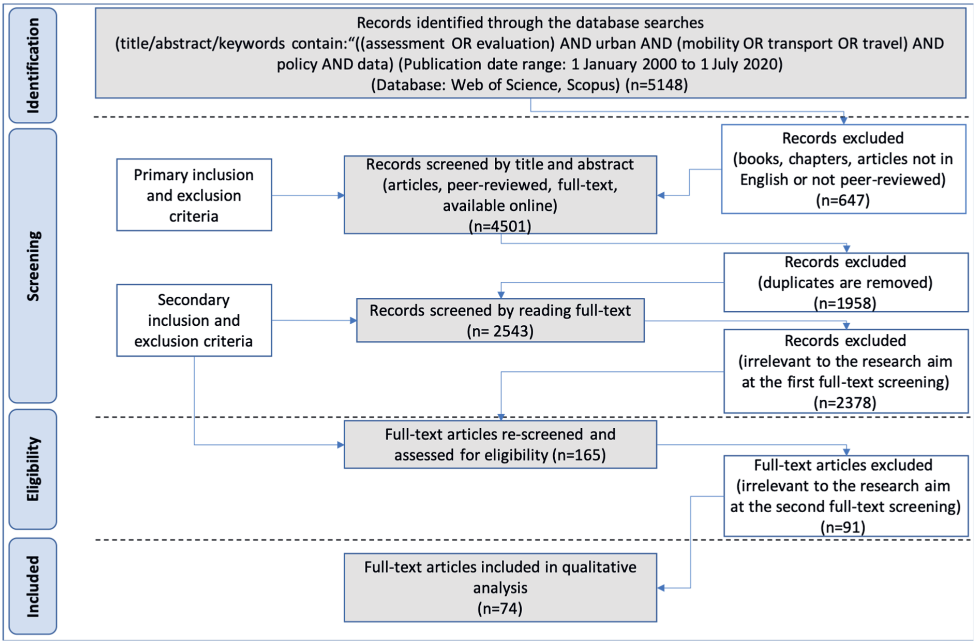

Figure 3.1. Information flow of literature search and review

The search term "(urban AND (mobility OR transport OR travel) AND policy AND data)" existed in title-abstract-keywords fields was used in Scopus and Web of Science. The date parameters of publication were limited to 2000-2020 and the search inspected all records published until 1st July 2020. The search in Web of Science led to 2266 records and the search in Scopus led to 2882 records, of which 647 books, chapters, articles not in English or not peer-reviewed were removed. Then 4501 articles were screened by title and abstract. After, these literatures were eye-balled to remove duplicates and the articles are not consistent with the search keywords. The number of literatures then cut to 2544.

In terms of selecting the studies that are relevant for this research in the full-text read process, the criteria for the selection is presented in table 1. By reviewing and understanding the data use in these literatures, we identify four different types of data that are frequently used in urban mobility studies and policymaking processes: survey data, statistical data, GIS data, and big data, which has been illustrated more in details in part 4. 166 papers met the criteria were selected for a second-round of full-text screening for eligibility. Finally, 74 of them were reviewed and analyzed in the case studies (more details about these cases are list in appendix 8.3.1). These final selected cases give most extensive insights about data use in their studies as well as show the state of art of how the data promote or impede policy evaluations. For the discussion part of this review, we also refer to other papers that are not included in the systematic review to discuss findings and for critical review.

Table 3.1. Literature selection criteria

1. The literature should be relevant to the research aim;
2. Identify the suitable literature focusing on data use in urban mobility policies;
3. Exclude the selected literatures without real place case studies;

3.4 Classification of Data Use in Urban Mobility Studies

Data has played a role in mobility policy planning for decades (Meyer, 2016) and forecasted travel demand, often based on extrapolation from historic traffic intensities, has been important. Also, household travel surveys have been a typical way to understand travelers' behavior and to evaluate specific mobility policy (Chen et al., 2016). Analyzing previous governmental statistical yearbooks and relevant policies, building spatial transportation models, as well as collecting commuters' daily travel data, are the key approaches to study the most important mobility issues including travel safety, transport system design, and sustainable mobility development (Hall, 2012). More recently, big data has emerged in mobility studies, which has been largely used in road user's behavior detections and travel modal shift operations (Welch and Widita, 2019). Across these data applications, we can identify four different types of data that are frequently used in urban mobility studies and policymaking processes: survey data, statistical data, GIS data, and big data.

3.4.1 Survey Data

Survey data has been widely used in various research domains (i.e. social science, economics, policy assessments, and risk management). In urban mobility research, they have largely applied through travel surveys to analyze the motivations and reasons of traveler behaviors in order to stimulate more sustainable mobility behaviors (Bamberg et al., 2003, Cao et al., 2008, Long and Thill, 2015). It is also a new trend to combine GPS, smart cards, and such kind of sensing data with survey data together to comprehensively understand urban mobility issues in different angles. These combinations give researchers more opportunities to upscale their studies (Long and Thill, 2015, Gong et al., 2016).

However, some critics argue that survey data is often constrained by unrepresentative sample sizes. For example, the household surveys by the Federal Highway Administration in the U.S. had a relatively small sample size compared to the size of the project (TMIP, 2013). Furthermore, it may also lose the representativeness if investigators choose unsuitable survey targets. Thus, it is critical to give a certain range of which sort of projects or researches are fitted to use survey data for their studies.

3.4.2 Statistical Data

Statistical data in this study is defined as the statistics compiled from statistical yearbooks and various related documents, which is normally sourced from data collection by official departments and published in governmental reports. It is significant to use statistical information for understanding and quantifying impacts of political decisions in a specific area, which also plays an important role in different research domains, especially in projects, policies, and social development evaluations (Huo et al., 2018, Liu et al., 2018, Yang et al., 2018).

In urban mobility studies, statistical data has been widely used by policy makers to assess mobility status and to evaluate the implemented planning and policies, also to indicate problems of the current policy making and implementing process (Cervero, 2013, Annema et al., 2017). The limitations of using this data are that it is hard to monitor the changes caused by one particular indicator and it usually does not contain all the indicators needed by assessments, which means that it can only support basic information to data analysts (Mozos-Blanco et al., 2018).

3.4.3 GIS Data

Geographic Information System (GIS) is a broadly used information technology that has transformed the ways investigators conduct research and has had tremendous effects on research techniques (Foote and Lynch, 1996). ArcGIS is one of the GIS applications using technologies that could help geographers to gain multiple categories of spatial data by working with maps and geographic information, which can also be used to compare the data in different timeframes, and to analyze mapped information applied in a wide range of research domains (Johnston et al., 2001). The main feature of GIS data is that it can provide visual displays for data analysts, especially for policy makers as it helps to transfer complicated data in a straightforward and understandable way (Scott and Janikas, 2010).

According to these characteristics of GIS data, it has been used in urban planning (Maantay and Ziegler, 2006), resource management (Pettit et al., 2008), public health (Hirschi et al., 2002), transportations (Thill, 2000), and also many other different fields. Researchers mainly applied it to acquire the information of landscapes, streets, public transport lines, and roads lines, which all of them are very useful for mobility studies (Greene and Pick, 2012). Increasingly urban mobility researchers combine GIS data together with the other types of data (i.e. GPS data, mobile phone data, and social media data) to detect urban travel modes and behaviors, which could compensate for the limited information provided by GIS data (Gong et al., 2012, Khan et al., 2016).

3.4.4 Big Data

Big data refers to data in large volumes, is heterogeneous, and has autonomous sources in decentralized control according to the techniques used to explore the complex relationships amongst the data (Wu et al., 2014). It has the potential to depict overall macrotrends with huge amounts of available, and with a high level of detail, information, which also helps to change traditional ways of collecting and analyzing data in practice and research (Pucci and Vecchio, 2019). Global Navigation Satellite Systems (GNSS), location-based services, public transportation cards etc. all generate numerous data as a by-product in these operations (Semanjski et al., 2016). Big data has been firstly used in business-oriented domains as the data could measure customers' performance in which providing rich information and knowledge about consumers' behaviors and preferences for companies to help them make commercial strategies (Linden et al., 2003, Hasan et al., 2009). From there, it has gradually spread into other fields. It is a new opportunity for experts to exhaustively grasp people's mobility behavior in order to implement corresponding policies by analyzing this data from multiple sources (Milne and Watling, 2019). Furthermore, it has already made big contributions to solve urban mobility-related issues, such as real-time traffic monitoring, traffic congestion regulation, and traffic accident management (Abdulazim et al., 2013, Calabrese et al., 2013). The typical application of big data in urban mobility studies employ GPS, smart cards, mobile phones and social media, which we discuss in a bit more detail.

Since the 2000s, it has been prevalent to collect GPS (Global Positioning System) data from GPS loggers, GPS-phones, and GPS-enabled PDAs (Personal Digital Assistant). With the size and weight of GPS devices becoming smaller and lighter, new potential for gathering people’s mobility information arose (Stopher et al., 2008). GPS data includes locations, time, speed and moving tracks (Stopher et al., 2008). Therefore, more and more projects intend to detect people’s travel behavior by analyzing individual movement from GPS data, especially when the cost of these devices has gradually decreased (Liao et al., 2006, Liao et al., 2007). In urban mobility studies, understanding transportation modes, improving traffic regulation, and evaluating management strategies of road networks are the most commonly applied GPS data fields (Mintsis et al., 2004, Bastani et al., 2011). However, the raw GPS data is usually analyzed directly, without understanding trip purposes or other related context (Gong et al., 2014).

Smart card data has been predominantly used by public transport systems around the world since the automated data collecting system emerged in the last few decades, which offers sufficient data to investigate travelers’ mobility behaviors for transport planning, traffic management and mobility policymaking (Pelletier et al., 2011). Two main characteristics of smart cards are that it is quite convenient to take and durable to use (Lu, 2007), which makes it easier to acquire data from smart cards while it also improves the quality of gathered data compared with magnetic cards. Privacy issue is the biggest concern for card users who do not want to share all of their personal data for analysis (Bagchi and White, 2005).

Mobile phones are becoming an important medium for data analysts to acquire large-scale sensing data used in various domains Urban spatial planning and management (Louail et al., 2014, Pei et al., 2014) as well as social networks (Phithakkitnukoon et al., 2012, Jiang et al., 2017) are two of the most common areas of study applying mobile phone data, which give fundamental knowledge and experience to other research fields. In terms of urban mobility studies, it not only serves new opportunities and perspectives for investigators to understand people’s mobility behavior by a lower cost approach with large sample size and frequently update datasets, but also supports policy makers to monitor the emerging mobility issues and respond correspondingly through measurements promptly (Calabrese et al., 2013). Meanwhile, analyzing raw mobile phone data is complex work that needs sufficient knowledge of modeling and computer science that are the basic requirement for data analysts to process the huge amount of data and to detect valuable information (Rojas IV et al., 2016).

Facebook, Twitter, Instagram, Weibo etc. are the most popular social media platforms for everyone to create their own accounts and share their personal data to others. This type of data has been predominantly used in business analytics in the last decade, for example, companies analyzing social media data to explore what are the most trends etc. for their business (Kaplan and Haenlein, 2010). In the urban mobility domain, social media data helps policy makers detect driving forces of people's movement behavior, which could be regarded as convincing evidence to make some changes of the current implemented policies according to travelers' real needs (Hasan et al., 2013). Although it can provide more in-depth data for experts compared with the other types of big data that we mentioned before, there is not a uniform format for social media data analysis, which means more attention is needed for classification of it (Grant-Muller et al., 2015). Moreover, the privacy issue should always be taken into consideration when such data is collected and used.

3.5 Case Studies Analyses

Figure 3.2 shows the main data type used in each study. There are 32 cases for survey data, 10 for statistical data, 9 for GIS data, and 23 for big data. 20 of these 74 cases combined at least two different types of data in their studies. Survey data is the most popular data type for combined data use, which has been applied in 14 of these 20 cases. GIS data and big data are also very commonly applied with other types of data in urban mobility policy related research, 10 and 9 out of these 20 cases respectively.

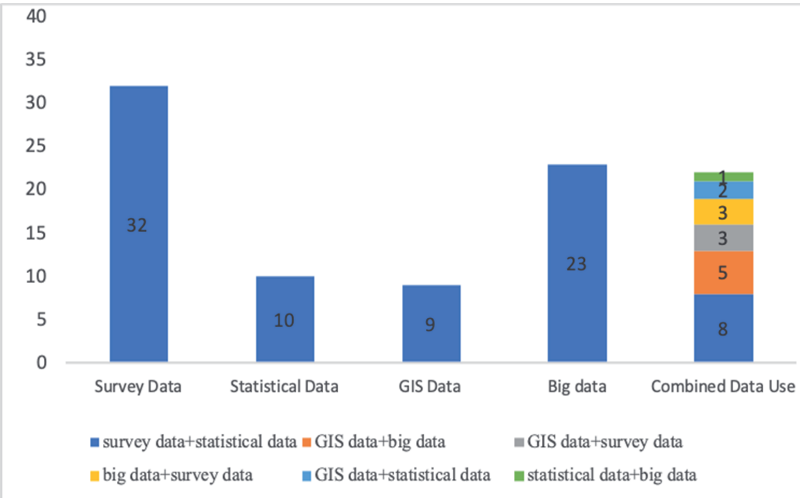

Figure 3.2. The number of cases for each type of data

Regarding the publication date of these articles, it could be seen from figure 3.3 that the research about data use in urban mobility policymaking becomes more popular after 2011, especially for survey and big data. Although big data use in mobility policymaking studies shows a rapid increase after 2015, survey data still plays the main role in this research domain.

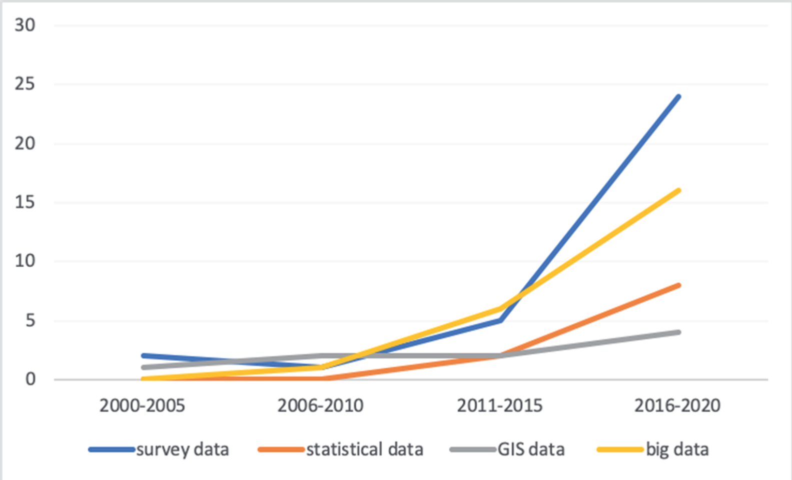

Figure 3.3. Publication year of the final reviewed literatures

3.5.1 Cases Analyses

Each case's main characteristics and core information, including data types, sources, subjects, regions, policy associated process (according to the policy cycle explained by Howlett et al. 2009, see figure 3.4), and how data used in the cases are summarized in detail in appendix 8.3.1. Specifically, what types of data used in each case associated with different processes in a policy cycle is illustrated in table 3.2 (please check the serial number of the articles in appendix 8.3.1). Furthermore, different types of these studies, including pure academic research and policy practice, are distinguished and shown in the same table as well, which shows that little research has been applied in a real policymaking process.

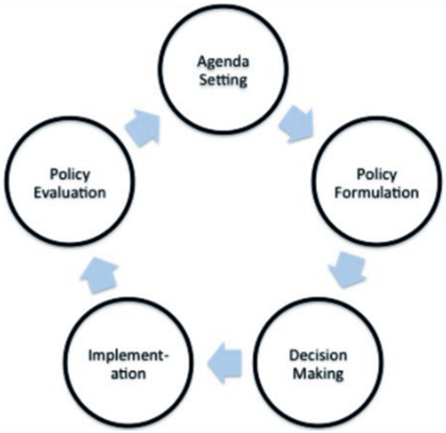

Figure 3.4. Policymaking cycle (Howlett et al., 2009)

Table 3.2. Policy associated process in the literatures

	Survey data	Statistical data	GIS data	Big data
Agenda setting	[1-3]			[52] [53]
Policy formulation	[4-9]	[33] [34]	[43] [44]	[54] [55]
Decision making	[10-13]	[35] [36]	[45-47]	[56-65]
Implementation			[48]	[66]
Policy evaluation	[14-32]	[37-42]	[49-51]	[67-74]

These cases found and analyzed are mostly academic studies published in scholar journals studying advancements in assessing policies. Some of them did policy assessments first and then took sustainability into account in the discussion, some of them focused on data use techniques for policy assessments but hardly in practice. There was only one SA case (De Oliveira Cavalcanti et al., 2017) from actual policy practice among all of these 74 cases, which evaluated the sustainability of five urban mobility projects in the Curitiba metropolitan region.

As table 3.2 shows, big data is becoming an important resource for urban mobility policy related studies. Comparably, survey data still plays an essential role in the same domain. By analyzing these case studies, we found the strength and limitations of different types of data used in the urban mobility policy related studies, as follows.

Valuable information and deep insights from different perspectives could be provided by survey data, especially if the respondents are experts in the urban mobility fields. For instance, Mansourianfar and Haghshenas (2018) analyzed interview transcriptions with local mobility policymakers and combined this with analysis of governmental documents in an ex-ante assessment of policy measures at the neighborhood level, which provided targeted and insightful recommendations for urban mobility policymaking (Mansourianfar and Haghshenas, 2018). On the other hand, small sample size and information being out-of-date are two common limitations of survey data applied in these studies, which had been shown evidently in Hirschi et al (2002)'s and McGuckin et al. (2005)'s studies (Hirschi et al., 2002, McGuckin et al., 2005).

All of the cases applying statistical data in their studies reflect that it is the most convenient way to collect historical mobility data through various document sources. Moreover, it also plays a vital role in comparing the same mobility policy measure implemented in different cities, such as Mozos-Blanco's (2018), which compares the sustainable urban mobility plans of 38 Spanish cities by analyzing the relevant documents (Mozos-Blanco et al., 2018). The same historical recorded data could be easily acquired through statistical year books and governmental documents among cities, which provides a stable source of data for policy assessments. One common limitation showed in these cases is that the resolution of statistical data is relatively low, which may cause information loss for the assessments. Wiersma's (2016), for instance, note that limitations in the statistical data available prevented them from taking social factors well into consideration in their study (Wiersma et al., 2016).

The biggest strength of GIS data is that it can provide adequate geographical transport information, including traffic lines, locations of transport infrastructures, and urban road networks both in national and regional scales. All the cases which applied GIS data as the main data source in their studies mention that various online GIS databases could be found to support their studies, whereas sufficient experience of relevant software use is required to process data and build models.

The prominent advantage of big data application in urban mobility policy studies is that it provides massive information that can give a comprehensive assessment of urban mobility policy measures based on traveler behavior analysis. For example, massive traffic data was applied in Paffum (2015) and Zeitler (2012) for the ex-ante assessments of policy options in a decision-making process. Moreover, big data also shows strong adaptability of use in different urban mobility policy domains combined with other types of data, especially with survey data in developing decision making support tools (Paffumi et al., 2015, Zeitler et al., 2012). This can be seen in Jiang (2017) and Wismans' (2018) studies (Jiang et al., 2017, Wismans et al., 2018). On the other hand, a limitation of employing big data in urban mobility policymaking is that it is difficult to structure the input data sourced or constructing models, which means it costs much more time to process and analyze these data. Jiang (2017) specifically mentions that, in practice, it will be challenging for urban mobility policymakers to have enough capacity to process and analyze big data.

3.5.2 Policy Related Analysis

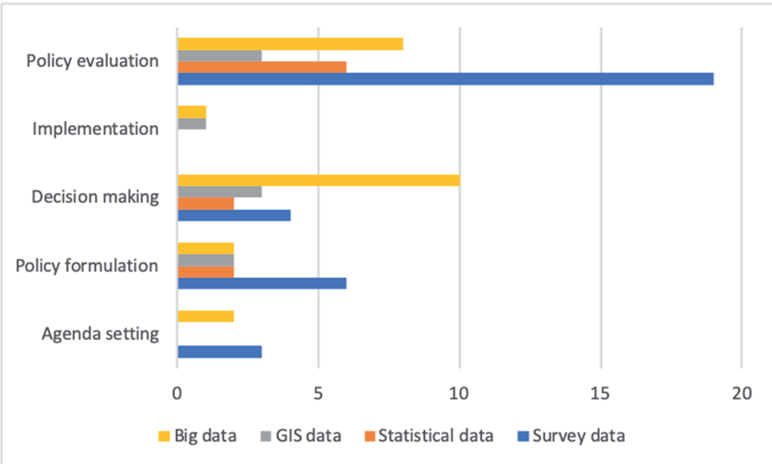

Figure 3.5. Different types of data use in policymaking cycle

Regarding the data use in the policymaking cycle, figure 3.5 shows that according to these cases, data use in urban mobility policymaking cycle mainly focused on policy evaluation, decision making, and policy formulation phases. Big data is the only type of data has been applied in all processes of the policy cycle and it has been mostly employed in decision making processes, focusing on decision-making tools development. For instance, Jiang et al.'s examined how to analyze raw mobile phone data combined with census data and geographical datasets in different models in order to see which model is more effective in translating and gaining information for sustainable urban mobility planning. In Andrenacci and Genovese's (2019) research, floating car data contains information on the travel speed, time and routes which were continuously detected by devices on board the cars, which helped to obtain information on the journey to be examined in models determining the best policy option (Andrenacci et al., 2019). Additionally, big data has also been widely used in policy evaluation, mainly focus on applying real-time traffic data to assess the impacts caused by implemented mobility policy measures in order to make prompt regulations. There are only two cases where data was employed in the implementation process, one of which is from big data. Maranzano et al. (2020) applied traffic data combined with GIS data to assess the early-stage impact of an extended limited traffic zone based on a developed traffic model, which provides in time insights for policymakers to adjust the policy according to the evaluation (Maranzano et al., 2020).

GIS data is another type of data which has been applied in implementation step to explore the optimized regulation methods for efficient mobility regulation improvement (Wang and Zhu, 2014). Notably, it has been relatively equally used in policy evaluation, decision making, and policy formulation phases as well, especially by combined with other types of data. It provides the basic information of road networks, regional maps, and other relevant traffic information for traffic model and decision-making tool development.

Statistical data is a valuable resource for both ex-ante policy assessment in policy formulation and ex-post assessment in policy evaluation, which could be easily acquired in different cities and regions and also easily be compared based on the same dataset. There is only one policy practice case among the 74 cases, which exacted the information from various governmental and academic documents to evaluate the sustainability of the Curitiba metropolitan region mobility projects (De Oliveira Cavalcanti et al., 2017). It provided the policymakers clear sustainability goals to achieve the evaluated mobility projects.

Survey data is the dominant data type used in almost all steps of the policy cycle except implementation and it is one of only two data types that has been embedded in agenda setting processes. Large-scale commuter travel surveys had been used in this step to detect mobility problems and then to set up corresponding policy measures, for instance, McGuckin et al. did a national survey to investigate participants' daily travel information so as to define mobility problems for policy measure design (McGuckin et al., 2005). Survey data is also the main resources for ex-post assessments of urban mobility policies-nearly 53% of all the cases in policy evaluation process employed survey data as the main database, which shows that big data has not replaced this traditional data type in urban mobility policy assessments.

3.6 Discussion

3.6.1 Comparisons of Strengths and Weaknesses of Four Different Data Types

Comparing the 74 cases, we can see that the most detailed information obtained for transport policy planning and assessment is from survey data. It not only contains each respondents' personal information but also tells of the motivations behind their travel behaviors directly, which is rather useful for developing sustainable policies. However, limited available data, related to the rather time-consuming nature of organizing surveys, is the main weakness of its application. One suitable way to solve this problem is to set a certain target group of responders, for example, 168 respondents in Soria's (Soria-Lara et al., 2015) research are EIA developers, transport planners, and some other professionals with transport planning or evaluating experience, providing sufficient valuable information to evaluate the EIA process for urban transportation planning in Spain. Besides this, web-based survey approaches can help to improve efficiency of the data collection by sending easy links to questionnaires to targeted groups.

The application of statistical data in mobility assessment studies is widely practiced as well, especially on a national scale. The main purposes of four (De Oliveira Cavalcanti et al., 2017, Mozos-Blanco et al., 2018, Haghshenas et al., 2015, de Grange et al., 2012) of the ten cases which applied statistical data were to establish assessment criteria and to make comparisons among different projects and policies. Another case (Wiersma et al., 2017) sheds light on combining statistical data and GIS data together to examine the driving force of car dependency in the Netherlands. The mixed use of data in this research has been analyzed in a spatial context, which provides sufficient knowledge for policymakers to study car dependency caused by different related factors as well as make it easier to see the variety of results among the cities in the Netherlands. Although a large amount of data used in this research aims to solve the research question- how does the spatial context shape conditions for car dependency, social factors, for instance education level, may cause people choose different ways to various destinations, which has not been taken into consideration because of a lack of data.

According to the case analyses, GIS data has an outstanding capacity to do ex-ante assessments for mobility policy decision making compared with other data types, because a variety of policy alternatives can be tested in models to see which one will have the best performance according to different key factors. Financial issues regarding urban transportation planning can be examined by together analyzing GIS and statistical data which was detected through constructing a new methodological approach to measure the spillover effects of transport infrastructure investments in a spatial context dealt with in ArcGIS software (Gutiérrez et al., 2010). It shows that GIS data has a somewhat different function in urban mobility research, mostly related to the opportunity to explain the results with maps to policymakers.

Big data has been widely applied together with survey data, road networks data, and GIS data in ex-ante assessment and decision-making tool development for urban mobility policy studies. The combination of survey data and GPS data in Zeitler et al.’s project (Zeitler et al., 2012) for identifying suburban environmental impacts and evaluating mobility policy options is instrumental to get insights into both travelers’ basic needs and motivations, as well as their actual travel behaviors, which help policymakers see the real requirements of commuters. One prominent characteristic of big data is that it can provide massive individual traveling information offered by tracking devices. This data can be used to depict selected groups of travelers’ activities and to assess efficiency of the relevant decision making. Nevertheless, only relying on big data, especially GPS and traffic data, will cause data sparsity problems, as noted in Zhan et al.’s research (Zhan et al., 2016). Not only are mobility researchers trying to explore the potential use of big data in sustainable transportation policies and governance development, but also data mining and analyzing scientists have begun to detect the valuable messages from it, extending the implementation fields of big data. A study (De Gennaro et al., 2016) published on ‘Big Data Research’ has developed five models based on the information provided by GPS and GIS data, aiming to better use data in urban mobility policy evaluation and governance. One issue observed through reflections on the big data cases is that big data use in the urban mobility policymaking process is still mainly supply-driven and hardly demand-driven.

Currently, there are some new opportunities for researchers and policymakers to develop better mobility policies since a new data type, social media data, has been used in the mobility policy assessment process. For instance, 1.5 million social media data elements from Weibo (the biggest Chinese microblogging platform) and 8 million smart card data units have been analyzed in Yang et al.'s (2019) study to explore connections between social activities and mobility behaviors (Yang et al., 2019a). This created insight in various spatial and temporal trends of urban transport. The study suggests that social media data can also reflect travel motivations from those data sharers, while taking less time to collect (than surveys), because it can be collected online. However, one common challenge for big data analysis in urban mobility studies is data processing. It is difficult to structure and format input data that are from various sources. Nevertheless, modelling and programming are both necessary skills that are required for analysts to deal with big data. Moreover, according to the features of transportation policymaking, real-time data monitoring and analyzing are both significant factors to have an effective assessment for urban mobility policies.

3.6.2 Potential better use of data in sustainability assessment of urban mobility policies

Sustainable assessment of mobility policies should give insight into the impact of policies in terms of accessibility, environmental and social indicators (Black et al., 2002, Costa, 2008). Ideally, sustainability assessments show possibilities to stimulate transport modal shifts, to reduce private car use, to cultivate people's green traveling consciousness, and to improve efficiency in urban transport systems (Banister, 2008). Data is an essential ingredient in these assessments. The case studies reviewed helped to learn the current use of different types of data in urban mobility policy assessments, of which most of them are academic studies. Furthermore, it also helps to explore the potential of available data innovations of applications for policy practice.

Da Silva, et al. (2015) emphasize that data availability and quality are the most important elements to run an assessment, which also depends on whether policymakers and researchers are involved in formulating assessment criteria based on their problem perceptions (da Silva et al., 2015). Data reliability should be a concern when analysts are going to deal with collected data as it determines problem solving and corresponding measures designing directions (Witlox, 2007). It is also necessary to weight the representativeness of data before using analyzed results into policy assessment, which has been highlighted for transport studies since 1993 (Schoonees and Theron, 1993). Moreover, privacy is the most common issue that we must care about when we use individuals' information for policymaking (Hwang et al., 2009, Kifer and Machanavajjhala, 2011, Callegati et al., 2015). A thoughtful way to deal with it is giving announcements to respondents who share their private data for a certain use as well as informing them on the final research results after assessments. Lastly, a practical issue has been mentioned by an EU mobility policymaker in 2019 EU Conference on Modelling for Policy support which was that most of the data currently available for urban mobility policymaking is supply-driven but not demand-driven, which causes policymakers to have limited space when choosing the data they really need. This requires more cooperation among different parties working together to give more opportunities for mobility policymakers gathering the data they need for policymaking.

