NEW URBAN MOBILITY OPTIONS: ALTERNATIVE FUTURES AND THEIR IMPACT IN TRANSPORT PLANNING TECHNIQUES

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ABSTRACT

The acceleration of technology evolution is changing urban mobility at a much faster pace than we have seen in previous decades, leading to an increasingly uncertain future within this field. It is very likely that current transport planning tools and techniques will have to be adapted to the increasing number of innovative mobility forms in order to maintain their usefulness in the urban policy cycle. In this paper, we present a series of explorative scenarios for European urban mobility and the consequent challenges that they imply for such tools and techniques. Two groups of scenarios have been developed for assessing two different uncertain relations. First, a set of exogeneous scenarios has been defined for studying how different urban mobility socioeconomic contexts could affect the evolution of emerging mobility solutions. These scenarios are adaptations of the IPCC's Shared Socioeconomic Pathways. Second, a set of pathways that these mobility innovations may follow has been shaped in order to determine to what extent each innovation will potentially pose new requirements on transport data sources, models and decision support tools. The methodology used for developing the scenarios started by a literature review covering the most prominent urban mobility trends.

Then, policy-makers and modellers were engaged in the process through a series of workshops and a Delphi poll. This served to gather inputs from a wide range of end-users and practitioners. The paper covers the results from these methodologies, unveils the resultant scenarios, and outlines the conclusions in terms of future plausible requirements for transport planning tools and techniques.

1. INTRODUCTION

Urban mobility is a dynamic field that is subject to continuous innovation. Different technologies and business models arise to meet the increasing demand for transportation in cities. In recent years, the rapid development of automation and digitalization technologies together with the expansion of shared economy has fuelled the emergence of new mobility solutions. Smartphone connectivity and advanced fleet management strategies based on GPS positioning have boosted the potential of vehicle sharing, either by providing users with a vehicle to drive (e.g., car sharing, bike sharing, e-scooter sharing) or by attending a trip request providing a car with a driver (e.g., ride hailing). In parallel, Mobility-as-a-Service (MaaS) platforms provide travellers with access to a unified gateway to plan, book and pay for a full multimodal door-to-door journey, so the user does not have to worry about who operates each service. All these innovations will face further transformations due to vehicle automation. CAVs are expected to revolutionise bus operation and boost services such as ride hailing, which is likely to become cheaper than current taxi-like services once no driver will be needed.

It has been recently acknowledged that the data analysis techniques, modelling frameworks and decision support tools used by transport planners require major adaptations to properly address emerging mobility solutions (Franco et al., 2020). The requirements guiding these adaptations depend on which will be the indicators and analyses most demanded in the future. Some prominent challenges that are highly likely to arise in any case have been already identified, such as the supply-demand interaction mechanisms in shared mobility services (Li et al., 2018) or the empty trips modelling in the context of vehicle automation (Friedrich et al., 2019).

However, any attempt to improve transport planning tools and techniques in this direction would benefit from more knowledge on the plausible future needs of transport stakeholders. This encompasses two main questions. First, it is highly uncertain how the societal and technological trends surrounding transport systems will evolve. Hence, it is not possible to anticipate a narrow development path for emerging mobility solutions. Second, it is highly uncertain which are the impacts and challenges that cities will face due to the expansion of mobility innovations. This implies that it is difficult to establish requirements for the tools and techniques that will assist transport planners in the implementation and management of new mobility solutions.

Given the importance of anticipation when evaluating the impacts of their decisions, transport stakeholders have usually resorted to scenario-making techniques. The provision of transport infrastructures and services has been traditionally based in deterministic estimations of future demands (Owens, 1995). These forecasts rely on the observed relation between historic travel demand trends and external socioeconomic variables. This approach has been criticized for failing to account for the inherent uncertainties of future travel behaviour (Lyons & Davidson, 2016). In the case of emerging mobility solutions this critique becomes more evident, as there is simply no enough historical data to infer how the demand for the new services will respond to different contexts. As a consequence, deterministic forecasting is ill-suited for anticipating the requirements that transport planning tools and techniques will face as a consequence of the expansion of mobility innovations. Instead, the development of alternative plausible futures seems to provide richer requirements that will lead to more resilient tools and techniques. In line with the two questions mentioned above, two types of scenarios have been developed:

- Exogeneous scenarios, which propose different alternative futures for a series of relevant external factors that shape transport systems (e.g., demographics, economics, etc.). These scenarios can be used to reflect upon the evolution of new mobility solutions in relation to those variables (e.g., for a given socio-demographic situation, what is the expected penetration of vehicle automation?).
- Endogenous mobility-related scenarios, which set up a range of different possible futures for emerging mobility solutions themselves (e.g., business models, levels of adoption, etc.). These scenarios can be used to reflect upon the adaptations that transport planning tools and techniques require depending on the role of these solutions in cities (e.g., for a given modal share of micromobility services, which improvements in transport models are needed?).

The use of these scenarios in stakeholder involvement opportunities facilitates the anticipation to the plausible range of demands that transport stakeholders will pose on data analysis techniques, modelling frameworks and decision support tools.

This paper explains how these future images can be created, describes the scenarios developed and shows how they can be used for exploring the future impact of mobility innovations in transport planning tools and techniques, taking shared mobility services as an example. The document is organised as follows: Section 2 provides the theoretical background for the scenario-making process, Section 3 explains the methodology followed for developing the scenarios, Section 4 presents the exogeneous scenarios for European urban mobility, Section 5 presents the endogenous scenarios related to shared mobility services, Section 6 shows how the scenarios were used to explore the uncertainties associated to shared mobility and its impacts on transport planning tools and techniques, and Section 7 summarises the research conclusions.

2. MOBILITY FUTURES AND SCENARIO-MAKING TECHNIQUES

The acceleration of societal and technological transformations during the 20th century led to a growing interest in the development of rigorous methods for foresighting (Masini, 2006). Future reflections have evolved from individual practices, linked to instinct and survival, to research approaches able to make meaningful contributions to humankind development (Slaughter, 1996). The scientific foundations of this task have been developed by the field called 'futures studies' (Bell, 1997), where the plural 'futures' is emphasized to acknowledge that is hardly ever possible to anticipate a deterministic future (Sardar, 2010).

Scenarios are the main product of futures studies. The notion of scenario is not free from polysemy. Although it clearly resembles the idea of reflecting upon the future, there is no consensus on whether it includes any image of the future or only images drafted under certain conditions or for certain purposes. One of the most common approaches is to embrace a broad definition that includes any 'possible, probable or preferable future' (Amara, 1981; Bell, 1997). This conceptualisation is often accompanied by taxonomies that help to interpret existing scenarios or guide the processes towards new scenarios. Börjeson et al., (2006) provides a synthetic classification that is suitable to many contexts, based on what is the underlying question that motivates the use of scenarios (Table 1).

Predictive scenarios *What will happen…?*	Forecasts	*…if the most likely development unfolds.*
	What-if	*…on the condition of near future events.*
Explorative scenarios *What can happen if…?*	External	*…if an external factor develops.*
	Strategic	*…we act in a certain way.*
Normative scenarios *How can a desired future be reached…?*	Preserving	*…by adjusting the current situation.*
	Transforming (or 'backcasting')	*…by changing current structures.*

Table 1: Scenario types (Börjeson et al., 2006).

The scenarios developed in this paper fall under the category 'explorative scenarios'. They provide a range of possible alternative futures. First, there are no prior assumptions about their likelihood. All of them must be plausible, to pose meaningful questions to transport practitioners, but none is developed to accurately predict the future. Second, there are no prior assumptions about their desirability. There is no prescription of a certain future associated to certain policies, since the goal is to test how transport planning tools and techniques would respond to different future mobility contexts and situations.

More specifically, all the alternative futures addressed in this paper can be classified as 'explorative external scenarios', given that the images are not based on decisions made by the target agents -those who develop transport planning tools and techniques-. Rather, the images are a result of complex societal changes and policy trends that provide a framework for action.

