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# Mobility externalities and sustainable urban development : the case of Shared Automated Vehicles

Ines Jaroudi

► **To cite this version:**

Ines Jaroudi. Mobility externalities and sustainable urban development : the case of Shared Automated Vehicles. Environment and Society. Université Paris-Saclay, 2024. English. NNT : 2024UPAST031 . tel-04650408

**HAL Id: tel-04650408**

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# Mobility externalities and sustainable urban development: the case of Shared Automated Vehicles

*Les externalités de la mobilité et le développement urbain durable : le cas des véhicules automatisés partagés*

## Thèse de doctorat de l'université Paris-Saclay

École doctorale n° 573 : approches interdisciplinaires, fondements, applications et innovation (Interfaces)  
Spécialité de doctorat : Génie industriel  
Graduate School : Sciences de l'ingénierie et des systèmes  
Réfèrent : CentraleSupélec

Thèse préparée dans l'unité de recherche **Laboratoire Génie Industriel** (Université Paris-Saclay, CentraleSupélec), sous la direction de **Guy FOURNIER**, professeur CentraleSupélec, le co-encadrement de **Julie BULTEAU**, maître de conférence HDR, UVSQ

Thèse soutenue à Paris-Saclay, le 14 Mars 2024, par

**Ines JAROUDI**

## Composition du Jury

Membres du jury avec voix délibérative

<b>Jean-Pierre NICOLAS</b> Directeur de recherche CNRS , HDR, LAET – ENTPE	President & Rapporteur
<b>Elodie CASTEX</b> Professeure, Université de Lille 1	Rapporteur & Examinatrice
<b>Isabelle NICOLAI</b> Professeure, Paris Saclay	Examinatrice
<b>Jaafar BERRADA</b> Directeur de domaine, Institut Vedecom	Examineur

**Titre :** Les externalités de la mobilité et le développement urbain durable : le cas des véhicules automatisés partagés

**Mots clés :** Externalités, véhicules automatisés partagés, développement urbain durable, SDGs

**Résumé :** Les villes sont des centres d'activité essentiels, mais leurs populations croissantes amplifient les préoccupations concernant la durabilité environnementale, la gestion des ressources et l'accès équitable à la mobilité. Pour relever ces défis, il faut opérer un changement de paradigme dans le domaine des transports urbains. Les innovations émergentes en matière de mobilité intelligente, notamment les véhicules partagés automatisés électriques (SAV), offrent une solution prometteuse pour redéfinir les cadres de la mobilité urbaine. Ces véhicules offrent le potentiel de révolutionner les transports en proposant des alternatives respectueuses de l'environnement et accessibles. Cependant, leur intégration réussie dans les environnements urbains nécessite une compréhension approfondie des stratégies de déploiement et de leurs impacts subséquents. Cette thèse vise à explorer les complexités entourant le déploiement des SAV et à étudier leurs implications potentielles pour le développement urbain durable dans les villes européennes.

Elle se concentre sur les stratégies de déploiement et leur intégration dans les systèmes de transport. En utilisant la planification de scénarios, des revues de littérature et des calculs d'externalités, elle évalue les stratégies potentielles, en soulignant le rôle crucial de l'intégration pour des impacts positifs dans différents contextes urbains. L'analyse met en lumière comment les minibus automatisés (AM) dans le cadre d'une Mobilité en tant que Service (MaaS) et d'un Système de Transport Intelligent (ITS) pourraient soutenir les transports publics et fournir une solution aux défis de la mobilité urbaine tout en favorisant simultanément le développement urbain durable. Les recommandations politiques mettent en avant l'adaptation des infrastructures, l'engagement des parties prenantes et la promotion des transports multimodaux, en soulignant l'intégration des SAV pour réduire les coûts externes et encourager des pratiques de transport durables dans les villes.

**Title:** Mobility externalities and sustainable urban development: the case of Shared Automated Vehicles

**Keywords:** Externalities, Shared Automated Vehicles, Sustainable mobility, Sustainable Urban Development, SDGs

**Abstract:** Cities are central hubs of activity, but their growing populations amplify concerns regarding environmental sustainability, resource management, and equitable access to mobility. To address these challenges, there needs to be a paradigm shift in urban transportation. Emerging innovations in smart mobility, specifically electric Shared Automated Vehicles (SAV), offer a promising solution to redefine urban mobility frameworks. These vehicles provide the potential to change the current transportation paradigm by offering environmentally friendly and accessible alternatives. However, their successful integration into urban settings requires a comprehensive understanding of deployment strategies and their subsequent impacts. This thesis aims to delve into the complexities surrounding the deployment of SAV, investigating their potential implications for Sustainable Urban Development in European cities.

It focuses on deployment strategies and integration into transportation systems. Using scenario planning literature reviews and externalities calculations, it assesses potential strategies, emphasising integration's crucial role in positive impacts across urban contexts. The analysis highlights how Automated minibuses (AM) within a Mobility-as-a-Service (MaaS) and an Intelligent Transportation System (ITS) could support public transport and provide a solution for urban mobility challenges in cities while simultaneously fostering Sustainable Urban Development. Policy recommendations highlight infrastructure adaptation, stakeholder engagement, and promotion of intermodal transport, emphasizing SAV's integration for reducing external costs and fostering sustainable transportation practices in cities.

## ***L'Ecole Doctorale Interfaces de l'Université Paris-Saclay***

L'Ecole Doctorale **INTERFACES - Approches interdisciplinaires: fondements, applications et innovations** rassemble des équipes dont les sujets de recherche se caractérisent par un positionnement principalement au **croisement de plusieurs disciplines** : la physique, la chimie, la biologie, mais également les mathématiques appliquées ou l'informatique.

L'ED Interfaces est co-opérée par 4 établissements de l'Université Paris-Saclay : Ecole Polytechnique, Université de Versailles - Saint-Quentin, CentraleSupélec, Ecole Nationale Supérieure des Techniques Avancées.

### ***Le Laboratoire Génie Industriel***

Le Génie Industriel se donne comme **défi scientifique** de "**maîtriser la conception et le management des systèmes complexes**".

- Maitriser c'est modéliser, simuler, optimiser, dimensionner, spécifier ...
- La conception est traitée en terme de faisabilité, utilité, utilisabilité, opérabilité, maintenabilité
- Le management est vu sous ses aspects performance, création de valeurs, risques, sûreté de fonctionnement, métriques

Les systèmes complexes abordés sont indifféremment des systèmes techniques, organisationnels, opérationnels, informationnels, décisionnels, tactiques, stratégiques

Le Laboratoire s'organise en quatre équipes de recherche :

- **Equipe DE : Design Engineering**
- **Equipe OM: Operations Management for production and distribution systems of goods and services**
- **Equipe R3: Risk, Resilience, Reliability**
- **Equipe SE : Sustainable Economy**

Les thèses se font principalement dans l'un des domaines scientifiques relatifs à une équipe, même s'il peut arriver qu'elles se fassent transversalement à ces dernières. C'est la complexité des approches (robust-design, axiomatic-design, approche systémique, recherche opérationnelle, modèles stochastiques, évaluation des performances ...) qui fait la force, la performance et l'originalité du Laboratoire.

## EXECUTIVE SUMMARY

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As urban populations continue to grow, accessible and sustainable mobility solutions aligned with Sustainable Development Goals (SDG), in particular SDG 11 are becoming increasingly crucial. Despite the European Union's efforts, transport-related emissions persist, highlighting the pressing need for cleaner transit options. Addressing transport externalities requires a comprehensive approach that urges regulation to align choices with societal costs. In this regard, Automated Vehicles offer promising potential in transforming transportation, particularly Shared Automated Vehicles like Automated Minibuses (AM) that are integrated within Mobility as a Service (MaaS). This thesis was part of the H2020 Project "AVENUE" (Autonomous Vehicle to Evolve to a New Urban Experience), which focuses on analysing AV deployment in public transport. Specifically, this thesis investigates the best strategies for deploying Shared Automated Vehicles (SAV) to foster sustainable urban development in European cities. The primary objective is to explore how externalities can guide the integration of electric SAV to achieve sustainability goals, aiming to offer actionable recommendations for AM integration in public transit for sustainable city growth.

Through a combination of qualitative scenario planning, systematic literature review, and quantitative assessment of external costs, the research aims to determine optimal strategies for integrating Shared Automated Vehicles as a smart mobility solution. To achieve the research objectives, a structured plan incorporating secondary questions will be implemented to gather the necessary information comprehensively. The study aims to address research gaps in urban mobility externalities, the definition of Sustainable Urban Development, Shared Automated Vehicles impacts, and the assessment of these vehicle externalities. By employing a mix of methodologies, including scenario planning, literature review, and external costs assessment, the thesis integrates diverse perspectives to provide a holistic evaluation. The thesis's key findings provide a detailed understanding of urban mobility externalities and their potential implications with the introduction of SAV, particularly AM. The study sheds light on the multifaceted dimensions of Sustainable Urban Development and its connection with sustainable urban mobility, presenting potential deployment scenarios and evaluating their impacts. It provides insights into externalities associated with Shared Automated Vehicles deployment and aligns these findings with policies related to sustainable urban development, emphasising the importance of SDG. The outcomes underscore the significance of deploying Shared

Automated Vehicles, especially AM, in Mobility-as-a-Service/Intelligent Transport Systems (MaaS/ITS) to mitigate negative externalities and leverage potential positive impacts. The policy recommendations emphasise accordingly integrating SAV into MaaS/ITS while emphasising alignment with SDGs, citizen engagement, and infrastructure adaptation. Overall, the thesis concludes that integrating Shared Automated Vehicles, particularly Automated Minibuses, presents a significant opportunity to foster sustainable urban development by mitigating negative externalities, enhancing mobility, and aligning with city sustainability goals.

## RESUME

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Alors que les populations urbaines continuent de croître, des solutions de mobilité accessibles et durables, conformes à l'Objectif de Développement Durable ODD 11 - Faire en sorte que les villes et les établissements humains soient ouverts à tous, sûrs, résilients et durables, deviennent de plus en plus cruciales. Malgré les efforts de l'Union européenne, les émissions liées aux transports persistent, soulignant le besoin pressant d'options de transport plus propres. La prise en compte des externalités liées aux transports nécessite une approche globale qui encourage la régulation afin d'aligner les choix sur les coûts sociaux. Dans ce contexte, les Véhicules Autonomes (AV) offrent un potentiel prometteur pour transformer les transports, en particulier les Véhicules Automatisés Partagés (SAV) tels que les Minibus Automatisés (AM) intégrés au sein de la Mobilité en tant que Service (MaaS). Cette thèse s'inscrit dans le cadre du Projet H2020 "AVENUE" (Véhicule Autonome pour une Nouvelle Expérience Urbaine), axé sur l'analyse du déploiement des AV dans les transports publics urbains. Plus précisément, cette thèse étudie les meilleures stratégies de déploiement des Véhicules Autonomes Partagés pour promouvoir un développement urbain durable dans les villes européennes. L'objectif principal est d'explorer comment les externalités peuvent guider l'intégration de SAV électriques pour atteindre des objectifs de durabilité, visant à proposer des recommandations opérationnelles pour l'intégration des AM dans les transports publics afin de favoriser la croissance urbaine durable. A travers une combinaison d'approches qualitatives et quantitatives telles que la planification de scénarios, de la réalisation d'une revue de la littérature systémique et d'évaluation quantitative des coûts externes, la recherche vise à déterminer des stratégies optimales pour intégrer les SAV en tant que solution de mobilité intelligente. Pour atteindre les objectifs de recherche, un plan structuré en 4 parties intégrant des questions secondaires sera mis en œuvre pour rassembler de manière exhaustive les informations nécessaires. L'étude vise à combler les lacunes de recherche concernant les externalités de la mobilité urbaine, la définition du Développement Urbain Durable (SUD), les impacts des SAV et l'évaluation des externalités spécifiques aux SAV. En utilisant un mixte de méthodologies comprenant la planification de scénarios, l'examen de la littérature et l'évaluation des coûts externes, la thèse intègre des perspectives diverses pour offrir une évaluation holistique. Les principales conclusions de la thèse fournissent une compréhension détaillée des externalités de la mobilité urbaine et de leurs implications potentielles avec l'introduction des SAV, en particulier des AM. L'étude met en lumière les dimensions multifacettes du SUD et sa connexion avec la

mobilité urbaine durable, présentant des scénarios potentiels de déploiement et évaluant leurs impacts. Elle offre des aperçus sur les externalités associées au déploiement des SAV et aligne ces résultats sur les politiques liées au développement urbain durable, soulignant l'importance des Objectifs de Développement Durable (ODD). Les résultats soulignent l'importance du déploiement des SAV, en particulier des AM, dans la Mobilité en tant que Service/Systèmes de Transport Intelligents (MaaS/ITS) pour atténuer les externalités négatives et tirer parti des impacts positifs potentiels. Les recommandations politiques mettent l'accent sur l'intégration des SAV dans (MaaS/ITS) tout en soulignant l'alignement sur les ODD, l'engagement des citoyens et l'adaptation des infrastructures. Dans l'ensemble, la thèse conclut que l'intégration des SAV, en particulier des AM, présente une opportunité significative pour favoriser un développement urbain durable en atténuant les externalités négatives, en améliorant la mobilité et en s'alignant sur les objectifs de durabilité urbaine.



## ***Acknowledgement***

The research work developed in this thesis received funding from the AVENUE project (Autonomous Vehicle to Evolve to a New Urban Experience), funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 769033.

## ***Disclaimer***

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## **Remerciement**

In the midst of challenge and adversity, the true test of character is revealed. I am forever grateful to those who have been a beacon of support and encouragement along this demanding path. As Helen Keller aptly said, "*Alone we can do so little; together we can do so much*". This thesis stands as a testament to the collective efforts and support of my mentors, colleagues, and loved ones.

I extend my deepest gratitude to my PhD supervisors, Guy Fournier and Julie Bulteau, for their guidance throughout this thesis journey. Their attentiveness and presence were invaluable, shaping every step of this process. My heartfelt thanks go to my team at Pforzheim University, particularly my colleagues Dorien Duffner-Korbee, Eliane Horschutz Nemoto, Adrian Boos, and professors Tobias Viere and Gabriele Naderer. I deeply appreciate the shared support, feedback, and knowledge exchange during our AVENUE collaboration.

Special mention goes to Tobias Viere, Dorien Korbee, and Julie Bulteau for their unwavering supervision and kindness during challenging times; their guidance was pivotal.

I extend my gratitude to my colleagues at Fraunhofer ISI, Inga Boie and Viktor Müller, for their encouragement. A heartfelt thank you also goes to the Centralesuplec staff, especially Suzanne and **Christèle**, for their assistance. To my family—my father, sister, and brother—I express my deepest appreciation for their continuous support and encouragement. My profound acknowledgement goes to my husband, whose unwavering support and understanding have been instrumental in this journey. I wouldn't have reached this milestone without his love and encouragement.

This work is dedicated to my mother, who is no longer with us. Her devotion and resilience, despite illness, have been a constant inspiration. I dedicate this achievement to her memory, aspiring to make her proud.

