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RESEARCH ARTICLE

The role of data in sustainability assessment of urban mobility policies

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Abstract

Data have 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 policymaking. This paper reviews how different types of data are employed in assessments published in academic journals by analyzing 74 cases. Our review finds that (a) academic literature has currently provided limited insight in new data developments in policy practice; (b) research shows that the new types of big data provide new opportunities for evidence-based policy-making; however, (c) they cannot replace traditional data usage (surveys and statistics). Instead, combining big data with survey and Geographic Information System 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.

Policy Significance Statement

This research helps urban mobility policymakers to get more insights in how to better use data in the policymaking process, which provides new opportunities for policymakers toward evidence-based policy-making. In this context, it answers the questions "Is big data increasingly employed and found more useful and powerful than traditional survey data?" "How are the new types of data applied in mobility policy practices" that policymakers usually have when they apply data in urban mobility policy evaluations. Based on the analysis of 74 cases, we summarize the strengths and limitations of different types of data and provide policymakers recommendations for how the potential use of data in sustainability assessment of urban mobility policy and decision-making can be better understood and tapped.

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 (European Commission, 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 et al., 2017; 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 are restricted—data are either not available at all, its use is restricted, or there is a fee for doing so (Chinellato et al., 2017). Additionally, many cities do not have experience with conceptualizing and conducting evaluations and selecting the most appropriate indicators (Chinellato et al., 2017).

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 policymaking. Open data are touted as having the potential to transform science and fast-track the development of new knowledge (Dietric et al., 2009). Urban data centers are emerging (Statistics Netherlands (CBS), 2019), 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 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 on how to better use data in the policymaking process and also provides new opportunities for policymakers toward evidence-based policymaking. It reviews the state of the art of data use in sustainability assessment (SA) of urban mobility policy in academic literature. Based on the review, this research gives insights on 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 SA are explained in more detail in Section 2. After that, we describe our research method in Section 3. Then, we classify the various types of data used in SAs of urban mobility policies and transportation management (Section 4). In Section 5, we describe a review of 74 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 SA of urban mobility policies. Finally, Section 7 concludes.

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2. Urban Mobility and Sustainable Assessment

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 travelers 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 (Com, 1992). In 1990, the belief that urban mobility was not sustainable as it was developing became more mainstream among local governments in Europe (Com, 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 (Holden et al., 2019). 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, and traffic free central areas).

At the beginning of the century, urban mobility had still not become more sustainable (Holden et al., 2019). 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; Ellis and Glover 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" (EU, 2011 p. 4), and stated that "curbing mobility is not an option" (EU, 2011 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, while also encouraging a shift toward more sustainable modes and improving transport accessibility for all.

An "Urban Agenda" for the EU was launched in May 2016. It represents a new multilevel 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 (PUM, EU, 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 multilevel 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, while 19% were eager to do so. There is a clear growth of cities with well-established SUMP's from 7 in 2011 to 19 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 (Chinellato et al., 2017, p. 17). Hence, it is

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"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 toward 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).

2.2. Sustainability assessment

According to the research of Intelligent Energy Europe, an EU Program, there are four key policy (making) challenges for sustainable urban mobility: participation, cooperation, measure selection, and monitoring and evaluation (European Commission, 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.

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 toward 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).

SA, like policy assessment and formulation, generally consists of four steps (De Ridder et al., 2007): (a) problem analysis, (b) finding options, (c) assessment of options, and (d) follow-up. Ideally, the problem analysis involves data-based evaluation, as 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, p. 437). 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 are 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 SA of urban mobility policy.

3. Materials and Methods

In order to understand the current state-of-the-art data use in urban mobility policy 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, and governmental documents that reported on them, available in academic databases. The whole process is depicted in Figure 1, followed the guidelines of Liberati et al. (2009).