In order to advance mobility policy assessments in terms of data use, exploring the role of data in various phases of the policymaking cycle and detecting what kinds of skills and expertise are needed for policymakers could be helpful. Firstly, in the agenda setting phase, historical data collection and processing can be used to define and frame problems (Doern, 1992). However, if the statistical data, such as the number of electric vehicles, charging stations, and PM 2.5 emissions, could not be measured periodically in this stage, it would be demanding work for policymakers to define actual mobility problems. This step also requires policymakers to select basic indicators that are easy to collect periodically which is essential for urban mobility issue defining. In the second phase, policy formulation, policy options should be developed and preliminarily ranked. Traditional survey data, GIS data and big data all show their usefulness for policy option formulation, especially the combined use of survey data and big data has been found to have a big potential to help understand traveler behaviors and corresponding motivations. This will help policymakers design more humane and sustainable transport policy measures. Besides this, ex-ante assessment can also be very useful in both this stage and next in the decision-making process, which helps policymakers select the most suitable solutions.

In the third phase, the final policy measure for implementation needs to be decided. Gathering GIS data and traffic data processed in ArcGIS software is an effective way to evaluate and compare different policy options. This gives governments more chances to see different forecast results based on varied scenarios and further to draw a bigger picture of their transportation planning. Analyzing the data in this step requires professional employees such as modelers and data analysts since sufficient data processing and modelling knowledge are needed to dig information from raw GIS and big data. Otherwise, it will cause a common problem facing policymakers where they have a lot of data but they do not know how to select and use it.

In the fourth step, selected policies should be implemented, and in the last phase, monitoring and evaluation of the policies should be conducted. In practice, these two steps are often not sequential but iterative (Hessing and Summerville, 2014) (. Big data, such as real-time traffic data, GPS data, mobile phone data, and social media data, can give more in-time reflections of implemented policies in this period, which could let policymakers make prompt adjustments responding to the problems showed in the policy implementation phase. Ex-post evaluation can also employ statistical data and survey data to compare outcomes of current policy with those of previous policies as well as to analyze feedback from travelers after policy trails, which is an important step to respond to potential problems. However, this also requires sufficient work capacity from the urban mobility departments to conduct monitoring and evaluations.

3.7 Conclusion

In this paper, we review recent (2000-2020) academic literature on urban mobility policy assessments to understand the current state-of-the-art of data use in these activities and further explore the potential of available data innovation in more evidence-based policymaking. The 74 case studies reveal a surge of attention and availability of open, big data, although, it cannot replace traditional data usage (surveys, statistics). We do find that the new types of data provide new opportunities for evidence-based policy-making.

Overall, the data use innovations in sustainability assessment for urban mobility policy can be concluded as follows: 1) big data shows the most potential for use in decision-making support tools development, especially combined with survey data which shows even higher effectiveness; 2) Specifically, big data (most of the available big data are location-based data) used in traffic models can more easily provide detailed information about travel patterns, but reveals less about motivation while traditional surveys remain more useful for this; 3) The use of new types of data in urban mobility policymaking requires policymakers and related working staff to have certain knowledge and skills for data analysis, modelling and extra working capacities.

Limitations and future research
In the literature search and selection process, it was a criterion that studies shed light on the use of data in urban mobility policies, especially for policy assessments towards sustainability. Because of this real-place particular focus, a broad range of mobility policy assessments in the literature are left out. Additionally, only one of the case studies is based on policy practice while the others are all academic research, so we can hardly conclude with extremely certain suggestions for urban mobility policymakers in practices.

Moreover, because the 74 cases are mostly academic studies, not from actual policy practice, it is a gap that should be addressed by future research since innovation in policy assessment likely takes place in practice as well. This can lead to better understanding of the use of state-of-art of data in practice and recommend the most optimal use of new data types used in urban mobility policymaking. The studies we reviewed did not reveal how policy makers appreciate the various data types and how they are involved in shaping data analysis. It seems like there is a tendency for supply-driven data in practice as well. Studies of innovation in policy assessments in practice can reveal the best applications, constraints, and potential of more demand-driven data use in mobility policy assessments.

Author Contributions
Conceptualization: M.D. and X.L.; Methodology: X.L. and M.D.; Data curation: X.L.; Data visualization: X.L.; Writing original draft: X.L. and M.D. All authors approved the final submitted draft.

4

Chapter 4

How more data reinforces evidence-based transport policy in the Short and Long-Term: Evaluating a policy pilot in two Dutch cities

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Abstract:

Data have played a role in urban mobility policymaking for decades. Especially since the emergence of big data, many researchers have shown how to advance data use to improve understanding transport policy effects, but there is hardly insight in how this is adopted in policy practice. This study aims to address this gap by answering two questions: (1) how is data currently embedded in urban mobility policy- and decision-making; and (2) what are the advantages and limitations of more data use in these processes? We chose two Dutch cities -Maastricht and Groningen-that were both involved in a national programme (BeterBenutten) that trialed (and funded) a more evidence-based policymaking approach. We did ten semi-structured interviews with the people work in the mobility department and analyzed the twenty-one most relevant policy reports to understand how more data reinforces/impedes transport policymaking in practice. We found that data use differed in long-term and short-term policy cycles. In the long-term policy cycle, data was regarded as less important than political and societal trends and developments; in the short-term cycle, data played a major role in prompting traffic regulations and policy adjustments.

Keywords:
Data; Evidence-based policymaking; Urban mobility

4.1 Introduction

Urban areas are faced with an increasing amount of challenges due to urbanization and climate change. More than 60% of greenhouse gas and carbon emissions are caused by cities while they also consume 78% of global energy (Finck et al., 2020a). Concerning urban mobility, more than 40% of CO_2 emissions are caused by road transport (Commission, 2007). Thus, in order to reduce CO_2 emissions as well as retain accessibility and liveability, urban mobility policy has become a vital field occupied by governments as well as different stakeholders that increasingly seek to contribute to achieve sustainable development goals (Gabrielli et al., 2014).

Currently, however, urban policies have struggled to deliver sustainable, low-carbon mobility. Private car mobility still represents about 80% of the kilometres driven by people in most EU countries, and a European average number of passengers per trip heads to around 1.7 (Parliament, 2019). Traditionally, increasing the effectiveness of policies is endeavoured by adapting aims, instruments and coordination mechanisms in general, but recently there is particular attention for more evidence-based policymaking through better use of data (Kitchin, 2014, RLI, 2021). Driven by success in financial analysis, online trading, computer science, product design, and medical testing (Kitchin, 2014, Sagiroglu and Sinanc, 2013), more data also seems to offer new potential for evidence-based mobility policy-making. That is what we focus on in this paper.

The neglect of policy assessment in policymaking is one of the principal obstacles of effective sustainable urban mobility development in most European cities (Susanne, 2016). The policy cycle is the common conceptualization of the main stages of the policymaking process, generally including agenda setting, policy formulation, decision making, implementation, and evaluation (Howlett et al., 2009), see figure 4.1. Data plays some role in every stage of the whole policy cycle, but has a key role in the policy evaluation stage (Gühnemann, 2016). Evidence-based policymaking is a process that '*helps people make well informed decisions about policies, programmes and projects by putting the best available evidence from research at the heart of policy development and implementation*' (Unit, 2004). It leads to a shift from traditional opinion-based decision making towards decisions based on reliable evidence and systematic research (Unit, 2004). Two procedures for evidence-based policy-making are ex-ante assessments and ex-post evaluations (Hill and Varone, 2014). However, ex-post evaluation of policy has less of a tradition in transport, and most of the post-evaluations that have been done are specific, large ('mega') projects, often applying cost-benefit analysis (Flyvbjerg, 2017). Lack of staff capacity, limited technical knowledge and skills of data collection & analysis and poor culture for monitoring and evaluation at governments are all restraints faced by policymakers for effective monitoring and evaluations(Gühnemann, 2016).

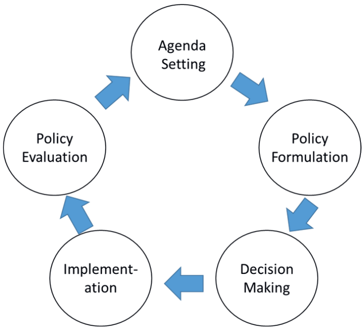

Figure 4.1. Policymaking cycle (Howlett et al., 2009)

Figure 4.2 shows the distinction in terms of the different time constraints between (a) rapidly responding to policy questions and (b) those for longer-term strategy development. In the latter, there is more time to collect and analyze data, but questions may also be more complex. The main finding of this research is to discover the differences of different types of data use between long-term and short-term policy cycles-briefly, data is stronger in the shorter cycle whilst having a less central role in the long cycle.

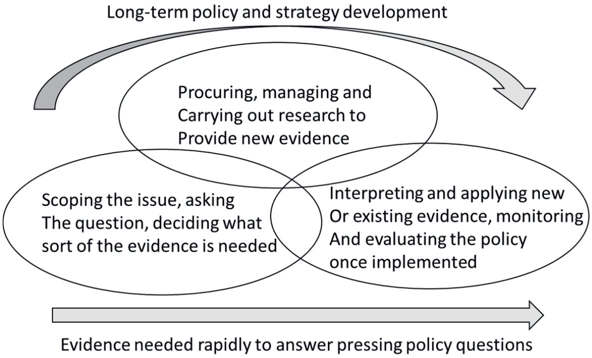

Figure 4.2. The flow of evidence in the policy process (Shaxson, 2005)

Big data-commonly feathered as the data with high volume (information), velocity (frequency of observation) and variety (diversity of data)-in this study refers to GPS (Global Positioning System)-based 'Track & Trace' data, mobile phone traced data, and social media data (see the details of each type of data application in transport policymaking in Harrison, et al., 2020 and Liu and Dijk, 2022), which might be a new blessing for urban mobility policy development (Milne and Watling, 2019, Laney, 2001, Harrison et al., 2020, Liu and Dijk, 2022b). There are academic studies that explore new data applications, but hardly insights from actual policy practices (Liu and Dijk, 2022b). Researchers have applied GPS data, mobile phone data, and social media data to draw pictures of traveler behaviors, for instance: Yang et al. analyzed 1.5 million social media data from Weibo (the biggest Chinese microblogging platform) to explore the connections between social activities and mobility behaviors (Yang et al., 2019b); Geurs et al. collected 18,000 trips' details through a smartphone app called MoveSmarter to understand traveler behaviors and to examine the efficiency of the app (Geurs et al., 2015); De Gennaro et al. developed five models based on GPS and GIS (Geographic Information System) data to enhance data use in mobility policy assessments (De Gennaro et al., 2016).

Compared with big data, another way to collect data is to do surveys. Although sometimes constrained by unrepresentative samples and limited time, survey analysis gives insights in 'why' of commuters' actions (Bamberg et al., 2003, McGuckin et al., 2005, Long and Thill, 2015). Most of these academic studies address larger cities. In order to understand how more data can reinforce evidence-based transport policy in practice, more research is needed in actual policymaking processes, probing into the potentials and constraints of data use in urban mobility policymaking practices. This paper addresses this gap by answering the following questions: (1) how is data currently embedded in urban mobility policy- and decision-making; and (2) what are the advantages and limitations of more data use in these processes? We address these questions by zooming into a specific mobility policy assessment program piloted by two Dutch cities, Maastricht and Groningen. A semi-structured interview approach (Whiting, 2008) is adopted to investigate how municipal officials use data in urban mobility policymaking.

We structure the paper as follows. The next section describes the research method and introduces the case studies in Maastricht and Groningen. 3.3 offers the results on data use in these two cities, based on interviews and document analysis. Through a cross comparison of the two cases, 3.4 discusses the advantages and limitations of more data in evidence-based policy making, while 3.5 concludes by answering our research questions.

4.2 Method

4.2.1 Case studies and case selection

In order to understand whether and how more data reinforces evidence-based urban mobility policymaking, we selected two Dutch cities that were both part of a national programme, BeterBenutten ('Better Utilize', in English), that trialed (and funded) a more evidence-based policymaking approach between 2011 and 2018. We opted for two cities rather than one in order to allow contrasting and comparison between the two and learn about uniqueness and similarities. We chose two and not more in order to allow sufficient detail for each case within the scope of our project. We chose two cities of, in our definition, small to medium size, i.e. between 120 and 200 thousand inhabitants, because the largest share of European cities is of this size, whilst they are typically the ones that struggle with limited numbers of policymakers dedicated to mobility (Dragutescu et al., 2020, Ryghaug and Skjølsvold, 2021). In the EU, there are only 93 cities of more than 300.000 inhabitants, but 252 cities of 100 to 300,000 inhabitants (Lewis, 2012). This increases the potential impact of our study in supporting evidence-based policymaking in practice. We will introduce the two case cities further in 3.4.

We opted for a qualitative approach to answer our research question because quantitative evaluations of policymaking are usually not capable to comprehend the role and impact of data (use). The complexity of policy systems calls for a qualitative approach that takes account of the details of policy instruments and their effects together with relevant situational characteristics (governmental organization, procedures, specific local mobility issues, infrastructure, projects, etc.). The integration of all these aspects into the analysis is best supported by a combination of qualitative methods, which we discuss now.

4.2.2 Data collection

Semi-structured interviews

Semi-structured interviews is a key method used in this research. The outline and questions of the interview are list in Appendix 8.4.1. We started by interviewing one of the most senior policy-maker and one of the most senior data expert (recommended and selected by relevant official websites, documents, and networks) who are fully involved in urban mobility policymaking and in charge of the BeterBenutten program in each city. Then we went on to select (subsequent) interviewees based on suggested people by interviewees ('snow-balling') with what followed from the analysis of written sources (positional approach). Snow-balling assumes that people working for the same field in a group are interconnected, they know each other personally or by reputation, so they will know when you ask who is relevant in this field (Myers and Newman, 2007). As Table 4.1 shows, this gave us a list of ten interviewees, five in each city. Since the fifth interview delivered hardly any new insights, we concluded we had reached data saturation by then. Semi-structured interviews gives the person who is being interviewed a certain degree of freedom to decide what, how much and how to say about questions (Fink, 2002b, Drever, 1995). We conducted the first five interviews in Maastricht in a face-to-face way in 2019, but since Covid-19 spread in the beginning of 2020 in the Netherlands, we had to convert to online meetings with our interviewees from Groningen. The durations of these interviews are ranging from sixty minutes to eighty-five minutes and all of the interviews were digitally recorded on an electronic device for transcriptions with the permission of all of the participants.

Table 4.1. List of the interviewees

Interviews	Interviewee Occupations	Work Contents	Role	Interview context	Duration (minutes)
1. Maastricht	Monitoring and Evaluation Advisor of Maastricht Bereikbaar; Market manager in MuConsult[11]	Work 1-2 days per week in Maastricht Bereibaar to advice on monitoring and evaluation of mobility related issues	Advisor	FTF[12]	75
2. Maastricht	Monitoring and Evaluation Advisor of Maastricht Bereikbaar; Advisor in MuConsult	As a coordinator of monitoring and evaluation team, providing advice; analyzing the data of Beter Benutten Program	Advisor	FTF	85

[11] MuConsult is a consultancy company for mobility issues, often for governments.
[12] FTF: face to face.

3. Maastricht	Maastricht Bereikbaar Marketing Advisor	Use the tools provided by other companies to extract the valuable information for data	Data analyst	FTF	60
4. Maastricht	Teammanager of Mobility & Environment in Maastricht municipality	Develop mobility policies and communicate with people work in Maastricht Bereikbaar	Program manager /Steering group	FTF	80
5. Maastricht	Senior Policymaker in Mobility and Traffic in Maastricht municipality	Develop mobility policies; used to be a project leader of Parking & Ride Maastricht Nord	Policy Maker	FTF	60
6. Groningen	Mobility Management of Groningen Bereikbaar	Develop questionnaires, analyze survey data and work together with other companies	Program manager	Online meeting	75
7. Groningen	Traffic Engineer of Groningen municipality; Data & Information Coordinator in Groningen Bereikbaar	Monitor the traffic flow and look for trends of traffic, collect, analyze and report the data, provide in-time advice for management group	Data analyst	Online meeting	65
8. Groningen	City Mobility advisor of Groningen municipality	Make traffic plan, give knowledge to policymaking, cooperate with data analysts, policymakers, and politicians for data use	Advisor	Online meeting	80
9. Groningen	Program Manager for Transport and Mobility in Groningen Municipality	Lead a group of 30 people for mobility policies development and optimization, deal with political issues	Program manager	Online meeting	70
10. Groningen	Senior policymaker for Traffic and Transport in Groningen provincial government	Develop urban planning and mobility policies for the province of Groningen	Policy Maker	Online meeting	60

Document analysis

We asked interviewees what they considered to be the most relevant policy reports or other reports regarding urban mobility. This gave us a list of about twenty reports that we included in the analysis (see Appendix 8.4.2). These reports were not coded, but they offered relevant information (i.e. measures introduced, data gathered, evaluations performed, etc.) that was used to give more context to the role and effects of data observed by the interviewees and make them more specific. Additionally, based on the written sources, we achieved a more complete insight in the projects executed. Accordingly, this advanced the credibility of our findings (Eisner, 2017).

4.2.3 Data analysis

For data analysis, the recorded interviews have been transcribed in order to allow for open coding analysis (Strauss, 1987, Strauss and Corbin, 1990). First, we coded the transcriptions line-by-line aiming to build and clarify different categories, which is also useful to define concepts (Khandkar, 2009). A qualitative data analysis software-Atlas.ti was applied in this process to code the interviews systematically and efficiently (Konopásek, 2007). Afterwards, various codes (e.g. survey data, big data, capacity, steering group, technical issues) were distributed to different categories such as long-term policy cycle, short-term policy cycle, advantages and limitations of data use in evidence-based policymaking (see Appendix 8.4.3). With these codes and categories from the ingredients to formulate how data played a role in each city, and after comparison, answer the central research question-does more data mean advanced evidence-based policymaking.

4.2.4 Case description

As noted we selected two Dutch cities that were both part of a national programme, BeterBenutten ('Better Utilize', in English), that trialed (and funded) a more evidence-based policymaking approach between 2011 and 2018.

The BeterBenutten program was initiated in 2011 by the Dutch National Government, running until 2014 (BB1), and then followed by a second term (BBV, 2015-2018). It had two overall aims: (1) promoting a policy shift from 'building more infrastructure' to 'influencing mobility behavior to utilize existing capacity more efficiently' (in order to foster accessibility); (2) promoting more evidence-based policymaking ('to measure is to know'). It provided 690,000 euros funding for twelve Dutch urban governments, including Maastricht and Groningen, to implement measures that promote behavioral shift towards car alternatives, to monitor & evaluate the impact of these measures, and, three, doing this in cooperation with employers and other stakeholders[13]. In total in the twelve regions, more than 460 measures were implemented (see Appendix 8.4.4 as an example shows the policy measures and activities have been implemented in Maastricht), often with a lasting effect.

In the Netherlands, the municipal authorities are primarily responsible for urban mobility policymaking. The main body in the municipality that develops and implements mobility plans and policies is formed by civil servants, headed up by an alderman on mobility, who is appointed by the municipal council. Different types of civil servants are involved in the policy making process, namely policymakers developing plans and policies, advisors providing knowledge and experience for policymaking and implementations, program/project managers serving and supporting plans and policies executions, engineers giving technical supports, data analysts digging useful information from different sources of data etc. Although some civil servants are responsible for developing plans and policies, the final responsibility still belongs to the alderman (who is part of the executive council). Then again, the municipal council is the highest administrative body of the municipality, which needs to approve these policies and supervises the implementations. However, within the mandates for policy development, civil servants can make some adjustments and changes in the implemented policies.

Maastricht and Groningen

Maastricht and Groningen are both provincial capital, university cities and largest city of their province (Limburg and Groningen, respectively) and centers of a functional region. Limburg is

[13] More specifically, the main purpose of BB1 was to reduce cars in rush hours in the busiest areas, while after 2014, more targets such as sustainability, CO_2 reduction and public health were added in BBV (Maastricht Bereikbaar, 2018; Groningen Bereikbaar, 2018).

the southernmost province in the Netherlands and Maastricht is adjacent to Belgium and Germany, which plays a significant role in international border transport. The population of Maastricht is 121,558 (CBS, 2020) living in a total area of 60.06 km^2. Additionally, Maastricht is a historical tourist region which attracts over three million tourists to the city annually (Tourism, 2020), with a well-developed transportation system including direct connection to the Dutch national motorway and railway network. Currently, there are fifty-two bus lines, three train stations, and a small airport to a few Mediterranean destinations (Arriva, 2017).

Groningen is the capital of the province with the same name, the northernmost province of the Netherlands. There are 232,299 (CBS, 2020) inhabitants living in a 180.21 km^2 area of Groningen city. Similarly, Groningen is also a historical city with more than 950 years history. It has been entitled as the 'World Cycling City' in 2007 since more than fifty percent journeys in the city are made by bike (GIB, 2007). In addition to the well construction of cycle-path in Groningen, it is also directly connected to the Dutch national motorway and railway network. There are fifty-one bus lines, two train stations, and a small airport that connects to a few holiday destinations. Before the start of BeterBenutten, both cities had a limited number of mobility civil servants, about 5-10 people.

Maastricht Bereikbaar and Groningen Bereikbaar
Funded by BeterBenutten, both Maastricht and Groningen have set up a special public-private organization to execute the three tasks: implement measures that promote behavioral shift towards car alternatives, monitor & evaluate the impact of these measures, and doing this in cooperation with employers and other stakeholders. The new organization, partly overlapping with the mobility department, implied about a doubling of staff working on public mobility issues in each city overall.

The public-private organization was structured in a number of programs, such as ITS, Bicycle, Behaviour, Logistics, Collaboration with employers, Public transport, P+R (Park & Ride), Rush hour avoidance, Infra adjustments, etc. Programs would execute various projects or measures (see examples in Appendix 8.4.4). The working teams reflect the public-private nature of the organization, consisting of policymakers from the municipal transport department, the public transport operator, advisors hired from consulting companies and representatives from covenant partners (i.e. local companies that agreed to collaborate with Maastricht Bereikbeer or Groningen Bereikbaar on mobility issues).

4.3 Results

4.3.1 New mobility data for policy-making

The *Beter Benutten Program* rendered three new sets of data in Maastricht and Groningen: enhanced Traffic Monitoring data, traveler survey data, and big data.

First, BeterBenutten allowed enhancement of the *Traffic Monitoring System*. The traffic monitoring systems in Maastricht and Groningen comprise road sensor cameras, traffic signals, processors to process signals, and the public transport e-paying system (OV chip card) (interview #1, 4, 6, 7). This is the most usual way for both Maastricht and Groningen to gather the daily traffic data, which grew after 2011 through BB funding. In Maastricht, they collect more data of the number and speed of cars on many roads, counting how many people use public transport, etc. (interview #5). In Groningen, they not only collected and analyzed the traffic data themselves but also employed a traffic engineering consultancy company called BonoTraffics helping them analyze the data and generating weekly reports with graphics mainly for short-term traffic management (interview #6, 7).

Second, BetterBenutten introduced two types of traveler- surveys (Interview #1). Every project piloting a particular measure had its participant evaluations. For instance, 'try an E-bike' was a pilot offering E-bikes to commuters at the covenant companies to be used for a week instead of their car. Participants filled out surveys after the trial, and there was also some GPS tracking data from a device on the E-bike. This data was instrumental to specifically monitor the effectiveness of a particular measure (in this case the offer of an e-bike) to reduce car use. The second type of traveler survey was done half-yearly for BB1 and yearly for BBV with a pool of more than 8,000 commuters in Maastricht and Groningen each, addressing how they traveled, why they traveled by this means, and whether the implemented measures changed their travel behaviors. This provided more insight in the aggregate impact of the set of measures as well as their relative contribution.

Third, BetterBenutten enabled a pilot with *mobile phone data* from a telecommunications company in Maastricht. It provided origin-destination, parking locations, and parking time information through mobile phone tracking sensors (with the permissions of the users). This was done in order to learn how mobile phone data could be useful to understand travelers' behaviors in Maastricht and, subsequently, better anticipate on congestion issues through policy measures, which was also seen as background data for Maastricht Bereikbaar to take mobility management measures (such as public travelling advice, temporary parkings or shuttles, etc.).

4.3.2 Data use in policy-making

How is the increased amount of data used in policymaking practice? In both Maastricht and Groningen, they distinguish two different types of policy cycles in practical urban mobility policymaking process: long-term policy cycle and short-term policy cycle (interview #2, 4, 5, 7, 8, and 9). The long-term policymaking process usually goes for several years to make the final decision, which is mostly for big constructions and long-term transport plans development. It needs to go to the executive & municipal council for consultation and decision-making. Regarding the short-term cycle, policy-making, implementation, and adjustments are mostly within a few months or even on a weekly basis to make small adjustments. Most of the short-term policy-making can be accomplished within Maastricht and Groningen Bereikbaar, but some instructions and advice would also be taken from other departments. We illustrate how data is used in these two different policy-cycles respectively in the following.

Organizational structure

Before we explain how is data used in the long-term and short-term policy cycle, we explain how the work is organized in six working groups involved in urban mobility policymaking. Figure 4.3 shows the working groups for both these two cycles. The main difference between the long-term cycle and short-term cycle is the loop via the transport policy steering group (which only the long cycle has, the rest is the same). The steering group consists of people who are from the executive council (who need approval of the municipal council) and the mobility policymakers who come from neighboring local municipalities and provincial or national governments. They are responsible for making agreements with provincial and national governments. This is also the group making final decisions of long-term policies and large programs. Political positions and relations are prominent in the steering group when decision-making is concerned.

In addition to the steering group working in the long-term policy cycle, there are two other committees consisting of people from various working groups and organizations. The first one is a 'board of managers'- meeting for which directors, managers and policymakers have periodic meetings (usually four times a year) on urban mobility related issues. Second, the advice committee consists of the professional people from various consultancy companies, which bring information by municipality.

Within Maastricht and Groningen Bereikbaar, there are five main working groups and one consultation team working together for urban mobility policymaking. The program management group consists of a program director and program managers. The director is in charge of the whole organization and responsible for advising and communicating with the steering group. Program managers are in charge of different urban mobility related programs ran in the regions, such as the employer approach, the logistics approach, or tackling disruptions. They have certain mandates given by steering group to adapt short-term policy measures. The project leaders and the civil servants implement specific projects and policy measures. The marketing and communication group is responsible for public communication of travel advice & campaigns, or the public recruitment of participants for specific measures or projects (e.g. 'try P+R'). This group includes 'Mobility brokers', who liaise between the organization and employers in the city and region, the 'covenant partners'. They are experts who are in touch with current and potential covenant partners, inquiring their current mobility problems and needs, offering these companies certain options to address their problems. They also sent out and collect the half-yearly/yearly surveys to commuters. The monitoring and evaluation group is responsible for evaluating the implemented projects. This group collects data (i.e. organizes the surveys), analyzes, and extract useful (policy) implications for the program management and, indirectly, the steering group. Next, in the advisor group, there are different types of advisors: some participating on behalf of the municipality, some hired from private consultancy companies. During policy development, evaluation, and adjustment processes, they will give advice based on their work experience and expertise.

The last team is consultation representatives who are from different departments, governments, companies and also public representatives, serving as coordinators and consultants. They bring the insights from their expertise domains for urban mobility policy development.