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## LIST OF ABBREVIATIONS

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<b>API</b>	Application Programming Interfaces	<b>PT</b>	Public Transport
<b>AM</b>	Automated Minibuses	<b>SAV</b>	Shared Automated Vehicles
<b>AV</b>	Automated Vehicles	<b>SECAP</b>	Sustainable Energy and Climate Action Plan
<b>CCAM</b>	Connected, Cooperative, And Automated Mobility	<b>SDG</b>	Sustainable Development Goals
<b>CH<sub>4</sub></b>	Methane	<b>SLR</b>	Systemic Literature Review
<b>CO<sub>2</sub></b>	Carbon Dioxide	<b>SO<sub>2</sub></b>	Sulfur Dioxide
<b>EU</b>	European Union	<b>SP</b>	stated preference
<b>EV</b>	Electric Vehicles	<b>SUD</b>	Sustainable Urban Development
<b>GDP</b>	Gross domestic product	<b>SUM</b>	Sustainable Urban Mobility
<b>GHG</b>	Greenhouse Gases	<b>SUMP</b>	Sustainable Urban Mobility Plans
<b>GWP</b>	Global Warming Potential	<b>ttw</b>	tank-to-wheel
<b>ICEV</b>	Internal Combustion Engine Vehicles	<b>V2X</b>	Vehicle-to-X
<b>ICT</b>	Information and Communication Technology	<b>VKm</b>	Vehicle Kilometer travelled
<b>ILA</b>	Intuitive Literature Approach	<b>VOT</b>	Value-of-Time
<b>IPA</b>	Integrative Propositional Analysis	<b>VSL</b>	value of statistical life
<b>IS</b>	Interdisciplinary Studies	<b>wtt</b>	well-to-tank
<b>ITS</b>	Intelligent Transportation System	<b>wtw</b>	well-to-wheel
<b>ITF</b>	International Transport Forum		
<b>LCA</b>	Life Cycle Assessment		
<b>MaaS</b>	Mobility As A Service		
<b>MC</b>	Marginal Cost		
<b>MRMT</b>	Microrecensements Mobilité Et Transports		
<b>N<sub>2</sub>O</b>	Nitrous Oxide		

<b>NMT</b>	Non-Motorised Modes
<b>NOx</b>	Nitrogen Oxides
<b>PCU</b>	Potential Capacity Unit
<b>PESTLE</b>	Political, Economic, Social, Technological, Legal, Environmental
<b>Pkm</b>	Person-Km
<b>PM</b>	Particulate Matter
<b>PRM</b>	People with Reduced Mobility

## **PUBLICATIONS**

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### Journal Articles

Jaroudi, I., Duffner-Korbee, D., Nemoto, E.H., Bulteau, J., Boos, A., Viere, T., Fournier, G., Potential Impacts Of Future Deployment Scenarios Of Shared Automated Vehicles European Transport Research Review -accepted with revision,

Jaroudi, I., Duffner-Korbee, D., Nemoto, E.H., Bulteau, J., Boos, A., Viere, T., Fournier, G., Deploying Shared Automated Vehicles For Sustainable Mobility: External Costs Assessment In Lyon-Viellemurbanne And Geneva - International Journal of Sustainable Transportation - Submitted

Leveraging Sustainable Urban Development through AM in MaaS/ITS: A Comparative Policy Analysis of Geneva and Lyon - Prepared for submission

### Conference Articles

Jaroudi, I., Nemoto, E.H., Korbee, D., Bulteau, J., Viere, T., Fournier, G. (Eds.), 2021. What is the potential impact of the transition from traditional transport to new mobility models (electric automated minibuses) in European cities? <https://gerpisa.org/node/6370>

Nemoto, Eliane Horschutz; Jaroudi, Ines; Fournier, Guy (2021): Introducing Automated Shuttles in the Public Transport of European Cities: The Case of the AVENUE Project. Nathanail E.G., Adamos G., Karakikes I. In: Nathanail E.G., Adamos G., Karakikes I. (eds) Advances in Mobility-as-a-Service Systems. CSUM 2020. Advances in Intelligent Systems and Computing: Springer, Cham (1278).

# 1 INTRODUCTION

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## 1.1 RESEARCH CONTEXT

### Meeting Urban Challenges through Sustainable Mobility

Urban areas are experiencing unprecedented growth, hosting a larger population than at any other point in history. This surge poses numerous challenges, primarily centred around accessibility. Accessibility is a central obstacle for urban centres, and mobility serves as a conduit to achieving it, as articulated by UN-Habitat (2013). It refers to the number of travel options within a given distance or time frame. It improves when new transport infrastructure allows reaching destinations faster or accessing farther places without increasing travel time, thus creating new travel opportunities (Nicolai and Le Boennec, 2018). Sustainable mobility is crucial to ensure accessibility to all. Banister (2008) defines sustainable mobility as: *"providing an alternative paradigm within which to investigate the complexity of cities and to strengthen the links between land use and transport"*. Sustainable Urban Mobility (SUM) is a cornerstone in achieving sustainable cities, highlighted by Sustainable Development Goal (SDG) 11, particularly through target 11.2. This target aims to establish *"safe, affordable, accessible, and sustainable transportation systems by expanding public transport, with a focus on vulnerable groups"*. By enhancing accessibility to safe, affordable, and efficient transportation while reducing the environmental impact of commuting, SUM addresses key objectives within SDG 11 for sustainable cities and communities (United Nations, 2015). Cities worldwide face many challenges in pursuing sustainable development, with inefficient and polluting transportation systems being a significant hurdle (Guzman et al., 2020). Road transport is a major source of air pollution and greenhouse gas emissions (GHG) in urban areas, resulting in societal costs of approximately €270 billion annually due to congestion (ECA, 2020).

### EU's Urban Mobility: Toward Sustainable Transformations

Public transport is at the core of sustainable mobility, forming the foundation for an accessibility-driven urban mobility paradigm. This sustainable approach offers a lens to comprehend urban complexities and fortify the interplay between land use and transportation (Hickman et al., 2013; Tan, 2018). Transitioning from cars to public transportation presents a formidable challenge for urban transport planners and

policymakers in European cities. Cars are often perceived as the most convenient travel choice. Therefore, experts stress the necessity of enhancing the appeal of public transport systems by integrating increased reliability, efficiency, security, and safety (UN-Habitat, 2013; Mattioli et al., 2020). The current mobility paradigm is unsustainable and requires drastic changes to mitigate its negative impact on cities (EEA, 2023). Despite recent efforts to modernise the transport sector and promote sustainable mobility practices in the EU, public transportation modal shares remain low, and the current status is not promising. Transport demand recorded a 20% increase in passenger travel and 18% in private motorised transport between 2000 and 2019 (EEA, 2023). In 2022, cars consumed half of the transport energy consumption, with fossil fuel still accounting for 91% of the energy share, resulting in CO<sub>2</sub> emissions at 30%. During the COVID restrictions, there was a remarkable drop in emissions, only for them to rebound to their normal increasing rates after the travel restrictions were lifted. In 2022, in the EU, CO<sub>2</sub> emissions were 1.5% higher than in 2000, and energy consumption was 8% higher, according to reports by Enerdata (2022), the European Commission (2020), and the IEA (2023).

Regarding energy efficiency, in 2022, transport only contributed to 17% of energy savings (households 44%, industry 33%, and services 9%), which is almost twice as low as its share of energy consumption. After COVID, public transport suffered, and in 2021, its modal share dropped from 20% to 15% in the EU. Only a few countries in the EU managed to increase the share of efficient public transport modes (IEA, 2023; Lapillonne and Payan, 2023).

### Addressing Urban Transport Externalities

To tackle urban congestion, it is not enough to just improve infrastructure. Effective management of travel demand is crucial. Implementing strategies to reduce excessive reliance on private vehicles and promote active transportation can greatly help in reducing congestion, easing parking strain, and improving public health (Guzman et al., 2020; Salihou et al., 2022). Recognising the dual influence of urban mobility on economic progress and the environment, the EU advocates for SUM. This entails crafting strategies that encourage a transition to cleaner and more sustainable transportation methods, including walking, cycling, public transit, and redefining patterns related to car usage and ownership (ECA, 2020). An external cost analysis offers a method to measure the broader societal implications arising from integrating Automated Vehicles (AV) into the transportation system. Pigou (1920) defined an externality as an extra cost or benefit

accruing to a third party because of an economic transaction between two other parties. This could be addressed with urban road pricing, such as Pigouvian taxes, to internalise the external costs by making the responsible parties pay for the societal harm they cause (Bulteau, 2016). Typically, these costs related to transport are not directly shouldered by the individual user, thus often overlooked when making transport decisions (Bösch et al., 2016; Jochem et al., 2016; Kaddoura et al., 2017; CE Delft, 2019b). Road transport imposes various negative externalities on society, encompassing environmental degradation, road damage, accidents, land use, congestion, noise, and reliance on oil. These costs, which are not typically factored into current market prices within the road transport sector, have significant societal impacts. For instance, the external cost of congestion is the added expenses and negative effects, like time delays, increased fuel use, and pollution caused by traffic jams, impacting both individuals and society (CE Delft, 2019a). To forge an effective mobility model for the future, it is imperative to consider the genuine costs associated with transportation. The regulatory framework must be tailored to incentivise individuals to shift to sustainable mobility choices (Santos et al., 2010a).

#### Automated Vehicles: Transforming Urban Transportation

Advancements in AV technology promise to transform transportation systems and urban development. AV are self-driving vehicles equipped with advanced technologies allowing them to navigate and operate without or with limited direct human control (SAE, 2018). Under the right conditions, AV could pave the way for a more environmentally friendly, accessible, and cost-effective mode of transportation (Berrada et al., 2020). Further investigation is needed to fully understand the effects of these new transportation methods. Researchers, policymakers, and industries seek to fully understand the long-term and short-term ramifications of their integration in a real-world setting by running pilot tests. The aim is to explore ways to introduce AV in a manner that enhances the quality of life in cities. The significant advancements in AV technology bring us closer to a future where they could take over as the primary mode of transportation. The impact of such a shift in modal transport will shape the transportation system (Zmud and Sener, 2017). AV studies have shown that deploying automated vehicles as a shared mode of transport can significantly reduce GHG emissions, accidents, and the need for parking spaces (Fagnant and Kockelman, 2015b; Krueger et al., 2016).

SAV is a broad term used to describe the integration of automated driving technology with sharing modes. 'Shared' typically encapsulates two distinct aspects: 'goods sharing'

and 'service sharing', which is explained more in Chapter 2. SAV includes different types of shared vehicles, such as automated minibuses and robotaxis, as well as ridesharing services, a mobility gap filler (Gruel and Stanford, 2016; Jing et al., 2019; Wang et al., 2021). If powered by renewable energy, SAV could reduce car use, traffic congestion, and air pollution. However, they could also lead to job displacement and cybersecurity risks. Deployment strategy must be carefully considered to maximise benefits and minimise negative impacts (Feys et al., 2020a; Narayanan et al., 2020b; Nikitas et al., 2021).

A form of SAV that is gaining more attention lately is the Automated Minibuses (AM), especially when seamlessly integrated into public transport and Mobility as a Service (MaaS) systems (UITP, 2017). Deploying AM to complement public transport within MaaS/Intelligent Transport Systems (ITS) can provide passengers with seamless, intermodal trips through digital platforms (Fournier et al., 2023). This strategy can potentially significantly impact both transportation systems and cities, offering sustainable, accessible, affordable, and environmentally friendly solutions. It is also predicted to generate positive externalities related to it.

AM integrated with public transport could support a welfare economy by providing efficient and accessible transportation options that enhance societal well-being and equity. It improves mobility for a broader population, promoting inclusivity and social welfare (Emory et al., 2022). Robotaxis provide a personalised transportation service that caters to individual preferences. Unlike SAV integrated with public transport services, the robotaxi model operated by private operators does not require ride-sharing and offers immediate door-to-door service. The pricing structure is based on demand, similar to market-based economies. This model aligns with market principles of tailored services and user-pay models of transit services (Antoniali et al., 2022)

Policymakers are faced with tremendous challenges to guide the transition from Internal combustion engine vehicles (ICEV) to automated and electric vehicles that support public transport to avoid repeating a car-centric urban development model (Alessandrini A, 2016; Acheampong et al., 2021)

The introduction of AV and SAV poses a multitude of challenges for decision-makers, including shifts in land use, altered travel patterns, and potential increased energy consumption with environmental implications due to rebound effects. However, balancing SAV deployment with equitable societal benefits poses a significant and

complex challenge. Urban and transport planners have adopted a "wait-and-see" approach, yet acknowledging the need for regulation to avoid conflicts with social and environmental goals. A "laissez-faire" governance approach may exacerbate congestion and accessibility issues, potentially deepening inequalities. Thus, more targeted policies are required (Milakis et al., 2017b; Milakis, 2019)

## 1.2 THESIS FOCUS AND METHODOLOGICAL APPROACH

### Main Research Objective

The primary objective of this thesis is to evaluate the potential deployment scenarios of SAV and their impact on sustainable urban development in European cities. Through a combination of qualitative scenario planning, systematic literature review, and quantitative assessment of external costs, the research aims to determine optimal strategies for integrating SAV as a smart mobility solution. The thesis explores how reducing externalities, particularly through introducing electric SAV, can contribute to achieving sustainable urban development goals. Furthermore, it seeks to provide actionable recommendations for effectively deploying AM in public transport systems within these cities.

**Main research question:** How can externalities help determine ways to deploy smart mobility like electric Shared Automated Vehicles to achieve sustainable urban development in European cities?

### Secondary Research Objectives

During the research process, it is important to have a well-structured plan in place to ensure that the necessary information is gathered. One way to achieve this is by utilizing a series of secondary questions that can help to clarify and expand on the primary research questions. These secondary questions can provide additional context and help to uncover any additional relevant information that may have been missed. Using a structured approach with secondary questions, the research can be conducted more thoroughly, leading to more accurate and comprehensive results (Taherdoost, 2021). Figure 1, at the end of this section, shows the overall structure of the thesis.

- **Research gap 1:** Understanding urban mobility externalities in relation to AV, SAV, and AM externalities



The concept of external costs is an important tool in highlighting the potentially harmful impacts of transportation (Verhoef, 1994). By assigning a monetary value to impacts that usually go unaccounted for and that society has to bear the burden of, external costs provide a powerful incentive for policymakers to make decisions that prioritise the well-being of their communities (Calthrop and Proost, 1998; Helbling, 2020).

When introducing new means of transport, such as AV and SAV, the same logic could apply. Policymakers could use externalities as a powerful indicator to determine which deployment scenario would benefit their cities. They could assess the externalities related to AV and determine whether the benefits of deploying them outweigh the potential costs (Nocera, 2021).

However, to evaluate the externalities related to AV, it is crucial to take a step back and research urban mobility externalities in general. It is important to understand the broader context of transportation externalities, including congestion, emissions, and accidents, and how they impact society as a whole. This understanding will help make informed decisions about the deployment of AV and their impact on the transportation system.