3. SCENARIO-MAKING METHODOLOGY

The scenario-making process conducted to generate the futures presented in this paper involved three steps:

- a desk research phase, which consisted of a literature review of previous initiatives that provide referential scenarios
- a generation phase, which produced an initial version of the scenarios by tailoring the ideas and concepts selected from the referential scenarios; and
- an stakeholder involvement phase, which included a Delphi poll aimed at refining the initial version of the scenarios with target agents.

3.1 First phase: referential scenarios from desk research

A total of 22 references were selected as a basis for the scenario-making process (Table 1). The selection of documents prioritised those focusing on transport sector, as well as those having Europe as geographical scope. As a result, a large number of different types of scenarios were reviewed.

Normative scenarios and R&D roadmaps	(Dotter et al., 2019; Eckhardt et al., 2017; ERTRAC, 2011a, 2011b, 2013, 2017; ERTRAC-ERRAC-Waterborne-ACARE-ECTP Task Force, 2013; European Commission, 2011; Lindsay, 2016; MaaS Alliance, 2017, 2019; Mobility4EU, 2019)
Explorative scenarios	(de Stasio et al., 2013; European Commission, 2017; Hill & Bates, 2018; Lutz et al., 2019; POSSUM, 1998; Seibt et al., 2012; Transport for NSW, 2016; TRANS-TOOLS, 2009)
Predictive scenarios	(de Stasio et al., 2013; Holden & Goel, 2016)
Mobility indicators	(WBCSD, 2015)

Table 1: References used as a basis for the scenario-making process.

The literature review was not restricted to the above selected references. In some cases, the documents led to discover other initiatives that have also worked with scenarios. Thus, a ‘snowball sampling’ technique was followed to ensure that a wide range of relevant scenario-making processes were reviewed. For each scenario contained in these documents, the following aspects were explored:

- the factors and elements that inform each scenario
- the temporal scope of the scenario and the criteria employed for its selection; and
- the links established between mobility futures and the evolution of socioeconomic variables.

3.2 Second phase: generation of the scenarios

The generation of the scenarios involves three tasks. First, certain factors identified in the referential futures are selected as candidates for their inclusion in the scenarios, together with predefined factors that may not be part of previous studies. In the case of exogeneous scenarios, the criteria that drives the selection is the impact of each factor on urban mobility. In the case of the endogenous scenarios, the criteria focus on how the factors contribute to a complete description of alternative mobility futures.

Second, all the factors that are expressed in global terms in the referential scenarios have to be geographically downscaled to the European urban context. Most of the quantitative factors are already segmented by continent in the original source (e.g., demographic figures) and others have been previously analysed either at European or at urban level by additional studies. Moreover, most of the qualitative trends refer to common situations in the well-developed countries, so no particular adjustments are needed (e.g., digitalisation). The factors that are not appearing in previous sources can be derived from the evolution of other dependent factors.

Finally, the resultant evolution of the factors is put together into narratives that provide a short description of the alternative future. In the case of the exogeneous scenarios the narratives are complemented with some basic quantitative figures.

3.2 Third phase: stakeholder involvement

The involvement of target agents is crucial for achieving robust scenarios (Larsen & Gunnarsson-Östling, 2009). In this case, the scenarios were contrasted with transport experts through a two-round Delphi poll conducted during Autumn 2019. This process engaged 16 respondents from transport administrations (50%), transport consulting firms (25%) and academia (25%). The feedback got from the participants in the first round was taken into account to provide a final version of the narratives.

4. EXOGENEOUS SCENARIOS FOR EUROPEAN URBAN MOBILITY

4.1 Socio-shared Socioeconomic Pathways (SSPs) and urban mobility

The desk research phase revealed that climate change research is a valuable source of exogeneous scenarios for transport applications. Anthropogenic climate change research deals with complex systems with a high degree of uncertainty. This implies that these researchers often rely on future scenarios to pose alternative evolutions of the systems involved in climate change (Moss et al., 2010). The production of climate change scenarios has been coordinated by the International Panel on Climate Change (IPCC). This organisation promotes and certifies a set of official scenarios that can be used as a common language by the climate change research community. It is possible to identify two strategies in the production of scenarios along the history of climate change research.

Until 2008, IPCC worked with sequential cause-effect scenarios, which posed certain assumptions on socioeconomical factors to justify different emission levels, which in turn produce different effects and impacts in climate. In 2008, IPCC decided to decouple socioeconomical scenarios from emission scenarios. Two reasons are behind this move (Moss et al. 2010):

- shorten the long process required by the sequential approach; and
- explore with more detail certain relations that were demanded by scenario users, such as adaptation measures effects (van Vuuren et al., 2011).

Therefore, there are currently two groups of climate change scenarios:

- Shared Socio-economic Pathways (SSPs), which focus on population, GDP and urbanization rate. They provide five alternative narratives describing how the societal, political, cultural and economic context may develop, in order to represent five levels of mitigation and adaptation challenges towards climate change (O'Neill et al., 2014).
- Representative Concentration Pathways (RCPs), which focus on the concept of radiative forcing, an indicator of the changes of energy flows into the Earth system caused by greenhouse gases (IPCC, 2014). These scenarios integrate the research conclusions about the possible evolutions of greenhouse gases concentrations and land uses (van Vuuren et al. 2011), which are the main components of radiative forcing.

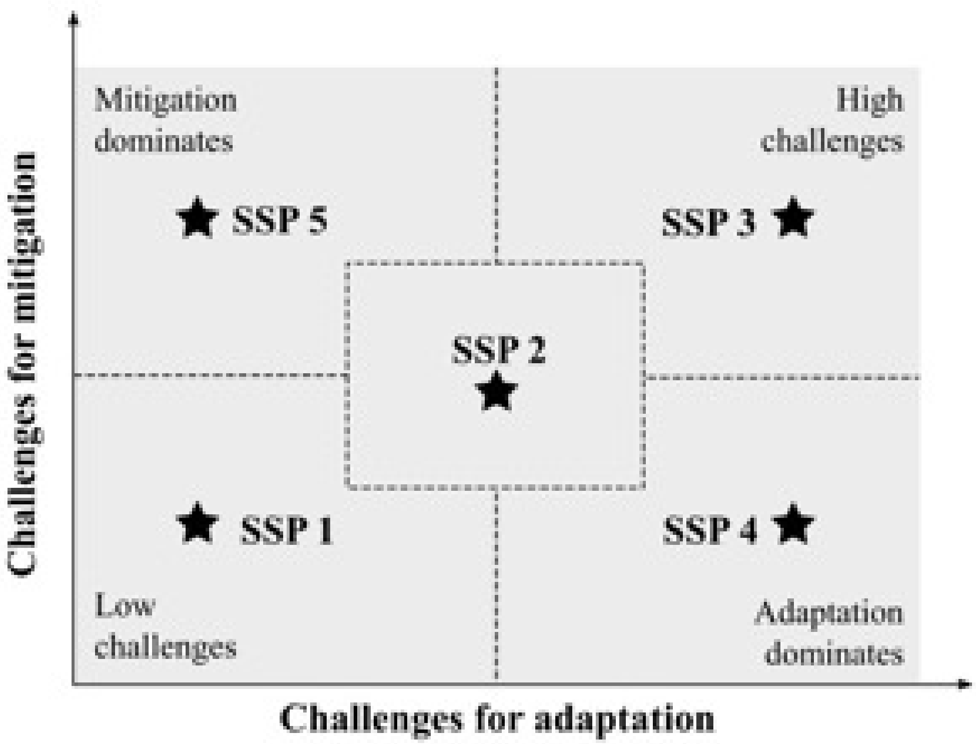

Figure 1: SSPs in the 'adaptation-mitigation challenges space' (O'Neill et al., 2014)

In this context, it is clear that the SSPs developed by the climate change research community have a great potential for inspiring exogeneous scenarios that provide several alternative contexts where urban mobility will have to operate.

There are five SSPs. Each of them produces different challenges for adaptation and mitigation of climate change (Figure).