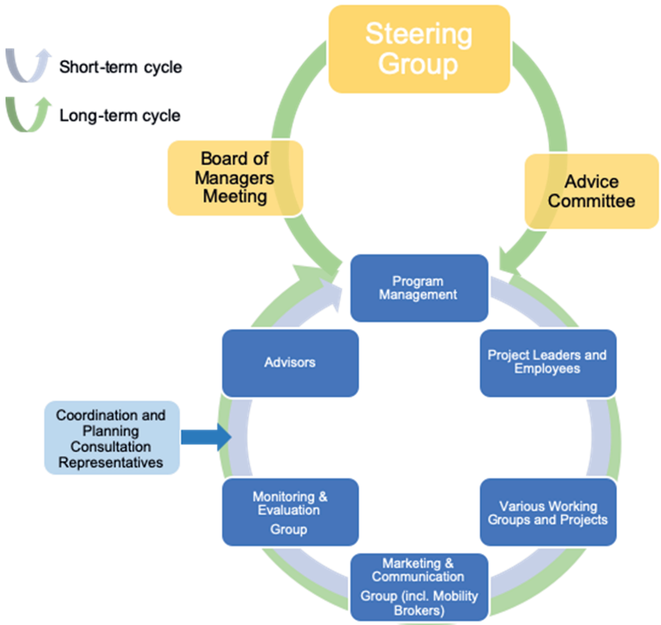

Figure 4.3. Urban mobility policy-making working groups (basic graph accepted from #10 interviewee and confirmed with minor adaptation according to other interviews)

Data use in long-term policy cycle

In both Maastricht and Groningen, the long-term policy cycle for urban mobility policy-making is the process of developing new mobility plans, implementing national and provincial policies as well as implementing programmes cooperated with different local governmental departments, which usually take four years and longer. The steering group (see 3.2.1) is the decision-making body, which receives the core information and reports in condensed form from the other groups for decision-makings. At the level of the steering group, the role of data is limited. Big data was hardly useful in the long-term policy cycle. For instance, two policymakers are members of steering groups indicated that:

'There was not that interesting information came out of the real-time tracking data' (Interview #5, M (Maastricht))

'For the long-term policy-making, data (big data) has a role but smaller role' (Interview #7, G (Groningen))

One policymaker (interview #5) explained that most of the big data applied in Maastricht urban mobility policymaking was not collected and chosen based on the policymakers' requirements so far, but was more depended on what data could be supplied by the covenant partners. A consultancy collected the data, in such amount that they did not know how to choose the most valuable data for policymaking. A policymaker (interview #10) from Groningen noted that political and societal trends had more weight in the decision-making process of the steering group than traffic monitoring data. Two other interviewees who are responsible for monitoring traffic flow, looking for traffic trends, and providing advice for management groups argued that:

'If you look at it, the big picture is the same and we do not learn anything new from this data, because we know where people are coming from, how long they stay. So, the data cannot add extra information to the big picture, but it adds to the smaller pictures I think' (interview #3, M)

'If you are talking about long-term policy-making and then I am thinking about real urban development about where do we have to build new parking sights, new houses, and new roads. Those kind of urban spatial development decisions that we are quite far away from' (interview #7, G)

A traditional way to use data in policy planning is to apply several years historical traffic data collected in a day-to-day basis for which to predict the traffic growth. It has been both applied in Maastricht and Groningen to examine if new long-term mobility plans could prevent traffic jams and make traffic safer (interview #3&10). But this could be only used when the steering group wants to develop new urban mobility visions for the next 5-10 years as ex-ante assessments of the plans (interview #9).

'You can ask lots of question about why and about their normal behavior. I'm more interested in what did they do and why they stop here rather than just know the number of cars' (interview #2, M)

'I could never see whether they were here in south Limburg on holidays or that they were everyday commuters from those tracking data. That kind of information doesn't provide by it. Therefore, I consider it as a basic fundament but you could never do without the specific information from surveys' (interview #3, M)

'When you use cameras to count cars, you can know how many cars or cyclists or whatever are using road and it can help you with algorithms to change or to manage traffic flow in real time. But for new urban mobility plan development, it doesn't give you information about why are people travelling, why they have behavior that they show' (interview #8, G)

In terms of survey data, both Maastricht and Groningen regarded residents and travelers' opinions and requirements as vital factors in long-term policy development (see above three quotations). This data provided more insights in travelers' behaviors for policymakers. This helped them develop soft policy measures aiming in facilitating sustainable mobility behavior (interview #1, 2, 5, 6 and 8).

Data use in short-term policy cycle

'What we mostly do is we monitor and evaluate policy measures and make small in-time changes of these measures. Everything we learn we give back to policy makers. Hopefully they use our input for better policy-making. This is as far as we can go at Maastricht Bereikbaar' (interview #1, M)

'Groningen Bereikbaar is a separate organization but we are getting to the task to do the short-term policy adaptions, to do the traffic management like Maastricht Bereikbaar, especially the executions of some traffic measurements' (interview #7, G)

The interviewees from both Maastricht and Groningen Bereikbaar stated that their main tasks include short-term policy measures' adjustments and traffic regulations, which are also the main objectives for short-term urban mobility policy cycle.

In the short-term cycle within Maastricht and Groningen Bereikbaar, program managers have their own mandates to adapt certain policy measures and projects, which is also the reason why the whole cycle could go much faster than long-term cycle (interview #2). Also because of the feature of short-term cycle, in-time information is necessary for traffic regulations. Big data plays a relatively more important role in this cycle compared with long-term cycle. This helps policymakers spending less time to extract useful information for keeping high accessibility in specific regions (interview #7).

In terms of the way for collecting and applying big data in short-term policy cycle, it differs between Maastricht and Groningen. Maastricht was used to cooperate with a multinational telecommunications company to get mobile phone data and processed it in a model provided by another private consultant company. The consultant company offered the information as how many hours people spend in one certain place, when people usually travel from one place to another place, and where they live. At the beginning when Maastricht Bereikbaar had this data, they found it helping them to develop small policy measures, for instance, offering more bicycle parking spots in city center during summer holidays (interview #3), whereas after 2-3 years, they stopped to run it since no new information they could learn from it (interview #5).

Real-time traffic data that shows strength in timely traffic regulations is getting more attention in Maastricht (interview #4 and 5).

'The work Groningen Bereikbaar does is really effective and it is intensively used to optimize the working processes, to optimize different projects. It is a really important factor in allowing projects to continue in short-term mobility regulations' (interview #9, G)

Regarding Groningen, based on the cameras on roads connected with other monitoring systems, minute by minute data of number of cars, cyclists, passengers on trains, users of parking facilities, and the information about, if buses run on time or too late, are all gathered (interview #7). These detailed data were used to develop timetable of public transport, monitor and analyze traffic trends, make prompt adjustments of traffic flows, and write monthly reports, all as supports for program managers to adjust policy measures (interview #7, 8, 9). This has been regarded as valuable fuels to keep the consistency of running short-term mobility projects (see the quotation above).

Survey data is also applied in short-term policy cycle but not as effective as traffic monitoring data. Although different ways, including social media, small surveys, group meetings, were all used for data collection, it still consumed too much time in the whole data collection and analysis process for policymakers to gain insights from small amount number of samples. Small surveys ran with few questions, only targeting on one policy measure via social media for assessments, was the main approach to gathering survey data in Groningen Bereikbaar (interview #10). Maastricht Bereikbaar focused more on the feedbacks from their covenant companies. The mobility brokers kept regular contacts with these companies and got the comments about some pilot projects and policy measures, which was used for policy adaptions and new measure development (interview #2).

Overall, based on the coding and document analysis, we distinguished five different categories to summarize the extent to which the different types of data are used in the short and long policy cycle (shown in table 4.2).

Table 4.2. Data use in different policy cycles

Main traveler data types used	Long-term policy cycle	Short-term policy cycle
Traffic data	*Little*[2]	*A lot*[5]
Survey data	*Sufficient*[4]	*Some*[3]
Big data	*Hardly*[1]	*Some*

[1]Hardly: has not been mentioned in the interviews and documents/no contribution to the mobility policymaking process; [2]Little: has been only mentioned few times in the interviews and documents/rarely contribute to the mobility policymaking process; [3]Some: has been mentioned several times in the interviews and documents/recognized contributions to the mobility policymaking process; [4]Sufficient: has been mentioned often in the interviews and documents/contribute sufficiently to the mobility policymaking process; [5]A lot: has been mentioned a lot in the interviews and documents/significant contribution to the mobility policymaking process.

4.4 Discussion

In this section, we first discuss the main similarities and differences in the way data is used between Maastricht and Groningen in the BeterBenutten program. Subsequently, the advantages and limitations of more data in urban mobility policy making are discussed.

4.4.1 Comparing data use of BeterBenutten Program in Maastricht and Groningen

Similarities

National funding gave both Maastricht and Groningen the opportunity to significantly expand the staff dedicated to monitoring and evaluation. Interviewees in both Maastricht and Groningen regard this expansion as a valuable resource to develop evidence-based policies (interview #2, 5, 6, 8).

'Without Maastricht Bereikbaar and BeterBenutten, there wouldn't be an assessment. It (i.e. the A2 tunnel) was just constructed to open and then that's it. Because of them, we did check the number of users, we did check the impact of it' (interview #5, M)

'If BeterBenutten wouldn't have been there, of course we would have been necessarily to find other means to work but the need of collecting data and cooperating with companies wouldn't been there anyway' (interview #8, G)

The prominent specialty of the BeterBenutten program for Maastricht and Groningen Bereikbaar is that they could cooperate with private companies (as liaison to commuters). Both introduced a large commuter survey with a large group of employers in the region. This was novel and helped to get better insight in their needs, whilst in return also providing advice and mobility measures to companies to solve their mobility problems. These measures were all evaluated separately. Accordingly, Maastricht and Groningen Bereikbaar were able to reach their aim to change participants' travel behavior (i.e. reducing rush hour car trips) by implementing policy measures effectively. This is why both program managers (interview #4 & 6) in Maastricht and Groningen see the program as successful.

Differences

The major difference between Maastricht and Groningen concerning data use in the BeterBenetten program was the application of yearly/half yearly evaluation reports in the long-term policy cycle. These reports show the assessment results of the (summed up) implemented policy measures and projects and also used to see if the mobility targets had been reached. In Maastricht, the reports have been regarded as regular resources to the steering group for long-term urban mobility policies development, while in Groningen, these assessment results have not been applied much for long-term policy-making, instead these reports are mainly used for short-term policy adaptions (interview #4 & 9).

'We use the reports not only evaluate the projects, but also use it to make policies in the council. They see the results and then to have discussions of continuing or stopping some programs' (interview #4, M)

'For us, the yearly reports are not that important. Within Groningen Bereikbaar, it is useful information to optimize the projects but we hardly use this information in our long-term policymaking' (interview #9, G)

4.4.2 Advantages and limitations of data use in evidence-based policymaking

When does more data reinforce evidence-based policymaking? Figure 4.4 shows what interviewees reported as the main advantages of more data (in red) and limitations (in blue), coded from the interview transcriptions. The larger circle reflects the long policy cycle, the smaller the short cycle, with an apparent overlap in perceived limitations.

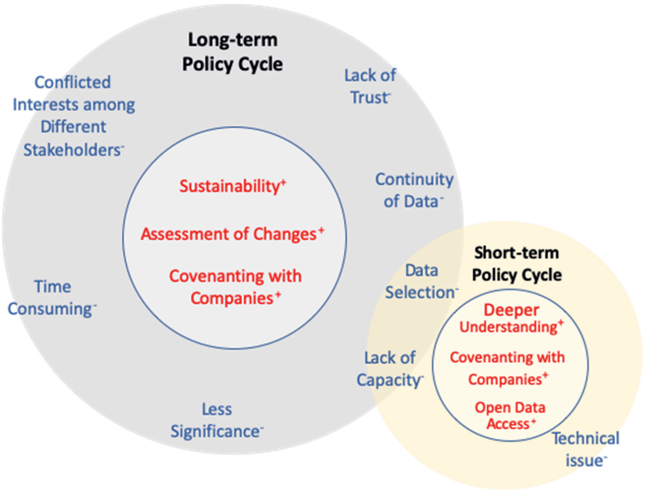

Figure 4.4. The incentives and limitations of data use for urban mobility policymaking in Maastricht and Groningen (respective coding quotations showed on Appendix 8.4.5)

Advantages

Sustainability, assessment of changes, and covenanting with companies are the three appealing traits of more data for urban mobility policy development in long-term policy cycle. Promoting sustainable mobility in particular is found to require good data. Modal shift, i.e. a shift from car mobility to car alternatives requires good data from all modes. This was reported by interviewees from both Maastricht and Groningen, but is in line with reports from the national government and European commission. For instance, European commission's mobility and transport group raised the concept of Sustainable Urban Mobility Plans (SUMPs) in order to encourage European cities to develop integrated mobility visions, with mobility data being an important ingredient (Commission, 2013). The Dutch national government adopted this concept legally and generated its own national guidelines (ELTISplus, 2012) as well as promoted certain programs to facilitate it. One of the programs called Intelligent Transport Systems (Optimizing Use Follow-up ITS) specifically aims to promote data use in traffic management for sustainable urban mobility development (RVO, 2017).

Second, improved assessment of changes is seen as big advantage of more data in Maastricht in Groningen. Especially, policymakers have seen the advantages of the large commuter survey, and this survey is continued even now the BeterBenutten funding is phased out. Both qualitative and quantitative data have provided more insights in the relation between measures and traffic effects, hence enhanced evidence-based policymaking.

Third, policymakers appreciate the increased engagement and cooperation with a large group of local businesses as a big advantage of this data gathering process. Gathering and providing more data with and for covenant companies has made the implemented measures more effective, hence easier to reach certain policy goals. This perceived advantage both counts for the long and the short policy cycle.

For the short policy cycle, respondents from Groningen also emphasized the advantage of a deeper understanding of differences between predictions generated by models and the real policy measures implementation results. Finally, these also mentioned the increased open access of the live traffic data and the smart mobility information from the website of Groningen Bereikbaar (see: https://www.groningenbereikbaar.nl/en/current-traffic-situation) as an advantage, which enables the public to change their travel behavior. Other research also shows that open data can not only give the citizens more information about how to travel smarter but also encompass data produced by them for advanced policy makings, which is a win-to-win approach (Soriano et al., 2018).

Limitations

When and how is more data not helpful? Regarding the limitations of more data in Maastricht and Groningen, our analysis confirms earlier studies, e.g. (Chinellato, 2018), that highlight data selection challenges and lack of (personnel) capacity as the two biggest issues in both long-term and short-term policy cycles. How to select the proper and valuable data (out of a much larger set) for different targets and what indicators are relevant for policymaking are the challenges that have been frequently mentioned by our interviewees (interview #3, 4, 7 & 8). Additionally, another problem is that nowadays it is easy to get huge amount of data for policymaking, but a limited number of competent data analysts and policymakers prevents them to analyze all data, or interpret the data sufficiently in depth to deliver policy messages (interview #4, 7 & 9).

Respondents from Groningen mentioned a few more limitations of data in long-term urban mobility policy development than those in Maastricht (which also confirms the difference discussed in 5.1.2). These limitations are: lack of significance, trust, and continuity of data collection. Especially from the policymakers' and program managers' perspectives, data is less important compared with political and societal issues. Besides, the continuity of certain data collection is also required in order to be useful for long-term policy outlooks, since fragmented data sets are hardly useful (interview #10). The data analyst and program manager noted that collecting data at the beginning of policy development as well as understanding it during policymaking period consumes too much time (interview #5 & 9). Conflicts among stakeholders is another limitation mentioned. There are always arguments among different stakeholders, i.e. the mobility policymakers, environment policymakers, covenant companies, and the steering group, about the common central target for surveys (usually decided by steering groups).

In terms of short-term policy cycle, there is one additional limitation mentioned in Maastricht, which is technical issues. Data lost, user-unfriendly data process models, model errors were claimed by the data analysts in Maastricht Bereikbaar (interview #3).

4.5 Conclusion

In this research we studied how additional and different types of data were used in local urban mobility policymaking through case studies of Maastricht and Groningen. We discussed advantages and limitations of more data for evidence-based policymaking in practice. Earlier academic studies on data use in transport policy were rather detached from policy practice and primarily on new potential use of data performed by academics. In this paper, we gave insight in the role of data in policymaking in two medium-sized cities, distinguishing between a long and short policy cycle, and highlighting various types of data.

Our analysis is based on ten interviews we did with professionals in different roles in the urban mobility policymaking process, including senior advisors, data analysts, program managers, and policymakers. Besides, twenty-one related documents have been analyzed as well. By analyzing and comparing two urban areas, there are a number of things we conclude for which would also be useful for other cities in the Netherlands and North-western Europe since the similar social conditions:

1) There is a trend towards using more data (to reinforce evidence-based policy), both triggered by the Dutch national government as well as the local government (Maastricht and Groningen). The (national) BeterBenutten program provided extra opportunities for local governments to do ex-post policy assessments, which has been regarded as valuable resources for decision-making by policymakers.
2) The cooperation with local companies is critical for policy effectiveness for three reasons. The cooperation delivers data on employee travel movements and motivations that is critical to evaluate policies; the cooperation enables tailor-made measures and support to employees to try car alternative and flexible working place; the cooperation delivers the employee an employer that is willing to facilitate mobility changes. In other words, the cooperation with local companies seems a requirement to achieve evidence-based policymaking.
3) The use of data in urban mobility policymaking differs in policy cycles. Data is stronger in the shorter cycle whilst having a less central role in the long cycle. In long-term policy cycle, data was regarded as less important than political and societal trends and developments. Comparatively, the data from survey with travelers and meetings with citizen representatives, is somewhat important in this process.
4) The increasing amount of available real-time traffic, mobile phone, and GPS mobility-related data has mostly been applied in short-term policy cycle for prompting traffic adjustments in cases of events and major road works.
5) The need to promote sustainable mobility is considered as a strong driving force for local governments (Maastricht and Groningen) for more data of urban mobility.
6) Getting more capacity to (competent) personnel on interpreting data and the expertise on how to select suitable data (out of a much larger set) would enhance the process evidence-based urban mobility policymaking.
7) A clear policy target is needed for different stakeholders to avoid the conflicts of the interests and shorten the time for data collections.

Through this research, we find that exploring better approaches to help policymakers select suitable and valuable data for practical urban mobility policymaking should be the next step of future research, which is the key difficulty needed to be solved in promoting evidence-based urban mobility policymaking.

Author Contributions
Xu Liu: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing - Original Draft, Writing - Review & Editing, Visualization Marc Dijk: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Resources, Writing - Original draft preparation, Supervision.

5

Chapter 5

GIS Models for Sustainable Urban Mobility Planning: Current Use, Future Needs and Potentials

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Abstract:

GIS models are currently available for a broad range of applications in mobility planning. However, it is not known how widespread the current use of GIS models is among European urban mobility planners, nor what their user experiences and needs are. There is therefore a risk that the development of GIS models for urban mobility planning will be mainly driven by technical possibilities and data availability rather than by the needs of the prospective users. To inform model developers and ensure a good match between model options and user needs, we conducted a survey investigating the current application of GIS models in urban mobility planning practice in Europe as well as model data availability and the needs and priorities of European mobility planners regarding GIS models. We received 51 valid responses from the transport departments of 42 cities from 21 European countries. For developers of GIS-based traffic models, the findings indicate that in Europe there is scope for wider adoption and further improvement. The models currently used are considered useful to support urban mobility planning, but more than 60% of the surveyed cities do not yet use them. Increased user-friendliness, in particular for non-experts, appears important to promote wider adoption. Availability of non-traditional types of data, such as real-time data or data at neighborhood level, is still limited in most cities, but this may rapidly change. Finally, there is also considerable interest in traffic models that integrate social and environmental aspects.

Keywords:
GIS; traffic model; transport model; urban mobility planning; mobility policy; Europe

5.1 Introduction

In 2019, the European Commission launched the European Green Deal, which consists of a series of policies targeted to reach a climate neutral Europe in 2050 (EU, 2019a). For the transport sector, the specific objectives are to increase the uptake of zero-emission vehicles and to make sustainable alternative solutions available, while supporting digitalisation and automation, and improving connectivity and access (EU, 2020). For cities, these objectives have been elaborated in the New European Urban Mobility Framework (EU, 2021). This policy framework mentions the importance of modeling "to support mobility decision making in an integrated matter". It also emphasizes the use of urban mobility data to support sustainable urban mobility planning. The framework proposes that in this context not only typical mobility-related aspects such as road safety and congestion should be covered, but also environmental aspects, such as emission of greenhouse gases and air pollution, as well as social aspects, such as access to mobility services and affordability of public transport (EU, 2021). Various studies showed that data-driven decision- and policy making can help to improve the effectiveness of plans and policies (Urbanek, 2018, OECD, 2016). Models play a major role in translating data into valuable information for decision- and policy making. For urban mobility planners, GIS models in particular can be an important help in achieving policy goals.

Due to their ability to process different types of data, graphic user interface and extensive map-based visualisation options, GIS models are functional, cost-efficient and user-friendly tools for (urban) mobility planning (Abousaeidi et al., 2016). The currently available GIS models for mobility planning cover three main subjects: travel safety assessment, public transport management, and route planning (Droj et al., 2022). For travel safety assessment, GIS models are integrated with decision support systems to simulate different traffic scenarios to predict the potential accidents and risks (e.g., (Rodrigues et al., 2015, Rahman et al., 2020). For public transport management and planning, GIS models are, for example, used to analyse investment plans for public transport to determine how the accessibility can be increased (Ford et al., 2015). Route planning covers travelling route planning, public transport network planning, and safe walking and cycling route planning. GIS models are often adopted in this domain due to their capacity to integrate the processing of spatial data with network analysis (Abousaeidi et al., 2016).

The functionalities and possible applications of GIS models have rapidly evolved and are still growing. This also applies to the domain of urban mobility planning. An emerging application concerns GIS-based analyses that merge different types of mobility data (GPS data, mobile phone data, location-based social media data) with spatial data and road networks. For instance, Droj and colleagues utilized real time traffic data in a network analysis to optimize public transport services and reduce traffic congestion in Oradea, Romania (Droj et al., 2022). Another emerging application concerns the integration of GIS models with other types of models. For example, Deng and colleagues integrated Building Information Modelling (BIM) and GIS to assess traffic noise in outdoor and indoor environments, as determined by exterior and interior walls, in order to evaluate traffic regulations (Deng et al., 2016).

Hence, academic studies show that GIS models are currently available for a broad range of applications in mobility planning. However, it is not known what the needs and priorities of urban mobility planners are in this respect (Isaksson et al., 2017). In fact, it is not even known how widespread the current use of GIS models among European urban mobility planners is, nor what their user experiences are (Liu and Dijk, 2022a). This means that there is a risk that the development of GIS models for urban mobility planning will be mainly driven by technical possibilities and potential data availability rather than by the needs of the prospective users and actual data availability. Thus, in order to guide future model development and to ensure a good match between model options and user needs, we conducted an exploratory survey to investigate the current use of GIS models in urban mobility planning practice in Europe, as well as the needs and future potentials. More specifically we addressed the following research questions: (1) How widespread is the current use of GIS models among European urban mobility planners? (2) What are their user experiences with these models? (3) What are their needs and priorities regarding GIS models? (4) What is the current av(Dijk et al., 2019)ailability of data for use in GIS models?

The paper is structured as follows. 5.2 describes our survey method, explaining how we collected and analysed the data, with the results presented in 5.3. Finally, 5.4 discusses the main findings and limitations of our study, the implications for research and GIS model development, and 5.5 concludes.

5.2 Methods

To answer our research questions, we conducted online survey. Online surveys have been proven to be as valid as paper-based surveys, easily combine different types of questions, are conveniently completed by participants, can be very widely distributed with little effort, and, lastly, help to avoid social desirability bias (Knapp and Kirk, 2003, Ball, 2019, Callegaro et al., 2015). The aim was to understand the current use of GIS models in urban mobility planning practice in Europe, model data availability, and mobility planners' experiences, needs and priorities regarding GIS models.

The questionnaire consisted of nineteen questions divided over four sections (Appendix 8.5.2). Respondents needed 6–15 minutes to fill out the questionnaire. The first section covered basic information, including the respondent's working location and position with corresponding activities, based on closed-ended questions. The second section addressed research questions 1 and 2, and asked questions about the current use of GIS models in urban mobility planning practice, including motivations for model use and the type of data used. This section combined closed-ended and open-ended questions. Open-ended questions were employed to identify the varied concerns regarding GIS models based on each respondent's situation and experience. The third section addressed research question 4, and only targeted respondents who work with data, such as data collection, analysis and modeling. The respondents were asked to indicate the availability, frequency, and reliability for nine different data types (Table 5.1), to examine the potential of traffic models based on new data combinations. As proposed by the New Urban Mobility Framework (EU, 2021), we included the social and environmental dimension in addition to the mobility dimension. The selection of the data types representing these three dimensions was based on the literature (Bueno et al., 2015, De Oliveira Cavalcanti et al., 2017, Dijk et al., 2019, Richards-Rissetto and Landau, 2014, Vassallo and Bueno, 2021). The scales used in the questions were based on Tafidis et al. (Tafidis et al., 2017). Finally, the fourth section addressed research question

3, and the respondents were asked to rate the relative importance of five factors or aspects that may be included in a GIS model: accessibility, livability, air quality, vehicle energy transition, and investment cost. The aim was to understand the priorities of European urban mobility planners and to provide guidance for developers of GIS-based traffic models.

Table 5. 1 Nine types of mobility data relevant for use in GIS models

Dimension	Type of data	Sources
Mobility	Real-time traffic data Public transport network coverage Mobility networks Travel distance to key services	(Richards-Rissetto and Landau, 2014, De Oliveira Cavalcanti et al., 2017, Bueno et al., 2015, Dijk et al., 2019, Vassallo and Bueno, 2021)
Social	Traffic fatalities and injuries Commuting travel time Affordability of public transport	
Environmental	PM2.5 air pollution at neighborhood level[1] Greenhouse gas emissions at neighborhood level	

[1]PM2.5: fine inhalable particles, with diameter of maximum 2.5 micrometer

Our study was exploratory in nature, and aimed at identifying broad patterns with respect to GIS model use in European urban mobility planning, without the aim to identify factors explaining the observed patterns. Therefore, for most of the responses, we use simple descriptive statistics to present the results, such as frequencies, means and standard deviations. We always indicate whether the results refer to individual respondents or cities, while specifying the total number involved (*N*). To determine the perceived relative importance of the five factors (accessibility, livability, air quality, vehicle energy transition, and investment cost), we employed analytic hierarchy process (AHP) (Saaty, 1980). This procedure allows to calculating the relative weight (importance) of multiple factors from pairwise comparison.

We conducted the online survey between September 2021 and February 2022 using the Qualtrics software platform (https://www.qualtrics.com/). Invitation letters (N=606) with a hyperlink to the online questionnaire were distributed through email to the transport (or mobility) departments of European cities (or urban regions) and 56 responses were received. The mail addresses for the invitation letters were obtained from the participants list of the European Mobility Week 2021. Details about the responses and respondents are provided in Appendix 8.5.1 We excluded five responses (marked in red in Appendix 8.5.1) since the time taken to fill out the questionnaire was less than 5 minutes and therefore the response was considered not valid for the analysis. The final data set consisted of 51 valid responses, covering 42 cities from 21 European countries. The average number of residents in these cities is about 415,000, while most of the responding cities (75%) have a population size between 100,000 and 1,000,000 inhabitants. The number of responses is higher than the number of cities, because sometimes more than one staff member of a city’s transport department filled out the questionnaire. Figure 5.1 shows the geographic locations of the 42 cities, which cover most of Europe.

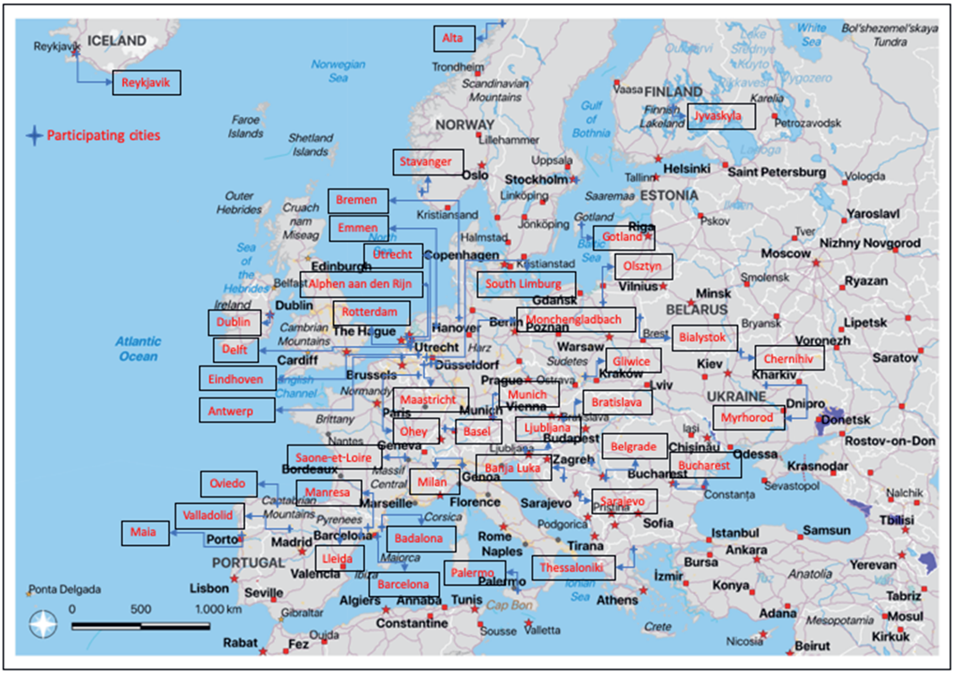

Figure 5.1. Location of the 42 cities or urban regions included in the survey (city name in square box)

Out of the 51 respondents, 37% (19) are advisors, 22% (11) are data analysts, 22% (11) are policymakers, and 16% (8) are program managers, while only about 6% (3) are researchers. Thirteen respondents (25%) specified their job as mobility planner (3), department officer (4), transport engineer (3), technologist (2) or GIS specialist (1). Thirteen respondents chose more than one position to specify their job. Activities of respondents cover the entire cycle from data collection, data analysis and model development, information support to policy makers, and traffic plan development, to monitoring and evaluation of policy measures (Appendix 8.5.1). This shows that urban mobility planning practice consists of a range of interconnected positions and activities associated with the development and evaluation of mobility plans, policies and measures. This being noted, we will use the terms urban mobility planners and planning throughout the paper to refer to the respondents and their activities.