In the end, AV and SAV will be deployed within the transportation system, and their impacts will depend on the changes in the different modal shares in the system. The deployment of AV could change how people travel, and policymakers need to be prepared to manage this change effectively. By taking into account the externalities related to AV and their impact on the transportation system, policymakers can ensure that the deployment of these vehicles benefits society as a whole.

**Research question 1:** What are the externalities attributed to urban mobility and the potential externalities of introducing shared automated vehicles?

**Method:** Literature review

- **Research Gap 2:** Lack of clear definition of sustainable urban development (SUD) and its relation to smart mobility

SUD comprises various dimensions, and there is no universal consensus on its definition. Its diverse interpretations emphasise the complexity and interdisciplinary nature of SUD. Generally, SUD aims to foster both livable and resilient cities amidst evolving climatic conditions and consists of economic, environmental, and social sustainability (Yigitcanlar and Teriman, 2015; European Commission, 2019). Urban mobility and development are intricately linked. Transport planning plays a crucial role in determining how well a city functions. This is because transportation is the backbone of urban life. It enables people to move around the city, commute to work, participate in education and social life outside

their immediate environment, and access essential services (Cervero, 2001). Well-designed transport infrastructure and services like highways, bike lanes, and public transit systems can reduce traffic congestion and travel time, improving productivity and economic growth.

Additionally, new and smart mobility, such as SAV, MaaS, and ITS, can reduce the number of ICEV on the road, which can help reduce negative externalities such as air pollution and improve the overall quality of life in cities (Stren, 2001). Understanding the impact of digitisation in transportation on sustainable urban development is crucial. The current research mainly concentrates on smart cities as a prerequisite for intelligent transportation systems. However, the misconception that smart cities are solely about technology also applies to smart mobility, including automated vehicles, which are viewed as innovative technologies rather than tools for sustainable development (Nikitas et al., 2020).

**Research question 2:** How to define sustainable urban development? And how it relates to sustainable urban mobility?

**Method:** Literature review

- **Research Gap 3:** Limited research exists on different SAV deployment scenarios, the interconnected contextual conditions and potential consequent impacts.

Simulation models play a crucial role in forecasting and understanding the potential impacts of introducing SAV in cities (Wang and Zhang, 2021). They provide valuable quantitative insights into various aspects like traffic flow, congestion levels, environmental impact, and more. However, relying solely on simulations has its limitations. These models often oversimplify or fail to capture the complex and context-dependent nature of urban environments (Abbasabadi and Ashayeri, 2019; Wu et al., 2023). They might not fully represent the intricate socio-economic, political, and behavioural aspects that influence SAV deployment and its subsequent impacts. Complementing simulation-based approaches with scenario narratives developed by experts offers a more comprehensive understanding. These narratives, derived from a deliberative process involving diverse stakeholders and experts, dive into the multifaceted conditions, contextual factors, and interdependencies surrounding SAV deployment. They incorporate nuanced details, considering social, economic, and governance dimensions that simulations might overlook. This qualitative assessment provides a relatable and communicative framework that policymakers can grasp more easily. It helps present a holistic view of the potential impacts of SAV deployment, enabling policymakers to better comprehend the real-world

implications beyond numerical models (Milakis et al., 2017b). It encompasses social, economic, environmental, land use, and safety impacts.

Moreover, this qualitative approach enhances stakeholder participation and collaboration, fostering an interdisciplinary understanding. It encourages diverse perspectives and local insights, often crucial in determining the success or failure of mobility initiatives in urban areas. Involving various stakeholders in the scenario narrative construction facilitates a participatory approach that considers the unique needs and preferences of different communities. This, in turn, enriches the field by providing a more inclusive, nuanced, and contextualised understanding of the potential impacts of introducing new and smart mobilities within urban spaces (Bracken et al., 2015; McBride et al., 2017).

**Research question 3:** How could shared automated vehicles be deployed, and what are the potential impacts on sustainable cities?

**Methods:** The research methodology employed two core elements: the Intuitive Logics Approach (ILA) to create realistic scenarios and a Systematic Literature Review (SLR) to analyze the impacts of SAV in urban settings. The ILA involved expert panels identifying driving forces uncertainties, constructing coherent narratives for varied scenarios, and integrating insights from the SLR to determine potential SAV impacts. The SLR phase encompassed planning strategies, review criteria, and categorization techniques, condensing 1278 documents into 61 pertinent files, and eventually associating scenario narratives with impacts from the SLR outcomes. This holistic approach blends expert-driven scenario building with evidence-based findings, offering insights into the potential implications of SAV deployment in sustainable cities.

- **Research Gap 4:** Lack of a comprehensive analysis of the externalities associated with SAV: robotaxis, AM, and AM in MaaS, as well as limited attention given to mode choice decisions and the potential modal shifts to SAV, neglecting their direct implications on external costs (building on research gap 1)

After thoroughly reviewing existing literature on urban mobility and SAV externalities and identifying qualitative categories, a gap in assessing SAV-specific externalities was identified: scarce research on SAV external costs (Ferdman, 2020; Sovacool et al., 2021). This research gap led to a comprehensive evaluation focused on emissions, noise, accidents, and congestion, in line with the first research question. There is also a lack of marginal cost values for AM, robotaxis, and manufacturing of different vehicles, including the SAV. To address this gap, the thesis estimates the marginal costs of these vehicles by drawing on influential sources such as the CE Delft (2019b) externalities handbook and

studies like Jochem et al. (2016), both at the EU level and within localised urban contexts such as Geneva and Lyon.

**Research question 4:** How should the externalities of shared electric vehicles and their impact on cities be calculated?

**Methods:** The study methodology comprises three main steps. Firstly, it involves analyzing the transport performance based on the transport census of the cities of Lyon and Geneva for a reference scenario. Secondly, it models the deployment scenarios of SAV, considering research question 3, for transport performance and modal shares. Thirdly, it estimates marginal external costs using reputable data sources such as CE Delft (2019). The four deployment scenarios for SAV consider various implementations that project changes in mode choice and trip lengths. The analysis uses comprehensive mobility behaviour data from the AVENUE large-scale representative survey and literature review to understand changes in modal shares associated with each scenario. Marginal costs for traditional road transport (buses and ICEV) are calculated from established values in France and Switzerland and adapted to the deployment scenarios. For SAV (AM and robotaxis), marginal costs are estimated for emissions, accident risks, and congestion impacts. Finally, marginal costs for manufacturing vehicles are also estimated. The analysis shows changes in total externalities for each envisioned scenario for all the considered impact categories, with reductions in external costs signifying a positive impact of introducing the SAV in the cities and an increase in external costs indicating a negative consequence.

- **Research gap 5:** Lack of understanding regarding the potential of smart mobility like the SAV to bolster Sustainable Urban Development (research gap 2)

The main objective of using external costs is to guide policymakers in planning for sustainable urban mobility (CE Delft, 2019b). To achieve this, a scenario is selected from the previous analysis covered in the previous research questions addressing the identified research gaps. In order to effectively demonstrate that this scenario aligns with the city's sustainability strategy, it is necessary to conduct an in-depth analysis of the policies and strategies designed to promote urban mobility. It focuses on social, environmental, economic, safety and land use impacts.

To answer the main question, the policy analysis and recommendations focus on how to integrate SAV into the transport system to support public transport and ultimately promote sustainable urban development. This will lead to resilient and sustainable cities

while investigating the extent to which deploying SAV as a pull strategy could support the city's goals and align with the SDGs.

The investigation aims to explore the relationship between the implementation of SAV in European cities and the broader policies adopted by these municipalities. It examines how these cities prioritise sustainability within the UN Sustainable Development Goals framework.

**Research question 5:** What are the recommendations for SAV deployment in cities?

**Methods:** The present study utilises the SDGs framework to investigate how the impacts of SAV deployment align with the cities' sustainability policies. Case studies of Geneva and Lyon-Villeurbanne provide empirical data to comprehend the effects of SAV deployment. The study employs policy document analysis and Integrative Propositional Analysis (IPA) to provide deeper insights into the relationship between SAV, sustainable mobility, and SDGs. A comparative policy analysis also highlights city-level strategies and aligns them with SDG targets. This offers policy recommendations that can enhance urban transportation and sustainability.

### 1.3 SIGNIFICANCE AND CONTRIBUTIONS

This PhD thesis is a comprehensive exploration of the impacts of electric SAV in the context of sustainable urban development. Existing research on AV tends to be narrow, focusing on specific areas such as congestion (Metz, 2018; Kumakoshi et al., 2021), increased vehicle kilometres travelled and fleet size (Fagnant and Kockelman, 2018; Moreno et al., 2018), environmental effects (Fagnant et al., 2016), or accidents (Dixit et al., 2016; Filiz, 2020). Even studies covering multiple impacts often concentrate solely on technological aspects or potential effects on transportation systems (Alazzawi et al., 2018), mostly using simulations (Childress et al., 2015a) or qualitative surveys (Zmud and Sener, 2017), and few would assess the impacts on city planning (Narayani and Kumar, 2021).

This thesis uses a blend of diverse methodologies, including qualitative and quantitative methods, to represent an interdisciplinary perspective. Adopting this holistic approach aims to comprehensively evaluate numerous impacts across various scenarios, using insights from experts and stakeholders. Moreover, the study extends beyond the technological realm, projecting the implications at the city level and assessing their alignment with sustainable development goals.

Methodological Uniqueness

This research stands out because it combines Mixed Methods Research (Muskat et al., 2012). The qualitative aspect involves utilising an intuitive logics approach in conjunction with a deliberative process that includes input from experts and stakeholders such as researchers and transport operator officials (Derbyshire and Wright, 2017). A systematic literature review serves as the basis for comprehending the diverse impacts of SAV, while case studies provide additional evidence to support the analysis (Rodrigues et al., 2023). Additionally, policy documents and comparative policy analyses are employed to explore how SAV can bolster SUD and contribute to achieving the SDGs. On the quantitative side, an external costs model is developed (Müller-Eie and Kosmidis, 2023).

### Assessment of Externalities

The assessment of externalities in this study represents a novel contribution. By employing predicted modal shifts derived from a large-scale representative survey and literature, data from life cycle assessments of SAV, and analyzing marginal external costs, the analysis unveils the marginal costs associated specifically with SAV, which are currently missing in research. This nuanced examination, particularly differentiating between robotaxis and automated minibuses, fills a critical gap in existing research on SAV. The externalities model helps test the proposed scenarios and estimate the total external costs for different impact categories and types of vehicles.

### European Horizon Project

Conducting doctoral research within the expansive framework of a European project brought immense value to this study on multiple fronts. Firstly, it granted invaluable access to empirical data, offering direct exposure to the real-world implementation of SAV within mixed-traffic environments. This hands-on experience provided a deep understanding of the practical implications arising from the introduction of cutting-edge technology in everyday settings. With its presence across six diverse pilot sites spanning medical centres, industrial areas, and residential zones in Geneva, Lyon, Copenhagen, and Luxembourg, the AVENUE project sought to establish an accessible, on-demand, automated minibus system (AVENUE, 2017). The involvement in this initiative extended to contributing to the design of a comprehensive large-scale survey (Korbee et al., 2023). This survey was instrumental in gathering data on travel behaviour, user acceptance, and the propensity to utilise and pay for AV and SAV, which is crucial for discerning modal shifts across varied scenarios.

Moreover, the collaboration within a substantial consortium comprising local governments, research institutions, transport operators, and digital and demand-responsive transport providers across these four cities proved immensely beneficial. This collaborative platform facilitated an interdisciplinary exchange of expertise, fostering a deliberative approach to scenario development. The interactions allowed for the validation of findings, presenting them to domain experts for critical review, which significantly bolstered the robustness of the research outcomes. Additionally, access to reports from local authorities and transport operators was instrumental. For instance, evaluating and comparing externalities estimates against real-world data ensured the accuracy and reliability of the study's outcomes (TPG, 2016; Beukers, 2019; Zuttre, 2019). This collaborative ecosystem within the AVENUE project provided essential data and facilitated validation processes critical for the credibility of the research findings.

This interdisciplinary approach significantly contributes to introducing AV in urban areas in order to foster sustainable urban development. This thesis aims to understand the impacts of SAV and offer insights to inform policy frameworks, urban planning strategies, and sustainable development initiatives.

## **1.4 OUTCOMES**

This thesis provides a comprehensive understanding of urban mobility externalities and the potential impacts of Shared Automated Vehicles, specifically Automated Minibuses. It clarifies the relationship between Sustainable Urban Development and sustainable urban mobility, presents potential deployment scenarios for Shared Automated Vehicles, evaluates their impacts, and offers policy recommendations to align SAV deployment with Sustainable Development goals.

- A comprehensive understanding of the externalities attributed to urban mobility and the potential externalities introduced by Shared Automated Vehicles, particularly Automated Minibuses.
- Clarification on the diverse dimensions of Sustainable Urban Development and its intricate relationship with sustainable urban mobility.
- Potential deployment scenarios of SAV and the potential impacts of Shared Automated Vehicles based on the context of deployment

- Evaluation and estimation of the externalities (marginal and total costs) associated with Shared Electric Vehicles, focusing on emissions, noise, accidents, and congestion.
- Understanding how SAV deployment aligns with policies related to sustainable urban development in case studies and
- Policy recommendations for SAV introduction in urban public transport automation, emphasizing alignment with Sustainable Development Goals.

## **1.5 THESIS STRUCTURE**

The thesis consists of 7 chapters, or building blocks, with the first chapter being the introduction. This chapter presents the context, objectives, questions, outcomes, and research structure. The second chapter is the literature review chapter, which answers two secondary questions by building on the conceptual background. These questions are about the definitions of SUD, sustainable mobility, their externalities, AV, and SAV concepts and their externalities. Chapters 3, 4, and 5 are the heart of the research.

Chapter 3 addresses the third research question, which explores the deployment possibilities and potential effects of shared automated vehicles within urban areas. This chapter delves into a systematic process that constructs diverse deployment scenarios of SAV within urban settings through a methodical expert panel-driven approach using scenario planning and the intuitive logics approach. In this process, contextual factors influencing the introduction of SAV in different forms are considered, connecting these introductions to their associated economic, environmental, social, land use, and safety impacts. These impacts are evaluated through a systematic literature review and carefully selected by a panel of experts involved in the process. The chapter provides a comprehensive analysis of the potential deployment options and effects of SAV in urban areas.

Chapter 4 addresses the fourth question about how the externalities of shared electric vehicles and their impact on cities should be calculated. It provides quantitative assessments of the scenarios and provides the externalities that will be used to address the main research question. The chapter uses external cost calculation accompanied by modal shares prediction determined by the analysis from a large-scale representative survey (n=1816) and literature review to estimate how the SAV within the scenarios



presented in the previous chapter would affect travel behaviour and, consequently, transport performance. The external costs start with the estimation of marginal costs based on the CE Delft (2019) report and are customised for each scenario. This is applied in two cities of the AVENUE project, Lyon Villeurbanne and Geneva, and they cover emissions (fuel cycle well to tank and tank to wheel, and vehicle manufacturing GHG emissions), noise exposure, accidents, and congestion. This gives the chance to compare the impacts in the form of changes in total externalities on the city of each scenario.