A complete description of the narrative and the quantitative figures associated to each scenario is available in O'Neill et al. (2017). Each scenario can be summarised as follows:

- SSP1 represents low challenges both for mitigation and adaptation, since society embraces Sustainable Development Goals (SDG) which facilitates an environmental and social sustainable growth.
- SSP3 represents high challenges both for mitigation and adaptation, since the high rivalry among worldwide regions would limit growth and governance capacity for achieving robust agreements.
- SSP4 implies high challenges for adaptation but low challenges for mitigation. This represents a two-speed society, where an upper class would be able to adopt sustainable life-styles helping to mitigate climate change, but the material restrictions suffered by the lower class would limit their capacity to adopt mitigation measures.
- SSP5 implies high challenges for mitigation but low challenges for adaptation. It assumes that technology will be ready to adapt society to climate change, but also that there are no incentives for mitigation.
- Finally, SSP2 is an intermediate scenario where neither mitigation nor adaptation challenges dominate.

It is possible to identify a set of advantages for the application of SSPs in the generation of exogeneous scenarios for European urban mobility:

- There are many studies that already make references to SSPs as a source for further scenario-making processes, providing values for indicators that are relevant to urban mobility.
- IPCC is a very well-known institution and the reports they produce using SSPs as a basis are highly disseminated among research communities and public opinion.
- Many climate change adaptation and mitigation factors are also relevant for the future of transport (Banister, 2011).

There are also some limitations that need to be taken into account when using SSPs for the purposes stated in this paper:

- Given that SSPs have been produced for the specific field of climate change research, there might be mismatches between the needed contents for the scenarios (Kok et al., 2019). However, it is expected that the aforementioned relation between climate change impacts and the transport sector will limit this effect.
- The spatial scope of SSPs is global, while the application seeked in this paper is European. Therefore, SSPs contributions need to be downscaled to European urban areas for being relevant to urban mobility. Downscaling can be problematic, since it assumes that the resulting local scenario will not deviate significantly from the original scenario (Absar & Preston, 2015; Pedde et al., 2019). The consistency during the downscaling process can be ensured by adopting similar approaches to previous research. In this case, there are examples of both European (Kok et al., 2019) and urban (Rohat et al., 2019; Terama et al., 2019) downscaling processes. In addition, the stakeholder involvement phase represents an additional opportunity to improve the adjustment of the alternative futures to the European urban context.

4.2 Adapting SSPs to European urban mobility drivers

The literature about SSPs and their applications provide a set of factors that can be included in the exogeneous scenarios. Each factor selected has specific needs in terms of geographical downscaling and sectoral application, as mentioned in the Methodology section. The following factors are selected to take part of the exogeneous scenarios:

4.2.1 Population growth, urbanisation rate and ageing

These quantitative factors are included in the global SSPs. The models from the International Institute for Applied Systems Analysis (IIASA) provide population forecasts for each SSP at continental level, and a detailed discussion of the results can be found in Kc & Lutz (2017). The US National Center for Atmospheric Research model has produced indicators related to urbanisation rates for each SSP. A discussion of the results can be found in Jiang & O'Neill (2017).

4.2.2 Education levels.

The proportion of citizens with tertiary education is provided also by IIASA models and discussed by Kc & Lutz, (2017) and Kok et al., (2019).

4.2.3 Gross Domestic Product (GDP)

This economic indicator is forecasted for each scenario by IIASA model, and discussed by Crespo Cuaresma (2017). Economic development is also part of European SSPs (Kok et al., 2019).

4.2.4 Technological development

The levels of technology advancements associated to each scenario are included in the SSPs global narratives (O'Neill et al., 2014) and in the European version by Kok et al. (2019).

4.2.5 Environmental consciousness

Each SSP implies a level of environmental consciousness among society. This is described in the global narratives (O'Neill et al., 2014) as well as in the European version (Kok et al., 2019).

4.2.6 Consumption levels

Depending on the economic trends, each SSP is linked to certain consumption trends, which are described in the narratives (Kok et al., 2019; O'Neill et al., 2014).

4.2.7 National income inequality

Income distribution is included in the global SSPs narratives (O'Neill et al., 2014) and is part of the definition of each European scenario in Kok et al. (2019). The role of inequality has been further analysed by Rao et al. (2019), leading to the following conclusions:

- SSP1: low inequality
- SSP2: medium inequality
- SSP3: medium-high inequality
- SSP4: high inequality
- SSP5: low inequality

4.2.8 Land use in cities and urban form

Land uses interact with transport supply and demand features. SSPs include urbanisation rates but they do not address how population is allocated in urban areas. However, the narratives and quantitative features of SSPs suggest correlative trends in urban form evolution.

The evolution of consumption preferences and the population pyramid can be related to preferred residential settlements and availability of land for other purposes (Rohat et al., 2019; Terama et al., 2019):

- SSP1: urban + suburban preference / overall increasing density
- SSP2: not addressed
- SSP3: suburban preference / decreasing density in suburban areas
- SSP4: urban preference / increasing density in urban areas
- SSP5: rural + suburban preference / decreasing density in suburban areas

4.2.9 Pride of ownership vs. shared economy

A contextual factor that is perceived as relevant for emerging mobility solutions is to what extent shared economy is going to challenge (vehicle) ownership models.

This aspect is not addressed by studies based on SSPs, but it is possible to look at the factors behind the intensity of the adoption of shared economy (Hawlitschek et al., 2016): there is a motivation for saving money (Böckmann, 2013) and it is driven by a trust-based collaborative lifestyle (Heinrichs, 2013).

Since economic prosperity and incentives to collaboration are central elements to SSPs, there is an opportunity for formulating an evolution of the pride of ownership in contrast to adoption of shared economies for each scenario:

- SSP1: much higher trust + higher growth → lower pride of ownership
- SSP2: medium trust + medium growth → medium pride of ownership
- SSP3: much lower trust + stagnated growth → high pride of ownership
- SSP4: lower trust + medium growth → medium pride of ownership among higher class, high pride among lower class
- SSP5: medium trust + much higher growth → high pride of ownership

4.2.10 Digital divide

Many emerging mobility solutions depend on the use of smartphones and Internet for the interaction of the end users with the services providers. Hence, the evolution of the digital divide plays a role in the spread of the new mobility options.

While SSPs do not address the evolution of the digital divide, it is clear that this is related not only to age but to income distribution (Haight et al. 2014). Economic indicators related to each SSPs and ageing can be associated with the intensity of the digital divide in each scenario:

- SSP1: high ageing + low inequality → medium divide
- SSP2: medium ageing + medium inequality → medium divide
- SSP3: low ageing + medium-high inequality → medium divide
- SSP4: limited ageing + high inequality → high divide
- SSP5: medium ageing + low inequality → low divide

4.2.11 E-commerce

Shopping trips generation rates might be lower due to the generalisation of e-commerce (Shi et al., 2019). While e-commerce is not directly addressed by SSPs, there are many factors included in these scenarios that have an impact in the potential evolution of e-commerce.

Societal trust, technology advances, urbanisation rate, education, consumerism, interest in diverse products and availability of a wide range of payment methods has been linked to e-commerce adoption (Chaparro-Peláez et al., 2016; Markus & Soh, 2003):

- SSP1: low consumption + high-tech advances + high trust → moderate expansion of e-commerce
- SSP2: medium consumption + medium tech advances + medium trust → moderate expansion of e-commerce
- SSP3: medium consumption + stagnated tech advances + much lower trust → limited expansion of e-commerce
- SSP4: unequal consumption + high-tech advances + lower trust → moderate expansion of e-commerce
- SSP5: very high consumption + high-tech advances + high trust → wide expansion of e-commerce

4.2.12 Teleworking

Work trips generation rates can change if teleworking gains popularity (Alonso et al., 2017; Larson & Zhao, 2017). Telework is feasible in job positions that are largely based in ICT.

The technological development achieved by future societies may ease telework or expand its application to other sectors (Messenger, 2017). Furthermore, it has been observed that telework is more frequent in households with children (Vilhelmson & Thulin, 2016), so a link with fertility can be established as well. Fertility rates are part of the demographic forecasts of each SSPs (Kc & Lutz, 2017).