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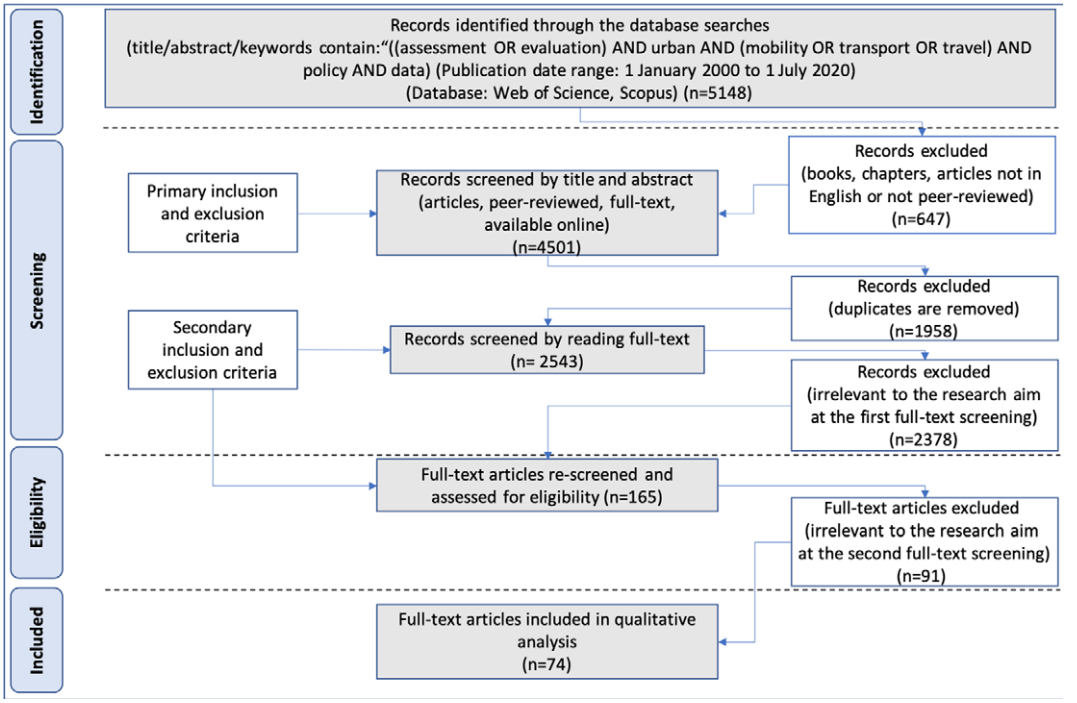

Figure 1. *Information flow of literature search and review.*

Table 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.

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 2,882 records, of which 647 books, chapters, articles not in English, or not peer-reviewed were removed. Then 4,501 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 2,544.

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, Geographic Information System (GIS) data, and big data, which has been illustrated more in details in part 4. Hundred and sixty-six 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 (see Table 2 and more details about these cases are list in Appendix A). 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.

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Table 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]

4. Classification of Data Use in Urban Mobility Studies

Data have 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.

4.1. Survey data

Survey data have 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 Global Positioning System (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 are often constrained by unrepresentative sample sizes. For example, the household surveys by the Federal Highway Administration in the United States 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.

4.2. Statistical data

Statistical data in this study are defined as the statistics compiled from statistical yearbooks and various related documents, which are 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, 2018).

In urban mobility studies, statistical data have been widely used by policymakers to assess mobility status and to evaluate the implemented planning and policies, also to indicate problems of the current policymaking and implementing process (Cervero, 2013; Annema et al., 2017). The limitations of using these data are that it is hard to monitor the changes caused by one particular indicator and it usually does

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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).

4.3. GIS data

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 policymakers 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 the limited information provided by GIS data (Gong et al., 2012; Khan et al., 2016).

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 among 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, location-based services, public transportation cards, and so on all generate numerous data as a by-product in these operations (Semanjski et al., 2016). Big data has been first 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 making 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 these 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; Tamblay et al., 2016). 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 data from GPS loggers, GPS-phones, and GPS-enabled PDAs. 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; Zheng-chang 2008). GPS data include 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 are usually analyzed directly, without understanding trip purposes or other related contexts (Gong et al., 2014).