Chapter 5 addresses the fifth research question, which is about recommendations for deploying SAV in cities, and it addresses the main research question of how SAV would foster sustainable urban development. This study investigates how the selected SAV scenario based on the externalities assessment aligns with SUD and SDGs using policy document analysis and IPA applied to Lyon Villeurbanne and Geneva. The analysis highlights policy recommendations, leverage points, and impacts, suggesting the transformative potential of SAV to propel SUD and achieve SDGs.

Chapter 6 is the discussion chapter, where the outcomes of the previous chapters are consolidated to explore the deployment scenario and externalities and address the main research question. It proposes an integrated land use and transport strategy to support SUD in European cities, addresses the limitations of the research, and expands to future research. The research concludes with chapter 7, which includes the final thoughts and findings of the thesis.

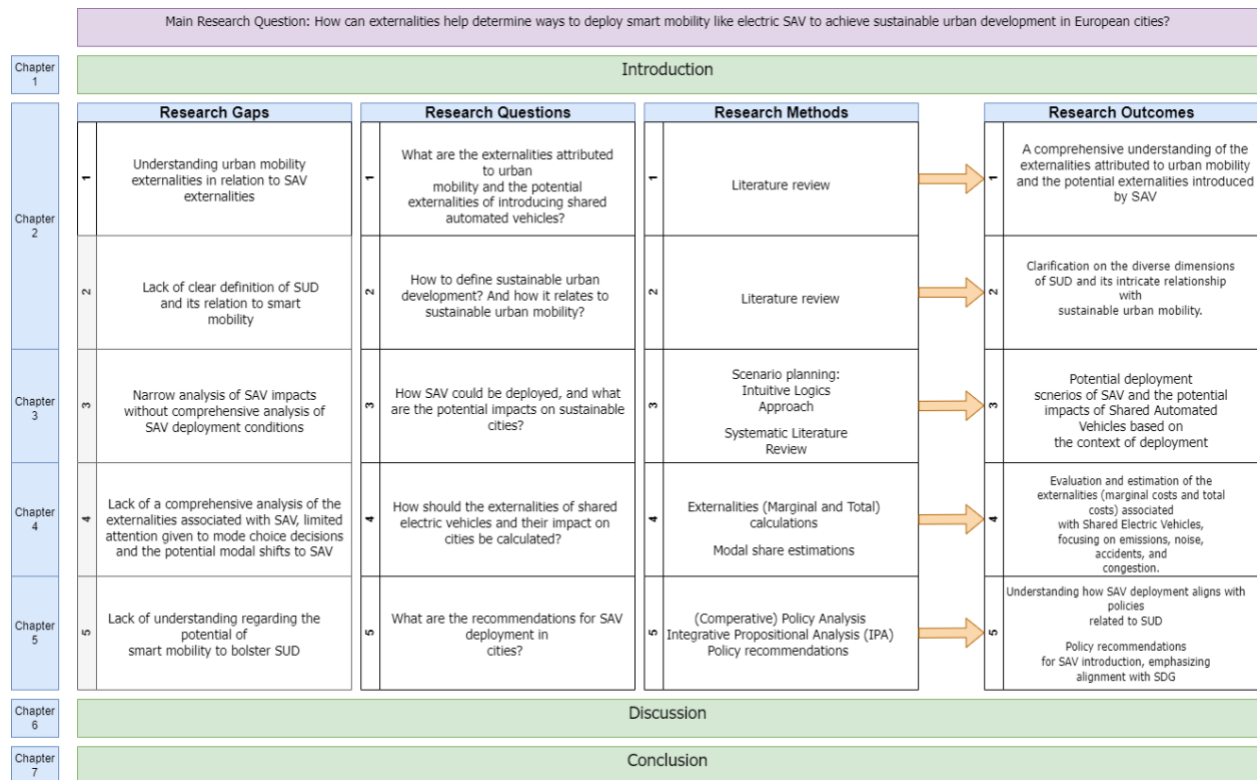


Figure 1: The Structure of the Thesis

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## 2 LITERATURE REVIEW

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### 2.1 INTRODUCTION

Transportation plays a crucial role in addressing various economic and social challenges by providing accessibility and connectivity to essential services such as employment, education, and healthcare. It is a fundamental aspect of modern society that promotes economic development and enhances social welfare. However, transportation is also the root cause of several sustainability challenges that threaten economic, social, and environmental well-being (World Bank, 2023). Urban road transportation, in particular, significantly impacts air quality, noise pollution, accidents, and congestion, affecting individuals' and communities' health and well-being. The prevalence of car-centric mobility approaches has resulted in urban sprawl, making it challenging to access vital services, such as healthcare and education. This lack of accessibility has created inequalities, exacerbating social and economic challenges for vulnerable populations (UN-Habitat, 2013).

Furthermore, transportation has significant environmental impacts. The overreliance on private vehicles for transportation has affected natural resources and habitats, leading to biodiversity loss. It is crucial to remember that the effects of urban transportation are not limited to mere inconveniences. Instead, they encompass the concept of 'external costs,' which presents the broader picture of the consequences of urban transportation. As we examine the results of urban transportation, it is clear these challenges should capture economists' concept of 'external costs. The concept of external costs, according to Pigou's (1920) "The Economics of Welfare", denotes the costs incurred by individuals due to economic activities and born by third parties that are not accounted for in the market price. Thus, market failures are represented in external costs. Negative externalities are secondary effects that produce inefficiencies in resource allocation. Positive externalities are external marginal benefits or benefits to third parties for which they do not pay. To bolster sustainable urban development, negative externalities must be mitigated, and positive ones must be fostered. Urban transportation, a vital aspect of sustainable development under SDG 11, is pivotal in shaping cities and communities. Ensuring safe, affordable, accessible, and eco-friendly transportation is crucial for sustainable urban progress (United Nations, 2023a).

In today's interconnected landscape, sustainable cities align with smart city concepts, integrating Information Technology and smart solutions into various aspects, notably mobility. Smart mobility, encompassing advancements like AV and SAV, holds significant promise in mitigating negative urban externalities while fostering positive ones.

Within the scope of this literature review, critical questions are focal: What are the externalities attributed to urban mobility and the potential externalities of introducing Shared Automated Vehicles (like automated minibuses)? Furthermore, there's a pressing need to define the concept of sustainable urban development and explore its relationship with SUM. This literature review encapsulates a comprehensive exploration across five distinct sections. Section 1 is the introduction. Section 2 elucidates the externalities within urban transportation. In contrast, Section 3 navigates SAV's landscape and potential externalities, followed by Section 4, which outlines the intersection between Sustainable Urban Development and Mobility. Section 5 is the conclusion.

## **2.2 URBAN MOBILITY EXTERNALITIES**

Understanding the broad spectrum of externalities within urban transportation is fundamental in comprehending the diverse impacts of transport systems on urban environments. This section delves into the existing body of research that scrutinises the multifaceted external costs across different scales, emphasising the need for a more comprehensive exploration at the local and city levels.

External costs represent the quantified monetary assessment of externalities, signifying the unintended impacts of transportation activities. These costs enable a standardised comparison of diverse externalities. Internalising these costs ensures pricing aligns with the genuine social cost, facilitating a more efficient allocation of resources (Merchan et al., 2019). Externalities can be positive or negative. Negative externalities denote secondary consequences resulting in inefficiencies within resource distribution, while positive externalities signify additional benefits or advantages to third parties, unaccounted for in their expenditure (Lazăr, 2018).

Transport external costs have been related to negative impacts such as congestion, noise pollution, air pollution, and accidents (Santos, 2017). They are costs not included in the pricing or decisions of transport users and imposed by them on society (Button, 1990). According to Santos et al. (2010c), they embody the disparities between the marginal social costs and benefits within transportation systems. These externalities signify a

market failure where the equilibrium, characterised by equalising marginal social costs and benefits, remains unattainable within the transportation market due to the unaccounted-for societal impacts and costs associated with transportation activities.

The European Commission's Mobility and Transport (2019) estimation outlines the external cost of transportation, constituting approximately 7% of GDP, around €1000 billion per year within the EU. Notably, 75% of this figure pertains to road transport and encompasses various factors such as accidents, noise, air pollution, climate change, and associated environmental impacts. CE Delft (2019) quantified negative road transport externalities at €871 billion in the EU28 in 2016, equivalent to 6.6% of the total GDP. This comprehensive assessment incorporates factors like accidents, air pollution, climate change, and congestion. It extends to other external costs associated with upstream and downstream processes, encompassing energy, vehicle, and infrastructure production (Gössling 2020).

Urban transportation presents a significant challenge within cities, marked by rising personalised travel modes contributing to heightened traffic density. This surge impairs travel efficiency, prolongs commute durations, diminishes average speeds, amplifies fuel consumption, elevates pollution levels, and heightens discomfort among road users (Sen et al., 2010). Urban mobility externalities are the unaccounted-for impacts of transportation in urban areas. For a mobility model to be efficient, it must consider the actual expenses involved in transport. This approach will ensure that the model functions optimally, delivering the desired results while being cost-effective (Santos et al., 2010c). In urban settings with scarce infrastructure and high population density, the transportation sector faces challenges that amplify external costs. Limited infrastructure capacity in densely populated areas exacerbates congestion issues, while the heightened urban density intensifies the adverse effects on other users, including increased accidents and environmental impacts (Maternová et al., 2023).

Understanding and addressing externalities in urban transportation is crucial due to their profound impact on society, the environment, and the economy (Verhoef and Nijkamp, 2003). Urban areas typically face heightened congestion, amplified pollution, and increased noise levels, affecting a larger population and posing more significant risks of accidents. Projections indicate that as much as 68% of the world's population will be in urban areas (United Nations, 2018).

Traditional policy interventions, like expanding infrastructure, face challenges in urban settings where limited space impedes construction and requires significant financial investments (Anupriya et al., 2023). Moreover, such expansions often exacerbate negative impacts and spur induced demand, creating a disadvantageous cycle that fails to resolve underlying issues (Hymel et al., 2010). The consequences of transport extend to health, environmental sustainability, and urban space, imposing direct or indirect costs on cities and societies. Failing to address these issues perpetuates an inefficient system that cannot offer accessible, safe, and affordable mobility to urban residents. Indeed, addressing urban mobility externalities is a focal point within the Sustainable Development Goals, specifically under SDG11 (aims to make "*cities inclusive, safe, resilient, and sustainable*"). Target 11.2 specifically focuses on providing access to safe, affordable, accessible, and sustainable transport systems for all, with special attention to the needs of vulnerable children, persons with reduced mobility (PRM), and older persons (United Nations, 2023a). This emphasis underscores the criticality of mitigating the adverse impacts of transportation on urban environments to foster sustainable and inclusive cities.

### 2.2.1 Types of Externalities

The analysis of the impacts of urban mobility falls into two broad categories: positive and negative externalities. While positive externalities signify unaccounted societal benefits from transportation investments, negative externalities encompass detrimental consequences impacting health, the environment, and society.

#### Positive external costs

Most analyses of the externalities of road transport are concerned with the negative external costs. The Sovacool et al. (2021) study shows that most of the 43 studies and 318 external cost estimations they have analysed were considered negative. Most studies argue that there are no positive externalities of transport, and the justification behind the focus on the negative sides is that the benefits of transportation are "captured by the market" (Blum, 1998). Rothengatter (1994) would argue that much of the proclaimed external benefits are internal to market processes and that many present positive externalities as a case against internalisation policies.

Frequently cited as external, the apparent benefits of road transport, including reduced production costs, diverse product choices, and swifter delivery, are inherently internal to market mechanisms. These advantages stem from the superior cost efficiency of road

transport when compared to alternative modes, eventually benefiting end consumers of transported goods, assuming no distortions within the broader economy (Verhoef, 1994)

Positive externalities stem from activities that bring unaccounted benefits to markets not directly involved (Konečný et al., 2017). In economic goods, transport investments, like roads, do not fit neatly into the traditional public (non-excludable and non-rivalrous) or private (excludable and rivalrous) goods categories due to congestion, transaction costs, and location. These nuances affect how these goods are valued and utilised, showing that the traditional classification system of the fourfold goods model does not fully capture these complexities. This, in turn, affects how positive externalities might be accounted for in these scenarios (Blum, 1998; Zeder, 2016; Helbling, 2020).

Joost Platje et al. (2017) outlined various potential positive externalities attributed to transport, including fostering economies of scale, reducing transaction costs, promoting division of labour and specialisation, enhancing accessibility to a broader range of goods and services, and facilitating increased mobility of production factors. Their research emphasises that improved infrastructure and mobility are proposed to underpin the advancement of competitive markets, which would cause lower prices and higher quality of transport service. Other potential positive externalities of road transportation are efficient emergency services accessibility due to efficient roads and better social interactions through increased accessibility caused by transport (Rothengatter, 1994; Gerritse and Arribas-Bel, 2018).

Positive externalities represent the potential social and environmental benefits of urban mobility. The Mohring effect, relating to economies of scale, highlights the cost efficiencies gained from increased usage, eventually strengthening the network effect by making transportation systems more attractive to passengers as their ridership increases. These concepts are connected, showcasing how urban transportation systems' societal, economic, and operational aspects are linked and how improvements in one area can amplify benefits across the entire transport network (Currie and Loader, 2010; Fielbaum et al., 2021). For instance, within MaaS, the integration of diverse transport options amplifies utility for users, operators, cities, and society. As transportation modes expand and combine, a network effect occurs, offering users enhanced choices, customised journeys, and a streamlined experience. Operators benefit from collaborative opportunities, creating comprehensive transport packages. This synergy within MaaS fosters economies of scope, magnifying benefits across the transportation ecosystem

(Fournier et al., 2023).

However, the convenience and efficiency of transport systems might encourage more travel, exacerbating the adverse effects of urban mobility. These unintended consequences are referred to as rebound effects. Studies have examined the rebound effect in passenger transportation using various data sources and statistical approaches. The estimates typically range between 10% and 30%, although exceptions exist. This range indicates the elasticity as an absolute value and a percentage rather than a fraction (Hymel et al., 2010).

### Negative external costs

The Handbook on the External Costs of Transport delineates various dimensions of external costs, including total, average, and marginal costs (CE Delft, 2019a). Total external costs encompass all external costs within a geographical boundary caused by a specific mode of transport, while average external costs express costs per transport performance unit. Marginal external costs refer to additional costs from increased transport activity, with short-run marginal costs being more relevant for internalisation purposes. The Handbook also distinguishes external cost categories such as air pollution, climate change, noise, land use, congestion, and accidents (Mayeres et al., 1996; CE Delft, 2019a; Schröder et al., 2023).

#### *Emissions: Air pollution and Climate change*

Emissions, such as air pollution and climate change, profoundly affect society and the environment. By 2030, climate change risks might amount to approximately 19% of the GDP of certain nations (Sovacool et al., 2021). Assessing the costs of climate change is intricate due to its global, long-term impacts. Transportation emits greenhouse gases, notably CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub>, contributing significantly to climate change. Transportation emits greenhouse gases, significantly contributing to climate change. Hence, evaluating the climate costs of transportation is crucial (CE Delft, 2019a). Climate change encompasses consequences linked to global warming, such as rising sea levels, biodiversity decline, challenges in water management, extreme weather occurrences, and crop failures. These effects are attributed to emissions of greenhouse gases, which are assessed through the avoidance cost approach (Jaroudi et al., 2021).