5.3 Results

5.3.1 Current use of GIS-based traffic models in European cities

According to the survey results, 37% (19) cities have experience with using traffic models for urban mobility planning and of these 84% (16) currently work with GIS-based traffic models. In 50% (8) of the cities, the use of these GIS models began already before 2010, the other half started using GIS models over the past 10 years (Figure 5.2). Most of the cities that work with GIS models are from Western and Southern European countries. In terms of data types used in the GIS models, GIS data, historical traffic data and survey data are most commonly used, whereas real-time traffic data and mobile phone data are still hardly used, while GPS data is not used by any of the cities in their GIS models.

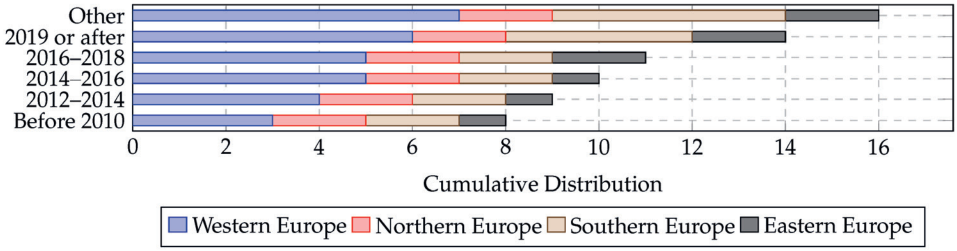

Figure 5.2. Starting year of GIS model use by region (N=16 cities)

There are several commercial GIS software tools that are used by more than one city. Basel, Badalona, and Barcelona employ TransCAD, a GIS-based tool for traffic analysis, transport modelling, and policy assessment. TransCAD is used by these cities for modelling of mid-term and long-term scenarios for mobility policy measures, assessing the impacts of mobility plans, and estimating air pollution. A mobility engineer from Badalona further specified that this model is used for logistics planning at neighborhood level, as input for traffic regulation measures. Bucharest and Munich use PTV Visum, a GIS tool to simulate traffic flows, for analyzing short-term policy measures and route networks, especially for regulating public transport. The biggest strength of PTV Visum is that it provides a visual modelling interface and allows users to select and edit network objects in GIS maps (Gentile and Noekel, 2009). Citylab's CUBE also provides an open GIS modelling mode for planners and engineers. A traffic data analyst from Milan specified that CUBE helps them to evaluate different policies at various time scales by simulating traffic flow in different scenarios.

Table 5.2 shows the main reasons why cities started to use of traffic models. For the cities with more than one respondent, we chose the answers of the respondent who selected the most options. *'To get more information about traffic flow and trends for decision-making'* and *'To use more actual data for evidence-based policymaking'* are the two most frequently selected reasons, chosen by more than half of the cities. Ex-ante (prediction) and ex-post (evaluation) assessments of measures and policies was almost equally important as a motivation for GIS model use (selected by 7 and 8 cities respectively). Only one city started using a GIS model to examine its usefulness.

Table 5.2. Reasons to start using GIS models (more than one answer possible, N=16 cities)

Motivation	Number
To get more information about traffic flow and trends for decision-making	11
To use more actual data for evidence-based policymaking	10
To evaluate the implemented policies	8
To predict the impacts of policy measures	7
We were obliged to develop and use the model	2
To learn about/test the usefulness of such a model	1
It was offered to us for free by the government	0

Other (please specify)	1

Concerning the perceived usefulness of GIS models in urban mobility planning, 11 out of 17 (65%) respondents from 16 cities (2 respondents are from the same city), considered that these models help them a lot or a great deal in urban mobility planning. Five respondents (29%) regarded their models of moderate help, while only one respondent chose ‘a little’, explaining that their model is not suitable to assess accessibility.

5.3.2 Mobility planners’ needs concerning GIS-based traffic models

All respondents, both GIS model users and non-users, were asked which type of information they considered GIS models should provide to support urban mobility planning. Table 5.3 shows that providing information about accessibility (78%), social aspects (64%), and environmental aspects (60%) are the three main domains that GIS models should cover. Information on urban health, more specifically impacts on residents’ health, is important for 42% of the respondents, whereas 22% of the respondents consider it important to integrate (the effects of) the energy transition into GIS-based analysis for mobility planning. Six cities, all GIS model users, made use of the ‘other’ option to indicate more specific requirements. These ranged from integrating more factors to model trip planning behavior, such as costs of parking, scenery along the route and comfort level, to more detailed output data including driven speeds, traffic volume, and citizens’ commuting habits for better planning of public roads and infrastructure transitions. Apart from these information requirements, nine respondents from different cities, of which six from Eastern European countries, indicated the need for more financial support for model development.

Table 5.3. The type of information that respondents consider GIS models should provide to support urban mobility planning (more than one answer possible, N=45 respondents)

Options	Number
Provide information and insights about traffic flow and accessibility	35
Provide information about social aspects (e.g. residents opinions about new road constructions or transport poverty)	29
Provide information about environmental aspects (e.g. how does the new urban mobility policy or plan affect the local air quality)	27
Provide information about the impacts on residents' health	19
Integrate (the effects of) the energy transition into the model analysis	10
It is fine as it is	1
Other	6

When asked about various aspects of user-friendliness of GIS models that require improvement, most of the respondents (76%) indicated that using the model should be made easier for staff who have less model and data processing knowledge. Providing more information at the neighborhood scale ranked second with 51%. Three other aspects of user-friendliness were less often chosen by the respondents: higher speed (36%), greater accuracy (27%), and more frequent upgrades (27%).

Following up on earlier questions about the need for information on social and environmental aspects, and information at the neighborhood scale, we asked the respondents to what extent and why (not) they are interested in having a GIS model that can evaluate the combined environmental and social effects of urban mobility policies and give results at neighborhood level. Two thirds of the respondents (68%) were 'extremely' or 'very interested' in this option. The main reason mentioned by the respondents was that this fits well with national and European environmental policies and could contribute to reaching greenhouse gas emission reduction goals. Another common reason mentioned (mostly by data analysts and advisors), is the need to provide more information to support plans and policies promoting a transition in travel behavior. About one third (30%) of the respondents was only 'somewhat interested', for example because they first want to have a better understanding of such a model or because they are satisfied with their current model.

5.3.3 Development potential of GIS-based traffic models

To explore potential development directions for GIS models, we asked respondents who mainly work with traffic data and models, about the availability, measurement frequency and reliability of nine types of data (Table 5.4 and Appendix 8.5.3). Higher mean scores indicate better data availability, more frequent measurements, and a higher reliability of the data, whereas the size of the standard deviation (SD) indicates the degree of variation between the cities. The mean score for data availability ranged from 2.3 (Greenhouse gas emissions accounted at neighborhood level) to 4.2 (Public transport network coverage). Interestingly, both data types also have the lowest and highest mean scores, respectively, for measurement frequency and reliability. In case of data on 'Greenhouse gas emissions accounted at neighborhood level', the low mean scores coincide with relatively high standard deviations, indicating large variation between cities, whereas the opposite is true for data on 'Public transport network coverage'. The differences between these two data types appear to represent a broader pattern of higher data availability, measurement frequency and reliability for the more traditional and/or static types of traffic-related data, such as data on transport networks and traffic safety, and lower scores for these attributes for newer types of data with higher spatial or temporal resolution, such as environmental data at neighborhood level and, especially for availability, real-time traffic data. These lower mean scores tend to coincide with relatively high standard deviations, indicating that availability, measurement frequency and reliability of these data is low for a major part of the responding cities, but high for a smaller group.

Table 5.4. Data availability, data measurement frequency, and data reliability for nine types of traffic-related data (mean and standard deviation, N=23 respondents)

Data type	Data availability 1)		Data measurement frequency 2)		Data reliability 3)	
	Mean	SD	Mean	SD	Mean	SD
Commuting travel time	2.9	1.6	3.6	1.3	3.4	1.0
Travel distance to key services	3.3	1.5	3.2	1.3	3.5	0.9
Affordability of public transport	3.0	1.5	3.8	1.3	3.8	0.8

Greenhouse gas emissions accounted at neighborhood level	2.3	1.4	3.2	1.4	2.9	1.3
PM2.5 pollution accounted at neighborhood level	2.9	1.6	3.2	1.5	3.2	1.4
Mobility (road/cycle path/pedestrian path) networks	3.7	1.3	3.9	1.2	3.8	0.9
Public transport network coverage	4.2	1.0	3.9	1.3	4.1	0.7
Traffic fatalities and injuries	3.8	1.2	3.6	1.3	3.9	0.9
Real-time traffic data	2.7	1.5	3.8	1.5	3.9	1.1

1) 1 = not available; 2 = available at a cost; 3 = available with special permission; 4 = freely available; 5 = freely available online
2) 1 = measurements ≧ 10 years; 2 = 3–10 years; 3 = 1–3 years; 4 = annually; 5 = monthly/daily
3) 1 = weak assumptions, significant inconsistency; 2 = debatable assumptions, considerable inconsistency; 3 = reasonable assumptions, moderate inconsistency; 4 = realistic assumptions, slight inconsistency; 5 = no assumptions, no inconsistency

Finally, we sought a better insight in the perceived relative importance of factors in urban mobility planning and how this differs between cities. This could to help to identify what should be covered by future, more integrated GIS-based traffic models. With an AHP analysis (see Methods), relative importance scores were calculated for five factors: accessibility, livability, air quality, vehicle energy transition, and investment cost. Figure 4 shows the relative importance scores per city, as well as the mean value of each factor, based on 23 valid answers. Accessibility, air quality and livability rank highest among the respondents, whereas investment cost and the vehicle energy transition rank lowest. It appears that in most European cities, the traditional concerns of urban mobility planning (accessibility, air quality and livability) are still considered more important than the reduction of greenhouse gas emissions from the transport sector. However, perhaps more striking than this average rank order of the five factors, is the large variation between the responding cities. Each city seems to have its own, more or less unique, order of priorities in urban mobility planning.

5.4 Discussion

5.4.1 Major findings and implications for GIS model development

Our investigation made clear that currently the use of traffic models among European urban mobility planners is fairly widespread and established. These models are used in about 40% of the 42 European cities covered in our survey, mostly in Western and Southern Europe. This concerned predominantly (85%) GIS-based models, which were already in use for over 10 years in about half of the cities concerned. These models are used to support decision making as well as policy development and evaluation, and the large majority of the respondents considered the models very useful for this purpose. Needs and interests of (prospective) users regarding the models, concern in the first-place provision of information about accessibility, but there is also strong interest in information about social, environmental and health aspects of mobility, as well as information at neighborhood level. Current commercial traffic models generally center around management of traffic flows (e.g. TransCAD and VISUM). Fast, GIS-based models for calculating travel times, which could provide information about accessibility, have been developed, but have not been published yet or offered on the market (Yan-Yan et al., 2016).

Other needs and interests concerned improved user friendliness, primarily (76%) in terms of easier use of the models by non-experts. Good (i.e., frequently measured and reliable) data for use in GIS models are available in most cities for more traditional data types, such as data on transport networks and traffic safety. However, for newer types of data, such as real-time traffic data and environmental data at neighborhood level, this is only the case for a minor part of the cities. In terms of main concerns, long-standing issues such as accessibility, air quality, and livability ranked highest, whereas the energy transition, a relatively new concern, ranked lowest. However, each city seems to have its own, more or less unique, order of priorities in urban mobility policy.

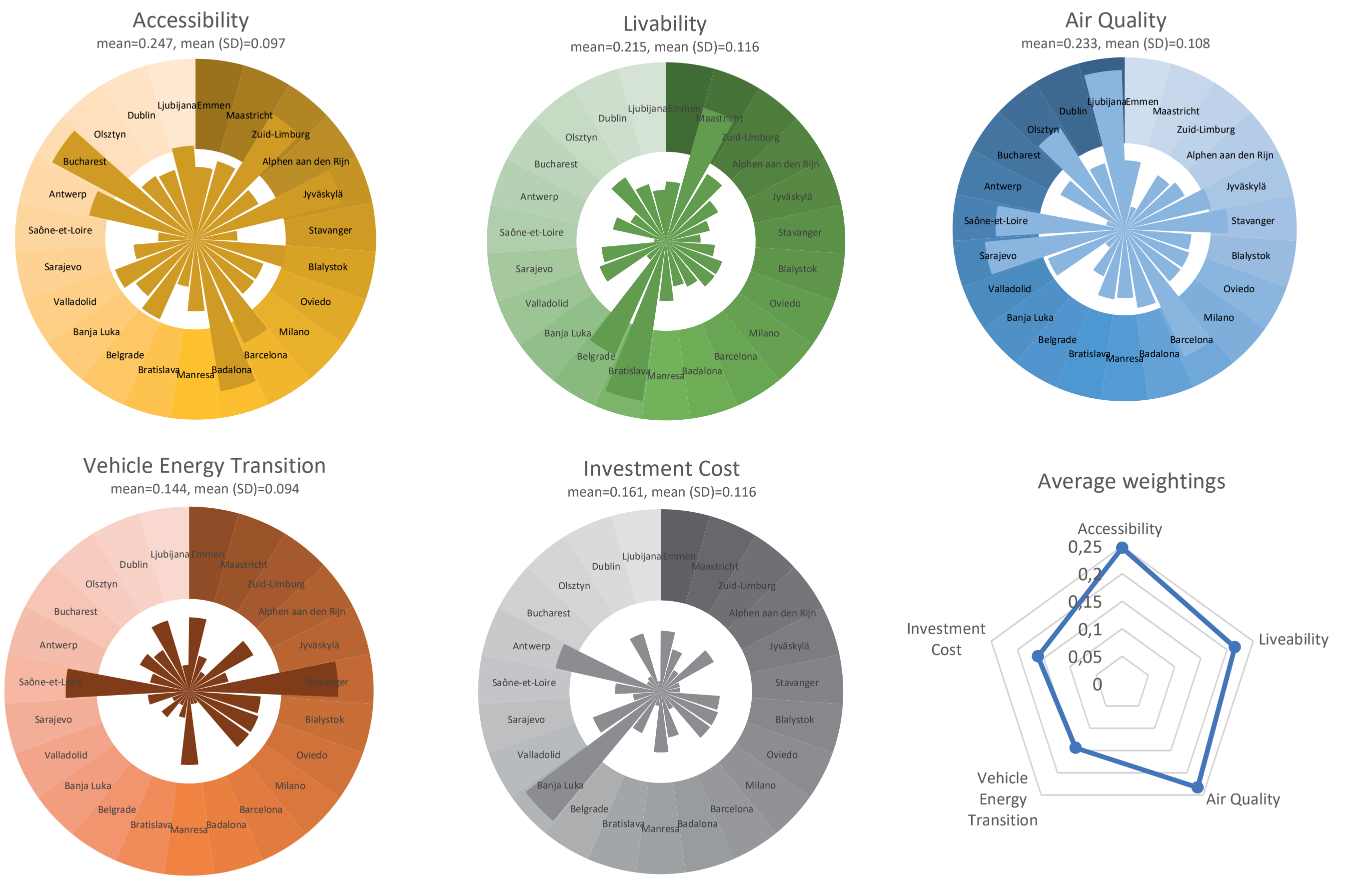

Figure 5.3. Perceived relative importance of different factors in urban mobility planning, per city and average score (N=23 respondents)

For developers of GIS-based traffic models, the findings indicate that in Europe there is scope for wider adoption and further improvement. The models currently used are considered useful to support urban mobility planning, but more than 60% of the surveyed cities do not yet use them. Increased user friendliness, in particular for non-experts, appears important to promote wider adoption. There is also considerable interest in integrating more aspects (social, environmental) and types of data (neighborhood level). At the moment, the required data are well available in only a minor part of the cities, but this may change rapidly in the future given the strong emphasis of EU policies on the integration of social (e.g., transport poverty) and environmental (e.g., decarbonization) aspects in sustainable urban mobility planning. This will also allow the use of GIS models that combine the more traditional and newer types of data. Given that cities differ considerably in terms of their priorities in urban mobility policy, the supporting GIS models should ideally cover a broad range of domains allowing the user to choose for the options or modules that are locally of most interest.

5.4.2 Limitations and research needs

Our survey covered European cities quite well, both geographically and in terms of size. However, with 42 responding cities from 21 countries, it is still a limited sample. Given the low response rate, we therefore focused on broad patterns rather than details. Furthermore, to restrict the time required to complete the survey, we chose to include mostly closed questions. Consequently, we have a clear indication that the major part of European cities does not (yet) use traffic models to support urban mobility planning, but we do not yet know why this is the case, and what the city-specific reasons or barriers are. Likewise, it is now clear that there are considerable differences between cities in availability and quality of traffic-related data and in priorities in urban mobility planning, but we still lack deeper insight into the causes of these differences. These questions could be addressed with different a type of survey questionnaire designed to identify explanatory factors through advanced statistical analysis. Based on our current experiences, we expect, however, that the large sample size that would be required would be difficult to achieve. An alternative approach to acquire these insights would be to conduct in-depth case studies with a limited but highly diverse set of cities would be needed to acquire such insights. This set could be selected from our sample of 42 European cities, of which the basic characteristics regarding GIS model use and needs are now known. These case studies could be combined with user participation in GIS model development, to ensure that further development of traffic models meets the needs and priorities of urban policy makers. User involvement in model development is strongly recommended, given the need to be adaptive to local requirements and conditions in the many decisions that are inherent to the development of models for decision and policy support. New developments in traffic models, such as high speed/high resolution models and models that use real-time data (Li et al., 2015; Wang, Lawson, & Shen, 2014; Zhao, Zhang, An, & Liu, 2018; Yan-Yan et al., 2016), come at a cost and depending on local budgets and priorities, this may be acceptable or not. Furthermore, the need and ways to deal with ‘old’ barriers to model use, such as the availability of certain types of data or data formats (McNally & Rindt, 2007; Loidl et al., 2016), or ‘new’ barriers, such as data privacy regulations (POLIS, 2021), will differ between cities. Finally, in model development for decision and policy support there is always the dilemma between complex, integrated models covering multiple domains and producing high resolution output versus simple, user-friendly and easy to-understand models (Givoni, Beyazit, & Shiftan, 2016; Fallah Shorshani, Bonhomme, Petrucci,-André, & Seigneur, 2014; Okraszewska et al., 2018). Also in this case, involvement of prospective users is essential to make a choice.

5.5 Conclusion

We conducted this study to inform further development of GIS-based traffic models for urban mobility planning in Europe. As the study was the first of its kind, the survey responses from the transport departments of 42 cities from 21 European countries, provided novel insights into how widespread the current use of GIS models by urban mobility planners is, what the perceived usefulness of these models is, and what the availability and quality of traffic-related model input data is. Furthermore, the study provided insight into the needs and priorities of mobility planners regarding GIS models, and how these vary between cities.

For developers of GIS-based traffic models, the findings indicate that in Europe there is scope for wider adoption and further improvement. The precise direction future model development should take is less clear, however, given the diversity in conditions, needs and priorities among European cities. We recommend that further in-depth research into this variation be done with a limited but diverse set of cities, possibly combined with GIS model development involving local, prospective users in Urban Living Lab type of settings.

Author Contributions
Conceptualization, X.L. and M.D.; methodology, X.L.; software, X.L.; validation, X.L. and M.D.; formal analysis, X.L. and P.P.; resources, X.L.; data curation, X.L. and P.P.; writing—original draft preparation, X.L. and P.P.; writing—review and editing, M.D. and J.d.K.; visualization, X.L. and P.P.; supervision, M.D. and J.d.K. All authors have read and agreed to the published version of the manuscript.

6

Chapter 6

Discussion and Conclusion

This thesis focuses on the role of data in supporting sustainable urban mobility transformations. Sustainable mobility is one of the main challenges facing cities. Especially reducing car mobility and promoting other modalities is a key concern of sustainable urban mobility policymaking. In practice, poor data and an associated lack of evidence of the performance of specific policies and measures is one of the main barriers to effective urban transport policies (May, 2015, Gühnemann, 2016, Awasthi et al., 2018). Recent developments in data collection and use seem to offer new opportunities for urban policymakers, but the current academic literature has mainly focused on developing decision support models for policy decisions about (bigger) investment in urban transport, especially infrastructure (Curtis et al., 2019, Kębłowski and Bassens, 2018). Those are less useful for urban policymakers that seek policy monitoring and evaluation to steer towards sustainable mobility (Banister and Hickman, 2013).

Current literature has neglected to create insight into the role of data in policy practice and how data can better support urban policymakers that seek to promote sustainable mobility. Through a combination of studies on the role of data in sustainable urban mobility planning in a multi-level governance context, this thesis sets out to investigate (1) the current role of data in urban mobility policy practice, and (2) how data could more effectively support urban policymakers in shaping sustainable urban mobility transformation. The four specific research questions have been addressed separately in the four preceding chapters, thus in this final chapter the answers are not merely repeated but synthesized to address the two overall objectives. It also discusses the contribution this thesis makes to the scientific literature as well as its limitations, and offers suggestions for future research on the topic. It ends with an overall, summarizing conclusion.

6.1 What is the current role of data in urban mobility policy practice?

In order to better understand the context in which urban mobility planners operate, answering this question started by exploring the multi-level character of policy and governance. Although local governments have the most specific legal power concerning urban mobility through the subsidiarity principle, sustainable urban mobility transition is clearly shaped by regional, national and supranational levels too. Therefore, it is relevant to understand how urban mobility policies relate to policies at the other governance levels (Chapter 2). After this, findings on the needs and priorities of urban mobility planners concerning data are discussed in this multi-level governance context (Chapters 3-5).

By understanding sustainable urban mobility transitions through the eyes of mobility policymakers from different governance levels, chapter 2 shows that (for our case country, The Netherlands) the the national level still mainly focuses on 'solving bottlenecks through infrastructure'. Although the European Commission started to encourage all of the member states to integrate data in sustainable transport planning and decision-making {EC, 2019 #3006}{EU, 2019 #165}, the EU lacks authority or influence to affect national policies. Cities found that it is difficult to acquire funding from the national level to support activities focussing on better data use in mobility planning and decision-making.

The main policy instruments including their primary effects on sustainable urban mobility differ per governance level. At the EU level these are primarily 'soft policies', such as Sustainable Urban Mobility Plans, but also investments in infrastructure (TEN-T funding). Respondents describe these soft policy measures as useful to develop knowledge and skills and as a source of inspiration for cities, but participation is voluntary. Moreover, the EU cannot support all cities in their actions, for example in case of the Open Data Directive, launced by the EU in 2019, which stimulates member states and cities to build connections by sharing data and contributing to smart policy solutions (EC, 2019). The impact of EU level policies therefore differs greatly between cities.

At the national level, the most important policy instruments are transport infrastructure-oriented, such as MIRT funding (Multi-year program Infrastructure, Spatial Planning and Transport), and their effect concerning sustainable urban mobility development is ambiguous. The Dutch national government recently adopted new strategies and targets, in correspondence with the EU Green Deal and EU Climate Agreement, most notably the Klimaatakkoord, which sets specific targets for CO_2 reduction in the transport sector. In terms of data use in sustainable urban mobility policymaking, the national level trialed some programmes, such as Smart Mobility and Mobility as a Service. These programmes have different projects, including collection of traffic data for road planning, monitoring data of parking for urban spatial planning, and road network data for planning new buildings. Most of these projects try to solve the mobility issues at the technical level. An exception is BeterBenutten (introduced in detail in chapter 4), a programme of the Dutch national government with the target to prevent car trips by supporting behavior change instead of (road) infrastructural development. It also focused on promoting more evidence-based policymaking. This programme provided additional capacities for local governments to assess different mobility policy measures, and has shown that more data-based policy assessments could facilitate sustainable urban mobility transitions.

Measures from the regional level have only a moderate influence, and mostly concern the provision of public transport and regional cycling infrastructure. Local governments have the authority for most direct car constraining or enabling policies, with as main policies the regulation of road space and the implementation of low or zero emission zones. In recent years, more sustainable mobility pilot projects have been trialed in cities, such as Try an E-bike, a 4-weeks free public transport card, and bike promotion campaigns. These projects provide opportunities for cities to promote sustainable mobility, but lack of financial resources and capacity for data-based policy assessment (including monitoring, collecting, selecting, and analyzing the data) constrained the further improvement of these policy measures. Additionally, local governments currently have poor data on cycling and walking, while most data they have is on car congestion (which anticipates investments in infrastructure). The latter is not sufficient to track modal shift effects of policies (chapter 2). The national BeterBenutten program gave the opportunity to 12 Dutch cities to evaluate policy measures targeting on different modalities. Based on the assessment data, the cities could decide whether they would continue or terminate these policy measures as well as how they could improve or upscale the successful ones.

After gaining a clearer insight into the multi-level context in which urban mobility planners operate and how this affects data use in urban mobility policy, we now turn to the current role of different types of data in urban mobility policymaking practice. Chapter 3 found that the new types of big data (mobile phone data, social media data, and GPS data) provide new opportunities for evidence-based policy-making but cannot replace survey data. Moreover, most studies on these new opportunities did not engage with policymakers, and so give little insight in the use of data in mobility policy practice.

Chapter 4 thus focused on the use of data in urban mobility policymaking processes by comparing two medium-sized cities taking part in the BeterBenutten programme. It found that data use differs per type of policy cycle (i.e. long-term versus short-term policy cycle). The main difference between long-term and short-term policy cycle is that the first involves transport policy strategy making. The strategy making team is responsible for making agreements with provincial and national governments, is partly shaped by local political positions, and takes the final decisions on long-term policies and large programs. The long-term policy cycle usually takes four years or longer to develop new mobility plans for which a strategic steering group is the final decision-making body, receiving different sources of information, reports, and data from other departments or working groups. We found that input of more data would play a limited role here. Survey data currently play a more important role than big data, because surveys (that can include ‘why’ questions) can give more insight into travelers’ behavior. This helps to develop soft policy measures aiming at facilitating sustainable mobility behavior. Big data, in contrast, was found to be hardly applied in the long-term policy cycle. The main tasks for short-term urban mobility policymaking include adjustment of short-term policy measures and traffic regulations. Traffic monitoring data play a more important role here. Program managers have a mandate to adapt certain policy measures and projects (run in short-term, such as pilot projects and experiments) based on in-time information in the form of traffic data and big data. The more common uses of big data in current short-term urban mobility policymaking are to monitor traffic to implement in-time policy measures to mitigate congestions especially during holidays, and to monitor the punctuality of public transport to improve public transport timetables. Survey data is also applied in the short-term policy cycle but not as much as traffic monitoring data.

Overall, better use of data in sustainable urban mobility policymaking is needed for a few purposes. First, it concerns better policy monitoring (chapter 3): using data to 'manage' the modal shift more effectively, and to keep the city accessible when car access is constrained. This requires data on the usage levels of the various modalities (bus, tram, shared bike, shares car, shared carriage bike, etc.), but also data on 'why' travelers prefer the various modalities. The car-alternatives need to be of sufficient quality (in terms of availability and resulting travel time, price and convenience). A second purpose is 'for legitimacy' (chapter 2). In order to get sufficient public support for car constraining and modal shift policies, better data concerning the CO_2 gains of the modal shift seem essential. This way, climate change targets can legitimize the car constraining policies. Finally, better data *for travelers* is important (chapter 4). Data can enhance the quality of multi-model travel time information and ticketing to travelers. Even more than individual car mobility and parking, multi-modal travelling (including transfers, multiple mobility providers etc.) requires good data in order to be of sufficient quality.

6.2 How can data more effective support urban policymakers in the sustainable urban mobility transformation?

This section discusses the implications for mobility policymakers, traffic modelers, and data experts on how data could be used more effectively to support sustainable urban mobility transformation.

The first implication of our findings is that sustainability and climate change ambitions are bringing more alignment between the governance levels in terms of (sustainable mobility) policy aims. Chapter 2 shows that the biggest synergy between multiple governance levels to facilitate the mobility transition is setting sustainability as a common goal, in which soft policy measures (i.e. European directives and national development plans) play an important role. For instance, the European Commission's mobility and transport group introduced the concept of Sustainable Urban Mobility Plans in order to encourage European cities to develop integrated mobility visions, with mobility data being an important ingredient (Commission, 2013). The Dutch national government adopted this concept in legislation and issued its own national guidelines (ELTISplus, 2012) and certain programs to facilitate it. One of the programs called Intelligent Transport Systems (Optimizing Use Follow-up ITS) specifically aims to promote data use in traffic management for sustainable urban mobility development (RVO, 2017). Although these directives and plans may need a longer time to be grounded, they can also guide other policies and decisions to have the same long-term vision. Zooming in on local practice, chapter 4 found that setting common, central goals (and associated key indicator, namely reducing car trips during rush hour) for the BeterBenutten program helped the national government and the municipalities to design and initiate projects in the same direction and more effectively support the transformation. These goals concerned promoting a policy shift from 'building more infrastructure' to 'influencing mobility behavior to utilize existing capacity more efficiently', and promoting more evidence-based policymaking ('to measure is to know').