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Smart card data have 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 policymakers 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 et al., 2016).

Facebook, Twitter, Instagram, Weibo, and so on 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, and so on for their business (Kaplan and Haenlein, 2010). In the urban mobility domain, social media data help policymakers 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., 2014). Moreover, the privacy issue should always be taken into consideration when such data are collected and used.

5. Case Studies Analyses

Figure 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. Twenty of these 74 cases combined at least two different types of data in their studies. Survey data are 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.

Regarding the publication date of these articles, it could be seen from Figure 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 play the main role in this research domain.

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 4), and how data used in the cases are summarized in detail in Appendix A. Specifically, what types of data used in each case associated with different processes in a policy cycle are illustrated in Table 2 (please check the serial number of the articles in Appendix A). 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.

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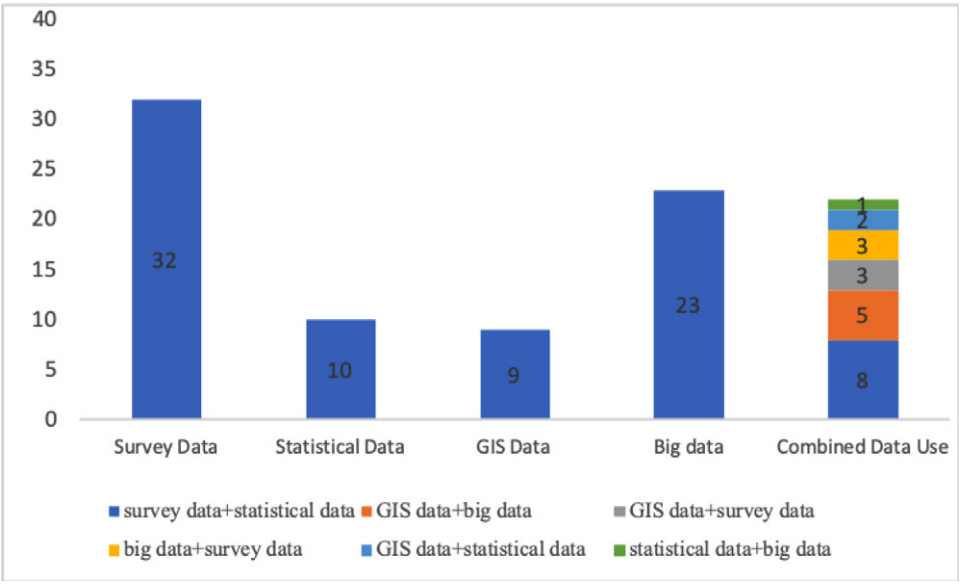