Concurrently, air pollution poses a significant threat to health due to its impact on many

individuals. Nearly 4.5 million people worldwide and 800,000 in Europe face premature mortality each year due to polluted air. Numerous studies have extensively analysed air pollution costs (see (Verhoef, 1994; Small and Kazimi, 1995; Mayeres et al., 1996; Calthrop and Proost, 1998; Int Panis et al., 2004; Bigazzi and Figliozzi, 2013; Musso and Rothengatter, 2013; Sánchez-García et al., 2021; Ward et al., 2021)). However, recent years have seen a lack of comprehensive international studies covering the entire emission-to-impact pathway and associated costs (CE Delft, 2019a). Nonetheless, ongoing research explores the relationship between air pollutant exposure and health risks, including productivity loss due to sickness and medical costs. These pollutants—PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>x</sub>, SO<sub>2</sub>, and NMVOC—are assessed, accounting for health effects, crop damage, building deterioration, and biodiversity issues such as soil and water acidification and ecosystem eutrophication (Jaroudi et al., 2021).

Bigazzi and Figliozzi (2013) stand out for examining on-road pollution exposure, particularly in congested traffic scenarios. They establish equations that factor in on-road pollution within marginal private and external costs. A sensitivity analysis demonstrates that on-road exposure constitutes a notable portion (18%) of social costs. Neglecting on-road exposure in pricing strategies could lead to welfare loss. They advocate for pricing mechanisms, emphasising the importance of considering on-road exposure costs in transportation evaluations.

Musso and Rothengatter (2013) evaluated the environmental emissions' external costs of electric, gasoline, and diesel cars across their lifecycles. It offers an alternative interpretation of ISO 14040 Life Cycle Assessment (LCA) results by assigning monetary values to environmental impacts. Comparing vehicle types for an average midsize car in Italy, the electric version demonstrated lower external costs related to air pollution. The study underscored the importance of managing emissions' geographical impact.

Zahedi et al. (2019) explored people's willingness to pay to reduce pollution emissions from private road transport, which aligns with external cost estimations. Their study examined psychological factors affecting this willingness and indicated a significant positive correlation between environmental concern and willingness to pay. Households in Catalonia expressed readiness to pay for pollution reduction policies.

Lindsey and Santos (2020) examined economic approaches to addressing transportation and environmental externalities. They highlighted policymakers' preference for carbon-

related measures over congestion tolls, reflecting challenges and disparities in public perceptions between climate change and traffic congestion. The paper stressed the need for nuanced economic insights to shape transportation and environmental policies, especially concerning externalities.

### *Accidents*

Understanding accident externalities hinges on grasping the relationship between traffic volume and accident occurrence (Newbery, 1988; Fridstrøm, 2011; Dabbour et al., 2020).

Accidents incur significant costs, categorised into material (e.g., vehicle damages, medical expenses) and immaterial (e.g., reduced lifespans, emotional suffering). While material costs can be computed using market prices, assigning values to immaterial costs remains challenging. Certain accident expenses, like insurance coverage and anticipated risks, are internalised and accounted for in specific scenarios (CE Delft, 2019a). Accidents encompass various costs, including material damage, production interruptions, administrative and medical expenses, and human suffering. Calculating accident costs often involves assessing the likelihood of a vehicle being involved in or causing an accident, typically measured as the ratio between injuries or fatalities and total vehicle-kilometres travelled (Vkm) (Jaroudi et al., 2021)

Numerous studies have investigated external expenses associated with road accidents across various transportation modes and specific infrastructure elements. They have identified driver groups posing escalated risks and examined economic contributions lost due to fatalities or injuries. For example, Pukalskas and Pečeliūnas's (2015) assess the economic impact of deaths or injuries from traffic accidents, covering material losses like vehicle damage and environmental damages, alongside direct costs such as medical care and indirect costs like production loss and property repairs.

Maternová et al. (2023) explore transportation's external costs, distinguishing between personal and societal costs. They emphasise the disproportionate harm caused by road transportation and advocate internalising these costs to promote environmental conservation, urging a transition away from ICEV toward other transportation modes. The European Commission's sustainable mobility policy aims to incorporate transportation effects into pricing, striving for fair competition among modes by 2030 and complete external cost recovery by EU transport users by 2050.



Some research looks into externalities under the scope of traffic density's impact on insurance costs. For instance, Edlin and Karaca-Mandic (2006) uncover externalities associated with ICEV accidents in high-traffic density areas, illustrating that high congestion significantly raises insurance costs for other drivers. They suggest Pigouvian taxes as a potential solution to mitigate externalities, aiming to lower driving and accident rates without increasing insurance premiums by exploring alternatives like per-mile insurance rates.

### *Congestion*

Congestion causes travel delays by slowing vehicle flow and increasing travel time. External costs increase travel time, traffic accidents, environmental pollution and fuel consumption due to driving manoeuvres by reducing and accelerating. Speed-flow relations influence the costs associated with road congestion in specific urban or inter-urban settings (CE Delft, 2019a). It leads to external costs due to temporary infrastructure inadequacy, causing delays, unpredictability, higher operational expenses, and economic activity loss (Jaroudi et al., 2021).

Theoretical discussions on congestion pricing emphasise how individual road users often overlook the external costs they impose on others, including time delays and increased fuel consumption at lower speeds (Pigou, 1920; Lindsey and Verhoef, 2001; Goodwin, 2004; Luo et al., 2007). Studies have aimed to quantify these impacts, with Russo et al. (2021) estimating marginal external costs and welfare losses from congestion-related travel delays in Rome, Italy. Their findings reveal significant external costs, around two-thirds of drivers' private time travel costs, particularly escalating during peak hours. Policy interventions to alleviate congestion could yield substantial welfare gains.

Parry et al. (2014) extensively examine the economic impact of traffic congestion caused by motor vehicles. Their analysis aims to assign a monetary value to delays resulting from reduced travel speeds, considering the value of travel time based on local wage rates. It includes broader implications beyond direct time losses, encompassing increased fuel costs, travel time variability, and the impact on daily planning due to uncertain travel times.

González-Guzmán and Robusté (2011) propose a mobility management strategy to internalise congestion externalities caused by private vehicles. This approach reallocates road space from private vehicles to public transport, anticipating improved overall

mobility and traffic flow while initially impacting private vehicle travel times. This method aims to internalise congestion's external costs and shows promise comparable to road pricing in reducing car travel demand. For instance, the London congestion charge, implemented in 2003, led to a significant decrease in various pollutants. The London and Stockholm congestion charges have resulted in significant reductions in pollution and congestion. These charges have proven to be effective measures in addressing the negative impacts of congestion while also yielding positive economic and environmental outcomes (Eliasson et al., 2009; Green et al., 2020).

It is worth noting that congestion exhibits a wide range of estimates and is considered one of the most costly externalities, varying from 1 cent US\$/km to 15 cent US\$/km Sovacool et al. (2021).

### *Noise*

Traffic noise, perceived as a disutility, incurs significant costs. The escalating urbanisation and traffic volumes compound this environmental issue. As traffic increases, so do noise levels, affecting more urban residents, thereby amplifying disutility. Even with advancements in noise-reducing technologies for vehicles, tires, and roads, the future anticipates a surge in traffic noise costs (CE Delft, 2019a; Nemoto et al., 2021).

It, typically unwanted sounds causing physical or psychological harm, stems from road traffic and induces annoyance and health effects in individuals. Assessing noise impact through a damage cost approach based on 5dB thresholds from EEA (2014) noise maps reveals the willingness to pay to avoid noise annoyance and the value-of-statistical-life linked to health concerns (Jaroudi et al., 2021).

Concurrently, Sigurd Weinreich et al. (1998) exad valuing noise nuisance in transportation using hedonic pricing and contingent valuation methods. It highlights noise's physiological and psychological effects on individuals, noting challenges in measuring marginal impacts and near-zero costs for low traffic density due to a logarithmic function governing sound sources. The external cost of noise in France stands at an estimated 147.1 billion euros yearly, with transportation responsible for two-thirds (66.5%) of these expenses. Among transport-related costs, road noise accounts for a significant 54.8%. These figures underscore the considerable impact of transportation-generated noise pollution on France's social and economic framework (ADEME, 2021).

While exploring the intricacies of noise nuisance, another study by Kaddoura and Nagel (2018) examines the relationship between traffic congestion and noise, revealing a negative link between them. It proposes a way to simultaneously reduce both by optimising tolls. By focusing on Greater Berlin, it suggests dynamic traffic management strategies, noise reduction in quieter hours, and congestion control during peak times. These studies collectively emphasise the need for holistic modelling encompassing additional factors like air pollution and accidents, essential for refining policy simulations and ensuring comprehensive evaluations.

### *Land use*

Transportation impacts nature, affecting landscapes and habitats mainly through habitat loss, fragmentation, and detrimental consequences due to emitted air pollutants, leading to biodiversity loss. Despite these significant effects, studies on the external costs of transport's impact on nature and landscape remain scarce. The adverse effects include habitat loss from infrastructure development, such as the case of space dedicated for parking and roads in urban areas, fragmentation causing separation of species, and habitat degradation due to emitted pollutants (CE Delft, 2019a).

Studies have tried to explore the external costs associated with habitat damage due to transport, focusing on various impacts on nature and landscape. The assessments consider habitat loss and fragmentation, addressing factors such as unsealing costs (related to the disruption of natural surfaces or ecosystems due to human activities caused by infrastructure development), restoration costs (expenses incurred in restoring ecosystems or landscapes that human activities have damaged), and specific estimations for different ecosystem types. For instance, the NEEDS (2006) project emphasises the costs of biodiversity losses and restoration, and it is an extensive bottom-up assessment of habitat damage costs. However, some studies, like the UBA (2018) and Fraunhofer ISI and Infrac (2018) Methodenkonvention 3.0, provide a broader overview analysis of habitat damage externalities. They touch on habitat loss and fragmentation. Precisely, studies like the Infrac and Ecoplan (2018) detail the external costs in Europe and Switzerland, respectively, emphasising unsealing costs and restoration expenses due to habitat loss and fragmentation caused by transport activities (van Essen H.P. et al., 2008; CE Delft, 2019a).

## 2.2.2 Existing Research on Urban Mobility Externalities

### Studies Related To Externalities In Urban Mobility

Studies analysing urban transportation externalities exhibit significant variations across countries due to methodological differences and varying assumptions (Verhoef, 1994; Mayeres et al., 1996; Verhoef, 2000; NEEDS, 2006; Santos et al., 2010b; Becker et al., 2012; Jochem et al., 2016; Konečný et al., 2017; Santos, 2017; Infrac and Ecoplan, 2018; Fernandes et al., 2019; Chatziioannou et al., 2020; Fournier et al., 2020; Sovacool et al., 2021). Literature since the 1970s has extensively addressed the external impacts of road transport through numerous studies (Verhoef, 1994; Timilsina and Dulal, 2011).

In the EU context, the "Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities" project, directed by the European Commission DG MOVE and executed by a CE Delft-led consortium, computed external costs for various transport modes in 2016. The study, utilising Eurostat and COPERT data, focused on environmental factors like noise, air pollution, climate change, and urban mobility systems. It detailed input and output values for total, average, and marginal external costs across 28 EU countries, revealing that road transport, especially ICEV, incurs the highest environmental costs. However, it highlighted lower average external costs for modes like high-speed trains and coaches, indicating more eco-friendly travel alternatives (CE Delft, 2019a; Hagedorn and Sieg, 2019).

In Germany, the "Methodological Convention 3.0 for the Assessment of Environmental Costs-Cost Rates," conducted by the German Environment Agency, calculated average German emissions costs, considering potential cross-border impacts. The study analysed various costs from conventional air pollutants and noise, using emission factors from HBEFA 3.3 and the TREMOD transport emission mode (HBEFA, 2017; Hagedorn and Sieg, 2019; Matthey and Bünger, 2019).

A pivotal Swiss study spanning 2010 to 2020 focuses on urban transport's external costs and benefits. It reveals unaccounted costs driving excessive travel and resource misallocation. Additionally, it highlights the societal benefits of activities like walking and cycling. The study advocates compensating those generating external benefits to promote eco-friendly transportation. With 72% of total external costs attributed to private motorised road transport, particularly in passenger transport, the study underscores the importance of these assessments in understanding urban transport's economic impact

(ARE, 2020).

The majority of studies delve into external costs at regional (Jochem et al., 2016; Santos, 2017; CE Delft, 2019a; Sovacool et al., 2021; UIC, 2023) and national scales (Musso and Rothengatter, 2013; Petro and Konečný, 2017; Matthey and Bünger, 2019; ARE, 2020; Euchí and Kallel, 2021; Sovacool et al., 2021; Ustaoglu and Aydinoglu, 2022), leaving limited research focused on the local and city levels (Button, 1990; Edlin and Karaca-Mandic, 2006; Fournier et al., 2020; Schröder et al., 2023)

Several studies provide critical insights into the external costs of urban transportation. Calthrop and Proost (1998) emphasised empirical research's necessity to identify specific costs like congestion and accidents and advocated considering all externalities in policy decisions.

In Munich, Schröder et al. (2023) present a comprehensive methodology to assess the external costs of various transportation modes, such as air pollution, climate, noise, land use, congestion, accidents, and health benefits in urban settings. Their results reveal the significant contributions of diesel and gasoline cars to overall external costs. Moreover, they explore scenarios promoting active mobility to reduce these costs, emphasising its role in increasing public transport or electrification rates.

Fernandes et al. (2019) introduce a sustainability indicator to assess the negative impacts of road traffic, encompassing congestion, noise, emissions, health effects and crashes in cities. Their real-world data-based model aims to aid decision-makers in formulating eco-traffic management policies. However, the studies also highlight limitations, such as fixed population exposure values and simplified time frame analyses. They suggest future research avenues, including real-time impact modelling and addressing traffic variations, to enhance the accuracy of assessments.

This body of research underscores the necessity of understanding and quantifying external costs in urban transportation. While methodologies differ, from empirical research and sustainability indicators to detailed transportation mode assessments, they all converge on encouraging more sustainable transportation modes and policies to mitigate urban transport externalities.

Methodologies

The estimation of urban transport external costs spans various methodologies, resulting in discrepancies in empirical estimates. This segment categorises and clarifies the diverse approaches utilised in assessing these externalities, elucidating the challenges and benefits associated with each. Additionally, it provides a more precise delineation of the methods employed for valuing these externalities. The estimation of urban transport's external costs is characterised by diverse interpretations of externalities and a wide range of methodologies, often resulting in significant discrepancies in empirical estimates (Verhoef, 1994). However, uncertainties in marginal external cost estimates predominantly stem from data quality in technical relationships rather than valuation techniques (Mayeres et al., 1996). Approaches employed in assessing externalities commonly grapple with the challenges of pricing adverse technological external effects, primarily classified into resource, avoidance, risk, and utility approaches (Blum, 1998).