The second implication is that a shift in the funding focus of the higher governance levels (supranational and national) from infrastructure to broader mobility solutions, is required to better support the use of data in urban sustainable mobility policymaking. Chapter 2 showed that the biggest conflict between the Dutch national and local governance levels is that the national funding does not contribute to promote urban sustainable mobility. The main stream of the funding still goes to constructing new infrastructure, such as road adaptations or extensions. This means that only limited financial support is available for the cities to improve data use in mobility policymaking. An exception is the BeterBenutten program (chapter 4), which showed that providing extra funding and capacity for local policymakers to support evidence-based policymaking brought more opportunities to implement policy measures that stimulate changes in travel behavior.

An important way to solve several constraints of data use in sustainable urban mobility policymaking, such as lack of capacity and knowledge to select and process the raw data, is to use traffic models. Chapter 3 and 4 found that policymakers can efficiently extract valuable information from raw data by applying traffic models as decision-making support tools. A commonly adopted type of tool is GIS models due to their capacity to integrate the processing of spatial data with network analysis (Abousaeidi et al., 2016). Chapter 5 thus investigated the current use of GIS-based traffic models in urban mobility planning and explored the needs and priorities in terms of advancing the models. Our survey (chapter 5) found that urban policymakers would like GIS models to include more social and environmental indicators in order to better fit national and European policies. This is also interesting from a data perspective, because, possibly, cities can benefit from the European support for (open) data in this regard. The EU launched an Open Data Directive in 2019, which mandates the release of public sector data in free and open formats. More open data seems to be instrumental for all three purposes of better data use mentioned above. There is a European network that develops open data tools to support cities. This type of EU support may compensate for the limited capacity for monitoring and evaluation in medium- and small-sized cities. For the moment, however, the latter remains a concern.

More data and better use of data is not a panacea, however. It cannot solve every problem in sustainable urban mobility policymaking and it may also lead to dilemmas. For instance, chapter 2 indicated that the national level dominates long-term urban mobility planning and policymaking and constrains the sustainable urban mobility transition. The need for a more equal power distribution cannot simply be solved by data interventions (Nochta et al., 2021). Moreover, some other challenges concerning the use of data in urban transport policymaking remain:

a. Data bias and inequity: the information reflected by data could be biased. Especially the current use of data in mobility policymaking is mainly supply-driven (chapter 2), which may lead to policy decisions poorly reflecting the needs and experiences of people and may cause social inequities. Pereira et al. (2019) examined how statistical bias in spatial data affected mobility policies regarding investment in public transport for the 2014 Football World Cup and the 2016 Olympic Games in Rio de

Janeiro. Their results show that the biased data caused inequities as the wealthier districts had much larger gains in access to opportunities than poorer districts.

b. Ineffective use of data: chapter 4 uncovered that for both long-term and short-term mobility policymaking, not only having sufficient data is a major challenge, but also lack of knowledge and capacity to deal with data for policy. Chapter 5 gave insights in how to improve decision-making support tools. However, as other traffic modelling studies show, the development of the desired models requires a massive financial and time investment (Okraszewska et al., 2018, Fallah Shorshani et al., 2014). Policymakers may not prioritize data-driven decision-making, or there may be a lack of resources or incentives to collect and use data effectively (Bibri, 2021). Additionally, different government agencies may not coordinate effectively, which can lead to data silos and a lack of integrated policymaking (Gonzalez-Feliu et al., 2018).
c. Data privacy: since the use of big data in policymaking started, there has been a debate about how to protect individual's data privacy. In 2002, the European ePrivacy Directive (Directive 2002/58/EC) was issued to protect the privacy of personal data handling on or via e-devices (GPS, mobile phone, smart cards, social media). Followed by this directive, each country developed its own legislation to regulate data application in different domains. However, when it comes to mobility policymaking practice, several challenges still remain. For instance, Godwin et al. argued that there is little attention paid to safe collection, storage and processing of traffic data on large scale, not to mention the challenge of protecting people's privacy in providing data (Godwin et al., 2019). McCarthy and Fourniol (2020) studied the potential of Privacy Enhancing Technologies in supporting governments to handle data in policymaking, and concluded that several concerns still need to be addressed, such as how data use can benefit the data providers and how disadvantages for certain social groups can be prevented.

6.3 Contributions to the Literature

6.3.1 Contributions to the literature

This section discusses the contributions of this thesis to the literature based on the research gaps identified in the introductory chapter (section 1.1.4). Current academic literature offers limited insight in and had little engagement with the role of data in urban mobility practice. It has mainly focused on developing decision support models for policy decisions about (bigger) investment in urban transport, especially infrastructure (Curtis et al., 2019, Kębłowski and Bassens, 2018). Those are less useful for urban policymakers that want to monitor and evaluate policy to steer towards sustainable mobility (Banister and Hickman, 2013). This PhD study offers a two-fold contribution to the literature. First, it gives a better insight in the role of data in current policy practice and, second, it offers suggestions on how data can be used more effective by urban policymakers that seek to promote sustainable mobility. The latter concerns specific 'next steps' in GIS model development, as well as more general 'next steps' for more effective use of data. Three major purposes of better data use were identified: for policy monitoring, for more legitimacy, and for better service to travellers. Better data use 'for policy monitoring' concerns the short-term policy cycle, and our findings suggest that a combination of big data and survey data (that can give more insight into why people travel as they do) is most instrumental. This is in line with earlier studies that argue to not only rely on quantitative data but also incorporate other forms of knowledge. For instance, (Nochta et al., 2021) argued that data-driven knowledge should be considered as one part of a multifaceted evidence-base to inform policy decisions, while incorporating knowledge from a diversity of communities is necessary as well. Our findings in chapter 3 and 4 also specify how adequate different types of data are used in the sustainable urban mobility policymaking process by distinguishing the long- and short-term policy cycle. This adds to Verstraete et al. (2021) who shed light on how to use data in the different steps of the policy cycle by emphasizing what approaches could be used to analyze data in each of the steps, based on both scientific literature review and practical case studies. Their work, which was part of EU project PoliVisu (https://www.polivisu.eu/) (Concilio et al., 2021), also found that limited data literacy is the key constraint to successful use of data in urban policymaking, but they did not highlight the distinct role of data in the short- and long-term policy cycle (chapter 4).

Although our study contributed to the gaps in the literature, there are many gaps left, which indicate future research directions. A first one is clarifying the most effective role and involvement of different actors in data-driven sustainable urban mobility policymaking. This is also flagged by Ronzhyn and Wimmer (Ronzhyn and Wimmer, 2021). Walravens et al. (2021) highlighted that collaboration among different actors is required to enable data-driven policy making (Walravens et al., 2021). Both our interviews with respondents at different governance levels, and the case study of the two cities proved that involving and collaborating with a broad range of actors is required to make sustainable and data-driven urban mobility policymaking effective. Future studies should clarify how this collaboration can be organized best.

6.3.2 Limitations and future research

This section reflects on the limitations of this research which also lead to suggestions for future research. A first limitation concerns the geographical generalizability of the findings. The studies are mainly based on the policy context in the Netherlands (Chapter 3 and 4), and/or medium-sized cities (Chapter 4). Although it seems that there are many similarities with other parts of Europe, future research should perform also case studies in those areas to verify this. Chapter 5 does provide insights beyond the Netherlands as it concerns a survey among European cities, quite well distributed across the European continent. It made sense to choose the Netherlands for the studies, because it has often been a pioneer in sustainable mobility policy with its tradition in cycling, more integrated planning, and well-established mobility infrastructures. Still, a fair question is to what extent the conclusions are applicable to other cities outside of the Netherlands. Interviewees (in Chapter 2) suggested a different situation in Central and Eastern Europe, which traditionally have very well-developed public transport systems, but currently rather invest in highways. Cities in these contexts likely can take different transition pathways towards sustainable urban mobility (e.g. by making use of their public transport systems), requiring different policy mixes. This is an interesting issue recommended for future research, while our research can be used as a starting point.

A second limitation is a narrow focus on mobility. As discussed in chapter 2, not only mobility policy measures but also other relevant policy domains (e.g. energy, spatial planning, open data) have impacts on the sustainable urban mobility transition. Future research should clarify how the mobility transition is connected with transformations in other domains. Chapter 2 did include several policy instruments that also target other domains, such as the EU Green Deal and the Netherlands National Climate Agreement. These policies play key guiding roles for all sectors concerning sustainable development. However, the effects of policies in other specific domains that are relevant to sustainable urban mobility transition were not addressed. For instance, the effects of sectoral mobility and energy policies need to be studied to avoid cross-domain policy conflicts and to promote synergies (Payakkamas et al., 2023). An additional motivation to study the transformation of mobility-energy nexus is to prevent unequal distribution of the benefits of sustainable energy and mobility options across different social strata (Boucher and Mérida, 2022).

A third limitation of this research is the strict focus on the role of data in policymaking, neglecting the role of data for the traveler and for mobility operators. For these stakeholders, data plays a significant role in enabling multi-modal trips, such as Mobility-as-a-Service, which can offer a tailored mobility package containing different transport modes in one ticket by collecting and analyzing massive amounts of multi-modal data (Jittrapirom et al., 2017, Servou et al., 2023). The development of digital platforms also enables the growing use of shared-mobility, for instance by indicating the nearest shared-mobility locations. Vice versa, based on data of how people use shared-mobility, further improvements of mobility sharing can be implemented. Future research could further explore how data for policy overlaps with the better use of data in other domains to promote the sustainable urban mobility transition.

A fourth limitation is that this research primarily followed a rational approach to policymaking, and payed less attention to the politics and messiness of the policymaking process. It is recognized that policy is not merely a rational problem-solving process, but rather complex and intricate, often involving hidden bureaucratic power or dominance, as noted by Mosse (Mosse, 2004). The analysis in this thesis helped to highlight the more functional and instrumental potential of data in policymaking. However, this should be seen as a first step, and future research should explore how new forms of data can also be misused for the interest of particular stakeholders (whether big tech firms or particular governmental departments or political parties). This should provide inside in the risks or disadvantages of particular forms of 'evidence-based' policymaking, in addition to the potential that is highlighted in this thesis.

A fifth avenue for future research is to extend the multi-level policy mix analysis for a sustainable urban mobility transition, by combining both vertical relations and horizontal relations (i.e. conflicts and synergies within each level of governance). It is the combination that shapes the reconfiguration of urban mobility. Most current studies either only focus on vertical policy mixes (e.g. chapter 2) or horizontal policy mixes (e.g. (Kern et al., 2017)), and do not combine both horizontal and vertical analysis. This is recommended for future studies as it enables a better understanding of conflicts and synergies between and within governance layers for sustainable urban mobility transformation.

Finally, the two core elements of this research, data and policy, partly overlap with a number of ongoing debates on related themes, such as: how reliable and trustworthy are the data used for policy, how to ensure the privacy of data use in policymaking, and would artificial intelligence perform better in urban mobility policymaking than policymakers? By addressing these questions in future research, better ways to apply data in promoting sustainable urban mobility transition could be identified.

6.4 Conclusions

The prevalent use of big data in every domain of our lives shows that we live in an increasingly digital world. Not only businesses and politicians use data to find out what products, services or speeches they could sell the best, but also governments employ data to support policy- and decision-making. This section concludes how data could better support sustainable urban mobility transformations.

Generally, the combination of different data types (big data, survey data, GIS data, etc.) holds more potential to promote the sustainable urban mobility transformation. One of the main contributions of big data for sustainable urban mobility policymaking is that it allows evaluation of policy measures that target different modalities (e.g. bus, tram, bike, subway). At the same time, survey data are irreplaceable as these can give information about why travelers choose these modalities.

In a multi-level governance context, we found that institutionalizing multi-level co-development of policies and shifting the funding focus from infrastructure to broader mobility is needed to better support the use of data in urban sustainable mobility policymaking. The EU has issued various plans and directives (i.e. Smart and Sustainable Transport Strategy, Open Data Directive) to support the better use of data in sustainable mobility policymaking, but so far these hardly had an impact on the national legislation of the member states. There are promising developments however. An example is the EU Green Deal (2019), acting as a fundamental guidance for the sustainable development of Europe, including mobility. Another good example is the Dutch BeterBenutten Programme. It shifts the focus from 'solving the mobility bottlenecks through infra' to 'influencing mobility behavior to utilize existing capacity more efficiently', and has demonstrated that more funding and capacity for data-driven mobility policymaking can help to reduce private car rides and promote other sustainable transport modalities.

In urban mobility policymaking practice, bringing in more capacities and knowledge to process raw data and extract valuable information for policymakers is essential, especially in the long-term policy cycle. Use of GIS-based models could contribute to this by more efficiently translating data into information for mobility decision- and policy-making. The main improvement of GIS-based models for mobility planning that urban policymakers would like to see is the inclusion of more accessibility, social and environmental aspects. However, for this desired model development, more data, especially higher-resolution data on a neighborhood-level, is required. In addition, the survey responses from 23 European cities show that accessibility, air quality and livability rank generally high in their mobility planning goals. This finding is also in line with the multi-level governance study (chapter 2) and the policy practice study (chapter 4) indicating that 'sustainability' (including air quality and livability) aligns policymakers from various departments and governance levels to work together in applying more data to support sustainable urban mobility transformation.

In summary, increasing amounts and new types of data offer new potential for sustainable urban mobility policymaking. We hope that the findings of this thesis also contribute to further tap this potential and support mobility policymakers, traffic modelers, and data experts in using data to more effectively support sustainable urban mobility transformation.

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8. Appendix

Appendix 8.2.1. The list of interviewees

Level	#	Organization	Work Position and Contents	Duration (minutes)	Date
EU (10)	1	Local Governments for Sustainability (ICLEI)	Coordinator Sustainable Mobility and Transport, the coordinator of SUMP	98	26/06/2020
	2	European Cyclists' Federation	Co-CEO of the European Cyclists Federation	46	01/07/2020
	3	European Commission	Working in the ministry for transport, was being responsible for air quality plans and air quality measures, as a to go to the European commission to gain some experience and	64	28/03/2021
	4	Eurocities	Senior project coordinator, coordinating the EUROCITIES Mobility Team, proposal development, project management, corporate representation and strategy	93	07/07/2020
	5	The Directorate-General for Mobility and Transport (DG MOVE)	Deputy director general in DG MOVE, European Coordinator for Road Safety and Sustainable Mobility	41	08/07/2020
	6	DG MOVE	Dealing with innovation research of urban mobility	71	05/03/2021
	7	The Directorate-General for Regional and Urban Policy (DG REGIO)	Team leader for all transport mobility related issues	94	05/02/2021
	8	Directorate-General for Environment (DG ENV)	Urban environment Policymaking, coordination with different departments on urban environment policy	86	06/01/2021
	9	Cities and Regions for Transport Innovation (POLIS)	Director of POLIS (Cities and Regions for Transport Innovation), initiating research activities, look at policy agenda for cities and the governance issues	70	07/07/2020
	10	European Institute of Innovation and Technology (EIT) Urban Mobility	EU affairs manager, funding horizon and innovation researches to help cities conceptualize a sustainable mobility plan	71	03/12/2020
National (9)	11	Milieudefensie (Friends of the Earth Netherlands)	Campaigner on traffic and climate justice.	57	05/01/2021
	12	Natuur & Milleu (Nature & Environment)	Program leader of mobility and market	89	23/02/2021
	13	Urban Mobility at German Institute of Urban Affairs	Team leader of urban mobility at German Institute of Urban Affairs, heads the "Local Mobility" team in the mobility research and the bicycle academy, which connects large and small municipalities from all over Germany and makes them fit for more and better cycling.	49	26/11/2020
	14	Planbureau voor de Leefomgeving (Netherlands Environment Assessment Agency)	Urban Planner	77	07/11/2020
	15	Ministry of Infrastructure and Water Management	Director of Mobiliteit en Gebieden Program	51	16/08/2021
	16	Ministry of Infrastructure and Water Management	Expert in developing mobility plan, link between the expert and the policymaker, the minister and our management.	69	23/09/2020
	17a&b	Ministry of the Interior and Kingdom Relations	a. Coordinator of spatial planning for the South Holland province	85	17/12/2020

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			b. Building bridges between knowledge and policymaking, making new connection, high quality public transport		
	18	Ministry of the Interior and Kingdom Relations	leading policy integration and science in the National environmental vision development, coordination of making the report	71	12/11/2020
Regional (7)	19	Rotterdam–The Hague metropolitan area	Project manager for Mobiliteit bij Metropoolregio Rotterdam–The Hague	76	05/01/2021
	20	Province Zuid Holland	Urban geographer, urban development, regional developments	66	16/12/2020
	21	Province Limburg	Senior policy advisor on smart/sustainable mobility, arranging investments and finding the corporations and some mutual interests with the other parties from different levels of governance	68	01/12/2020
	22	Province Gelderland	Regional mobility coordinator	86	29/01/2021
	23	Arnhem Nijmegen Region	Sustainable urban mobility development, connect with EU	92	08/10/2020
	24	Arnhem Nijmegen Region	Program manager on transport, sustainable mobility, accessibility in the Arnhem Nijmegen city region	84	12/02/2021
Local (6)	25	Maastricht Bereikbaar	Policy researcher and advisor, Cluster Mobility & Traffic, Programming regional mobility policy (North and Central Limburg & West Brabant), Monitoring & Evaluation Roermond Accessibility, Research into the introduction of e-scooter sharing for GoedopWeg & Municipality of Utrecht	72	22/09/2020
	26	Rotterdam City	Program manager, organizing programs of the mobility department	85	03/12/2020
	27	Department of Sustainability, Rotterdam City	Work together with the department of mobility for sustainable urban mobility development, responsible for the climate agreement, work on the zero-emission mobility policy	82	17/12/2020
	28	Rotterdam City	Coordination, policy advisor, more focus on freight transport and city logistics	80	30/09/2020
	29	Maastricht City	Mobility policymaker, urban planner	89	18/09/2020
	30	Maastricht City	Project leader of Omgevingsvisie (spatial planning and urban development vision)	74	07/08/2020
	31	Nijmegen City	Program Manager of Smart and Clean on The Road	95	12/06/2020

Appendix 8.2.2. Interview outline

1. How do you view or define the concept of sustainable urban mobility at your department or organization?
2. What is your role at your department or organization concerning urban mobility?
3. What do you see as the main policies or instruments at your governance level affecting sustainable urban mobility?
4. What do you see as the main policies at other governance levels (EU, national, regional and local) in shaping sustainable (urban) mobility?
5. How do instruments interfere with each other?
6. Who do the instruments primarily affect: travelers (i.e. their capabilities or perspectives), local planners (idem), public transport operators, parking operators or vehicle sharing operators, local infrastructures?
7. How do these policies and incentives play out in cities? Do you see specific differences across cities and/or countries, or do you mainly see recurring patterns? If so, what are these differences and similarities?
8. What are the main (governance) challenges in effectively promoting sustainable (urban) mobility? Who is to blame for the lack of success? Do you see more a problem of inertia by people, conflicting policies or both?
9. In your view, what should be done to promote sustainable urban mobility by each level? Who should take the lead in this?
10. In your view, who else should we talk to?

Appendix 8.2.3. All reported contradictions and synergies in promoting sustainable urban mobility development

Contradictions (-)	EN	ER	EL	NR	NL	RL	Synergies (+)
Lack of money (7[a])		E^{++}	E^{++++}	N^{+}	$L^{-------b}$ N^{+++}	R^{++}	Provide funding (12)
Funding mainly for (car/road) infrastructure (6)			E^{+}	N^{----} N^{+}	N^{--} N^{+}	R^{+}	Subsidy for SUM projects (4)
Funding still for promoting car use (3)	E^{+}	E^{+}	E^{-} E^{+}	N^{+}	N^{--} N^{+}	R^{+}	Offer SUM projects (6)
Have different targets (6)	E^{--} E^{+}	E^{++}	E^{+}	N^{-} N^{+++}	N^{--} N^{++++}	R^{++++}	Set common goals (15)
Lack of influence/power (10)	E^{---}		E^{-} E^{+}		L^{---c}	R^{-} L^{-}	Set guidelines (1)
Lack of information (1)			L^{-} E^{++}				Good networks (2)
Lack of knowledge and capacity (2)			L^{-} E^{++}			L^{-}	Provide trainings and webinars (2)
Lack of adaptability (3)	E^{+}	E^{-} E^{+}	E^{-}			R^{-}	Prompt process for SUMD (2)
Lack of communication (5)		E^{-} R^{-}		N^{+++} R^{+++}	N^{-} N^{+++} L^{+++}	R^{-} L^{-} R^{++} L^{++}	Good cooperation (16)
Not practical (1)			E^{-}	R^{+}			Evaluating the implemented projects (1)
Conflicts with legislation (2)			L^{++}		N^{--} N^{+}		Ambitious (3)

[a]: the number of '-' or '+' were mentioned by different interviewees; [b]: the number of '-' and '+' represent the corresponding contradictions and synergies mentioned by how many different interviewees; E: European level; N: national level; R: regional level; L: local level; EN: relations between European level and national level; ER: relations between European level and regional level; EL: relations between European level and local level; NR: relations between national level and regional level; NL: relations between national level and local level; RL: relations between regional level and local level; c: This is mainly reflected by the local level that the national level has too much power to decide what the policy instruments can be implemented instead of the local governments can decide for themselves.

Appendix 8.2.4. The references and sources of the related policy instruments

Policy instruments	Sources (all the links are acquired on 16th February, 2023)
EU Green Deal	EC 2019. The European Green Deal. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691
Sustainable Urban Mobility Plan	EC 2013. Sustainable Urban Mobility Plan. https://www.eltis.org/guidelines/second-edition-sump-guidelines
EU Air Quality Directive	EC 2022. EU Ambient Air Quality Directives. https://environment.ec.europa.eu/topics/air_en
CLean and Better Transport in Cities (CIVITAS)	EU Horizon 2020. CLean and Better Transport in Cities. https://civitas.eu/projects
EU White Paper on Transport	EC 2011. White paper 2011. https://transport.ec.europa.eu/white-paper-2011
Urban Mobility Package	EU 2013. Together towards competitive and resource-efficient urban mobility. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52013DC0913
Urban Agenda	EC 2016. Urban Agenda. https://futurium.ec.europa.eu/en/urban-agenda/pages/what-urban-agenda
Smart and Sustainable Transport Strategy	EU 2020. Sustainable and Smart Mobility Strategy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789
Regional Development Funds	EC 2021. European Regional Development Fund. https://ec.europa.eu/regional_policy/funding/erdf_en
EU Car Emission Regulation	EC 2019. CO2 emission performance standards for new passenger cars and for new light commercial vehicles. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019R0631-20210301
EU Emission Norms	EC 2016. Euro 6. https://eur-lex.europa.eu/eli/reg/2016/646/oj
EU Infrastructure Funding (TEN-T)	EC 2013. Trans-European Transport Network. https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en
EU Alternative Fuel Infrastructure	EC 2014. Directive 2014/94/EU of the European Parliament and of the Council on the deployment of alternative fuels infrastructure. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC161135/
Public Service Obligations	EC 2007. Public service obligations. https://transport.ec.europa.eu/transport-themes/public-service-obligations_en
EU 100 Intelligent City Challenge	EC 2020. 100 Intelligent City Challenge. https://www.intelligentcitieschallenge.eu/
EU Driving Urban Transition Partnership	EU Horizon 2020. European Partnerships. https://www.era-learn.eu/partnerships-in-a-nutshell/european-partnerships/general-information
Green City Award	EC 2008. European Green Capital Award. https://environment.ec.europa.eu/topics/urban-environment/european-green-capital-award_en
Mobility Week Campaign	EC 2002 till now. European Mobility Week. https://mobilityweek.eu/the-campaign/
Open Data Directive	EU 2019. Directive 2019/1024 of the European Parliament and of the Council on open data and the re-use of public sector information. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561563110433&uri=CELEX:32019L1024
Klimaatakkoord	NCA 2019. National Climate Agreement. https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands
Omgevingswet Agenda	GONL 2023. Omgevingswet. https://www.rijksoverheid.nl/onderwerpen/omgevingswet
Program Mobility as A Service	I&W 2017. Mobility as a Service. https://www.rijksoverheid.nl/onderwerpen/mobiliteit-nu-en-in-de-toekomst/mobility-as-a-service-maas
Multiyear Fund Infrastructure, Space, and Transport Program (MIRT)	I&W 2018. The Dutch Multi-Year Programme for Infrastructure, Spatial Planning and Transport (MIRT). https://www.government.nl/documents/leaflets/2018/02/07/the-dutch-multi-year-programme-for-infrastructure-spatial-planning-and-transport-mirt---summary
NOVI (national spatial vision)	BZK 2020. Nationale Omgevingsvisie. https://denationaleomgevingsvisie.nl/default.aspx
Program MoVe	Leerplatform MIRT. https://leerplatformmirt.nl/themas/adaptief-programmeren/move-programma/
Smart Mobility (program)	I&W 2016. Smart Mobility. https://www.rijkswaterstaat.nl/en/mobility/smart-mobility
Logistical Laws	Transport & Logistiek. https://transportlogistiek.nl/branche/wet-regelgeving/
Car Taxation	Belastingdienst 2023. https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/prive/auto_en_vervoer/belastingen_op_auto_en_motor/motorrijtuigenbelasting/
Charging Infrastructure	RVO 2020. The National Charging Infrastructure Agenda. https://english.rvo.nl/sites/default/files/2020/10/Factsheet%20The%20National%20Charging%20Infrastructure%20Agenda.pdf

National Zero Emission Bus	I&W 2016. National Administrative Agreement Zero Emission Buses (BAZEB). https://www.interregeurope.eu/good-practices/national-administrative-agreement-zero-emission-buses-bazeb-in-2016-in-the-netherlands
Beter Benutten Program	I&W 2012-2018. Beter Benutten. https://www.rijksoverheid.nl/documenten/brochures/2013/09/20/beter-benutten
POVI (provincial spatial vision)	Provincie Limburg 2021. De Omgevingsvisie Limburg. https://www.limburg.nl/onderwerpen/omgeving/omgevingsvisie/
Parking Norms	I&W 2019. Parking Policies in the Netherlands. https://ecf.com/sites/ecf.com/files/ECF%20-%20Parking%20in%20the%20Netherlands_0.pdf
Car Sharing	I&W 2021. Deelauto- en deelfietsmobiliteit in Nederland file:///C:/Users/m.dijk/Downloads/Deelauto-+en+deelfietsmobiliteit+in+Nederland-Ontwikkelingen,+effecten+en+potentie-pdfA.pdf
Concession for Electric Vehicles	I&W 2023. Subsidieregeling elektrische personenauto's particulieren. https://wetten.overheid.nl/BWBR0043600/2023-01-01
Tendering process public transport operator	Concessions and tenders. https://www.government.nl/topics/mobility-public-transport-and-road-safety/public-transport/consessions-and-tenders
South Limburg Bereikbaar	Funded by the national Beter Benutten programme. South Limburg Bereikbaar. https://www.zuidlimburgbereikbaar.nl/en/about-us/
Fast Bike Lane	Rijkswaterstaat 2023. https://rwsduurzamemobiliteit.nl/@209367/factsheet-fietsinfrastructuur/
City Climate Agreement	Rotterdam municipality 2019. Rotterdam Climate Agreement. https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410faa2f42204838f7990/5be174d6337f770010c1b69f/files/1.2.2_Rotterdam_Climate_Agreement_ENG.pdf
Sustainable Procurement Policy	RIVM 2015. Sustainable procurement. https://www.rivm.nl/en/topics/sustainable-procurement
GOVI (Municipal spatial vision)	VNG 2023. https://vng.nl/artikelen/gemeentelijke-omgevingsvisie
Stedelijk Verkeersplan (Urban Traffic Plan)	Rotterdam municipality 2017. Rotterdam Stedelijk Verkeersplan. https://mkb-rotterdam.nl/wp-content/uploads/2021/09/Stedelijk-Verkeersplan-Rotterdam-20170123_compressed.pdf
Zero Emission Logistics Agreement	I&W 2021. New agreements on urban deliveries without CO2 emission. https://www.government.nl/latest/news/2021/02/11/new-agreements-on-urban-deliveries-without-co2-emission
Low Emission Zone	Amsterdam municipality 2008. Low Emission Zone. https://www.rai.nl/en/route/low-emission-zone/
P&R (Park and Ride)	Maastricht Bereikbaar. P+R facilities. https://www.maastrichtbereikbaar.nl/en/info-for-travellers/car/pr-facilities-in-limburg/
E-hubs	Nijmegen Municipality. eHubs. https://www.nijmegen.nl/nieuws/nieuwsdossiers/dossier-nijmegen-goed-op-weg/deelvervoer/
Intelligent Traffic Lights	I&W. Intelligent Traffic Light Installations. https://www.rijkswaterstaat.nl/en/mobility/smart-mobility/talking-traffic/intelligent-traffic-light-installations