It has to be noted that this research was conducted before the COVID-19 pandemic, that has boosted teleworking at a much faster pace than expected. Regardless of the expansion driven by the pandemic consequences, the following can be expected:

- SSP1: high-tech advances + high rate of tertiary educated + low-medium fertility → moderate expansion of telework
- SSP2: medium tech advances + medium rate of tertiary educated + medium fertility → moderate expansion of telework
- SSP3: stagnated tech advances + low rate of tertiary educated + low fertility → limited expansion of telework
- SSP4: high-tech advances + low rate of tertiary educated + low-medium fertility → moderate expansion of telework
- SSP5: high-tech advances + high rate of tertiary educated + high fertility → wide expansion of telework

Apart from the downscaling and application process behind the conceptualisation of the factors, two additional aspects have to be defined:

- The scenarios have to be related to a specific time horizon. A SSPs-based approach provide flexibility given that the models for quantitative figures are publicly available and can be used up to 2100. In this case 2050 was used, according to the European urban mobility policies furthest horizon.
- The convenience of a middle-of-the-road scenario. SSPs do include an intermediate scenario (SSP2). In this case only extreme scenarios have been used: by developing an even number of scenarios there is no central future that can be confounded with a predictive scenario (Moss et al., 2010).

4.3 A set of exogeneous scenarios for European urban mobility

The result of the generation phase is a set of four narratives for alternative future context of urban mobility in Europe, together with quantitative figures coming from the corresponding SSP model (Table 2).

Indicator	Sc. 1	Sc. 2	Sc. 3	Sc. 4
EU GDP/PPP annual average growth	+3.0%	+0.9%	+2.5%	+4.9%
EU population total growth	+6.9%	-9.1%	-1.1%	+18.1%
EU urban population growth	+20.7%	-4.4%	+9.3%	+33.4%
EU population over 65 years (2018: 19.7%)	33.8%	31.3%	32.9%	30.7%
EU population aged 30-34 years with tertiary education (2018: 40.7%)	70.5%	31.9%	26.5%	70.6%

Table 2: Quantitative figures associated to each exogeneous scenario (2050).

4.3.1 Scenario 1 – Mixed compact cities in a sustainable Europe (SSP1)

"European society shifts towards sustainability driven by the generalisation of environmental concerns and the popularity of sustainable development goals in public opinion. Changes are reflected both in urban daily life, with lower consumption and higher trust among citizens, and in urban governance, with higher cooperation between authorities. Access to public services is generalised limiting urban segregation and inequalities. The strong efforts for completing the energy transition have boosted European economy, with cities demanding many qualified workers for the green industry. Renewable energies and small-scale storage solutions provide relatively cheap and versatile energy to European cities. The benefits generated by high-tech green industry are reinvested in improving public services, increasing social equality across urban areas. Improvements in life expectancy of all population layers result in an elder population, but with a limited digital divide thanks to the integration measures. Specialty products are delivered by green e-commerce but convenience products are based on proximity and purchased through local consumer communities. Telework is a feasible tool for improving work-life balance, but it is not highly demanded.

Pride of ownership is declining and urban citizens seek collective solutions to daily-life problems. Urban sustainable life-styles are popular and accessible, attracting people to densified urban cores. The high demand for residential areas impacts suburban rings, that become much denser, and are also attractive for certain people given the proximity to natural parks. There are almost no greenfield developments. Mixed compact developments within urban cores host offices and high-tech industry."

4.3.2 Scenario 2 – Stagnant individualist cities in a nationalist Europe (SSP3)

"European society becomes dominated by a climate of distrust where individual and national interests have priority over collective and global targets. Environmental concerns are a residual driver for citizens, so people consume as much as their limited economic resources enable. Few households have managed to improve their living conditions, even in the upper classes. Clean energy research programs suffered from a lack of funding, so fossil fuel dependency remains stable. Tensions between global regions have an extraordinary impact on energy prices in Europe given the lack of own resources. E-commerce becomes standard for specialty products but the limited growth is a barrier for a definite expansion. Telework is only used by qualified workers. Elderly people have limited access to the latest technological developments. Ownership is not only related to a certain social status but also key for feeling safe given the successive economic crises and the security concerns in cities.

The degradation of urban cores intensifies and there is limited demand for living in dense areas, which are associated with high crime levels and high pollution. Urbanisation rate slows down in Europe and the increasing need of national supply of food and energy have reactivated rural areas and the suburban ring of small cities, where low density developments become more and more extensive. Industries remain in current locations and do not need more space due to the economic stagnation. However, offices and institutions tend to move from urban cores to suburban areas."

4.3.3 Scenario 3 – Segregated green cities in an unequal Europe (SSP4)

"European society is unable to limit the growth of inequality in the continent. On the one hand, a highly educated cohort achieves high incomes thanks to the flourishing green economy. Business and political power are concentrated in this exclusive population layer, which is worried about climate change. On the other hand, large sectors of the society fail to improve their conditions due to limited public education investments. They struggle to access a European labour market where old low-tech industry is not generating as many jobs as in the past. There is progress in the energy transition towards renewable sources, but these are still not accessible to everyone due to high prices. Elites rely on e-commerce for almost all products but face-to-face trade still holds for the rest of the population. Similarly, upper classes are familiar with telework, while unemployment and precariousness are the rule among lower income communities. The limited fertility rates lead to an ageing population.

Retirees from higher-income classes have much better access to technology than those from lower-income groups. While ownership is not trendy among urban upper-class, larger lower-income population perceives ownership as positive for achieving social status. The taste of upper classes for creative environments have fuelled the completion of gentrification processes in European urban city centres, limiting suburban growth and low-density developments both in large and small cities. Lower-income groups tend to live in high-density neighbourhoods with stretched social services. Leading high-tech industry settles in the renovated industrial areas within the urban cores, since proximity to the workplace is highly valued by qualified workers."

4.3.4 Scenario 4 – Sprawling technological cities in a vibrant Europe (SSP5)

"European society experiences a period of prolonged growth thanks to the development of climate change adaptation technologies and the cheap energy prices. There is no special consciousness on the effect of the lifestyle on the environment, since technology keeps most people away from the consequences of the nature degradation. As a result, consumption trends move towards resource intensive lifestyles. Fossil fuels are still the main energy source since the exploitation of new deposits is now possible and much cheaper than before, opening the room for the large-scale extraction of shale gas. This benefits European countries and cheapens energy.

There is extensive and promising research related to adaptation measures to issues such as sea level rise or extreme weather effects, with big investments in new smart infrastructures.

E-commerce and teleworking boost allow people to live in small cities and work for companies based in big cities, causing small cities to grow above average. Face-to-face commerce is residual. The high fertility rates spurred by good economy perspectives limit European population ageing. The efforts to enhance human and social capital limit digital divide, although rapid changes in technology make it hard to keep the pace for some elder people. Given societal convergence, pride of ownership is not related to social status but to a strong sense of freedom in cities and their surroundings. Suburban areas become attractive and host the major part of the urban population growth in large cities. Larger properties are highly demanded and therefore many rural municipalities become suburban."

5. ENDOGENEOUS SCENARIOS FOR EUROPEAN URBAN MOBILITY

5.1 'Plausible yet challenging' scenarios

The purpose of endogenous scenarios is to depict different implementation levels and business models of the mobility innovations. As it is the case with exogeneous scenarios, these are explorative alternative futures that have to be plausible but challenging, in order to stimulate creative thinking among the target agents (Banister & Hickman, 2013). The factors analysed for the development of the endogenous scenarios are discussed in detail in Burrieza-Galán et al. (2021).

Three elements were crucial:

- *Particular coverage of each innovation*. In order to emphasize the particularities of each solution, it was decided to separate them and prepare tailored groups of scenarios. Hence each of the following innovations are associated to a group of scenarios: carsharing services, micromobility services, Demand Responsive Transport services, Connected Autonomous Vehicles, Urban Air Mobility and Mobility-as-a-Service.
- *Number of scenarios for each innovation*. In order to keep the number of scenarios manageable but cover alternative evolutions, the approach selected was to provide two opposite scenarios for each innovation. This allows the target agents to better perceive the full range of effects that the development of emerging mobility solutions may entail for the tools and techniques under evaluation (Schwartz, 2012).
- *Temporal scope*. Some developments can take decades to materialize while others may require less time. This implies that the richness of the set of scenarios can benefit from using two different temporal scopes. Following the same criteria than for the exogeneous scenarios, 2050 was set as a limit and 2030 was used as an intermediate milestone, in line with European policy targets.