Furthermore, studies have employed varied methodologies for monetising urban transport externalities. Six methodological groups are delineated based on Sovacool et al. (2021) analysis, including:

- Contingent Valuation/Choice Experiment: Surveys measure willingness to pay for transport improvements.
- Hedonic: Evaluates how environmental changes affect property values.
- Impact Pathway Approach: Studies cause-and-effect between transport and societal/environmental impact.
- Life Cycle Assessment: Analyses environmental consequences from raw materials to disposal.
- Meta-analysis: Combines interdisciplinary data for a comprehensive view.
- Multiple Methods: Uses a mix of techniques to capture diverse impacts.

These approaches aim to capture externalities' monetary value through contingent valuation, preferences affecting property value, willingness to pay and impacts through the life cycle of energy systems.

The methods to value these externalities include the damage cost approach, avoidance cost approach, and replacement cost approach. Using individual preferences as indicators, the damage cost approach is a preferred option to value external costs. Conversely, the avoidance cost approach bases external cost valuation on achieving policy targets, such as CO<sub>2</sub> reduction targets. In contrast, the replacement cost approach estimates costs by

assessing the expenses of replacing or repairing adverse impacts caused by externalities (CE Delft, 2019). The data needed could be classified as general, such as climate and air pollution cost factors (HBEFA, 2017), noise cost rates (WHO, 2022), health benefits, and value of statistical life (OECD, 2012), or vehicle data such as LCA (ecoinvent, 2020), modal shares, and vehicle emission (COPERT, 2023).

## **2.3 SHARED AUTOMATED VEHICLES**

### **2.3.1 Definitions**

SAV emerges as a potential solution to urban mobility challenges. This section navigates the definition, significance, and potential impacts of SAV in addressing urban externalities. By analysing the promises and potential pitfalls, we aim to uncover their role in fostering sustainable urban development.

#### Automated Vehicles

Amid the conversation about external costs associated with urban mobility, finding innovative, sustainable transportation solutions provides a viable alternative. Automated vehicles emerge as a potential solution to the shortcomings of the current urban mobility paradigm. They are regarded as seminal innovations within the urban mobility socio-technical transition (Nemoto et al., 2023). AV rely on advanced sensors, computing systems, and Artificial Intelligence (AI) to operate without human manoeuvring. Automation levels categorise the progression of AV: from Level 0 with no driving automation to Level 1 providing driver assistance, Level 2 featuring partial driving automation, Level 3 with conditional driving automation, Level 4 offering high driving automation, and finally, Level 5 achieving full driving automation (SAE, 2018), Appendix A.

The advent of AV offers a distinctive chance to change the urban mobility paradigm, potentially fostering healthier, more dynamic, and environmentally sustainable cities (Berrada and Leurent, 2017). However, realising these benefits hinges upon proactive involvement from policymakers and transport operators to seamlessly integrate AV into a robust public transport system. Embracing Shared Automated vehicles such as robotaxis and AM and promoting efficient carsharing programs could significantly augment public transportation (UITP, 2017; Ainsalu et al., 2018b; Nemoto et al., 2023). The deployment of SAV is predicted to occur as soon as the 2030s (Litman, 2021).

AV primarily rely on AI-driven software utilising deep learning techniques. They encompass two primary elements: hardware, including computers, sensors, and actuators, and software, comprising algorithms for object detection and perception, and fundamental software components. To operate effectively, AV depend on big data concerning their environment, including traffic signals, road signs, markings, nearby vehicles, lighting, and weather conditions (Chong et al., 2013; Singh et al., 2022)

### Shared Automated Vehicles

SAV encapsulate the sharing of goods (such as carsharing, bicycle sharing, scooter sharing, etc.) and services (including ridesharing, ride pooling, ride-hailing, etc.) and could offer cost-effective, on-demand services, addressing last-mile challenges, bridging mobility gaps, and complementing public transport (Stocker and Shaheen, 2017; MOQO, 2020; Fournier et al., 2023).

SAV encompass various types designed to meet diverse transportation needs, based on ITF (2023) and SAE (2018). Some of the key types:

- Robotaxis: self-driving taxis specifically designed for shared use, offering shared rides door-to-door services. They can adapt to different group sizes and are summoned through a mobile app similar to ride-hailing services like Uber.
- Automated Minibuses: They accommodate more passengers than regular cars but are smaller than typical buses. They operate by picking up multiple passengers along set routes or on-demand, and the service can be ordered through a mobile app or a multimodal platform. Automated minibuses can be used for ride pooling and first and last mile when integrated in MaaS. They differ from automated shuttle services used for short distances on fixed routes like airport shuttles.
- Automated Bus Services: They are similar to traditional buses with a capacity of up to 70 passengers. They are automated and operate on fixed routes, accommodating multiple passengers and serving urban or suburban areas.
- MaaS Platforms: MaaS platforms provide service sharing. They integrate various modes of transportation, including SAV, through a single app or platform. Passengers can seamlessly plan, book, and pay for different transportation options(SAE, 2018; ITF, 2020).

Shared mobility, such as SAV, represents an effective solution for alleviating transportation challenges in congested urban areas, aiming to diminish traffic congestion and air pollution and reduce the prevalence of ICEV on roads (Adler et al., 2019).



Innovative technologies such as MaaS, ITS, and AI are crucial in advancing shared mobility, improving customer experiences, and enhancing the efficiency of shared mobility services. In major cities, buses play a pivotal role in transit systems, and AI innovations can further improve their operations. For instance, AI applications can optimise on-demand reservations based on spatio-temporal correlations and location history (Singh et al., 2022).

One of the key studies about AV is by the International Transport Forum (ITF) (2015b), an extensive review of SAV that presents compelling insights into their potential impact on urban mobility. Notably, combinations of TaxiBots (AM or robotaxis with ridesharing and high-capacity public transport) could significantly reduce car usage, removing up to 9 out of 10 cars in a mid-sized European city. However, certain scenarios indicate increased overall car travel, particularly in AutoVot systems (door-to-door single rides robotaxis) without robust public transport, potentially doubling car-kilometres travelled. The analysis emphasises that managing the transition to AV will pose challenges, especially in balancing shared self-driving vehicles and traditional cars, as a shift toward shared fleets may lead to substantial increases in overall vehicle travel. Moreover, AV deployment could transform public transport and necessitate policy adaptations to harness the benefits of freed urban space while addressing environmental impacts and redefining urban transport governance.

### Automated Minibuses

Ainsalu et al. (2018b) describe AM as a service that could offer on-schedule or on-demand services and has an occupancy of 5-10 passengers with pick-up and drop-in of street stop points or door-to-door. Although AM and AV are comparable, there are unique features that distinguish them, such as low speed, shared service and geofencing (limited operational domain) (Cregger et al., 2018).

AM are a potentially significant development, combining state-of-the-art technology with environmentally responsible urban transportation. They could change urban transportation and provide a solution addressing environmental responsibility and efficiency. It could solve first/last mile gaps as a feeder service to long-distance transport (Cregger et al., 2018; Fournier et al., 2023)(Cregger et al., 2018; Fournier et al., 2023). They could reduce emission pollution and parking spaces (Vleugel and Bal, 2018). AM present an opportunity to serve as a feeder to public transport, essentially substituting less

occupied bus services. This substitution could offer broader coverage at lower expenses and render dynamic route planning and on-demand services more feasible (Butler et al., 2022)

Several cities are actively testing AM as part of their efforts to explore the potential of innovative, sustainable, and complementary to public transport. Among the key pilot projects in the EU CityMobil2<sup>1</sup>(2012-2016), SHOW<sup>2</sup> (2020-2023), ULTIMO<sup>3</sup>, and AVENUE (2018-2022) (Mahmoodi Nesheli et al., 2021). AVENUE deployed six pilot sites of SAV deployment in four European cities: Geneva, Lyon, Copenhagen, Luxembourg, Sion and Esch-sur-Alzette. It is a European-funded project to support public transport by deploying innovative urban mobility services, such as automated, on-demand and door-to-door trips (AVENUE, 2018). The project included an impact assessment work package specifically targeting the social, economic, and environmental effects of implementing automated minibuses to bolster public transport in European cities. One of the studies conducted within this scope involved analysing the externalities associated with automated electric minibuses.

### 2.3.2 Potential Externalities of Shared Automated Vehicles

Research regarding the externalities of automated electric minibuses remains limited, mirroring the constraints faced by studies on AV (Ferdman, 2020; Ercan et al., 2022) and SAV (Kaddoura et al., 2017; Winter et al., 2017; Fournier et al., 2020) due to their status as emerging technologies.

Qualitative assessments, like Gurney's (2022), identify reduced pollution, decreased congestion, enhanced safety, and improved land utilisation as envisaged positive externalities of AV. However, Gurney emphasises that these outcomes are contingent upon specific assumptions. Furthermore, the study highlights unintended externalities,

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<sup>1</sup> Cities demonstrating cybernetic mobility, demonstration phase with 7 selected cities (Alessandrini A (2016).

<sup>2</sup> SHared automation Operating models for Worldwide adoption (2020-2023), with 13 European countries and over 20 cities (SHOW (2023).

<sup>3</sup> ULTIMO - Advancing Sustainable User-centric Mobility with Automated Vehicles initiative aims to implement on-demand AV public transit system in 3 cities: Oslo, Geneva and Herford. (ULTIMO (2023).

including a decline in organ donations due to fewer fatal accidents, enhanced public health and community well-being stemming from the absence of human-driven vehicles, and reduced short-distance air travel owing to the increased reliability of AV and SAV trips. As Brown (2019) exemplified, quantitative analysis relies on analytical models to explore the potential externalities of congestion of AV and SAV. The study analyses that AV could worsen urban traffic instead of improving it due to induced demand.

Furthermore, it highlights that as more AV hit the roads, they might end up causing more congestion due to certain passenger behaviours, like empty vehicles searching for parking spots. This unexpected consequence could create a "tragedy of the commons" scenario, where individual choices add up to make traffic worse for all. Russo et al. (2019) stress how AV could increase commuting, worsening congestion and urban sprawl. Their proposed solution involves targeted road tolls to address these challenges. Meanwhile, Carreyre et al. (2023) present the economic effects of introducing AV, in general, in urban settings, emphasising their externalities. The study highlights that while AV offer benefits, their integration under a private ownership model might lead to increased congestion and longer travel times. To address these concerns, automated public transport services such as the AM should be considered when incorporating AV into cities. These studies and others raise concerns about AV potentially causing more negative external costs than mitigating urban transport system impacts.

Recommendations lean towards integrating automated public transport services, such as the AM, as a solution to urban mobility challenges posed by AV. The studies often begin by addressing potential risks associated with AV, concluding with recommendations for shared AV, like SAV, to harness their positive impact. While research on SAV-specific externalities is emerging, it mainly revolves around robotaxis. For instance, Fournier et al. (2020) introduce scenarios for deploying robotaxis as a form of SAV in Berlin and Stuttgart. They demonstrate that with high market penetration rates, these vehicles could significantly reduce congestion, accidents, and external costs related to emissions. Another study by Carreyre et al. (2023) shows that in urban settings, the adoption of on-demand door-to-door robotaxis could increase external costs, including congestion, emissions, and accidents. While offering convenience, this model is associated with negative societal impacts due to heightened congestion, resulting in increased overall external costs. This underscores the necessity of exploring alternatives like AM services to counteract these challenges.

Meanwhile, Winter et al. (2017) explore SAV as robotaxis service within a grid network. It focuses on vehicle relocation strategies and their externalities related to passenger wait times, empty travel distances, and parking requirements. Other studies proposed potential solutions to promote the use of SAV instead of AV. Gurumurthy et al. (2019) propose solutions favouring SAV over AV, showing how moderate-to-low fare levels make ride-sharing cost-effective despite privacy concerns. Although road pricing during peak hours decreases VKm by 2% and boosts SAV demand and revenue, profitable margins hinge on maintaining low fares.

However, research on the externalities of AM or MaaS remains limited. Moreover, the impacts of these technologies are predominantly studied within transportation systems rather than exploring their broader implications on sustainable cities.

## **2.4 SUSTAINABLE URBAN DEVELOPMENT AND SUSTAINABLE MOBILITY**

SUD intersects significantly with mobility in urban spaces. This section outlines the comprehensive definition of SUD, its relationship with sustainable urban mobility, and the pivotal role of transport networks in achieving broader sustainability goals. By examining the core principles and strategies various entities advocate, we aim to underscore the intrinsic link between urban development, mobility, and sustainability.

### **2.4.1 Sustainable Urban Development**

As global hubs, cities grapple with many challenges, including road congestion, housing affordability, and social exclusion, often exacerbated by urban sprawl (OECD, 2018). Brundtland Commission (1987) define sustainability as: " ... *meeting the needs of the present without compromising the ability of future generations to meet their own needs*". This necessitates an integrated approach to addressing economic, social, and environmental challenges. The sustainable city bridges the gap between sustainability and the broader concept of sustainable development (Hassan and Lee, 2015).

SUD is usually used interchangeably with urban sustainability. According to P. Berke and M. Manta (2002), SUD aims to create better living spaces and healthier ecosystems—connecting to 'reproduction.' Secondly, it strives for balance among environmental, economic, and social aspects. Thirdly, SUD extends beyond local interests to consider global needs, acknowledging broader community roles. Lastly, SUD is an ongoing, dynamic process, continually assessing trends, engaging citizens, resolving conflicts, and

updating plans for sustained progress towards sustainability.

The concept of SUD is interpreted differently. For instance, policymakers may focus on particular aspects of SUD, primarily environmental sustainability, addressing emissions, energy efficiency, and climate change impacts. SUD can be achieved by tackling urban environmental challenges such as air and water pollution, promoting green infrastructure, curbing biodiversity loss, enhancing resource efficiency, and implementing measures to mitigate GHG emissions (OECD, 2015; Yigitcanlar and Teriman, 2015; United Nations, 2023b). SUD can be viewed from different perspectives. Some emphasise on the economic sustainability aspects of SUD. In this regard, SUD is seen as a consequence of elevated socio-economic, demographic, and technological advancements. It seeks to strengthen the foundational aspects of urban systems, thus enabling a new level of socio-economic development (Nijkamp, 1990; European Commission, 2019).

On the other hand, SUD can be viewed as social sustainability, which underscores the importance of citizens and society in achieving sustainable urban and societal progress. It embodies an inclusive sustainability strategy where all individuals have equal opportunities for social advancement regardless of their backgrounds (Almusaed et al., 2020). Additionally, another definition of SUD emerges through urban design and planning, which aims to create livable environments. It encompasses the holistic development of densely populated regions, municipalities, and neighbourhoods (Almssad and Hong, 2021).