Appendix 8.3.1 Analysis Highlights of the Reviewed Literature

Table. Analysis Highlights of the Reviewed Literature

Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
An analysis of active transport in Melbourne baseline activity for assessment of low carbon mobility interventions (Taylor and Thompson, 2019)	Urban Policy and Research	understanding the current state of active transport-walking and cycling- use in Melbourne, providing implications for low carbon mobility planning	Melbourne, Australia	Agenda setting	The household travel survey data were applied to understand the overall travel behavior of Melbourne residents	Academic research	1
Trip-chaining trends in the United States: understanding travel behavior for policy making (McGuckin et al., 2005)	Transportation Research Record	Understanding Travel Behavior for Policy Making	The United States	Agenda setting	Respondents' daily travel information has been used to examine mobility behavior-changing trends in America	Academic research	2
Measuring social effective speed to improve sustainable mobility T policies in developing countries (Meira et al., 2020)	Transportation Research Part D	To explain the social effective speed costs measures to demonstrate that these costs could help improve sustainable urban mobility policies	Metropolitan Region of Recife, Brazil	Agenda setting	Data from the 2018 Origin-Destination Survey of the Metropolitan Region of Recife (Brazil) were used to estimate social effective speeds	Academic research	3
Towards Sustainable Urban Logistics: Creating Sustainable Urban Freight Transport on the Example of a Limited Accessibility Zone in Gdansk (Matusiewicz, 2019)	Sustainability	To identify the conditions for the implementation of deliveries in the Limited Accessibility Zone (LAZ) in Gdansk	Gdansk, Poland	Ex-ante assessment (policy formulation)	The data from interviews with drivers were used to detect the impacts caused by the policy measure and also to understand the most effective factor in the implementation of the instrument	Academic research	4
Travel Demand Management (TDM) case study for social behavioral change towards sustainable urban transportation in Istanbul (Batur and Koc, 2017)	Cities	To estimate potential impacts of TDM policies for decreasing congestion levels in Istanbul	Istanbul, Turkey	Ex-ante assessment (policy formulation)	A model developed to process data from the surveys were used to predict travel demand	Academic research	5
Designing sustainable transportation policy for acceptance: a comparison of Germany, The Netherlands and Switzerland (Hirschi et al., 2002)	German Policy Studies	Developing Sustainable Transportation Policy for Acceptance	Germany, the Netherlands and Switzerland	Policy formulation	The data has been used to explore who can learn from whom in the process of developing sustainable transportation policy	Academic research	6
An Investigation on the Effectiveness of Joint Receiver–Carrier Policies to Increase Truck Traffic in the Off-peak Hours (Holguin-Veras et al., 2008)	Networks and Spatial Economics	To quantify the effectiveness of various policies for off-peak deliveries reductions	New Jersey and New York, the US	Policy formulation	The survey data has been used to understand carriers' behaviors and their requests for off-peak travel transitions, which is also applied for scenario analysis	Academic research	7
Rethinking the taxi: Case study of Hamburg on the prospects of urban fleets for enhancing sustainable mobility (Schatzinger et al., 2018)	Green Energy and Technology	Case Study of Hamburg on the Prospects of Urban Fleets for Enhancing Sustainable Mobility	Hamburg, Germany	Policy formulation	The interview data has been employed to explore the potential of Hamburg's taxi service towards sustainable transformation in the future	Academic research	8

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Distributional effects of public transport policies in the Paris Region (Bureau and Glachant, 2011)	Transport Policy	To assess the distributional effects of different public transport policies scenarios in the Paris Region	Paris, France	Policy formulation	To use disaggregated data from the 2001–2002 Global Transport Survey analyzing trip patterns in the Paris Region	Academic research	9
Decision Support Systems for Smarter and Sustainable Logistics of Construction Sites (Guerlain et al., 2019)	Sustainability	To help decision-makers improve the construction logistics and supply chain with evidence-based decision-making model	Luxemburg city, Luxemburg	Decision making support tool development	Data observed over eight months of activity in a real construction sites and road networks data from Open Street Map were used to examine the developed data-drive decision making support model	Academic research	10
Micro-scale sustainability assessment of infrastructure projects on urban transportation systems: Case study of Azadi district, Isfahan, Iran (Mansourianfar and Haghshenas, 2018)	Cities	To evaluate the sustainability of urban mobility infrastructure projects	Isfahan, Iran	Ex-ante assessment (decision making)	Based on the expert interviews, and governmental documents data, nine scenarios are proposed to improve the traffic situation and has been tested and compared	Academic research	11
Personal and societal impacts of motorcycle ban policy on motorcyclists' T home-to-work morning commute in China (Guo et al., 2020)	Travel Behaviour and Society	To explore the societal and individual impacts of motorcycle ban policy on the home-to-work morning commute of motorcyclists	Foshan City, China	Ex-ante assessment (decision making)	Travel survey data from 3578 households were obtained for identifying the current travel patterns and potential mode shift responses to the motor-cycle ban policy.	Academic research	12
Sustainability impact assessment of transportation policies - A case study for Bangalore city (Verma et al., 2015)	Case Studies on Transport Policy	Sustainability Impact Assessment of Transportation Policies	Bangalore, India	Ex-ante assessment (decision making)	11,822 household's data, containing personal information, travel preference, travel purpose, and so on were obtained to test the mobility measures against sustainability	Academic research	13
The Contribution of Different Policy Elements to Sustainable Urban Mobility (Foltynova and Jordova, 2014)	International Scientific Conference on Transport and Mobility	Evaluation of the Different Policies' Contributions to Sustainable Urban Mobility	25 European cities	Ex-post assessment (policy evaluation)	The collected interview data has been used to determine the important factors for policymaking and it also has been regarded as a basis to weight each indicator	Academic research	14
Subsidisation of public transport fares for the young: An impact evaluation T analysis for the Madrid Metropolitan Area (Arranz et al., 2019)	Transport Policy	To analyse the distributive impacts of the policy intervention for public transport according to Madrid households' travel pass demand	Madrid, Spain	Ex-post assessment (policy evaluation)	Data acquired from the Spanish Households Budget Survey (HBS) from 2014 and 2016 were applied to measure the effect of the Subsidisation of public transport fares for the young	Academic research	15
Environmental impact assessment in urban transport planning: Exploring process-related barriers in Spanish practice (Soria-Lara et al., 2016)	Environmental Impact Assessment Review	Environmental Impact Assessment (EIA) in Urban Transport Planning	Granada and Seville, Spain	Ex-post assessment (policy evaluation)	The data help to get in-depth views from respondents and further to be used in analyzing the barriers of EIA process	Academic research	16

Monitoring the first dockless bike sharing system in Greece: Understanding user perceptions, usage patterns and adoption barriers (Bakogiannis et al., 2019)	Research in Transportation Business & Management	To assess the efficiency of the Dockless Bike Sharing System (DBSS) *(combined with statistical data)	Rethymno, Grace	Ex-post assessment (policy evaluation)	Survey data from 534 DBSS users was used to understand the use and effectiveness if the DBSS in Rethymno	Academic research	17
Policy tools for sustainable transport in three cities of the Americas: Seattle, Montreal and Curitiba (Mercier et al., 2016)	Transport policy	To explore which policy measures and styles of regulation the three cities have been using to implement their transport systems and how are the effects *(combined with statistical data)	Seattle, Montreal and Curitiba, the US	Ex-post assessment (policy evaluation)	The interviews conducted with people who are responsible for the design, decision making and implementation of the urban mobility instruments provide insights on the effectiveness of these policy measures	Academic research	18
Short-term planning and policy interventions to promote cycling in urban centers: Findings from a commute mode choice analysis in Barcelona, Spain (Braun et al., 2016)	Transportation Research Part A	To answer the question of how policy interventions are related to cycling and provides an indication of which strategies could have the strongest influence *(combined with statistical data)	Barcelona, Spain	Ex-post assessment (policy evaluation)	The data drawn from a travel survey conducted in 2011-2012 and from geographic information system were applied to evaluate the effectiveness of the policy interventions towards the bicycle use	Academic research	19
Providing quantified evidence to policy makers for promoting bike- sharing in heavily air-polluted cities: A mode choice model and policy simulation for Taiyuan-China (Li and Kamargianni, 2018)	Transportation Research Part A	To explore the effectiveness of different policy measures aiming at increasing bike-sharing ridership *(combined with GIS data)	Taiyuan, China	Ex-post assessment (policy evaluation)	Questionnaires data acquired from the citizens combined with census data applied to investigate residents' opinions towards the implemented bike-sharing policy instrument	Academic research	20
Analyzing users' attitudes and behavior of free-floating bike sharing: an investigating of Nanjing (Chen et al., 2019)	Transportation Research Procedia	To help urban mobility policymakers advance the bike sharing regulations and to provide recommendations for enterprises improving the service	Nanjing, China	Ex-post assessment (policy evaluation)	The questionnaire data were analyzed to assess the use of free-floating bike sharing by citizens in Nanjing	Academic research	21
An experimental customer satisfaction index to evaluate the performance of city logistics services (Paddeu et al., 2017)	Transport	New Customer Satisfaction Index is proposed to evaluate Urban Freight Consolidation Centre service quality for improving the service perceived as the worst	Bristol and Bath, the UK	Ex-post assessment (policy evaluation)	The experimental data collected within the CIVITAS RENAIS- SANCE Project has been used for the index to provide information to the decision makers for better understanding the service provided and for developing sustainable measures.	Academic research	22
Policy transfer and the introduction of road pricing in Valletta, Malta (Attard and Enoch, 2011)	Transport policy	To present a case study of road pricing in Valletta and the role played by policy transfer in its introduction *(combined with statistical data)	Valletta, Malta	Ex-post assessment (policy evaluation)	Data gathered from literatures, interviews and observations involved in the policy development were used to analysis the policy transfer in Valletta	Academic research	23

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The effects of driving restrictions on travel behavior evidence from Beijing (Gu et al., 2017)	Journal of Urban Economics	To evaluate the impacts of driving restrictions on individual travel behavior in Beijing	Beijing, China	Ex-post assessment (policy evaluation)	Using the 2010 Beijing Household Travel Survey data to explore what are the effects caused by the driving restriction policy measure	Academic research	24
Sustainable mobility: Policy design and implementation in three T Norwegian cities (Bardal et al., 2020)	Transportation Research Part D	To assess the sustainable mobility policies implementations in three cities in Norway for understanding the barriers and success factors *(combined with statistical data)	Bodø, Trondheim and Bergen, Norway	Ex-post assessment (policy evaluation)	Data obtained by interviewing key informants and relevant documents were applied to understand how different types of "transportation policy packages" promoting sustainable mobility	Academic research	25
Receivers' response to new urban freight policies (Domínguez et al. 2012)	15th meeting of the EURO Working Group on Transportation	To analyze the different effects of the receivers in response to the new urban freight policy	Barcelona and Santander, Spain	Ex-post assessment (policy evaluation)	A stated preference survey has been used to investigate how each variable of these policies influence the receiver's behaviors	Academic research	26
Does license plate rule induce low-carbon choices in residents' daily travels: Motivation and impacts (Zhang et al., 2020)	Renewable and Sustainable Energy Reviews	To assess the impacts of license plate rule on commuters' travel choices, especially towards low-carbon travels	Beijing, China	Ex-post assessment (policy evaluation)	Survey data is applied to understand personal behavior when facing traffic restriction policies and to explore whether the vehicle policy of license plate rule has a significant impact on the low-carbon choice of residents' daily travel	Academic research	27
Dataset on commuting patterns and mode-switching behavior under prospective policy scenarios for public transport (Tosa et al., 2019)	Data in brief	To assess the willingness of travelers to switch to a more sustainable transportation through an alternative public transport ticketing policy	Cluj Metropolitan Area, Romania	Ex-post assessment (policy evaluation)	Data were collected by computer-assisted telephonic interview of respondents' day-by-day travel patterns and perceptions about their willingness to travel transitions	Academic research	28
Urban residents' response to and evaluation of low-carbon travel policies: Evidence from a survey of five eastern cities in China (Geng et al., 2018)	Journal of Environmental Management	To assess the effectiveness of the implemented policies from the perspective of public opinion	Five eastern cities from China	Ex-post assessment (policy evaluation)	Survey data from 5 cities of 1977 urban residents were applied to understand public opinions towards the low-carbon travel policies	Academic research	29
Do car restriction policies effectively promote the development of public transport? (Zhang et al., 2019)	World Development	To evaluate the effect of car restriction policy (CRP) on the public transportation development *(combined with statistical data)	Beijing, Guiyang, Lanzhou, Chengdu, Guangzhou and Shenzhen, China	Ex-post assessment (policy evaluation)	The public traffic passenger data obtained from China City Statistic Year Book (1986-2016) of six cities were used to compare the different performances influenced by the implemented CRP policies	Academic research	30

Influences on urban freight transport policy choice by local authorities (Akgün et al., 2019)	Transport Policy	To explore how local authorities, seek and select urban freight transport policies	11 cities, England, Sweden, Scotland	Ex-post assessment (policy evaluation)	The data obtained from interviews and relevant documents were applied to establish the differences between the cities in terms of their actual policy choices	Academic research	31
Climate change and air pollution: the connection between traffic intervention policies and public acceptance in a local context (Weiand et al., 2019)	Environmental Research Letters	To reveal travelers' attitudes on 'hard' policy instrument and to obtain insight for effectively mobility policy design	Potsdam, Germany	Ex-post assessment (policy evaluation)	3553 participants responded to a survey conducted prior to the implementation of the traffic measure	Academic research	32
How does the spatial context shape conditions for car dependency? An analysis of the differences between and within regions in the Netherlands (Wiersma et al., 2016)	Journal of Transport and Land Use	Understanding Spatial Context Shape Conditions for Car Dependency *(combined with GIS data)	Regional scale, the Netherlands	Policy formulation	The GIS data provides basic information of average distance from residential homes to local amenities of Dutch cities, which helps to measure the degree of car dependency; the statistical data offers regional travel times, used to calculate the congestion level	Academic research	33
Smart city as a tool for sustainable mobility and transport decarbonization (Zawieska and Pieriegud, 2018)	Transport Policy	To explore the potential contribution of smart city instruments and their impact on future transport-related greenhouse gas emissions (GHG)	Warsaw, Poland	Ex-ante assessment (policy formulation)	The data mostly obtained from Polish and international institutions were applied in the model to predict the potential impact on GHG levels caused by the transport policies	Academic research	34
Evaluation of sustainable policy in urban transportation using system dynamics and world cities data: A case study in Isfahan (Haghshenas et al., 2015)	Cities	Assessment of Sustainable Urban Transportation Policy: A case study in Isfahan	Isfahan, Iran	Ex-ante assessment (decision making)	These world databank data were applied to develop a model that could be applied for policymakers to identify the best policy regarding sustainability	Academic research	35
An integrated model of Park-And-Ride facilities for sustainable urban mobility (Ortega et al., 2020)	Sustainability	To help selecting the most user preference P&R mode	Cuenca, Ecuador	Decision making	The data provided by the SUMP are used in the mathematical model to calculate potential demand for P&R facility.	Academic research	36
Sustainability of urban mobility projects in the Curitiba metropolitan region (De Oliveira Cavalcanti et al., 2017)	Land Use Policy	Sustainability Assessment of Urban Mobility Projects in Curitiba Metropolitan Region	Curitiba metropolitan region, Brazil	Ex-post assessment (policy evaluation)	The data was extracted from various documents that has been used to evaluate the sustainability of the urban mobility projects	Policy practice	37
The way to sustainable mobility. A comparative analysis of sustainable mobility plans in Spain (Mozos-Blanco et al., 2018)	Transport Policy	Comparative Analysis of Sustainable Mobility Plans in Spain	38 city members of the Spanish Network of Smart Cities	Ex-post assessment (policy evaluation)	These data were counted in the analysis of 38 cities' SUMPs documents in Spain based on different criteria in assessment framework	Academic research	38

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Smart urban planning: evaluating urban logistics performance of innovative solutions and sustainable policies in the Venice Lagoon—the results of a case study (Mazzarino and Rubini, 2019)	Sustainability	To evaluate the effectiveness of a mixed passenger and freight transport system *(combined with survey data)	Venice Lagoon, Italy	Ex-post assessment (policy evaluation)	Statistical data, observation surveys and interviews data were applied in this study to evaluate and compare scenarios, consisting of the reduction of spare capacity of public transport	Academic research	39
Policy lessons from the flexible transport service pilot Kutsuplus in the Helsinki Capital Region (Jokinen et al., 2019)	Transport policy	To get the lessons from the flexible transport service pilot policy and planning *(combined with survey data)	Helsinki, Denmark	Ex-post assessment (policy evaluation)	Data acquired from documents and experts' interviews were used to understand the success or failure of the pilot project	Academic research	40
Did cycling policy and programs advance cycling in the city of Zagreb? (Pilko et al., 2016)	4th International Conference on Road and Rail Infrastructure	To evaluate the effects of the implemented policy interventions on promoting cycling	Zagreb, Croatia	Ex-post assessment (policy evaluation)	The data from documents and city office are applied to analyze the current state of cycling traffic in Zagreb	Academic research	41
An empirical evaluation of the impact of three urban transportation policies on transit use (de Grange et al., 2012)	Transport Policy	Assessing the impact of three urban transport policies-metro or rail transit network expansion, public transit subsidy, and automobile regulation	41 world cities	Ex-post assessment (policy evaluation)	The statistical data collected from 41 world cities has been used to evaluate the impacts of the three urban mobility policies, which is aiming to provide insightful information for policymakers developing more sustainable transport polices	Academic research	42
An assessment framework to support collective decision making on urban freight transport (Golini et al., 2018)	Transport	Developing a framework for decision makers to facilitate formulating policy options and early engaging stakeholders in urban freight transport	Bergamo, Italy; Luxembourg city, Luxembourg	Policy formulation	The developed GIS tool used in the cases helps to identify and compare different urban mobility features of a city and also helps to engage different stakeholders in early stage the of policy solutions development.	Academic research	43
Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment (Gutiérrez et al., 2010)	Journal of Transport Geography	Assessing Spatial Spillovers of Transport Infrastructure Investment *(combined with statistical data)	Regional scale, Spain	Ex-ante assessment (policy formulation)	The GIS data has been analyzed by ArcGIS and employed to calculate the origin-destination travel time matrices and further to do scenario analysis	Academic research	44
A GIS-based decision support system for planning urban transportation policies (Arampatzis et al., 2004)	European Journal of Operational Research	Evaluating urban mobility policies by using the computer model to estimates road traffic and assesses the implications.	The Greater Athens Area, Greece	Decision making support tool development	GIS database has been used in a decision support system to evaluate different traffic regulation measures and to see which scenario would be the most efficient	Academic research	45

Assessing the implications of the recent community opening policy on the street centrality in China: A GIS-based method and case study (Yu, 2017)	Applied Geography	To evaluate the potential changes caused by community opening policy on the street and to give insights that would affect the decision making to urban managers	Shenzhen, China	Ex-ante assessment (decision making)	Building footprint data run in the model was applied to understand the structural properties of road networks and examine the impacts of community street opening policy	Academic research	46
A GIS-based decision support system for measuring the territorial impact of transport infrastructures (Ortega et al., 2014)	Expert Systems with Applications	Assessing the Territorial Effects of Transport Infrastructures via a GIS-based Decision Support System	Spain	Ex-ante assessment (decision making)	The whole GIS-based decision support system is consisted of four different modules. Each of them has their own database that was used for calculating and assessing the territorial effects of transport plans	Academic research	47
Encapsulating urban traffic rhythms into road networks (Wang et al., 2014)	Scientific Reports	Developing a Model based on Target Road Clusters for Urban Mobility Efficiency Improvement *(combined with mobile phone data)	San Francisco Bay area and the Boston area, the United States	Policy implementation	The data was used to verify the developed model and to explore the optimized regulation methods to improve mobility efficiency of two American cities	Academic research	48
Evaluation of the impact of Bus Rapid Transit on air pollution in Mexico City (Bel and Holst, 2018)	Transport Policy	To quantitatively evaluate the short-term impact on air quality of the implementation of a BRT network in Mexico City *(combined with air quality monitoring data)	Mexico City, Mexico	Ex-post assessment (policy evaluation)	Data acquired from automatic air quality monitoring stations is used to compare the differences between before the new BRT network ran and after	Academic research	49
How does ‘park and ride’ perform? An evaluation using longitudinal data (Zhao et al., 2019)	Transport Policy	To assess the effect of various factors on the utilization rate of ‘park and ride’ lots *(combined with statistical and survey data)	King County, Washington, the US	Ex-post assessment (policy evaluation)	Various types of data (GIS, statistical, survey data) have been used in the evaluation framework to assess the use of ‘park and ride’ lots	Academic research	50
Assessing policy measures for the stimulation of intermodal transport: a GIS-based policy analysis (Macharis and Pekin, 2009)	Journal of Transport Geography	Intermodal Transport Policy Assessment based on GIS Data	Belgium	Ex-post assessment (policy evaluation)	Road networks, inland waterways, rail networks and terminal haulage networks data have been used to build a GIS-based model for assessing Belgian intermodal transport policies	Academic research	51
Bike route choice modeling using GPS data without choice sets of paths (Zimmermann et al. 2017)	Transportation Research Part C	Building route choice models to provide insights about transport regulations for stimulating cycling	Eugene, the US	Agenda setting	GPS observations data reveals cyclists’ travel preferences and quantifies trade-offs between different network attributes	Academic research	52
Commuter cycling policy in Singapore: a farecard data analytics-based approach (Kumar et al., 2016)	Annals of Operations Research	To provide insights in promoting cycling in Singapore for mobility policymaking	Singapore	Agenda setting	Farecard data is used to estimate the potential of cycling commuter and further to support data-driven mobility policymaking	Academic research	53

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Citywide traffic volume estimation using trajectory data (Zhan et al., 2016)	IEEE Transactions on Knowledge and Data Engineering	Estimating Urban Traffic Volume	Beijing, China	Policy formulation	Traffic flow data can help to build the functional relationship between speed and flow, then a small set of ground truth volume data was added into the constructed prediction model	Academic research	54
Analysis and assessment of the electrification of urban road transport based on real-life mobility data (De Gennaro et al., 2013)	2014, 2013 World Electric Vehicle Symposium and Exhibition	Assessment of the Electrification of Urban Road Transport based on real-life mobility data *(combined with GIS data)	Modena and Firenze, Italy	Policy formulation	16,000 vehicles and 2.6 million trips data recorded by GPS were used to analyze urban mobility demand and assess the ability of real electric vehicles to meet this demand	Academic research	55
Transport efficiency of off-peak urban goods deliveries: A Stockholm pilot study (Fu and Jenelius, 2018)	Case Studies on Transport Policy	To assess the impacts of the Stockholm off- peak deliveries pilot	Stockholm, Sweden	Ex-ante assessment (decision making)	GPS data from the receivers on the trucks are used to monitor the behaviors and to evaluate the effects of the trucks	Academic research	56
Assessment of the potential of electric vehicles and charging strategies to meet urban mobility requirements (Paffumi et al., 2015)	Transportmetric-a A: Transport Science	To examine the potential of battery electric vehicles (BEVs) to meet the mobility needs in urban areas	Modena and Firenze, Italy	Ex-ante assessment (decision making)	28,000 vehicles, 4.5 million trips and 36 million kilometers data were processed to realize whether various types of BEVs and recharging policies could meet users' needs	Academic research	57
Mobility and active ageing in suburban environments: Findings from in-depth interviews and person-based GPS tracking (Zeitler et al., 2012)	Current gerontology and geriatrics research	Ex-ante Assessment of Mobility Options for Ageing People *(combined with survey data)	Brisbane, Australia	Ex-ante assessment (decision making)	GPS tracking data was used to create transport maps by analyzing participants' daily travel dairies; interviews and questionnaires were used to design travel options based on the respondents' needs	Academic research	58
Who, where, why and when? Using smart card and social media data to understand urban mobility (Yang et al., 2019b)	ISPRS International Journal of Geo-Information	Understanding urban mobility behavior based on smart card and social media data	Shenzhen, China	Decision making support tool development	The smart card data and social media data has been processed by mathematic model for which to show Shenzhen's travelers weekly mobility behaviors with corresponding social activities	Academic research	59
Big data for supporting low-carbon road transport policies in Europe: Applications, challenges and opportunities (De Gennaro et al., 2016)	Big Data Research	Developing models to explore potential use of big data for mobility policy assessment and governance *(combined with GIS data)	Modena and Firenze, Italy	Decision making support tool development	28,000 vehicles' trajectory data monitored over one month have been used to examine the developed models and establish its own algorithms	Academic research	60

Improving a priori demand estimates transport models using mobile phone data: a Rotterdam-region case (Wismans et al., 2018)	Journal of Urban Technology	Mobile Phone Data used for upgrading Transport Models to support decision making *(combined with survey data)	Rotterdam, the Netherlands	Decision making support tool development	Origin-Destination (OD) matrix is extracted from Calling Detail Record (CDR), which is used to compare with OD obtained from survey data to see the differences between these two types of data	Academic research	61
Activity-based human mobility patterns inferred from mobile phone data: A case study of Singapore (Jiang et al., 2017)	IEEE Transactions on Big Data	Analysis of human mobility behaviors based on CDR data for sustainable urban mobility planning *(combined with survey data)	Singapore	Decision making support tool development	The raw mobile phone data has been analyzed and filtered in different models combined with the data gained from census and geographical datasets, which are used to translate the inner knowledge of data for sustainable urban mobility planning	Academic research	62
Using Google Analytics to evaluate the usability of e-commerce sites (Hasan et al., 2013)	International Conference on Human Centered Design	Understanding urban mobility patterns based on social media data	New York, the United States	Decision making support tool development	The original datasets were collected from three different American cities to make comparison of the sizes of these datasets and then the largest one was selected as the research object	Academic research	63
Experiences in the modelling of traffic policy measures for ambient air quality management in Lithuania (Kliucininkas et al., 2008)	International Journal of Environment and Pollution	To estimate the air pollution emitted by motor vehicles for traffic policy measures development in Kaunas	Kaunas, Lithuania	Decision making support tool development	The real-time traffic data has been used to predict the air emissions caused by the vehicles	Academic research	64
Comparison of different scenarios of users' distribution among charging infrastructure in an urban area (Andrenacci et al., 2019)	2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive	To analysis the supply and demand of fast recharging stations in urban areas	Rome, Italy	Decision making support tool development	Floating car data contains information of speed, travel time and directions were continuously detected by devices on board the cars, which helps to obtain information on the journey	Academic research	65
Statistical modeling of the early-stage impact of a new traffic policy in Milan, Italy (Maranzano et al., 2020)	International Journal of Environmental Research and Public Health	To assess the early-stage impact of multi-year progressive policy based on an extended limited traffic zone on vehicle-generated pollutants *(combined with statistical data and GIS data)	Milan, Italy	Implementation	Traffic data used in the statistical model for time series policy intervention analysis	Academic research	66
Inferring dynamic origin-destination flows by transport mode using mobile phone data (Bachir et al., 2019)	Transportation Research Part C	To develop an assessment tool for on urban mobility policy evaluations based on mobile phone data	Paris, France	Tool development (policy evaluation)	360 million trajectories for more than 2 million devices from the Greater Paris region has been applied to understand the traveler behaviors	Academic research	67

Changes in Service and Associated Ridership Impacts near a New Light Rail Transit Line (Lee et al., 2017)	Sustainability	To evaluate the use of transit service and to understand the causes for the reduction of transit ridership	Los Angeles, the US	Ex-post assessment (policy evaluation)	Aggregate data has been used to track changes in ridership before and after the opening of new light rail transit services	Academic research	68
Impacts of vehicle restrictions on urban transport flows: The case of Santiago, Chile (de Grange and Troncoso, 2011)	Transport policy	To evaluate the effects of vehicle restrictions on private and public transport passenger flows in Santiago, Chile	Santiago, Chile	Ex-post assessment (policy evaluation)	Using traffic flow data to estimate the effects of the implementation of two car restrictions measures	Academic research	69
Impacts of Public Transportation Fare Reduction Policy on Urban Public Transport Sharing Rate Based on Big Data Analysis (Zhang et al., 2018)	2018 the 3rd IEEE International Conference on Cloud Computing and Big Data Analysis	To examine how the change of bus fare policy affects the bus travel in Beijing	Beijing, China	Ex-post assessment (policy evaluation)	Historical traffic data was used to see the differences before the bus fare adjustments and after	Academic research	70
Are HOV/eco-lanes a sustainable option to reducing emissions in a medium-sized European city? (Fontes et al., 2014)	Transportation Research Part A	To assess the application and effects regarding emissions and traffic performance of HOV/eco-lanes in three different types of roads	Aveiro, Portugal	Ex-post assessment (policy evaluation)	Traffic volumes, time, and average speed was used in the developed model to simulate the inclusion of eco-lanes in an urban area.	Academic research	71
Analyzing passenger and freight vehicle movements from automatic-Number plate recognition camera data (Hadavi et al., 2020)	European Transport Research Review	Providing evidence-based knowledge into transport flows to better recognize the impacts of policymaking	Mechelen-Willebroek district in Belgium	Ex-post assessment (policy evaluation)	Data generated by Automatic Number Plate Recognition (ANPR) cameras combined with GPS data from Heavy-Goods Vehicles were applied to evaluate the effect of car-reduced zone policy measure in the region	Academic research	72
The impact of truck access restriction on toll road traffic performance (Yusuf and Tambun, 2019)	MATEC Web of Conferences	To construct a traffic stream model and analyze the performance of Jakarta Intra Urban Toll (JIUT) due to the truck restriction regulation	Jakarta, Indonesia	Ex-post assessment (policy evaluation)	24-hour observation in a certain segment of JIUT way were obtained to develop a traffic flow model to show the effect of truck restriction	Academic research	73
Sustainability assessment of retail logistics solutions using external costs analysis: a case-study for the city of Antwerp (Papoutsis et al., 2018)	European Transport Research Review	To answer the question of "what are the effects of retail logistics solutions on total costs and sustainability performance? *(combined with statistical and GIS data)	Antwerp, Belgium	Ex-post assessment (policy evaluation)	Different types of data (traffic, statistical, and GIS data) were used in the developed sustainability assessment framework to evaluate the performance of different policy measures	Academic research	74

Appendix 8.4.1. Interview outline

Introduction
At first glance: more/big data → better sustainability (policy) assessment
But at second glance:

- Is the data processed into meaningful indicators? [is there capacity to do this?]
- Are the indicators useful for the policymakers and policy discourse?
    - Is the capacity to align the definition of indicators with the policymakers?
    - Interpretation (e.g. weighting) of indicators is not always straightforward. Are the indicators interpreted in a stakeholder participatory/reflexive way?