5.2 Endogeneous scenarios for shared mobility service in Europe.

As mentioned above, the endogeneous scenarios cover up to six different mobility innovations. The complete set is reported in (Burrieza Galán et al., 2021). Here, the two pair of scenarios most closely related to shared mobility services are presented (carsharing and micromobility).

5.2.1 Alternative scenarios for carsharing services

5.2.1.1 Medium term

The electric carsharing operates as an additional transport mode in the cities. The implementation of stricter urban vehicle access regulations and parking management policies in the metropolitan areas imposes limitations in the use of the private cars.

The transport sector is characterized by multimodality, combining mass transport for long-haul trips and individual transport for last-mile. This situation combined with the high acquisition cost of the electric cars benefits the integration of sharing schemes in the transport sector increasing its modal share up to 20-25%.

Electric vehicle infrastructure has also been developed at certain urban areas in order to serves the increasing use of electric vehicles sharing schemes. Electric carsharing is fully integrated with public transport modes and the new mobility services offer more flexibility and better quality of combined transport options.

5.2.1.2 Long term

A holistic housing solution has been developed, which integrates aspects such as mobility, housing, energy distribution and ICT networks. In this scenario the electric sharing vehicle schemes are included in the modern collective housing policies. The different urban electricity needs throughout the day are balanced through smart energy grids. Thus, the holistic housing-mobility approach leads to an easily accessible community-based electric vehicle scheme are developed with low parking requirements. The large-scale implementation of this approach contributes to the homogeneous modal share of electric vehicle solutions.

5.2.2 Alternative scenarios for micromobility services

5.2.2.1 Medium term

Micromobility mainly substitutes other transport modes in short distance trips. The safety regulatory framework for micromobility has been defined in most cities and dedicated lanes for e-scooters and similar vehicles are provided to road users.

Thus, they are used for daily short distance trips instead of car and taxi rides since car ownership appears a decline especially in young people who prefer new transport modes based on pay-per-use rather than a car purchase mode. In addition, and once the policy framework has become mature, operators will be able to explore new business schemes openly pursuing pilot projects and market’s needs, since all of the competitors in the field are subjected to the same regulation.

5.2.2.2 Long term

Micromobility becomes a part of a longer combined trip providing most flexible, efficient, and sustainable transport options. It is combined with public mass transport and following a strict regulatory framework it is completely integrated in the transport system. The mobility packages provided to travelers through MaaS platforms include the micromobility option mainly as a mode to reach or leave the transition stations or combined with the private car in Park&Ride solutions. The design has evolved to be more user friendly for people suffering from motor impairment such as those with injuries, disabilities, or even just old age.

6. MAKING USE OF THE SCENARIOS: RESILIENT TOOLS AND TECHNIQUES FOR TRANSPORT PLANNING

6.1 Basic mobility indicators under different exogeneous scenarios

There are some transport-related factors that are very much linked to the variables that characterise each exogeneous scenario. Hence, the Delphi poll started by exploring how car ownership, trip rates and average trip distances would change under each scenario. **Table 3** shows the average estimations among respondents and **Table 4** shows the variability across the panel.

The main results are the following:

- Sustainable futures are perceived by the experts as linked to decreases in car ownership, average trip distance and even trip generation rates. The remaining scenarios would lead to increases in the three indicators.
- The variable that produces more diverging opinions and also more differences between the four scenarios is car ownership.
- Scenario 4 is associated to a higher relative dispersion, where somewhat contradictory drivers (e.g., telework versus income growth) may introduce additional uncertainties. This suggests that further research on the mobility impacts of the interaction between digitalisation effects and increased purchase power is likely to be welcomed.

These conclusions were already clear after the 1st Round of the poll, but the dispersion of the opinions decreased in the 2nd Round, in particular for the responses to the average trip distance estimation (-25% in the standard deviation).

Exogeneous scenario	Car ownership	Trips / person	Avg. trip distance
1 - Mixed compact cities in a sustainable Europe	Moderate to large decrease	Slight decrease	Slight to moderate decrease
2 - Stagnant individualist cities in a nationalist Europe	Slight to moderate increase	Slight increase	Slight increase
3 - Segregated green cities in an unequal Europe	Unchanged	Slight increase	Slight increase
4 - Sprawling technological cities in a vibrant Europe	Slight to moderate increase	Slight increase	Moderate to large increase

Table 3: Average estimation of the evolution of basic mobility indicators

Exogeneous scenario	Car ownership	Trips / person	Avg. trip distance
1 - Mixed compact cities in a sustainable Europe	Low dispersion	High dispersion	Medium dispersion
2 - Stagnant individualist cities in a nationalist Europe	High dispersion	Medium dispersion	Low dispersion
3 - Segregated green cities in an unequal Europe	Very high dispersion	Very low dispersion	Low dispersion
4 - Sprawling technological cities in a vibrant Europe	Very high dispersion	Very high dispersion	Very low dispersion

Table 4: Relative dispersion among estimations of the evolution of basic mobility indicators

6.2 Shared mobility services under different exogeneous scenarios

The participants in the poll were asked about the expected modal share for these services. More than 70% of participants convey that it will raise above 10% in large cities, regardless of the scenario considered. The average estimation for this figure ranges from 15% in Scenario 2 to 30-35% in Scenario 1, although opinions appeared to be dispersed for most scenarios. Interestingly, there are no major differences in the estimations with regard to city size, as they were are only slightly lower for smaller cities. The 2nd Round produced less disperse results, but converging in the average estimations already obtained in the 1st Round (Figure 1 and Figure 2).

Assuming that not all shared mobility trips are induced demand, part of these trips were based on different transport modes prior to the implementation of the services. According to the participants, the impacts of shared mobility services on other modes would not be the same under all alternative futures. Participants consider that Scenario 1 opens the room for shared mobility services that compete with car instead of with public transport, which would not be the case for the remaining scenarios (Figure 3). Trip induction rates would be low (Figure 4). The results with regard to these impacts did not change from the 1st Round to the 2nd Round.

Figure 1: Shared mobility modal share in large cities across scenarios

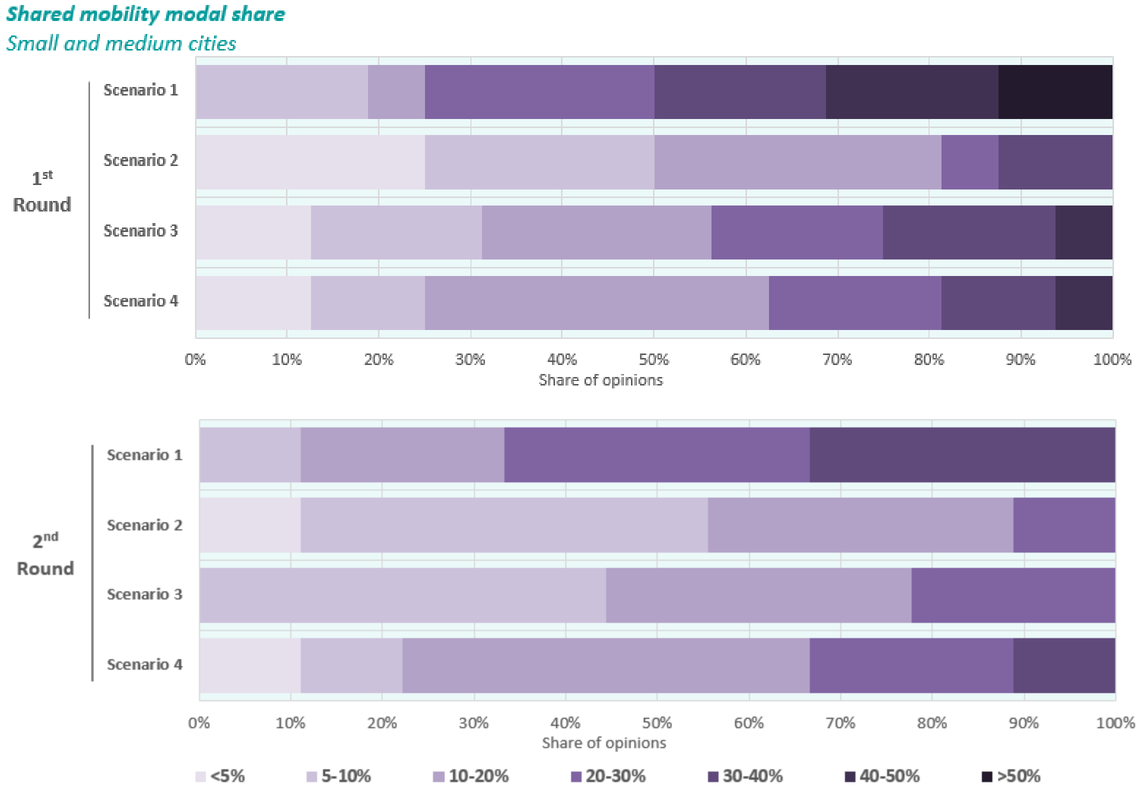

Figure 2: Shared mobility modal share in small and medium cities across scenarios