Lastly, SUD encompasses the ongoing process of urbanization, characterised by the increasing urban population share and the expansion of urban areas (Almssad and Hong, 2021). Hassan and Lee (2015) position SUD as the propelling force behind sustainability in urban areas, identifying three SUD role models:

- Compact city: characterised by high population density and efficient land use, designed to minimise urban sprawl by promoting mixed land use, walkability, and proximity between residential, commercial, and recreational areas (OECD, 2018).
- Smart city: characterised by the use of advanced technologies and data-driven solutions to enhance efficiency, sustainability, and quality of life for its residents (Lom and Pribyl, 2021).

- Zero-carbon city: produce minimal or zero net carbon emissions by utilising renewable energy sources, efficient infrastructure, and carbon-neutral practices (ECO-LIFE, 2019)

The OECD (2018) advocates for drafting policies to reverse unsustainable urban development. Their primary objectives should be to promote "*socially desirable levels of population density*" and mitigate the negative environmental and economic impacts caused by individuality.

The EU's approach to sustainable urban development centres on core principles: creating a strategic vision, engaging multiple stakeholders, and ensuring diverse funding sources with robust monitoring frameworks (European Commission, 2019). These strategies focus on districts, cities, and functional areas, mainly targeting cities due to the global shift to urban living (United Nations, 2023a). They align with the SDGs, especially SDG 11, which addresses urban development and sustainable mobility. However, as of 2022, only half of the world's urban population had convenient access to public transportation, indicating persistent issues with urban sprawl and limited public spaces (United Nations, 2023b, 2023c). Nearly 40% of European and North American urban areas lack public transport, highlighting the urgent need to integrate motorised and active mobility via sustainable urban plans and policies (United Nations, 2016a, 2023a).

## 2.4.2 Relationship between Sustainable Urban Development and Mobility

### Sustainable Mobility

The assessment of cities' sustainable practices significantly hinges on efficient, affordable, safe, clean, and accessible transport networks that veer from individual motorised mobility. Sodiq et al. (2019) emphasise that a sustainable transportation system should acknowledge four evolving fields in urban transit: mobility, city logistics, intelligent system management, and livability. The concept of mobility relies on an inclusive transportation system encompassing various modes, such as cars, public transport, cycling, and walking, along with their respective infrastructures. Simultaneously, the transport system adjusts to meet the diverse demands of mobility (François et al., 2021).

Sustainable mobility is an alternative to the traditional car-centric model, fostering sustainability within cities by reducing travel necessity and promoting shifts towards sustainable transport. It aims to curtail travel distances, enhance efficiency through

technology, and align seamlessly with broader sustainable urban development principles, bridging concepts of land use, urbanism, and transportation systems (Banister, 2008). Developing sustainable mobility that caters to citizens' needs while managing negative impacts is crucial for accessibility and promoting healthy living. Many cities face challenges in providing efficient transport systems and controlling adverse effects. To achieve efficient urban transport, cities must support intermodal travel and promote sustainable modes of transport and shared use of urban space. Cities typically rely heavily on ICEV, causing congestion and environmental issues. Efforts to combat inefficiencies include promoting cycling, discouraging car usage through penalties like congestion charges, and enhancing public transportation. (UNECE, 2021). Sustainable mobility plays a pivotal role in smart, compact, and zero-carbon cities under sustainable urban development. It diminishes reliance on private vehicles, enhancing accessibility and efficiency, and forms a core component of smart cities reliant on transportation, Information and Communication Technology (ICT), and energy (Russo and Rindone, 2023).

Specifically, this approach harmonises with compact cities by prioritising walking, cycling, and public transport over cars. Integrating mixed-land use, transit-oriented development, and green spaces effectively minimises travel distances, congestion, and emissions, thereby nurturing more interconnected and environmentally conscious urban areas (Bibri et al., 2020). Sustainable mobility significantly contributes to zero-carbon cities by promoting low-carbon transportation modes, reducing pollution, and fostering a greener urban environment, aligning with environmental sustainability objectives (Kenworthy, 2006).

#### Strategies: Sustainable Urban Mobility Plans (SUMP)

Transitioning from the discussion on fostering sustainable mobility, the focus shifts to the pivotal role of Sustainable Urban Mobility Plans (SUMPs) in the EU context. SUMP play a crucial role in fostering sustainable mobility in European cities. A SUMP aims to cater to the movement needs of urban areas by integrating principles of integration, participation, and assessment. It encompasses the city and its commuting zones, considering actual traffic patterns, and encourages collaboration across government levels and policy areas. This comprehensive approach ensures diverse, sustainable transportation choices for safe, efficient, and eco-friendly travel while prioritising residents' well-being and urban environmental conservation (European Commission, 2018).

The systematic approach of SUMP involves key steps such as scoping and assessment, identifying stakeholders, establishing a vision and goals, and developing strategies and action plans. This process emphasises integration among various transportation modes and policies, underscores financial planning, and highlights continuous monitoring and public engagement. With the flexibility to adapt based on ongoing evaluations and evolving circumstances, the SUMP aims for a comprehensive and adaptable plan addressing current needs (Eltis, 2021). Their role in creating sustainable cities cannot be overstated, prioritising eco-friendly and efficient transportation that reduces congestion emissions and enhances accessibility, aligning with broader goals for urban sustainability (Russo and Rindone, 2023).

SUMP significantly impact sustainable urban development across three key dimensions of sustainability:

- Environmental dimension: SUMP focus on reducing urban transportation's environmental impact by encouraging cleaner modes of travel, such as public transport and active mobility. They aim to reduce air and noise pollution, conserve energy, and decrease greenhouse gas emissions by lessening reliance on private vehicles (SUMP-UP project, 2022).
- Social dimension: These plans prioritise accessibility, ensuring that transportation is inclusive for all segments of society. By improving public transit, cycling infrastructure, and pedestrian pathways, SUMP enhances mobility options for vulnerable groups and promotes community cohesion by creating shared spaces and safer environments (UNECE, 2021).
- Economic dimension: SUMP contribute to economic growth by optimising transportation systems, leading to cost savings and increased efficiency. By reducing congestion and improving public transit, these plans save time, decrease road maintenance costs, and enhance connectivity to job opportunities, education, and businesses, thus stimulating economic growth (Torrise et al., 2020).

SUMP serve as a robust framework for implementing smart mobility solutions like SAV. CoEXist, an H2020 project, identifies eight SUMP principles for road vehicle automation, addressing governance changes, long-term plans, performance assessment, stakeholder collaboration, citizen involvement, monitoring structures, and quality assurance (CoEXist, 2019; Jaroudi et al., 2021).



Sustainable Energy and Climate Action Plan (SECAP) and SUMP are interconnected. While SECAPs cover a broader spectrum of sustainability strategies, SUMPs are dedicated plans solely focused on urban mobility. SECAPs delineate comprehensive strategies for cities to reduce greenhouse gas emissions and advance sustainability. Within SECAPs, Sustainable Mobility Planning concentrates on crafting environmentally sound transportation networks, encouraging walking, cycling, public transit, and shared mobility while reducing dependence on private vehicles to curb emissions (Climate ADAPT, 2023).

### Smart Mobility Relation to SUD

Having explored the impact of SUMP, the discussion now delves into the realm of Smart Mobility, a paradigm shift leveraging digital networks and innovative technologies. The term paradigm shift refers to changes in attitudes and patterns of use as well as innovations in technologies (Nicolai and Faucheux, 2015). Smart mobility represents a transformative departure from traditional car-centric models, utilising digital networks to optimise urban infrastructure and services by integrating new information technologies. Often associated with ICT, its focus remains on meeting community needs. Smart mobility aims to establish and sustain an eco-friendly, safer transportation network through modern technology and innovative methodologies (Papa and Lauwers, 2015; Butler et al., 2022). Within the urban transportation context, three domains of innovation have been distinguished: advancements in-vehicle technologies (such as electrification and hydrogenation), approaches focused on services (like car-sharing, ride-sharing, and public transport), and strategies for managing transport demand (including softer modes, urban toll systems, and traffic restrictions) (Buisson et al., 2021). Recent advancements like MaaS have emerged within the smart mobility landscape, addressing accessibility gaps between the first and last mile alongside efficient public transportation (Butler et al., 2022).

Meanwhile, Singh et al. (2022) explore the transformative potential of blockchain and AI in revolutionising urban mobility, spotlighting AI's role in intelligent transportation and blockchain's promise for transparent and trusted transportation systems, all while acknowledging scalability and data privacy challenges. AV and SAV emerge as pivotal technologies advancing smart mobility, catalysing sustainable cities. These innovations represent a part of the smart solutions proposed to address sustainability challenges in urban settings by encompassing reliable, accessible, and safe transport networks (Seuwou et al., 2020; Bayoumi, 2022). Measures such as integrating ridesharing technologies, MaaS,

ITS<sup>4</sup>, and public-private partnerships aim to address pollution and congestion, aligning with the broader goal of sustainability through technological advancements in mobility (Bıyık et al., 2021).

While smart mobility focuses on technological advancements, there's a need to integrate other aspects of mobility planning, such as citizen and stakeholder engagement (Papa and Lauwers, 2015; Bıyık et al., 2021; Butler et al., 2022). This techno-centric approach lacks clear comparisons between technological and conventional solutions, leading to conflicting goals. To achieve effective, sustainable urban mobility, it is vital to establish clear, measurable objectives and promote ongoing learning (Müller-Eie and Kosmidis, 2023). The linkage between sustainable mobility, smart mobility, and sustainable urban development is evident in Figure 2. Frameworks like SUMP and the SDGs serve as guiding principles, ensuring cities effectively implement these concepts to attain sustainability goals.

Numerous studies have aimed to connect sustainable and smart urban mobility, striving to close the gap between the two concepts. SUD benefits from the integration of eco-friendly and intelligent transportation methods under the smart mobility paradigm. This involves deploying transportation systems that minimise environmental impacts, increase accessibility, promote social equity, foster economic growth, and cater to the diverse needs of urban communities (UNECE, 2021; European Commission, 2023; Müller-Eie and Kosmidis, 2023).

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<sup>4</sup> ITS optimises road transport by using tech to manage traffic, reduce congestion, and enhance safety. Using ITS can enhance road safety and efficiency, cut travel times, save energy, reduce pollution, and improve emergency responses (UNECE, 2021).

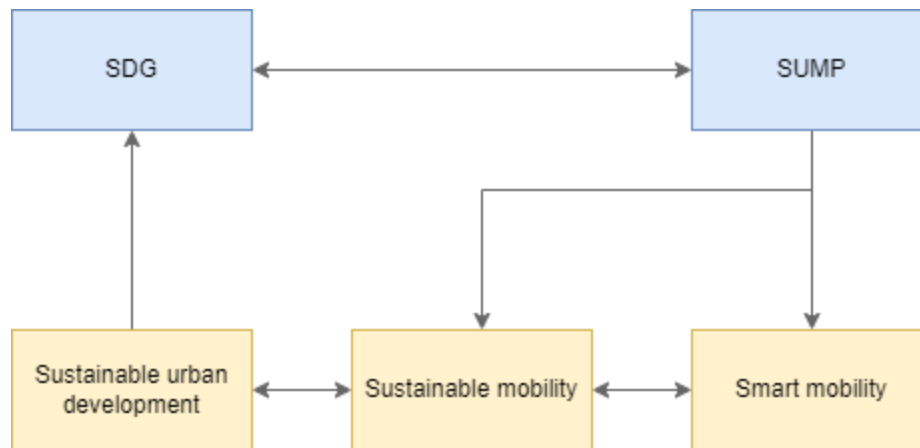


Figure 2: Sustainable Urban Development And Mobility Ecosystem, based on Papa and Lauwers (2015)

However, these studies do not offer theoretical explanations or frameworks describing how these concepts are interrelated or function together in practice (Müller-Eie and Kosmidis, 2023). As the discourse unfolds on the transformative nature of smart mobility, insights from key studies shed light on the practical alignment of smart mobility with sustainable urban development. For instance, Müller-Eie and Kosmidis (2023) embark on answering the question, "*How sustainable is smart mobility?*". They examine how smart mobility initially aligns with urban sustainability in Nordic cities. It finds that while these initiatives contribute to sustainable mobility by promoting active travel and improving efficiency, they often lack clear comparisons between technological and conventional solutions. Conflicting goals emerge when efficiency-focused measures contradict environment-friendly travel ones. This highlights the need for clear, measurable goals and continuous learning to achieve sustainable urban mobility effectively. Using Nigerian cities as a case study, Okafor et al. (2023) evaluate essential factors for successful smart mobility systems within smart city development. It identifies key success factors like sustainable transportation, ICT availability, and local transport infrastructure. Despite their significance, experts note a low application level in Nigeria. The findings serve as a guideline for cities, urging improvements in urban transportation infrastructure and emphasising the critical role of these success factors in achieving smarter mobility systems in cities.

Butler et al. (2022) investigate how smart mobility connects to sustainable cities, using Australian cities as a case study to understand attitudes toward smart mobility. It identifies barriers like resistance to shared transport and reliance on private vehicles. Insights aim to shape policies for smart mobility in urban areas, emphasising the need to improve

public transport in areas with good coverage and enhancing commuter experiences where public transport is lacking. The study highlights challenges in implementing smart mobility in cities and calls for regional integration in transport planning to align local schemes with higher-level objectives. These studies across different regions like Nigeria and Australia emphasise the critical role of ICT availability and improved urban transportation infrastructure in successfully implementing smart mobility systems in sustainable cities. These insights underscore the necessity of overcoming barriers such as resistance to shared transport and ICEV dependency reliance while emphasising the need for improved public transport and regional integration in transportation planning to align with overarching objectives of sustainable urban development.

Finally, some projects and action plans incorporate tools of smart mobility to reach sustainability in European cities, such as FAME. It aims to establish shared tools and approaches for sharing top practices among stakeholders in Europe's Connected, Cooperative, And Automated Mobility (CCAM) sector. Its aim aligns with the European Commission's objective of harmonizing research, testing, and assessment within this domain (CCAM, 2023).

## **2.5 CONCLUSION**

Urban mobility generates positive and negative externalities, from congestion and pollution to social and economic impacts. Introducing smart mobility, like shared automated vehicles, specifically automated electric minibuses, offers a promising solution, potentially reducing pollution and parking and serving as a feeder to public transport. However, there's limited research on the externalities of these minibuses if they are to be deployed in cities.

Sustainable urban development encapsulates creating better living spaces, aligning economic growth with local needs, and considering global needs in urban planning. It is an ongoing process that requires environmental, economic, and social harmony. Sustainable urban mobility, crucial in this context, aims to minimise negative impacts by promoting cleaner modes of travel and enhancing accessibility. Strategies like SUMP are pivotal in fostering eco-friendly transportation systems within cities and achieving SDGs. Understanding and mitigating the externalities of urban mobility are essential for sustainable urban development. As cities strive for sustainability, balancing economic growth, social inclusivity, and environmental conservation becomes paramount.

Integrating innovative solutions like automated electric minibuses within a framework of sustainable urban mobility contributes to achieving eco-friendly and efficient transportation systems under the umbrella of sustainable urban development.