We seek to learn from successful and failing, recent data-driven projects.

Questions (1-4 more for 'data analysts; 5-6 more for policymakers)

7. [check] we have understood that you ran the same program with Maastricht called 'BeterBenutten Program' in the period of 2012-2018. Is that correct?
8. [check] we understood that, in terms of monitoring & analysis, there were yearly report, effect measurements, that explicitly how the different measures (how many measures you have implemented in total?) affect the key indicator 'avoided car trips in rush hour'. Is that correct?
9. How many full-time equivalent was roughly working on collecting and analyzing the data?
10. If you would have had more capacity for analysis, do you think more useful analysis could have been done? Which?
11. How were the monthly and yearly reports generated from data used? What was their effects?
    a. [only tracking progress of project targets, or also adapting the measures over time=steering]
12. [How] could the reports have been further/more exhaustively?[what would you have needed for this?]

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Appendix 8.4.2. List of the Documents Analyzed

Type of Document	Document Title (English translation)	Author	URL to access the document
Projects' Results Report	Research into commuter travel behavior Maastricht – 2012 clustered effect measurement	MuConsult B.V. (2012)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2013 clustered effect measurement	MuConsult B.V. (2013)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2014 clustered effect measurement	MuConsult B.V. (2014)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2014 clustered effect measurement	MuConsult B.V. (2015)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2015 clustered effect measurement	MuConsult B.V. (2015)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2016 clustered effect measurement	MuConsult B.V. (2017)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2017 clustered effect measurement	MuConsult B.V. (2017)	Municipal Private Document
	Research into commuter travel behavior Maastricht – 2018 clustered effect measurement	MuConsult B.V. (2018)	Municipal Private Document
	GSM (Global System for Mobile Communications) Maastricht Monthly Report	View. DAT (2018)	Municipal Private Document
	Groningen Mobility Impact Measurement- final report	MuConsult B.V. (2019)	Municipal Private Document
Reginal Report	Maastricht Annual Plan 2019-Smart and Sustainable Mobility	Maastricht Bereikbaar (2018)	https://www.zuidlimburgbereikbaar.nl/media/1966/sg55003ajaarplan2019.pdf
	Groningen Residents Work-Home Traffic Analysis	Groningen Bereikbaar (2019)	Municipal Private Document
	Organizational scheme of Groningen Bereikbaar	Groningen Bereikbaar (2020)	Municipal Private Document
Governmental Report	The Dutch Public Service- Organization and functioning of the government in the Netherlands, the position of civil servants and the main developments	The Minister of the Interior and Kingdom Relations (2016)	file:///Users/mayday/Downloads/the-dutch-public-service%20(2).pdf
	The Dutch political system in a nutshell	Netherlands Institute for Multiparty Democracy (2008)	https://nimd.org/wp-content/uploads/2015/02/Dutch-Political-System.pdf
European Report	WHITE PAPER, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system	European Commission (2011)	https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52011DC0144
	CH4LLENGE-Addressing Key Challenges of Sustainable Urban Mobility Planning	European Commission (2016)	https://www.polisnetwork.morrischapman.com/uploads/Modules/PublicDocuments/ch4llenge_project_gent-workshop_programme_finalv3b.pdf
Press Release	Maastricht	Netherlands Tourism (2020)	http://www.netherlands-tourism.com/maastricht/

Population Development of the Netherlands	Statistics Netherlands (2020)	https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37230ned/table?ts=1582726286753
Maastricht Transport Networks	Arriva (2017)	https://www.arriva.nl/lijnennetkaarten.htm

Appendix 8.4.3 List of the Codes

Code groups:

BeterBenutten Program (BB)
Members:
● Basic information about BB ● BB program use in the policymaking process ● BB program central indicator selection ● changes of BB program after 2017 ● difficulties and challenges with BB program ● extra expectation from this project ● motivations to start BB ● number of the survey respondents ● successful factor ● use of evaluation reports

Policymaking
Members:
● data used in long-term policymaking ● data used in short-term policymaking ● Monitoring and evaluation in municipality ● policy makers' role in BB program

Big Data
Members:
● big data compare with survey data from data user's opinion ● big data used ● Consultants companies of big data analysis ● Initiated motivation of using big data ● new plan of big data use in municipality ● traffic model

Different Actors in data use
Members:
● communication group ● aldermen ● MuConsult ● OV panel ● project leader ● society ● steering group ● the monitoring and evaluation group ● Consultants companies of big data analysis ● mobility brookers group ● Program Manager ● Research group

Limitations of data use
Members:
● budgets ● capacity ● choose important indicators ● conflictions among different stakeholders ● consume much time ● continuity of certain data ● interpretation ● Lack of cooperation among cities ● Lack of information ● lack of trust ● less significance ● technical issue ● user friendliness ● valuable data selection

Appendix 8.4.4 Measures for BeterBenutten Program in Maastricht (2012-2018)

Periods / Package of Measures	BB1	BBV
General promotions	Come on! Choose the smart campaign The Game (Komop! Kies Slim)[a] Smart Parking[b] Website Maastricht Bereikbaar News flash Maastricht Bereikbaar (e-mail update) Travel advice on Maastricht Bereikbaar website[c]	Website Maastricht Bereikbaar The Smart map on Maastricht Bereikbaar website[o] Travel advice on the Maastricht Bereikbaar website[c] News flash Maastricht Bereikbaar Facebook Maastricht Bereikbaar Twitter Maastricht Bereikbaar
Bicycle/E-bike	Purchase an E-bike with discount Purchase a bicycle with discount Try an E-bike[d] Burn Fat Not Fuel[e] Burn Fat Not Fuel app for smartphone Special event parking spots for bicycles	Pick up E-bike at work location Pick up E-bike at city centre Purchase an E-bike with discount Purchase a bicycle with discount South Limburg on the Move[p] Cycle & Win promotion of storage facilities Next bike yearly subscription for €60[q]
Public transport	Come on! Take public transport[f] Welcoming offer for public transport[g] Season ticket Veolia with discount Autumn promotion 2014 for public transport[h] Spring promotion 2015 for public transport[i] The Maastricht Bereikbaar €2 train ticket[j] Bus line 50/Bus line 150[k] €1 bus ticket for P+R Maastricht Noord-City Center round-trip[l]	Come on! Take public transport[f] Welcoming offer for public transport[g] Season ticket Veolia with discount South Limburg on the Move[r] The Maastricht Bereikbaar €2 train ticket[j] The Maastricht Bereikbaar €2 bus-ticket (offered during the closure of the Noorderbrug bridge in Maastricht) €20 unlimited travel by bus (offered during the closure of Noorderbrug bridge in Maastricht) Better tour pass during the closure of Noorderbrug P+R Maastricht Noord–centre, € 2 bus ticket day return[s] P+R Maastricht Noord–centre, season bus ticket €20p.m.
Parking		South Limburg on the Move[r] P+R Maastricht Noord–centre, € 2 bus ticket day return[s] P+R Maastricht Noord–centre, season bus ticket €20p.m. Reserve parking spaces on Maastricht Bereikbaar website This is my P+R day![t]
Work smart	Chair sharing[m] Smart work pilot[n]	Smart work pilot[o]

Note: [a]The Game (Komop! Kies Slim): a short game on the website komop.nu designed to get an idea of the advantages of traveling 'smart'; [b]Smart parking: parking your car in Maastricht using the 'Slim Parkeren' app; [c]Travel advice on Maastricht Bereikbaar website: this travel advice compares the costs and travel time for a ride with the bicycle, E-bike, public transport or car.; [d]Try an E-bike: several promotions such as one week free E-bike trial; [e]Burn Fat Not Fuel: a reward of 10 cents per kilometer by bicycle. With the associated smartphone app, you can keep track of your bicycle-rides and more; [f]Come on! Take public transport: four weeks of free public transport use for commute, to experience whether public transport is a viable alternative for the car; [g]Welcoming offer for public transport: a deal for employees who are switching from car to public transport to get (another) 4 weeks of free public transport; [h]Autumn promotion 2014 for public transport: a reward for yourself or a charity if you can persuade your colleagues to travel to work using public transport; [i]Spring promotion 2015 for public transport: a temporary reward for people who travelled to work by public transport. [j]Maastricht-Bereikbaar €2 train ticket: affordable retour ticket on the train between Kerkrade and Maastricht; [k]Bus line 50/bus line 150: Bus line50 Gulpen–Maastricht central/150 Randwijck-Maastricht Station(from April 2012); [l]€1 bus ticket for P+R Maastricht Noord-City Center round-trip: during the weekends there's a shuttle bus to the city centre, for €1 you can buy a round-trip ticket which is valid for 5 people; [m]Chair sharing: working one or more days per week on a workstation other than your regular place; [n]Smart work pilot: a pilot at your employer to encourage you to start working elsewhere or avoiding the rush hour at least one day on the week; [o]On the Smart Map on the website of Maastricht Bereikbaar: you can find current information about construction works, traffic updates, the availability of parking spaces for car and bike; [p]South Limburg on the move(starts in June 2016): you can set a goal for yourself to use the bicycle more often and monitor your progress with the TimesUpp smartphone app. You save up credits per ride, which you can later trade for cash or presents; [q]Next bike yearly subscription for €60: this is a sharing system for renting bicycles with a mobile app. The Next bike can be found on different locations in the city, including the Maastricht Central Station, Maastricht Noord and the city central of Maastricht; [r]South Limburg on the Move (in Beweging): you can set a goal for yourself to use the public transport more often and monitor your progress with the TimesUpp smartphone app. You save up credits per ride, which you can later trade for cash or presents; [s]P+R Maastricht Noord–centre, € 2 bus ticket day return: during the week (07:00-19:00) and on weekends (10:00-19:00), you can travel by shuttle bus for €1 per person return to the Market; [t]This is my P+R day!: 4 weeks free usage of P+R location

Appendix 8.4.5 The incentives and limitations of data use for urban mobility policymaking in Maastricht and Groningen with respective coding quotations

a. Incentives

Policy Cycle	Codes	#Interview	Quotations
Long-term Policy Cycle	Sustainability	4 Maastricht	*'Nowadays the sustainability is a new issue, we have to combine information about the effects of mobility also on climate change, CO_2 pollution, another issue is what to do with the health of people. So, I think that's the next step in the evaluation we have to make and data we have to collect'*
		8 Groningen	*'Our goals will be guidance to sustainability and our actions will continue and will even be identified. Now it becomes one of our main goal'*
	Assessment of Changes	4 Maastricht	*'There is big needs to evaluate every year to learn about the changes in the area of Maastricht'*
	Covenanting with Companies	4 Maastricht	*'One issue is very important to have also data from other areas, even learn about international projects or international data, so we can collect the right data from other areas which is interesting for us'*
Short-term Policy Cycle	Covenanting with Companies	1 Maastricht	*'I would love to see a bit more about the policy from the employers, what is the effect the employers have on the mobility, and what is the effect of the policy making on employers'*
		6 Groningen	*'I think with all the data we collected last year, we can make the next step to help individual companies and to make their process within the company better'*
	Deeper Understanding	7 Groningen	*'We would like to have a deeper understanding between the predictions beforehand and the measurements afterwards and what explains the differences'*
	Open Data Access	7 Groningen	*'The data we have is a lot. I think the next step is to make it open, to create an online dashboard for companies and people, to give them more insights and to help them make changes like changing shopping time, travel a little bit smarter'*

b. Limitations

Policy Cycle	Codes	#Interview	Quotations
Both	Data Selection	4 Maastricht	*'We have lots of data, but we have to select what data is relevant for our policy-making, that is a new issue for us, which data is relevant to collect and which data helps us to evaluate our policy and which data is necessary to think about the future'*
		7 Groningen	*'It is huge amount of data, where do we start? This is the question you have to ask yourself constantly'*
	Lack of Capacity	4 Maastricht	*'We have data, but we don't have capacity to really analyze the data'*
		7 Groningen	*'It's huge amount of data which is going around there. And it is thrown away each minute. Nobody is collecting'*
		9 Groningen	*'We don't have enough people to understand these data'*
Long-term Cycle	Conflicted Interests among Different Stakeholders	5 Maastricht	*'The policymakers are interested in data used for evaluation but the politics want to use for new projects, new goals, because just looking backwards and check if the previous government has achieved their goals is not interesting for them*

	Time Consuming	5 Maastricht	*'It will cost a lot of time to really understand data, and to really use it'*
		9 Groningen	*'When the early development of plans, we use the data, we present data, and always a lot of discussion about is this data good, does it fit out ambitions. It actually gives more discussion'*
	Less Significance	8 Groningen	*'My experience is of course data is important, technical knowledge is important, but the political and the social aspects are maybe even more important than what you might conclude just on the basis of data'*
		8 Groningen	*'You always have to combine, data on one side, commonsense in the middle and politics on the other side. So, data helps, but it's not the whole reality'*
		9 Groningen	*'The decision-making processes is of course built on these data but it is also based on political issues or the conversation we have with the people living in the city'*
		10 Groningen	*'The long-term goals that I started with where we do with less data, because we use our commonsense for insights'*
	Lack of Trust	9 Groningen	*'There are always a lot of people doubt the data, and they use these doubts to express their own ambitions on other issues'*
	Continuity of Data	10 Groningen	*'I think the data we get is enough and I think we have more problems that always the continuity of certain data'*
Short-term Cycle	Technical Issue	3 Maastricht	*'One major problem with this big data is technical problem'* *'It lacks of user friendliness that convinces me not to continue the collaboration with the company provided this model'* *'The problem was that the ViewDAT tool wasn't easy actually, there was so much data presented so that it was too complicated for a normal person to log in and hard to find where should I start, what do I get out of it, what does it bring me'*

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Appendix 8.5.1 Basic information about the responses and respondents (the cities shown in red were excluded from the analysis)

Number	City	Country	Population	Position(s)	GIS model use (year)	Response date	Duration (min)
1	Maastricht	the Netherlands	121,565	Advisor	No	14/09/2021	27,23
2	Maastricht	the Netherlands	121,565	Policymaker	Since before 2010	16/09/2021	16,33
3	Maastricht	the Netherlands	121,565	Policymaker	Since 2012-2014	16/09/2021	10,13
4	Maastricht	the Netherlands	121,565	Project manager	No	17/09/2021	9,03
5	Maastricht	the Netherlands	121,565	Policymaker; Advisor	No	16/09/2021	16,55
6	Emmen	the Netherlands	107,113	Advisor	Since 2012-2014	15/09/2021	12,23
7	Emmen	the Netherlands	107,113	Advisor	No	15/09/2021	6,40
8	Rotterdam	the Netherlands	651,157	Advisor	No	16/09/2021	6,32
9	Rotterdam	the Netherlands	651,157	Researcher	No	16/09/2021	4,77
10	Zuid-Limburg	the Netherlands	597,400	Data analyst; Advisor; Researcher	No	20/09/2021	7,85
11	Eindhoven	the Netherlands	231,642	Policymaker	No	21/09/2021	8,78
12	Alphen aan de Rijn	the Netherlands	110,986	Data analyst	We use models since before 2010. Our actual model is since 2019.	22/09/2021	16,07
13	Utrecht	the Netherlands	361,742	Advisor; Designer	No	27/09/2021	7,62
14	Delft	the Netherlands	103,163	GIS advisor/specialist	No	19/10/2021	7,58
15	Munich	Germany	1,488,202	Data analyst	Since 2014-2016	23/09/2021	12,42
16	Bremen	Germany	566,573	Program manager	No	24/09/2021	0,92
17	Bremen	Germany	566,573	Program manager	No	23/09/2021	17,72
18	Cologne	Germany	1,083,498	Program manager	Other	28/09/2021	2,08
19	Mönchengladbach	Germany	259,665	Mobility planner	other(not sure)	23/09/2021	6,93
20	Oviedo	Spain	214,883	Advisor	Other	30/09/2021	12,78
21	Lleida	Spain	137,856	Policymaker; Program manager; Advisor; Researcher	No	30/09/2021	8,38
22	Barcelona	Spain	1,620,343	Program manager	2020	01/10/2021	32,60
23	Badalona	Spain	217,741	Data analyst; Mobility engineer	Since 2019 or after	01/10/2021	20,08
24	Manresa	Spain	76,250	Mobility Planner	Since before 2010	01/10/2021	7,97
25	Valladolid	Spain	299,715	Policymaker	Since 2019 or after	04/10/2021	30,83
26	Palermo	Italy	676,118	Technical officer	No	24/09/2021	8,75

27	Milano	Italy	1,399,860	Policymaker; data analyst; Advisor	Since before 2010	30/09/2021	31,92
28	Alta	Norway	20,789	Advisor	No	24/09/2021	45,48
29	Stavanger	Norway	144,877	Advisor	No	28/09/2021	31,95
30	Reykjavik	Iceland	131,136	Data analyst	Since before 2010	27/09/2021	8,77
31	Reykjavik	Iceland	131,136	GIS manager	No	28/09/2021	1,08
32	Jyväskylä	Finland	144,477	Advisor; Project manager	No	25/09/2021	7,62
33	Gotland	Sweden	58,595	Mobility planner	No	27/09/2021	146,78
34	Stockholm	Sweden	978,770	Project coordinator	Yes (not sure which year)	07/10/2021	1,78
35	Lund	Sweden	94,393	Program manager	Since before 2010	20/10/2021	5,67
36	Maia	Portugal	135,306	Municipal mobility technician	No	27/09/2021	4,45
37	Bialystok	Poland	296,401	Policymaker; Data analyst; Program manager	Passenger collecting system was fully implemented in 2003, E-ticketing was developed in years 2012-2014	29/09/2021	18,30
38	Gliwice	Poland	177,049	Data analyst	No	01/10/2021	86,98
39	Olsztyn	Poland	171,249	City officer	No	25/10/2021	19,97
40	Myrhorod	Ukraine	38,447	Policymaker	No	01/10/2021	10,63
41	Chernihiv	Ukraine	285,234	Head of the Department of Transport, Transport Infrastructure and Communications	No	01/10/2021	12,87
42	Bratislava	Slovak	475,000	Advisor	No	01/10/2021	79,72
43	Belgrade	Serbia	1374,000	Policymaker; Advisor; Program manager	No	04/10/2021	6,37
44	Sombor	Serbia	47,623	Data analyst; Program manager	No	07/10/2021	0,88
45	Banja Luka	Bosnia and Herzegovina	138,963	Policymaker; Program manager	No	04/10/2021	14,25
46	Sarajevo	Bosnia and Herzegovina	275,524	Program manager	No	06/10/2021	11,98
47	Saône-et-Loire	France	551,493	City officer	No	07/10/2021	8,83
48	Antwerp	Belgium	523,248	Data analyst	Since 2019 or after	07/10/2021	31,58
49	Ohey	Belgium	5,090	Advisor	No	07/10/2021	10,07

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50	Bucharest	Romania	1,883,425	Advisor; Engineering consultant	Since 2016-2018	08/10/2021	10,37
51	Thessaloniki	Greece	325,182	Mobility officer	No	11/10/2021	5,30
52	Basel	Switzerland	177,595	Data analyst	Since before 2010	18/10/2021	22,65
53	Dublin	Ireland	554,554	Mobility officer	No	17/11/2021	6,23
54	Dublin	Ireland	554,554	Project manager; Project Engineer	No	22/11/2021	13,32
55	Ljubljana	Slovenia	295,504	Advisor	Since before 2010	01/02/2022	12,22

Appendix 8.5.2 Survey questionnaire

Note: For each question, we indicated the number of respondents (N), and for each of the answer options, the number of respondents that chose this option (number in red). The numbers refer to all 56 responses that were received.

Introduction

Computer models are regularly used in planning and policy making for ex-ante and ex-post assessments. They can be helpful to evaluate different plans and policy options and assess the effects of policy measures. With respect to urban mobility planning, integrated 'Geographical Information System' (GIS) models could process location-based data (i.e., GIS data, GPS data), and integrate indicators such as accessibility, CO_2 emissions and aspects of health, and visualize the results for policymakers.

You have been selected to complete the following questionnaire which aims to understand what you think about integrated GIS models used in urban mobility planning and policy making and what you expect from these models for your work.

Your contribution is highly appreciated. The questionnaire takes 8-12 minutes and there is no right or wrong answer. If there is a question that you prefer not to answer, please skip it and move on to the next. The research is scientific and has no profit-seeking purposes. Your data will be anonymized and treated confidentially.

Part 1: Basic Information

Q1. At which city do you work? (N=56)

____

Q2. Which label best indicates your position in the municipality? (multiple answers are possible) (N=56)

- ☐ Policy maker (1) 11
- ☐ Data analyst (2) 13
- ☐ Program manager (3) 13
- ☐ Advisor (4) 19
- ☐ Researcher (5) 3
- ☐ Other (please specify) (6) ____ 19

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Q3. What does your work involve? (multiple answers are possible) (N=55)

- ☐ Survey data collection (1) 17

- ☐ Traffic data collection (2) 23
- ☐ Survey data analysis (3) 18
- ☐ Real-time traffic data monitoring and analysis (4) 9
- ☐ Traffic plan development (5) 28
- ☐ Policy decision-making (6) 15
- ☐ Providing knowledge and information to policy makers (7) 34
- ☐ Communicating and cooperating with different work groups (8) 40
- ☐ Monitoring and evaluating policy measures (9) 24
- ☐ Model development (10) 19
- ☐ Other (please specify) (11) ____7

Part 2: Current Use of GIS Models in Urban Mobility Planning and Policymaking

Q4. Have you ever worked with a traffic model for urban mobility policymaking? (N=56)

- ○ Yes (please simply describe the model) (1)
  ____19
- ○ No (2) 37
- ○ Other (please specify) (3) ____0

Q5. Do you currently work with a GIS model for urban mobility policymaking?

- ○ Yes (1) 17
- ○ No (2) 35
- ○ Other (please specify) (3) ____4

Skip To: Q12 If 5. Do you currently work with a GIS model for urban mobility policymaking? = No

Q6. Please simply describe this model for and how it is applied in urban mobility policymaking: (N=16)

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____
____
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Q7. What was your motivation to start working with this model? (multiple answers are possible) (N=16)

- ▢ We wanted to use it to predict the impacts of policy measures for urban mobility plans and policy development (1) 7
- ▢ We wanted to use it to evaluate the implemented policies and to see the impacts of these policy measures (2) 8
- ▢ We wanted to get more information about traffic flow and trends based on data for decision-making (3) 11
- ▢ We wanted to use more actual data for evidence-based urban mobility policymaking (4) 10
- ▢ We wanted to learn about / test the usefulness of such a model (5) 1
- ▢ We were obliged to develop and use the model (6) 2
- ▢ It was offered to us for free by the national government (7) 0
- ▢ It was offered to us for free by the provincial government (8) 0
- ▢ It was offered to us through a consultancy as part of another project (9) 0
- ▢ Other (please specify) (10) ____1

Q8. Since when has your municipality worked with this model? (N=17)

- ○ Since before 2010 (1) 7
- ○ Since 2012-2014 (2) 2
- ○ Since 2014-2016 (3) 1
- ○ Since 2016-2018 (4) 1
- ○ Since 2019 or after (5) 3
- ○ Other (please specify) (6) ____3

Q9. What types of data do you use as inputs to this model? (multiple answers are possible) (N=17)

- ▢ GIS data (1) 14

8

- GPS data (2) 0
- Mobile phone data (3) 2
- Real-time traffic data (4) 3
- Historical traffic data (5) 12
- Survey data (6) 10
- Other (please specify) (7) ____1

Q10. What are the sources of your data? (multiple answers are possible) (N=17)

- Central Bureau of Statistics (1) 5
- Local road sensor cameras (2) 9
- Public transport cards (3) 4
- Social media (4) 0
- Other companies (i.e. mobile phone data provided by Vodafone) (5) 4
- Other (please specify) (6) ____10

Q11. To what extent do you think this model contributes to urban mobility policy development? (N=17)

- A very great deal (1) 2
- A lot (2) 9
- A moderate amount (3) 5
- A little (4) 1
- Not at all (5) 0

Q12. GIS model users: Which aspect of GIS models do you think should be improved? Non-users: What knowledge would you want to get from these models? (multiple answers are possible) (N=45)

- Provide more information and insights about traffic flow and accessibility (1) 35
- Provide more information about social aspects (e.g. residents opinions about new road constructions or transport poverty) (2) 29
- Provide more information about environmental aspects (e.g. how does the new urban mobility policy or plan affect the local air quality) (3) 27

- Provide more information about the impacts on residents' health (4) 19
- Integrate (the effects of) the energy transition into the model analysis (5) 10
- Provide more financial support for model development (6) 9
- It is fine as it is (8) 2
- Other (please specify) (7) ____ 6

Q13. Which aspects of user-friendliness of GIS models do you think should be improved? (multiple answers are possible) (N=45)

- Make model use easier for staff who have less model and data processing knowledge (1) 34
- The model should provide data and information at the neighborhood scale (2) 23
- The model should process the data faster (3) 16
- The accuracy of information given by the model should be improved (4) 12
- The model should be upgraded more frequently (5) 12
- It is fine as it is (7) 1
- Other (please specify) (6) ____ 4

Q14. To what extent you are interested in having a GIS model that can evaluate the combined environmental and social effects of urban mobility policies and give (visualized) results at neighborhood level? (N=47)

- Extremely interested (1) 10
- Very interested (2) 22
- Somewhat interested (3) 14
- Not so interested (4) 0
- Not at all interested (5) 1

Q15. Could you shortly explain why are you interested/not interested in having a GIS model that can evaluate the combined environmental and social effects of urban mobility policies and give (visualized) results at neighborhood level? (N=29)

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Part 3: Data availability, measurement frequency and reliability (N=23)

This part is only for those who are working with data (i.e. data collection, data analysis, model development). The aim is to assess the availability, measurement frequency and reliability of data that could be used to develop or apply a GIS model for urban mobility policymaking.

Q16. Data availability

	Not available (1)	Available at a cost (2)	Available with special permission (3)	Freely available (4)	Freely online available (5)
Commuting travel time (1)	○	○	○	○	○
Travel distance to key services (2)	○	○	○	○	○
Affordability of public transport (3)	○	○	○	○	○
Greenhouse gas emissions accounted at neighbourhood level (4)	○	○	○	○	○
PM2.5 pollution accounted at neighbourhood level (5)	○	○	○	○	○
Mobility (road/cycle path/pedestrian path) networks (6)	○	○	○	○	○
Public transport network coverage (7)	○	○	○	○	○
Traffic fatalities and injuries (8)	○	○	○	○	○

Real-time traffic data (9)	○	○	○	○	○

Q17. Data measurement frequency

	Measurements≧10 years (1)	3-10 years (2)	1-3 years (3)	Annually (4)	Monthly/daily (5)
Commuting travel time (1)	○	○	○	○	○
Travel distance to key services (2)	○	○	○	○	○
Affordability of public transport (3)	○	○	○	○	○
Greenhouse gas emissions accounted at neighbourhood level (4)	○	○	○	○	○
PM2.5 pollution accounted at neighbourhood level (5)	○	○	○	○	○
Mobility (road/cycle path/pedestrian path) networks (6)	○	○	○	○	○
Public transport network coverage (7)	○	○	○	○	○
Traffic fatalities and injuries (8)	○	○	○	○	○
Real-time traffic data (9)	○	○	○	○	○

Q18. Data reliability

(1: weak assumptions/significant inconsistency; 2: debatable assumptions/considerable inconsistency; 3. reasonable assumptions/moderate inconsistency; 4. realistic assumptions/slight inconsistency; 5. no assumptions/no inconsistency)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
Commuting travel time (1)	○	○	○	○	○

8

Travel distance to key services (2)	○	○	○	○	○
Affordability of public transport (3)	○	○	○	○	○
Greenhouse gas emissions accounted at neighbourhood level (4)	○	○	○	○	○
PM2.5 pollution accounted at neighbourhood level (5)	○	○	○	○	○
Mobility (road/cycle path/pedestrian path) networks (6)	○	○	○	○	○
Public transport network coverage (7)	○	○	○	○	○
Traffic fatalities and injuries (8)	○	○	○	○	○
Real-time traffic data (9)	○	○	○	○	○

Part 4: Comparative Importance of Different Factors (N=40)

In this part, we want to investigate the importance of different factors in urban mobility policy-making. This could to help to identify what should be covered by an integrated sustainability assessment GIS model for urban mobility policymaking.