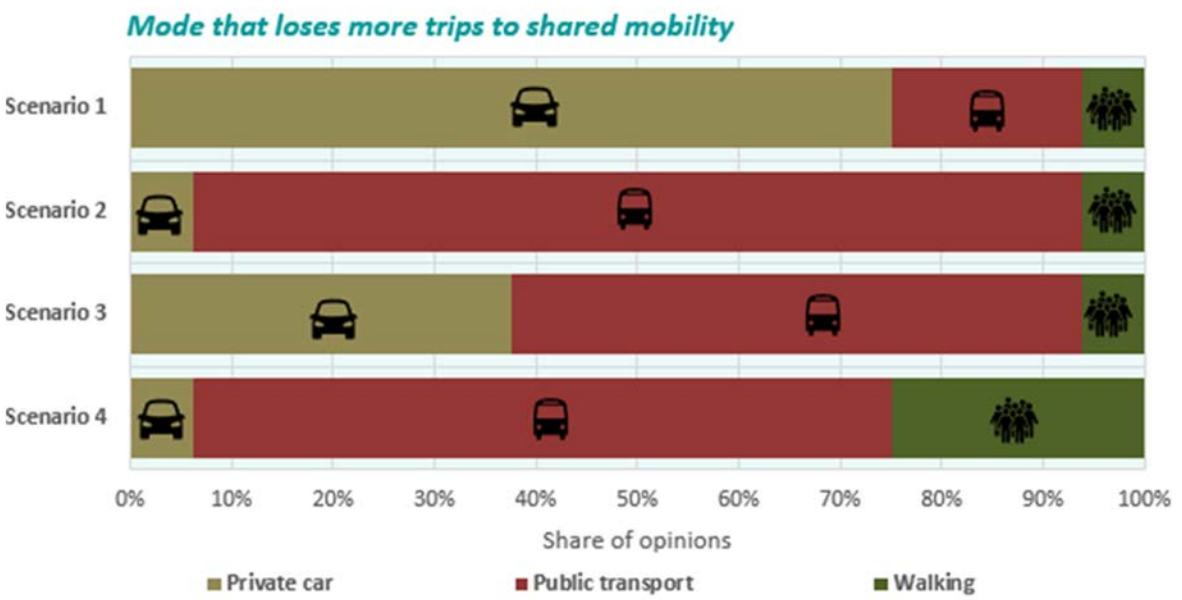

Figure 3: Relative modal shifts to shared mobility across scenarios (1st Round)

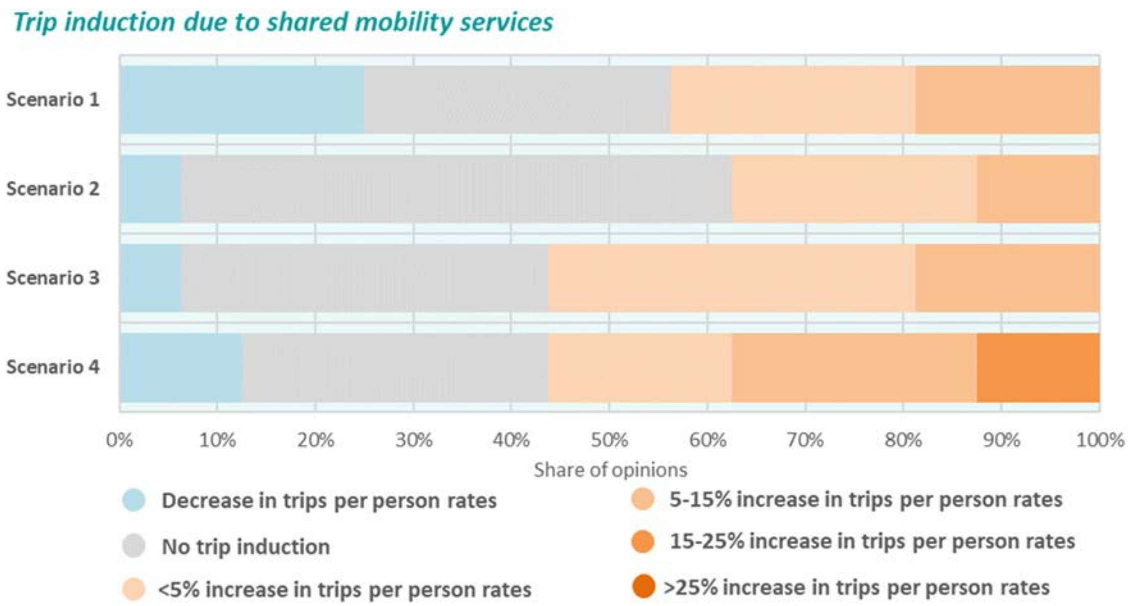

Figure 4: Trip induction estimations due to shared mobility services (1st Round)

The participants were asked also about the likelihood of some trends in how shared mobility systems are provided:

- the achievement of stable agreements between cities and operators,
- the public operation of the services,
- the integration in MaaS platforms,
- the convergence between car sharing and ride sharing due to vehicle automation an
- a general increase in prices to meet profitability targets.

The integration of the services in MaaS platforms is the trend regarded as most probable (Table 5), with low dispersion of opinions within and among scenarios already in the 1st Round (Table 6).

The evolution of the remaining trends seems to be more uncertain, since the dispersion was higher and did not decrease significantly after the 2nd Round. Some trends would depend a lot on the future scenario or present higher dispersion among opinions, such as the agreements between operators and cities to complement public transport.

All scenarios would lead to an increase in prices of these services in order to reach profitability, but the dispersion is higher for this trend than for the ones related to MaaS integration and public transport complementarity.

Exogeneous scenario	Agreements operator-city	Cities as operators	Integration in MaaS	Carsharing = Ridesharing	Increase in prices
1 - Mixed compact cities in a sustainable Europe	Likely to very likely	Likely	Likely to very likely	Slightly likely	Slightly likely
2 - Stagnant individualist cities in a nationalist Europe	Slightly unlikely to unlikely	Slightly likely	Likely	Slightly unlikely	Slightly likely to likely
3 - Segregated green cities in an unequal Europe	Slightly likely	Slightly unlikely to unlikely	Likely to very likely	Slightly unlikely	Slightly likely to likely
4 - Sprawling technological cities in a vibrant Europe	Slightly likely to likely	Slightly unlikely	Likely to very likely	Slightly unlikely	Slightly likely

Table 5: Likelihood average estimation of trends in shared mobility systems (1st Round)

Exogeneous scenario	Agreements operator-city	Cities as operators	Integration in MaaS	Carsharing = Ridesharing	Increase in prices
1 - Mixed compact cities in a sustainable Europe	Very low dispersion	Medium dispersion	Very low dispersion	High dispersion	Medium dispersion
2 - Stagnant individualist cities in a nationalist Europe	Low dispersion	High dispersion	Medium dispersion	Low dispersion	High dispersion
3 - Segregated green cities in an unequal Europe	Medium dispersion	High dispersion	Very low dispersion	Low dispersion	Medium dispersion
4 - Sprawling technological cities in a vibrant Europe	High dispersion	Very high dispersion	High dispersion	Medium dispersion	High dispersion

Table 6: Relative dispersion among the estimated likelihood of trends in shared mobility systems (1st Round)

6.3 The impacts of shared mobility services in cities

Once the participants had reflected about how the exogeneous scenarios will have an influence on the evolution of shared mobility services, they evaluate which impacts these services have on cities. The scenarios are not directly used in the questions of this section of the poll, but had served to put the participants in a creative mode of thinking that allows them to be aware of all plausible impacts. In the 1st Round the opinions were gathered through two open questions addressing current and future impacts, and in the 2nd Round rankings of adverse and positive impacts were requested. Table 7 summarises the answers to the open questions, Figure 5 shows the importance of adverse impacts and Figure 6 shows the importance of positive impacts.