Figure 2. *The number of cases for each type of data.*

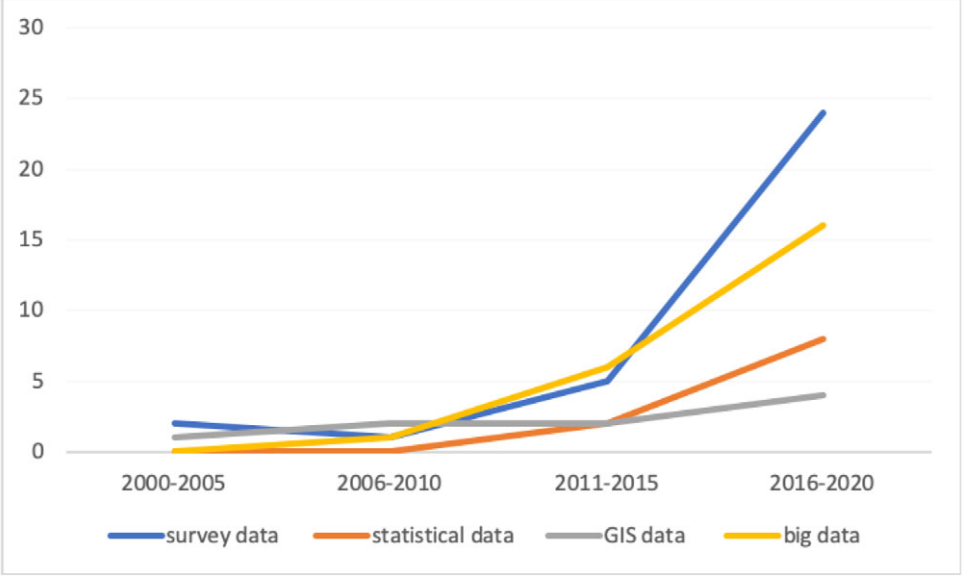

Figure 3. *Publication year of the final reviewed literatures.*

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 cases (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 2 shows, big data is becoming an important resource for urban mobility policy-related studies. Comparably, survey data still play an essential role in the same domain. By analyzing these case

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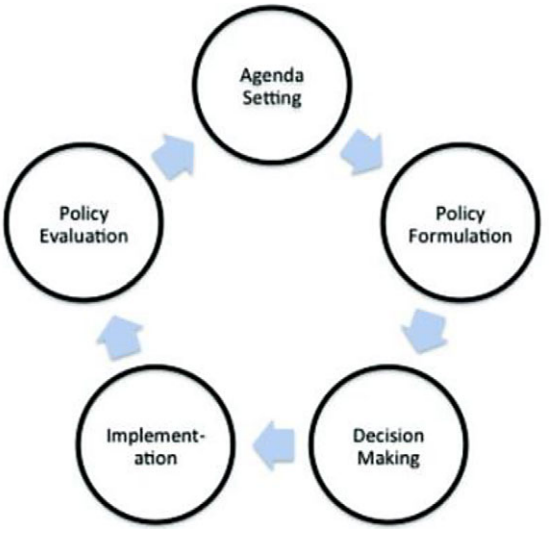

Figure 4. *Policymaking cycle (Howlett et al., 2009).*

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. 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.

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 (Mozos-Blanco et al., 2018), which compares the sustainable urban mobility plans of 38 Spanish cities by analyzing the relevant documents. 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 et al. (2016), for instance, note that limitations in the statistical data available prevented them from taking social factors well into consideration in their study.

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 were applied in Paffumi et al. (2015) and Zeitler et al. (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. This can be

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seen in Jiang et al.'s (2017) and Wismans et al.' (2018) studies. 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 et al. (2017) specifically mentions that, in practice, it will be challenging for urban mobility policymakers to have enough capacity to process and analyze big data.

5.2. Policy-related analysis

Regarding the data use in the policymaking cycle, Figure 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 that 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. 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 were 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.

GIS data are another type of data which have been applied in implementation step to explore the optimized regulation methods for efficient mobility regulation improvement (Wang et al., 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.