Q19. Please compare the following factors:
If you compare for example accessibility and livability and you click the dot in the middle, it means that you consider both factors equally important. If you click the dot closer to accessibility, it means that you consider accessibility more important than livability. If you click the dot closer to livability, it means that you consider livability more important than accessibility.

1 (1) 2 (2) 3 (3) 4 (4) 5 (5) 6 (6) 7 (7) 8 (8) 9 (9)

Accessibility	○	○	○	○	○	○	○	○	○	Livability
Livability	○	○	○	○	○	○	○	○	○	Air quality
Air quality	○	○	○	○	○	○	○	○	○	Accessibility
Vehicle energy transition	○	○	○	○	○	○	○	○	○	Accessibility
Livability	○	○	○	○	○	○	○	○	○	Vehicle energy transition
Vehicle energy transition	○	○	○	○	○	○	○	○	○	Air quality
Accessibility	○	○	○	○	○	○	○	○	○	Investment cost
Investment cost	○	○	○	○	○	○	○	○	○	Livability
Air quality	○	○	○	○	○	○	○	○	○	Investment cost
Investment cost	○	○	○	○	○	○	○	○	○	Vehicle energy transition

Appendix 8.5.3 Percentage of respondents per answer option on data availability, data frequency, and data reliability for GIS model development and operation

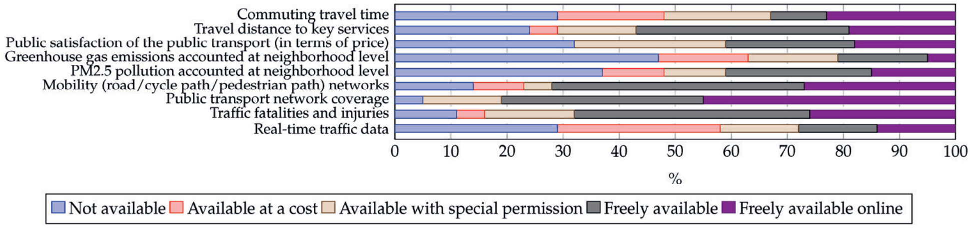

Figure 1. Data availability (N=23)

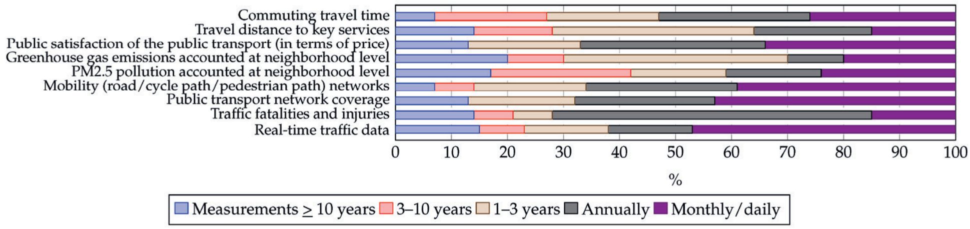

Figure 2. Data frequency (N=23)

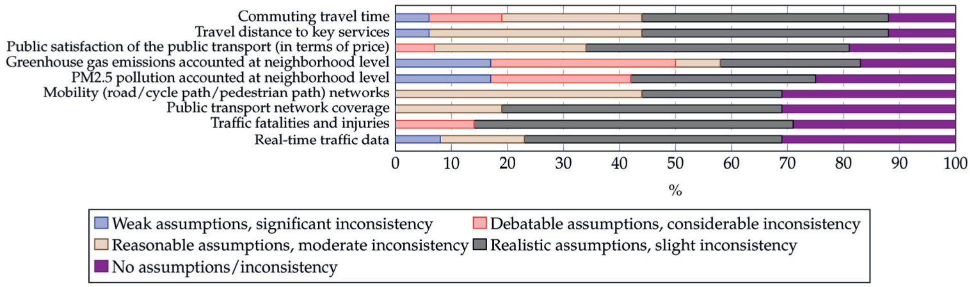

Figure 3. Data reliability (N=23)

Summary

One of the main challenges facing European cities and a matter of concern for many EU citizens is the transition towards sustainable urban mobility (ECA, 2020). Mobility plays a role in most economic and social activities, and, accordingly, enables economic growth and societal and human development. At the same time, however, urban areas are burdened with negative impacts from transport activities, such as congestion, harmful emissions, traffic accidents, and noise. Transport is a major source of greenhouse gas (GHG) emissions, and one of the few sectors in Europe where emissions did not decrease between 1990 and 2017 (EEA, 2019). Modelling of abatement options has shown that new, cleaner propulsion technologies (e.g. electric vehicles) will not reduce CO2 emissions of transport sufficiently to achieve the European climate goals (EC, 2021). Various ways to address these issues have been proposed. Car trips should be replaced by public transportation and, at shorter distances, by 'active travel' (i.e. walking, cycling, e-biking) (Brand et al., 2021). Avoiding the need to travel in the first place, (for instance through online working) is another possible strategy.

Recently, another way to contribute to this transition is raised by the New European Urban Mobility Framework (EU, 2021), emphasizing the importance of modeling "to support mobility decision-making in an integrated matter". Among others, it highlights the use of urban mobility data and how this could bring new opportunities. Despite an increasing number of studies on the potential of data for mobility policy, it is unclear whether and how this is adopted in policy practice. It is also not known what the needs and priorities of urban mobility planners are in this respect (Isaksson et al., 2017). This thesis thus aims to explore how data could better support sustainable urban mobility transformations. The more specific objectives are to investigate the current role of data in urban mobility policy practice and to investigate how data can support urban policymakers more effectively in the sustainable mobility transformation.

Chapter 2 first seeks to better understand the context in which urban mobility planners operate, which has a multi-level character concerning policy and governance. Although local governments have the most specific executive policy power concerning urban mobility through the subsidiarity principle, the sustainable urban mobility transition is clearly shaped by regional, national and supranational levels too. The different policy instruments employed at different governance levels jointly affect urban mobility and also affect each other (i.e. form a 'policy mix'). Based on 32 semi-structured interviews with mobility policymakers from various governance levels, this chapter highlights the key multi-level governance conflicts for urban sustainability mobility transformation, being a bias in funding towards 'solving bottlenecks through infrastructure', and the national level having significant influence on the local level, whilst itself being hardly influenceable by the other levels. It also further explores the ways to overcome these conflicts: 1) shifting the focus from 'infrastructure' to 'broad mobility' (e.g., enhance the number of 'innovation projects', such as Urban Living Lab experiments, to learn how to tailor mobility solutions in practices according to local circumstances); and 2) institutionalizing multi-level co-development (e.g., 'MoVe'-the Dutch national-local collaborative programme on urban development).

Chapter 3 gives an overview of the role of data in urban mobility policy assessments through a systematic literature review, focusing on 74 papers in more detail. This study answers research questions about the current role of big data in sustainability assessment of urban mobility policies, whether some types of data are found more useful than others, and whether big data are increasingly employed and found more useful than traditional survey data. The results show that to date academic literature provided limited insight in new data developments in policy practice and that the new types of big data offer new opportunities for evidence-based policy-making but cannot replace traditional data (surveys and statistics). Moreover, the study suggests that combining big data with survey and Geographic Information System data in ex-ante assessments, as well as in developing decision support tools can support mobility policymaking more effectively. Further studies should engage with policy practitioners to reveal best practices, constraints, and the potential of more demand-driven data use in mobility policy assessments.

Chapter 4 builds on chapter 3 with a study that zooms in on data use in urban mobility policymaking practice in two Dutch cities - Maastricht and Groningen. These cities have trialed a more data-driven policymaking approach, funded through a national programme (BeterBenutten). Ten semi-structured interviews with the people working in the mobility departments and document analysis of twenty-one policy reports were conducted to understand how data is currently embedded in urban mobility policy- and decision-making and what the advantages and limitations of more data use are in these processes. This study finds that data use differed in long-term and short-term policy cycles. (The main difference between the two cycles is that the long-term cycle goes via the transport policy steering group). In the long-term policy cycle (which usually takes four years or longer), data was regarded as less important than political and societal trends and developments. In the short-term cycle, data played a major role in prompting traffic regulations and policy adjustments. Insights about how data could be more effectively used in sustainable urban mobility policy practice delivered in this research include: (1) Support from national/regional level (e.g., the BeterBenutten program) could provide extra opportunities for local governments to do ex-post policy assessments, which are regarded as valuable resources for evidence-based decision-making by policymakers. (2) Survey data still play a significant role in urban mobility planning by providing more insight in the ‘why’ of traveller behaviour than big data. (3) Transport policymakers need to strengthen their abilities in selecting suitable data (out of a much larger set) and need more (competent) personnel capacity to interpret data. (4) Promoting sustainable mobility is a strong driving force for the local governments to enhance data use.

Chapter 5 further focuses on how to help transport mobility policymakers increase their capacities to use and interpret data. The literature indicates that GIS-based transport models are functional, cost-efficient and user-friendly tools for (urban) mobility planning (Abousaeidi et al., 2016). They are currently available for a broad range of applications in mobility planning. However, it is not known how widespread the current use of GIS models is among European urban mobility planners, nor what their user experiences and needs are. There is therefore a risk that the development of GIS models for urban mobility planning will be mainly driven by technical possibilities and data availability rather than by the needs of the prospective users. To inform model developers and ensure a good match between model options and user needs, we conducted a survey investigating the current application of GIS models in urban mobility planning practice in Europe as well as model data availability and the needs and priorities of European mobility planners regarding GIS models. We received 51 valid responses from the transport departments of 42 cities from 21 European countries. For developers of GIS-based traffic models, the findings indicate that in Europe there is scope for wider adoption and further improvement. The models currently used are considered useful to support urban mobility planning, but more than 60% of the surveyed cities do not yet use them. Increased user-friendliness, in particular for non-experts, appears important to promote wider adoption. Availability of non-traditional types of data, such as real-time data or data at neighbourhood level, is still limited in most cities, but this may rapidly change. Additionally, there is also considerable interest in traffic models that integrate social and environmental aspects.

Finally, a synthetic discussion is provided in chapter 6 about the current role of data and how data can more effectively support urban policymakers in sustainable urban mobility transformation. Overall, this thesis concludes that big data bring new opportunities for sustainable urban mobility policymaking (e.g., it allows mobility policymakers to evaluate policy measures targeting different modalities), while survey data give more in-depth information about why travelers choose the corresponding modalities. However, data, especially big data, are not widely used in urban mobility policy practice. The main reason is that urban policymakers lack the needed financial support and capacity to process data. This requires support from the higher governance levels, such as national programmes or the EU Open Data Directive. Sustainability and climate policy ambitions are bringing more alignment between the governance levels in terms of sustainable mobility policy aims, which could help to support the urban level. In addition, shifting the higher governance levels' (supranational and national) funding focus from infrastructure to broader mobility solutions could better support the use of data in sustainable urban mobility policymaking. Another opportunity would be the further development of GIS-based traffic models according to the needs and requirements of urban mobility policymakers.

Although our study filled several gaps in the literature, there are many gaps left, which indicate possible future research directions. The first concerns clarifying the most effective role and involvement of different actors in sustainable urban mobility policymaking. This is also flagged by (Ronzhyn and Wimmer, 2021)). Walravens et al. (2021) also highlighted that collaboration among different actors is required to enable data-driven policy making (Walravens et al., 2021). Our interviews with respondents at different governance levels as well as from the two-case study cities, indicated that involving and collaborating with a broad range of actors is required to make sustainable and data-driven urban mobility policymaking effective. Future studies should clarify how this collaboration can best be organized.

Samenvatting

Een van de belangrijkste uitdagingen waarmee Europese steden worden geconfronteerd en een bron van zorg voor veel EU-burgers, is de overgang naar duurzame stedelijke mobiliteit (ECA, 2020). Mobiliteit speelt een rol in de meeste economische en sociale activiteiten en draagt bij aan economische groei en maatschappelijke en menselijke ontwikkeling. Tegelijkertijd worden stedelijke gebieden echter geconfronteerd met negatieve gevolgen van transportactiviteiten, zoals congestie, schadelijke emissies, verkeersongevallen en geluidsoverlast. Transport is een belangrijke bron van broeikasgasemissies (GHG) en een van de weinige sectoren in Europa waar de emissies tussen 1990 en 2017 niet zijn afgenomen (EEA, 2019). Modellering van opties voor emissiereductie heeft aangetoond dat nieuwe, schonere aandrijftechnologieën (bijv. elektrische voertuigen) de CO2-emissies van transport niet voldoende zullen verminderen om de klimaatdoelstellingen van Europa te halen (EC, 2021). Verschillende manieren om deze kwesties aan te pakken zijn voorgesteld. Autoreizen zouden moeten worden vervangen door openbaar vervoer en, op kortere afstanden, door 'actieve mobiliteit' (d.w.z. wandelen, fietsen, e-biken) (Brand et al., 2021). Het vermijden van de noodzaak om te reizen in de eerste plaats (bijvoorbeeld door online te werken) is een andere mogelijke strategie.

Onlangs is een andere manier om aan deze overgang bij te dragen naar voren gebracht door het Nieuwe Europese Stedelijke Mobiliteitskader (EU, 2021), waarin wordt benadrukt hoe belangrijk modellering is "om mobiliteitsbesluitvorming op een geïntegreerde manier te ondersteunen". Onder andere benadrukt het het gebruik van stedelijke mobiliteitsdata en hoe dit nieuwe kansen kan bieden. Ondanks een groeiend aantal studies over het potentieel van data voor mobiliteitsbeleid, is het onduidelijk of en hoe dit wordt overgenomen in beleidspraktijken. Ook is niet bekend wat de behoeften en prioriteiten zijn van stedelijke mobiliteitsplanners op dit gebied (Isaksson et al., 2017). Deze scriptie heeft daarom tot doel te onderzoeken hoe data duurzame stedelijke mobiliteitstransformaties beter kunnen ondersteunen. De meer specifieke doelstellingen zijn om de huidige rol van data in het beleid en de praktijk van stedelijke mobiliteit te onderzoeken en om te onderzoeken hoe data stedelijke beleidsmakers effectiever kunnen ondersteunen bij de duurzame mobiliteitstransformatie.

Hoofdstuk 2 probeert allereerst een beter begrip te krijgen van de context waarin stedelijke mobiliteitsplanners opereren, die een meerlaags karakter heeft wat betreft beleid en bestuur. Hoewel lokale overheden de meeste specifieke uitvoerende beleidsmacht hebben met betrekking tot stedelijke mobiliteit door het subsidiariteitsbeginsel, wordt de duurzame stedelijke mobiliteitstransitie duidelijk mede beïnvloed door regionale, nationale en supranationale niveaus. De verschillende beleidsinstrumenten die op verschillende bestuursniveaus worden ingezet, beïnvloeden gezamenlijk stedelijke mobiliteit en beïnvloeden elkaar ook (vormen een 'beleidsmix'). Op basis van 32 semigestructureerde interviews met mobiliteitsbeleidsmakers van verschillende bestuursniveaus, benadrukt dit hoofdstuk de belangrijkste conflicten in de governance op meerdere niveaus voor duurzame mobiliteitstransformatie in de stad: een neiging tot financiering van 'knelpunten oplossen via infrastructuur' en het nationale niveau heeft aanzienlijke invloed op het lokale niveau, terwijl het zelf nauwelijks beïnvloedbaar is door de andere niveaus. Het verkent ook verder de manieren om deze conflicten te overwinnen: 1) het verschuiven van de focus van

'infrastructuur' naar 'brede mobiliteit' (bijv. het vergroten van het aantal 'innovatieprojecten', zoals experimenten met Urban Living Labs, om te leren hoe mobiliteitsoplossingen in de praktijk kunnen worden aangepast aan lokale omstandigheden); en 2) institutionalisering van meervoudige co-ontwikkeling (bijv. 'MoVe', het Nederlands nationaal-lokaal samenwerkingsprogramma voor stedelijke ontwikkeling).

Hoofdstuk 3 geeft een overzicht van de rol van data in beleidsbeoordelingen voor stedelijke mobiliteit via een systematische literatuurstudie, waarbij 74 papers nader worden onderzocht. Deze studie beantwoordt onderzoeksvragen over de huidige rol van big data in duurzaamheidsevaluaties van stedelijke mobiliteitsbeleid, of sommige soorten data nuttiger worden geacht dan andere, en of big data steeds vaker worden gebruikt en nuttiger worden geacht dan traditionele enquêtedata. De resultaten tonen aan dat de academische literatuur tot nu toe beperkt inzicht heeft geboden in nieuwe dataontwikkelingen in de beleidspraktijk en dat de nieuwe soorten big data nieuwe mogelijkheden bieden voor op bewijs gebaseerde beleidsvorming, maar traditionele data (enquêtes en statistieken) niet kunnen vervangen. Bovendien suggereert de studie dat het combineren van big data met enquête- en geografische informatiesysteemdata in ex-ante beoordelingen, evenals bij het ontwikkelen van beslissingsondersteunende tools, mobiliteitsbeleidsvorming effectiever kan ondersteunen. Toekomstige studies moeten zich bezighouden met beleidspraktijkmensen om best practices, beperkingen en het potentieel van meer vraaggestuurd gebruik van data in mobiliteitsbeleidsbeoordelingen te onthullen.

Hoofdstuk 4 bouwt voort op hoofdstuk 3 met een studie die inzoomt op het gebruik van data in de praktijk van beleidsvorming voor stedelijke mobiliteit in twee Nederlandse steden - Maastricht en Groningen. Deze steden hebben een meer op data gebaseerde benadering van beleidsvorming uitgeprobeerd, gefinancierd via een nationaal programma (BeterBenutten). Er werden tien semigestructureerde interviews gehouden met mensen die werkzaam zijn in de mobiliteitsafdelingen en documentanalyse van eenentwintig beleidsrapporten om te begrijpen hoe data momenteel zijn ingebed in het beleid en de besluitvorming voor stedelijke mobiliteit en wat de voordelen en beperkingen zijn van meer gebruik van data in deze processen. Deze studie constateert dat het gebruik van data verschilde in langetermijn- en kortetermijnbeleidscycli. (Het belangrijkste verschil tussen de twee cycli is dat de langetermijncyclus via de transportbeleidsstuurgroep loopt). In de langetermijncyclus (die meestal vier jaar of langer duurt), werd data als minder belangrijk beschouwd dan politieke en maatschappelijke trends en ontwikkelingen. In de kortetermijncyclus speelde data een belangrijke rol bij het bevorderen van verkeersregels en beleidsaanpassingen. Inzichten over hoe data effectiever kunnen worden gebruikt in de praktijk van duurzaam stedelijk mobiliteitsbeleid die in dit onderzoek zijn geleverd, omvatten: (1) Ondersteuning van het nationale/regionale niveau (bijv. het BeterBenutten-programma) kan extra kansen bieden voor lokale overheden om ex-post beleidsbeoordelingen uit te voeren, die door beleidsmakers worden beschouwd als waardevolle hulpmiddelen voor op bewijs gebaseerde besluitvorming. (2) Enquêtedata spelen nog steeds een belangrijke rol in stedelijke mobiliteitsplanning door meer inzicht te geven in het 'waarom' van het gedrag van reizigers dan big data. (3) Vervoersbeleidsmakers moeten hun vaardigheden versterken in het selecteren van geschikte data (uit een veel grotere set) en hebben meer (bekwame) personele capaciteit nodig om data te interpreteren. (4) Het bevorderen van duurzame mobiliteit is een sterke drijvende kracht voor lokale overheden om het gebruik van data te versterken.

Hoofdstuk 5 richt zich verder op hoe transportmobiliteitsbeleidsmakers hun capaciteiten kunnen vergroten om data te gebruiken en te interpreteren. De literatuur geeft aan dat op GIS gebaseerde transportmodellen functionele, kosteneffectieve en gebruikersvriendelijke tools zijn voor (stedelijke) mobiliteitsplanning (Abousaeidi et al., 2016). Ze zijn momenteel beschikbaar voor een breed scala aan toepassingen in mobiliteitsplanning. Het is echter niet bekend hoe wijdverbreid het huidige gebruik van GIS-modellen is onder Europese stedelijke mobiliteitsplanners, noch wat hun gebruikerservaringen en behoeften zijn. Er bestaat dus het risico dat de ontwikkeling van GIS-modellen voor stedelijke mobiliteitsplanning voornamelijk wordt gestuurd door technische mogelijkheden en databeschikbaarheid in plaats van door de behoeften van potentiële gebruikers. Om modelontwikkelaars te informeren en een goede match te garanderen tussen modelopties en gebruikersbehoeften, hebben we een enquête uitgevoerd om het huidige gebruik van GIS-modellen in de praktijk van stedelijke mobiliteitsplanning in Europa te onderzoeken, evenals de beschikbaarheid van modeldata en de behoeften en prioriteiten van Europese mobiliteitsplanners met betrekking tot GIS-modellen. We ontvingen 51 geldige reacties van de transportafdelingen van 42 steden uit 21 Europese landen. Voor ontwikkelaars van op GIS gebaseerde verkeersmodellen geven de bevindingen aan dat er in Europa ruimte is voor bredere acceptatie en verdere verbetering. De momenteel gebruikte modellen worden als nuttig beschouwd ter ondersteuning van stedelijke mobiliteitsplanning, maar meer dan 60% van de ondervraagde steden gebruikt ze nog niet. Toenemende gebruiksvriendelijkheid, met name voor niet-experts, lijkt belangrijk om bredere acceptatie te bevorderen. De beschikbaarheid van niet-traditionele datatypen, zoals real-time data of data op wijkniveau, is nog steeds beperkt in de meeste steden, maar dit kan snel veranderen. Daarnaast is er ook aanzienlijke interesse in verkeersmodellen die sociale en milieufactoren integreren.

Tot slot wordt in hoofdstuk 6 een synthetische discussie gegeven over de huidige rol van data en hoe data de stedelijke beleidsmakers effectiever kunnen ondersteunen bij de duurzame stedelijke mobiliteitstransformatie. Over het algemeen concludeert deze scriptie dat big data nieuwe mogelijkheden bieden voor duurzaam stedelijk mobiliteitsbeleid (bijv. het stelt mobiliteitsbeleidsmakers in staat beleidsmaatregelen te evalueren die gericht zijn op verschillende modaliteiten), terwijl enquêtedata meer diepgaande informatie verschaffen over waarom reizigers de corresponderende modaliteiten kiezen. Data, vooral big data, worden echter niet veel gebruikt in de beleidspraktijk van stedelijke mobiliteit. De belangrijkste reden is dat stedelijke beleidsmakers de benodigde financiële ondersteuning en capaciteit om data te verwerken ontbreken. Dit vereist ondersteuning van hogere bestuursniveaus, zoals nationale programma's of de EU Open Data-richtlijn. Duurzaamheids- en klimaatbeleidsambities zorgen voor meer afstemming tussen de bestuursniveaus wat betreft de doelstellingen van duurzaam mobiliteitsbeleid, wat de stedelijke niveau kan helpen ondersteunen. Bovendien zou het verschuiven van de focus van de hogere bestuursniveaus (supranationaal en nationaal) van infrastructuur naar bredere mobiliteitsoplossingen het gebruik van data in duurzaam stedelijk mobiliteitsbeleid kunnen bevorderen. Een andere kans zou de verdere ontwikkeling van op GIS gebaseerde verkeersmodellen zijn, in overeenstemming met de behoeften en eisen van stedelijke mobiliteitsbeleidsmakers.

Hoewel ons onderzoek verschillende hiaten in de literatuur heeft gevuld, zijn er nog veel hiaten over die mogelijke toekomstige onderzoeksroute aangeven. De eerste betreft de verduidelijking van de meest effectieve rol en betrokkenheid van verschillende actoren bij duurzaam stedelijk mobiliteitsbeleid. Dit wordt ook aangekaart door Ronzhyn en Wimmer (2021). Walravens et al. (2021) benadrukten ook dat samenwerking tussen verschillende actoren vereist is om op data gebaseerd beleid mogelijk te maken (Walravens et al., 2021). Onze interviews met respondenten op verschillende bestuursniveaus en uit de twee casestudiesteden gaven aan dat het betrekken en samenwerken met een breed scala aan actoren nodig is om duurzaam en op data gebaseerd stedelijk mobiliteitsbeleid effectief te maken. Toekomstige studies moeten verduidelijken hoe deze samenwerking het beste kan worden georganiseerd.

Scientific and Social Impacts

This thesis studies the current role of (big) data in sustainable urban mobility policymaking and explores how data could be more effectively used in this process. The (potential) implications of this research for science and society are discussed in this section.

Scientific contribution
The scientific contribution relates to the research field of sustainable urban mobility transformation and more specifically the knowledge about data use in urban mobility policymaking. Current scientific literature offers limited insight in and had little engagement with the role of data in urban mobility practice. It has mainly focused on developing decision support models for policy decisions about (bigger) investment in urban transport, especially infrastructure (Curtis et al., 2019). Those are less useful for urban policymakers that want to monitor and evaluate policy to steer towards sustainable mobility (Banister and Hickman, 2013). This PhD study gives a better insight in the role of data in current policy practice and it offers suggestions on how data can be used more effectively by urban policymakers that seek to promote sustainable mobility. The analysis of multi-level governance conflicts sheds light on the complex relations among different governance layers in sustainable urban mobility transitions, which addresses the gap in understanding of the urban mobility multilevel policy mix. By identifying conflicts and proposing strategies to address them, this study adds nuance to the understanding of governance dynamics in mobility policymaking. Better data use for policy monitoring concerns the short-term policy cycle, and our findings suggest that a combination of big data and survey data (that can give more insight into why people travel as they do) is most instrumental. This is in line with earlier studies that argue to not only rely on quantitative data but also incorporate other forms of knowledge. Chapter 3 and 4 also specify how different types of data are used in the sustainable urban mobility policymaking process by distinguishing the long- and short-term policy cycle. This adds to Verstraete et al. (2021) who shed light on how to use data in the different steps of the policy cycle by emphasizing what approaches could be used to analyze data in each of the steps, based on both scientific literature review and practical case studies (Verstraete et al., 2021). Their work, which was part of EU project PoliVisu (https://www.polivisu.eu/) (Concilio et al., 2021), also found that limited data literacy is the key constraint to successful use of data in urban policymaking, but they did not highlight the distinct role of data in the short- and long-term policy cycle (chapter 4).

Social contribution
The main societal contribution of the work presented in this thesis relates to its value for application in sustainable urban mobility policymaking practice by municipal decision makers, urban spatial planners, and developers of decision support tools. The identification of barriers and opportunities in data utilization offers practical insights for policymakers. The emphasis on multi-level collaboration underscores the importance of institutionalizing multi-level co-development. The recognition of the value of different types of data in mobility policy assessments (chapter 3) shows the state of the art to the policymakers, assisting them to better understand which type of data is suited in which policymaking steps. The case study of the two Dutch cities, Maastricht and Groningen (chapter 4), provides practical 160 examples of data-driven policymaking. Insights can be derived from this research on how data can be better embedded in policymaking practice, such as

providing more opportunities for local governments to do ex-post policy assessments, more data knowledge needed for data selection and processing, and setting a common indicator for the data analysis. Moreover, the distinction between long-term and short-term policy cycles, and the importance of national/regional support, highlight actionable strategies for municipalities aiming to integrate data into their decision-making processes. In order to ensure a good match between model options and mobility policymakers needs, a survey was conducted in this research to investigate the current application of GIS models in urban mobility planning practice in Europe as well as model data availability and the needs and priorities of European mobility planners regarding GIS models. It provides guideline for modelers to develop traffic models based on the mobility policymakers' needs as well as the insights in how the model should be tailored in different circumstances.

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I’ve tried numerous times to start writing the real final part of my thesis, which is here, the acknowledgement. I thought it would be easy-without scientific proof, literature review, revisions, oh but it still needs grammar check. Well, now since the deadline is on my face, I decided to shortly narrate my whole PhD journey and show my appreciations to the people who lighted up different parts of the journey.

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Xu Liu was born on July 1, 1993, in Liaoyang (China). She obtained the bachelor degree of Environmental Science and Engineering at Hangzhou Normal University in 2015. At the same year, she started her master study of Environmental Management at Xiamen University. From 2015 to 2017, she participated in a regional government project known as the 'Strategic Environmental Impact Assessment of Shishi Marine Biotechnology Industrial Park Planning.' This experience spurred Xu's interest to transition from the realm of science and engineering to social science, with a specific focus on embedding sustainability into society.

In 2018, Xu was granted a scholarship by the Chinese Scholarship Council for her Ph.D. studies at the Maastricht Sustainability Institute (MSI) of Maastricht University in the Netherlands. Her research primarily focuses on data usage in the policymaking process for sustainable urban mobility. Additionally, she has embarked on two research projects related to sustainability transitions: one concerning alignment gains in Sustainable Energy-Mobility Transitions and the other revolving around Online Education for Sustainable Development.

Beyond her research, Xu took the initiative to launch the MSI PhD Research Lunch Seminar and co-coordinate the MSI Triple S seminar. Additionally, she has contributed to teaching and toturing courses in 'Environmental Impact Assessment,' 'Environmental Basic Experiment,' and 'Sustainable Development' at Xiamen University and Maastricht University respectively.