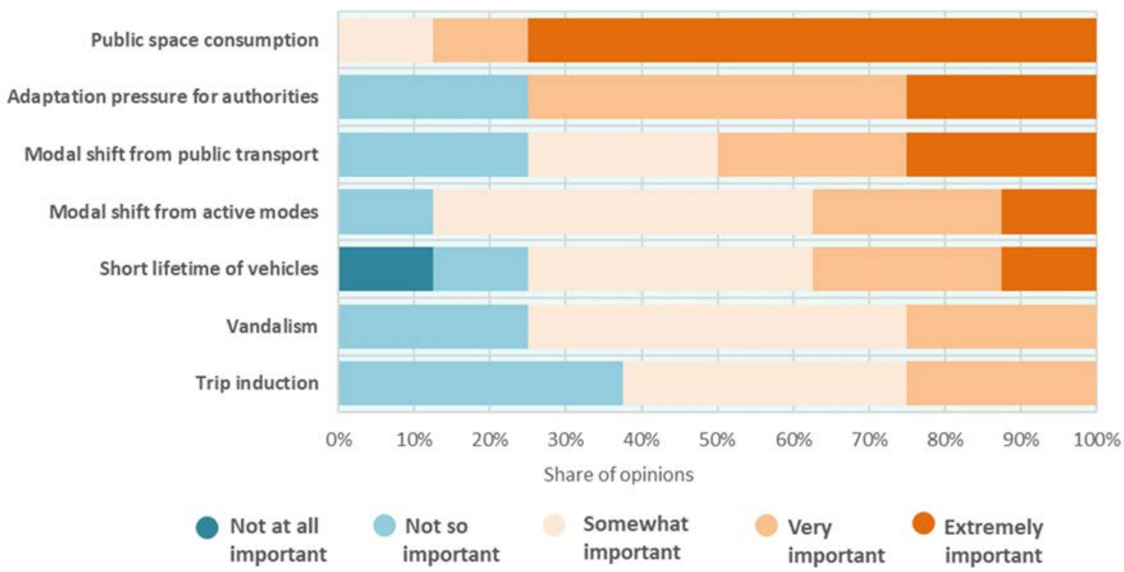

Figure 5: Importance of adverse impacts of new mobility options for cities

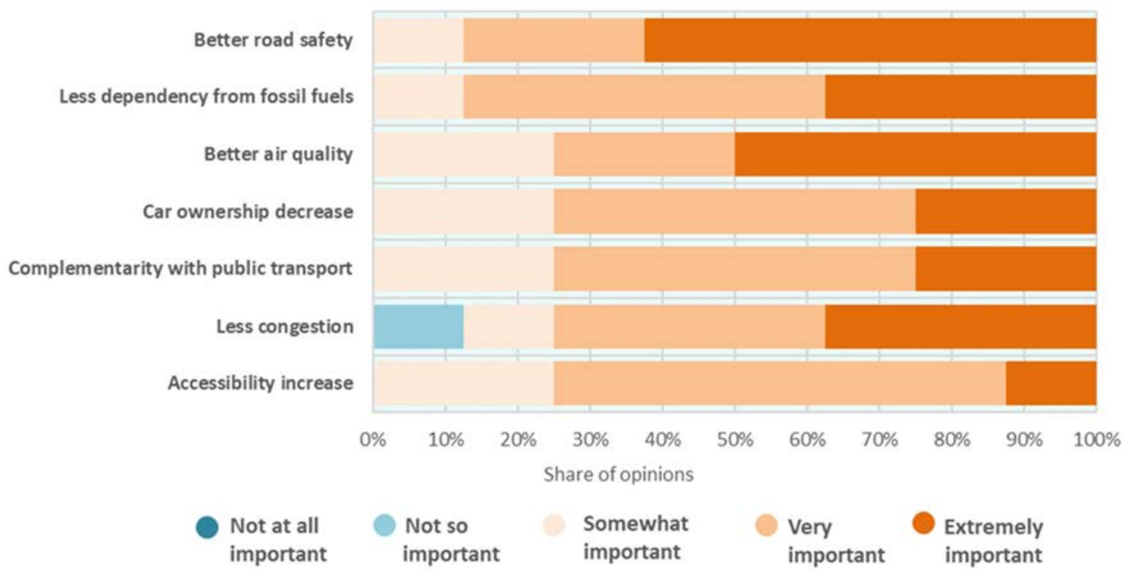

Figure 6: Importance of benefits of new mobility options for cities

Current impacts	Future impacts
Modal shift from public transport services.	A reduction in private car use and ownership. This would lead to an increase in walkability of inner-city areas, less need for parking space, less congestion and better air quality.
Modal shift from active mobility modes (i.e., walking and cycling).	An improvement of accessibility, especially in suburban areas.
Public space consumption, leading to conflicts with pedestrians in sidewalks and with other traditional modes	A replacement of scheduled public transport services, especially in low-density areas.
Short life time of micromobility vehicles drive cities away from sustainable mobility principles.	A reduction in the dependency of urban mobility in fossil fuels.
Increased pressure to public authorities for adaptation to new solutions.	An improvement in road safety.
Vandalism	An improvement of the overall economic performance of the city.
Trip induction.	A series of regulatory challenges for public authorities.
Increase of accessibility.	Modal shifts from traditional modes to emergent modes.
Car ownership decrease.	

Table 7: Potential impacts of shared mobility services in European cities according to participants, from most to least mentioned.

In the 1st Round, a quarter of them reported no current impacts but were aware that they may have impacts in the future. Among those that cited effects of these solutions that are already in place, negative aspects prevailed. Modal shifts from sustainable modes were the ones most mentioned. Interestingly, the answers to the future impacts of emerging mobility solutions were by far more positive, with few exceptions that report that no positive impacts are to be seen. The role of emerging mobility options as a potent alternative to private car use stand out as the most mentioned future impact. The 2nd Round positioned the pressure on public spaces as the most relevant negative impact and safety and energy improvements as the most relevant positive impacts.

6.4 Consequences for transport planning tools and techniques

The final section of the Delphi poll addressed the consequences of emerging mobility options for the transport planning tools and techniques. This subsection reports the results for shared mobility services. First, the participants were asked to evaluate when do they consider that shared mobility services are challenging for data analysis techniques, modelling frameworks and decision support tools. Table 8 shows the results of the analysis. Two thirds of the participants conveyed that shared mobility is already posing significant challenges. About

43% of the respondents consider that a 4% modal share is enough to consider adaptations in the tools and techniques used in transport planning. This percentage climbs up to 68% if the threshold is situated at 6%. This question was also presented as a temporal matter. All respondents considered that shared mobility should be included in supply models before 2040, and a majority of respondents considered that this should have happened before 2020 (the Delphi poll was conducted in late 2018).