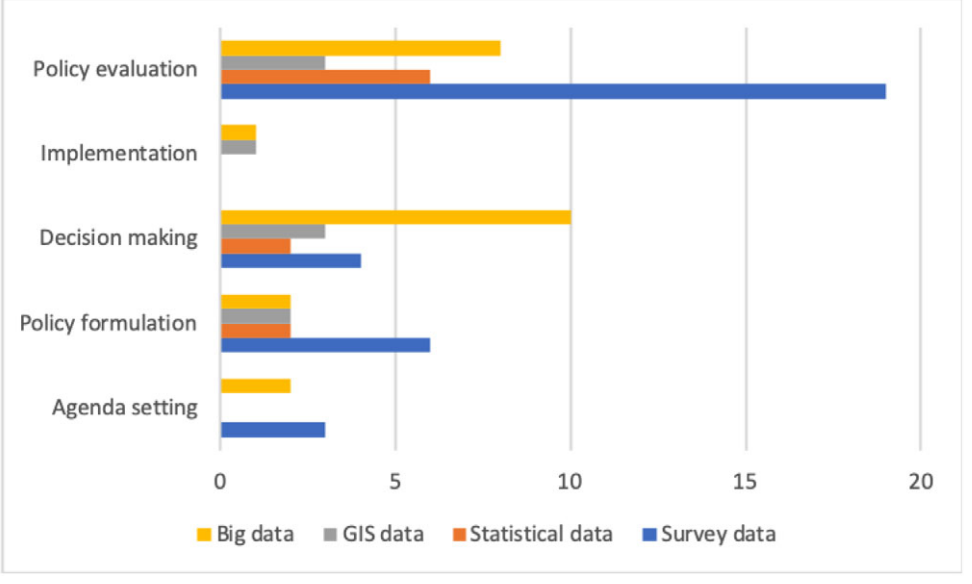

Figure 5. *Different types of data use in policymaking cycle.*

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Statistical data are 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 are 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. (2005) did a national survey to investigate participants' daily travel information so as to define mobility problems for policy measure design. Survey data are 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.

6. Discussion

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 Grange et al., 2012; Haghshenas et al., 2015; De Oliveira Cavalcanti et al., 2017; Mozos-Blanco et al., 2018) of the 10 cases which applied statistical data were to establish assessment criteria and to make comparisons among different projects and policies. Another case (Wiersma et al., 2016) 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 have 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 have 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

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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. These 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 (2016) research. 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. 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, modeling 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.

6.2. Potential better use of data in SA 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, SAs 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 are 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. 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

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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 and Phidd, 1983). 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 modeling 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.

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 policymaking.

Overall, the data use innovations in SA for urban mobility policy can be concluded as follows: (a) big data shows the most potential for use in decision-making support tools development, especially combined with survey data which shows even higher effectiveness; (b) 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; and (c) The use of new types of data in urban mobility policymaking requires policymakers and related

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working staff to have certain knowledge and skills for data analysis, modelling and extra working capacities.

7.1. 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 toward 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 policymakers 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.

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Appendix A

Table A1. *Analysis highlights of the reviewed literature*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
Survey data (32)	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 Koç, 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

(Continued)

Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	An Investigation on the Effectiveness of Joint Receiver–Carrier Policies to Increase Truck Traffic in the Off-peak Hours (Holguín-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 United States	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
	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 8 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

(Continued)

Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	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 (Foltýnová and Jordová, 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	Seattle, Montreal and Curitiba, the United States	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	Academic research	18

(Continued)

Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
			effects *(combined with statistical data)			provide insights on the effectiveness of these policy measures		
	Short-term planning and policy interventions to promote cycling in urban lefts: 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)	Questionnaire 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 RENAISSANCE 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	Valletta, Malta	Ex post assessment (policy evaluation)	Data gathered from literatures, interviews and observations involved in the policy development	Academic research	23

(Continued)

Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
			*(combined with statistical data)			were used to analysis the policy transfer in Valletta		
	The effects of driving restrictions on travel behavior evidence from Beijing (Gu and Long 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 (Toșa 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

(Continued)

Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	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
Statistical data (10)	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	Transport Policy	To explore the potential contribution of smart city instruments and their	Warsaw, Poland	Ex ante assessment (policy formulation)	The data mostly obtained from Polish and international institutions were applied in	Academic research	34

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	(Zawieska and Pieriegud, 2018)		impact on future transport-related greenhouse gas emissions (GHG)			the model to predict the potential impact on GHG levels caused by the transport policies		
	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. 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
	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

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	Did cycling policy and programs advance cycling in the city of Zagreb? (Pilko et al., 2017)	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
GIS data (9)	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:	Applied Geography	To evaluate the potential changes caused by community opening policy on the street and to give insights that would affect	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	Academic research	46

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	A GIS-based method and case study (Yu, 2017)		the decision-making to urban managers			impacts of community street opening policy		
	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 United States	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

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
Big data (23)	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 United States	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
	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., 2014)	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

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	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., 2019)	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 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

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	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 and Genovese, 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 United States	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

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Table A1. *Continued*

Data types	Title	Publications	Subjects	Regions	Policy associated	Data used in the case	Study type	Number
	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