Question	Options	% respondents
1. At current implementation levels in your city, do you think that shared mobility is already challenging transport planning tools and techniques?	Yes	66,7
	No	33,3
2. From which implementation level (in terms of modal share) do you expect that the following mobility solutions will require major changes in transport planning tools and techniques?	>2%	25,0
	>4%	18,8
	>6%	25,0
	>8%	6,3
	>10%	25,0
3. When do you think that shared mobility services should be added as a mode option in the transport models with a suitable treatment of the provision of their level of service (supply model)?	Now	43,8
	Before 2020	56,3
	Before 2030	93,8
	Before 2040	100

Table 8: Consequences of shared mobility for transport planning tools and techniques

Second, the participants were asked about the research gaps they find in the area. Data sharing between operators and policy-makers was highlighted by many respondents. Apart from this repeated issue, the following gaps seem to be relevant according to the 1st Round:

- The lack of solid and stable agreements with operators introduces uncertainties to the approaches needed for coping with these solutions. There is a lack of monitoring tools and normative models that would be valuable for policy-makers and regulators.
- The limited cooperation of urban planning and transport planning is also perceived as a gap in relation to this particular issue of emerging shared mobility services.
- The nature of the new options requires disaggregated demand modelling approaches taking into account improved behavioural models and the household context, e.g., in terms of car availability.
- The dynamism of shared mobility supply requires improvements in supply modelling techniques to be useful for the management of these systems.
- The lack of models for assessing specific impacts of these solutions, such as empty trips modelling or car type choice in shared mobility systems.
- The lack of strategies for data fusion, e.g., generation of synthetic populations from mobile phone data and household survey data.
- The limited real-life data available for performing analyses.
- The lack of skills by transport planners to deal with the advances in transport modelling tools.

The 2nd Round served to prioritize these gaps in terms of importance for the accurate modelling of the new mobility options. Figure 7 shows the results for the aspects related to the context of modelling practices, Figure 8 shows the results for data analysis techniques, and Figure 9 reports the results for modelling approaches. Technical skills, data sharing agreements and disaggregated modelling are perceived as most relevant factors.

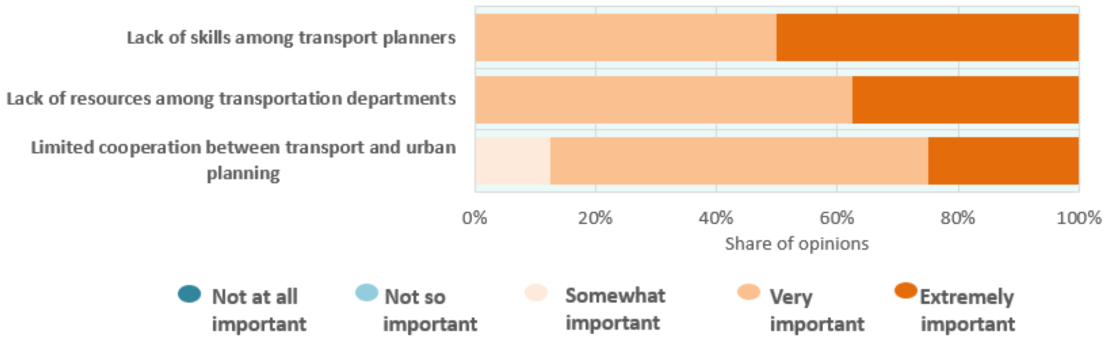

Figure 7: Importance of urban mobility planning cycle barriers

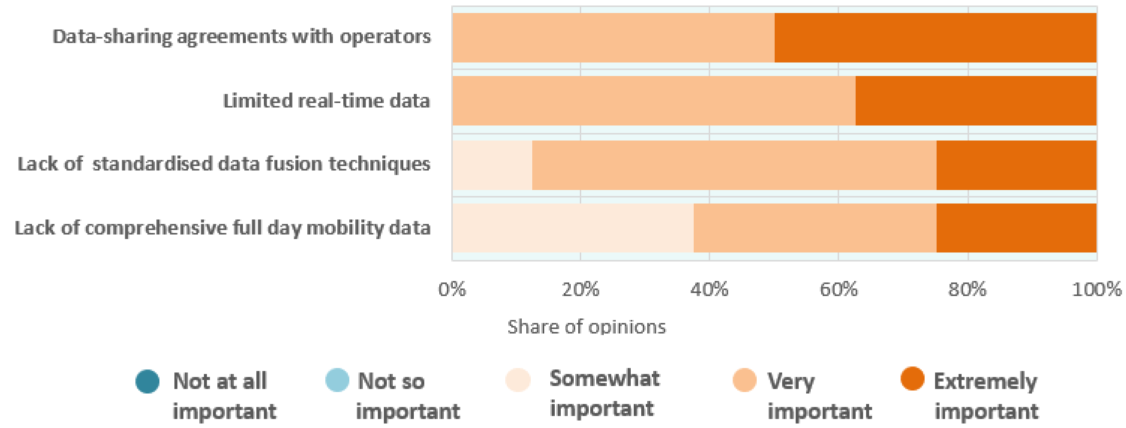

Figure 8: Importance of transport data sources gaps

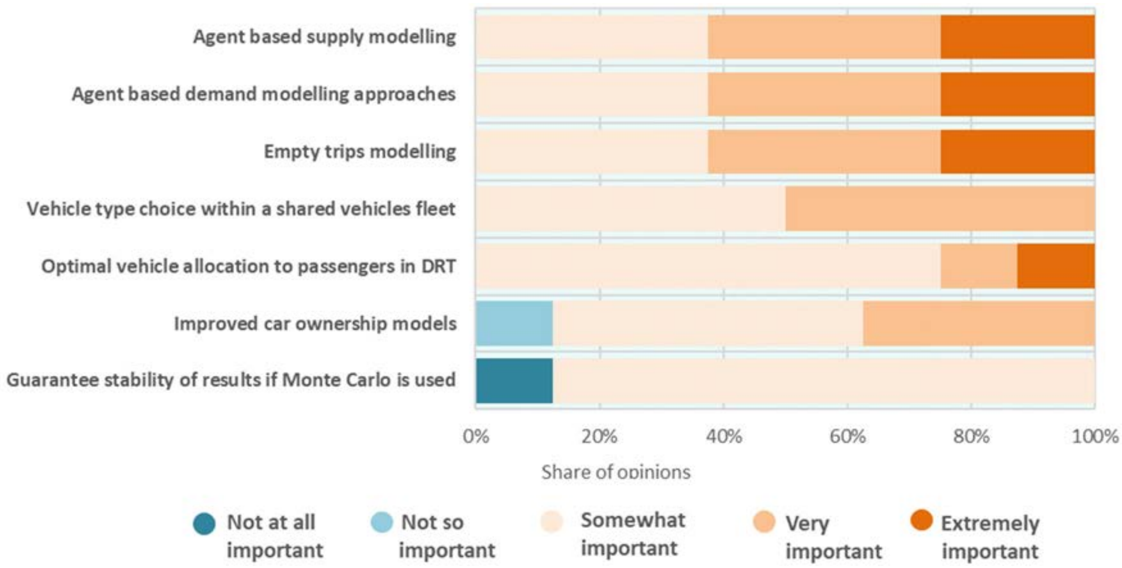

Figure 9: Importance of transport modelling gaps

7. CONCLUSIONS

The rapid development of new technologies and solutions in the transport sector calls for a continuous update of our data analysis techniques, modelling frameworks and decision support tools. This paper shows how the development of explorative scenarios for European urban mobility can facilitate a discussion about the impacts that emerging mobility options have on transport planning tools and techniques. The extensive literature on climate change research provides a good starting point for defining exogenous scenarios that cover the relevant variables that have an influence on how the emerging mobility options will develop in the following decades. The exogeneous scenarios can be complemented with endogenous scenarios that set different implementation levels for the different innovations.

In order to identify which are the requirements that future transport planning tools and techniques will have to meet in order to effectively support cities in the implementation of shared mobility services, a Delphi poll was organised. The poll engaged 16 transport experts and used the exogeneous scenarios as a tool for creative thinking among the participants. The results show that shared mobility is likely to reach modal shares above 10% before 2050 in any scenario.

The societal progress towards sustainability goals and the associated measures will define if the captured demand will come from private cars or from public transport and active mobility. Indeed, a potential modal shift from sustainable modes was the adverse impact most highlighted by the experts. At the same time, the role of shared mobility as an attractive alternative to private car use is seen as the most relevant potential positive aspect.

In order to assess these impacts, the experts claimed that shared mobility services should be included in the transport modelling tools in the next years. The majority agreed that this should happen before they reach modal shares above 4-6%.

Finally, the participants in the poll noted that the main gaps for achieving the integration of the new modes in transport models are the difficulties for reaching data sharing agreements with service providers, the availability of fine-grained data about the demand of the services and the challenges associated to disaggregated modelling. This will require not only technical adaptations but also new skills among practitioners.

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