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### 3 POTENTIAL IMPACTS OF FUTURE DEPLOYMENT SCENARIOS OF SHARED AUTOMATED VEHICLES

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#### **Abstract**

The introduction of Shared Automated Vehicles (SAV) raises multiple questions regarding their potential impacts, varying from supporting sustainable mobility to reinforcing car-dependent models. Thus, understanding deployment strategies and associated impacts is crucial to achieve their potential. This is the goal of this study. We relied on a deliberative process of scenario planning with transportation experts to construct potential deployment scenarios. We conducted a systematic literature review to study the potential economic, social, safety, and land use impacts. This highlights the importance of shared automated vehicle integration in transportation systems and cities. Our study results indicate that the impacts identified through SLR and chosen by experts for each scenario vary depending on the scenario's context. Deploying automated minibuses as a first-last mile solution could positively impact deployment areas. These results could guide policymakers to better introduce this innovation to support sustainable mobility in sustainable cities.

**Keywords:** shared automated vehicles, sustainable mobility, scenario planning, systematic literature review



### 3.1 INTRODUCTION

The introduction of AV<sup>5</sup> has been heralded as a solution to the current mobility paradigm shortcomings. AV can serve new passengers, reduce environmental footprints, and improve congestion and road safety (Milakis et al., 2017b; Huber et al., 2022). However, high uncertainty levels remain associated with the introduction of AV (Ross and Guhathakurta, 2017) and determining AV impacts requires an interdisciplinary approach (Lyons, 2022). Whether AV can realise their potential depends on their deployment within the transportation system. Extensive literature covers potential private AV deployment (Zhang et al., 2018; Moore et al., 2020). Alternatively, AV can be integrated as a shared transportation option, complementing Public Transport (PT) (Pettigrew et al., 2020).

This study focuses on SAV. SAV refers to the combination of automated driving and sharing modes and services. Hence, it includes fleets of shared vehicles (e.g. automated AM and robotaxis), ridesharing services, on-demand services, and door-to-door mobility (Gruel and Stanford, 2016; Jing et al., 2019; Wang et al., 2021). Depending on the deployment strategy, SAV could reduce or increase negative externalities (Gelbal et al., 2017; Vleugel and Bal, 2017; Feys et al., 2020b; Hilgarter and Granig, 2020; Nemoto et al., 2021; Piatkowski, 2021; Huber et al., 2022). Many studies explore specific forms of SAV deployment, such as AM. For instance, (2020) discussed the potential social implications of replacing conventional modes with AM.

Other studies have focused on exploring the consequences of different SAV operational aspects. These aspects include fleet size, service areas, trip frequency within dynamic ridesharing frameworks, and penetration levels (Fagnant and Kockelman, 2014; Burghout et al., 2015; Childress et al., 2015b; ITF, 2015b; Fagnant and Kockelman, 2018; Jones and Leibowicz, 2019; Fournier et al., 2020; Overtoom et al., 2020; Kumakoshi et al., 2021).

Furthermore, certain studies have examined SAV impacts without delving into the intricate contextual factors leading to these impacts (Shaheen and Bouzaghrane, 2019; Narayanan et al., 2020). A few articles examining the interconnected context of deployment and its impacts tend to focus primarily on AV, only briefly mentioning SAV (Townsend, 2014;

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<sup>5</sup> The use of "automated" is more accurate than "autonomous", autonomous is a misnomer because it implies self-governing and does not account for human intervention needed to operate these vehicle [SAE (2018)].

Milakis et al., 2017a).

However, these studies have not thoroughly investigated the deployment conditions of SAV, including technical, social, economic, environmental, and governance dimensions. Consequently, a gap exists in comprehending how the intricate interplay of political, economic, social, technological, and legal factors shapes the nature of SAV deployment. This interrelation influences the selection of deployment strategies that, in turn, impact various dimensions such as society, environment, economy, safety, and land use. While the factors represent the contextual influencers in shaping deployment strategies, the impacts delineate the outcomes cities aim to achieve and the actual effects these factors can bring about. This research aims to bridge this gap by envisioning SAV deployment forms and their impacts in European cities. It expands qualitative research on the future of SAV and seeks to fill this knowledge gap through an interdisciplinary approach that combines strategic planning methods with a literature review. Hence, this study seeks to answer the following question: What are the potential future deployment scenarios for SAV in European cities, and what are their potential environmental and socio-economic impacts? Methodologically, this study relies on scenario planning and a systematic literature review (SLR). Scenario planning produces scenario narratives, while SLR helps present each scenario's possible consequences. The scenarios were developed within the AVENUE<sup>6</sup> project.

The study is structured as follows: the second section presents the conceptual background to present scenario planning and SAV and their impacts. The third section delves into the methodology used. This section describes the application of the scenario planning method and how the SLR is used to reinforce the study. The fourth section presents the results of the qualitative analysis and the impacts deduced using the SLR. The fifth section includes the discussion, and the study is completed with a conclusion in section six.

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<sup>6</sup> The AVENUE project (2018-2022), sponsored by H2020 and with 20 institutions, runs 6 pilot projects in four European cities: Geneva, Lyon, Copenhagen, Luxembourg, Sion, and Esch-sur-Alzette to test automated minibuses integrated in public transport in mixed traffic SAE (2018).

## 3.2 CONCEPTUAL BACKGROUND

### 3.2.1 Scenario planning

It is difficult to find a unified definition of scenario planning in the literature (Lindgren and Bandhold, 2009; Ramirez et al., 2015). It is employed across various fields, including military intelligence, policymaking, and innovation management (Ringland, 2010; Edgar et al., 2013). It is designed to broaden and challenge decision-makers perspectives, allowing them to reconsider the standard assumption of 'business as usual'.

Moreover, scenario planning has become increasingly relevant in situations of uncertainty and complexity because it seeks to capture the depth and breadth of possible outcomes, encouraging decision-makers to explore adjustments they might otherwise overlook. Scenario planning has three key goals: understanding future events, challenging conventional thinking, and improving decision-making (2013). This approach differs from contingency planning, sensitivity analysis, and simulations. The most commonly used scenario planning method is the Intuitive Logics Approach. This approach supports strategic change by accommodating unpredictable elements transitioning from business circuits to scientific research (Zmud et al., 2015). It relies on group intuition and a social reasoning process, fostering dialogue and theory building (Derbyshire and Wright, 2017). The analysis identifies political, economic, social, environmental, and legal aspects, often challenging to predict. The two most uncertain forces impacting the focal issue create a scenarios matrix (Figure 3), guiding narrative development.

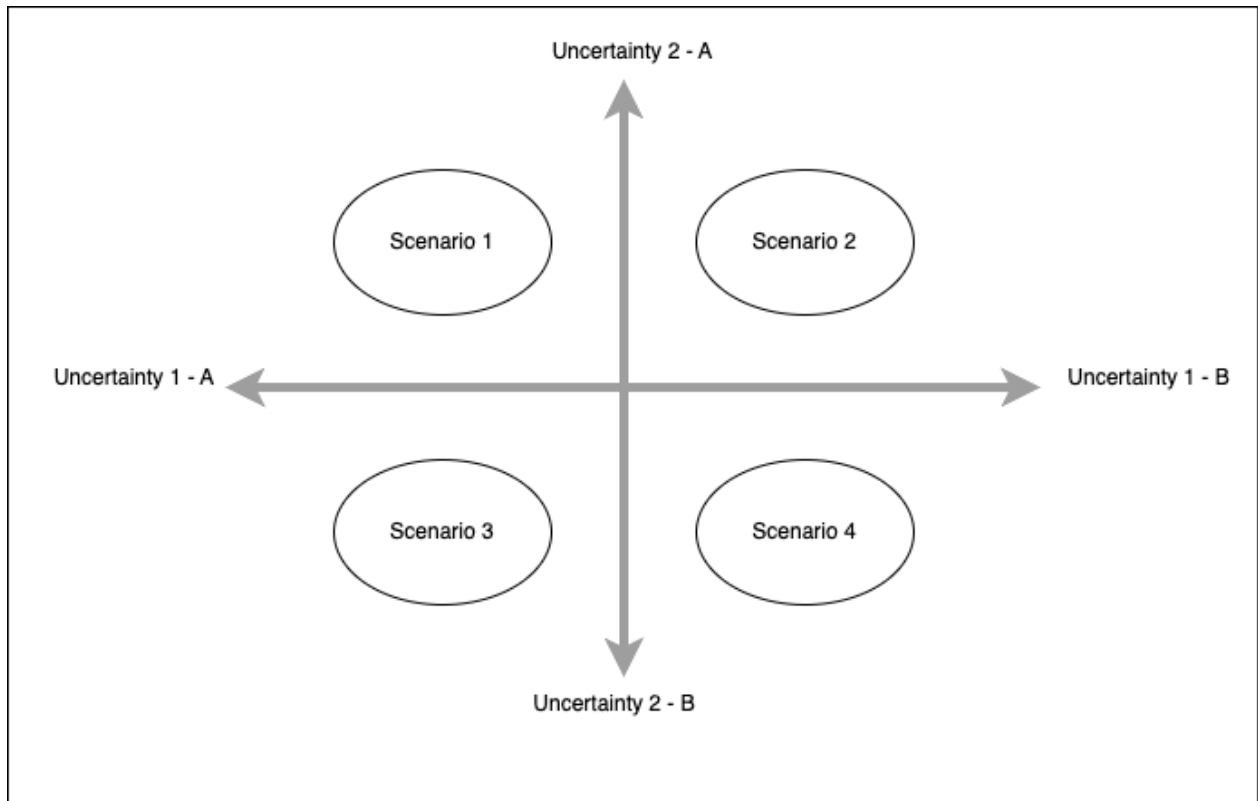


Figure 3: ILA scenario matrix based on (Derbyshire and Wright, 2017)

When applied to disruptive technologies like SAV, scenario planning helps organizations anticipate uncertainties and risks. A disruptive technology is an innovation that could alter an existing industry or service by introducing a new approach that reshapes the market (Nicolai and Faucheux, 2015). Key uncertainties include the regulatory environment—how policies and laws might influence SAV and AV introduction—and user acceptance: whether people will opt for SAVs over traditional transport and to what extent (Milakis et al., 2017b; Korbee et al., 2023). Various scenarios explore the impact of SAV on traditional transportation, PT integration, and land use strategies, highlighting potential benefits like cost reduction, increased accessibility, and reduced congestion. New mobility services, such as MaaS and ITS, are poised to disrupt the current mobility paradigm (Nemoto et al., 2021).

### 3.2.2 Shared Automated Vehicles impacts

#### SAV deployment

AV are rated on a scale from 0 to 5, indicating their level of automation, with 0 being no

automation and 5 representing full automation (SAE, 2018). SAV offer affordable on-demand last-mile solutions and shared mobility services, including carsharing and ridesharing (Wenwen Zhang et al., 2015; Lim Linda and Tawfik Aly, 2018). They are commonly used for short-to-medium urban trips, appearing as taxis, minibuses, or buses and can be integrated with MaaS to assess their overall impact (Kamargianni et al., 2015). SAV pilots operate in various settings, including urban areas, campuses, and tourist destinations (Okeke, 2020). SAV deployment methods include publicly owned fleets, private fleets, automated public transit, and Corporate SAV (Kassens-Noor et al., 2020; Narayanan et al., 2020a; Hunter, 2021).

This study examines deployment in urban centres and clusters, categorised by urbanization level. High-density clusters have  $\geq 1,500$  people/km<sup>2</sup> and  $\geq 50,000$  population, while urban clusters/suburban areas have  $\geq 300$  people/km<sup>2</sup> and  $\geq 5,000$  population (Eurostat, 2023). We also consider that SAV should be deployed in geofenced<sup>7</sup> areas. The time horizon of SAV introduction varies based on the evolution of technology and deployment context. It ranges from 2020 to 2050 (Zmud et al., 2015; Litman, 2022). This study considers SAV deployment in the near future, with an initial introduction by 2030. SAV would follow the speed limits in dense urban areas, thus limiting their speed to 30km/h and are operated by electric powertrains (Dinh and Kubota, 2013).

### Impacts

The Federal Transit Administration (2020) and International Transport Forum (2023) present a mobility performance metric framework investigating new and traditional mobility systems and their regional and national impacts. Accordingly, city impacts concern environmental, economic, social, safety, and land-use impacts (Figure 4). A more detailed analysis of the various impacts is presented in the results.

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<sup>7</sup> Geofencing entails employing GPS or other location-based technology to set virtual borders or zones where SAV can operate. These limits are often established by the service provider or regulatory bodies (Hansen et al. (2021).

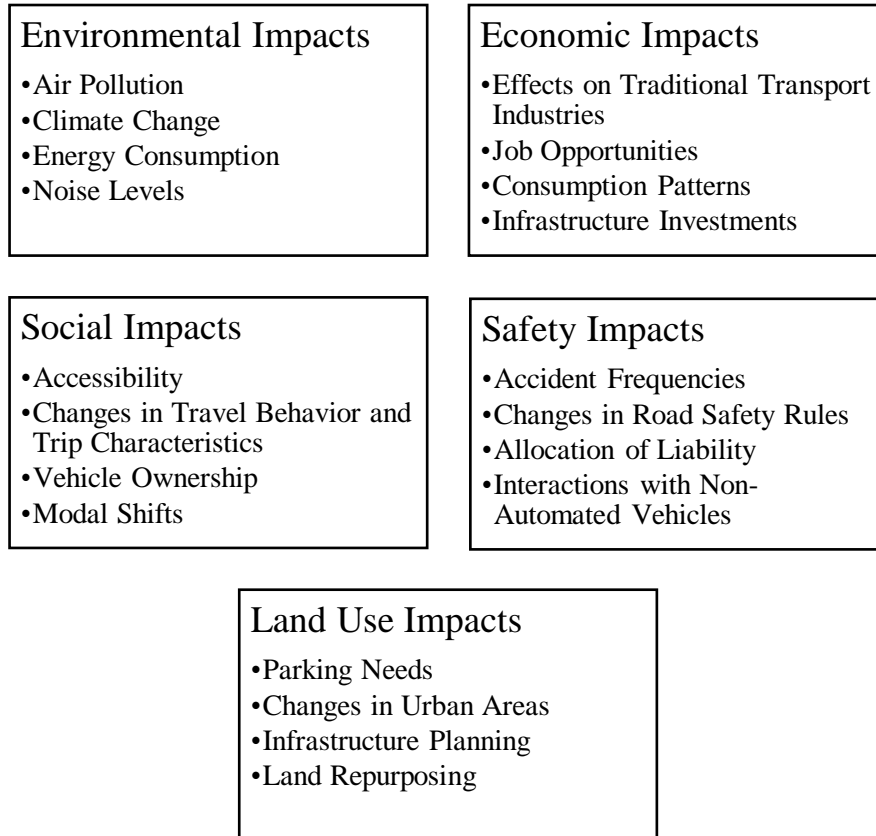


Figure 4: SAV Impacts, based on FTA (2020) and ITF (2023)

### 3.3 **METHODOLOGY**

The methodology consists of two main components (Figure 5). First, we employ the ILA to construct plausible scenarios. Second, we analyze these scenarios using SLR to explore SAV implications. The aim is to identify SAV deployment strategies and anticipate their impacts.

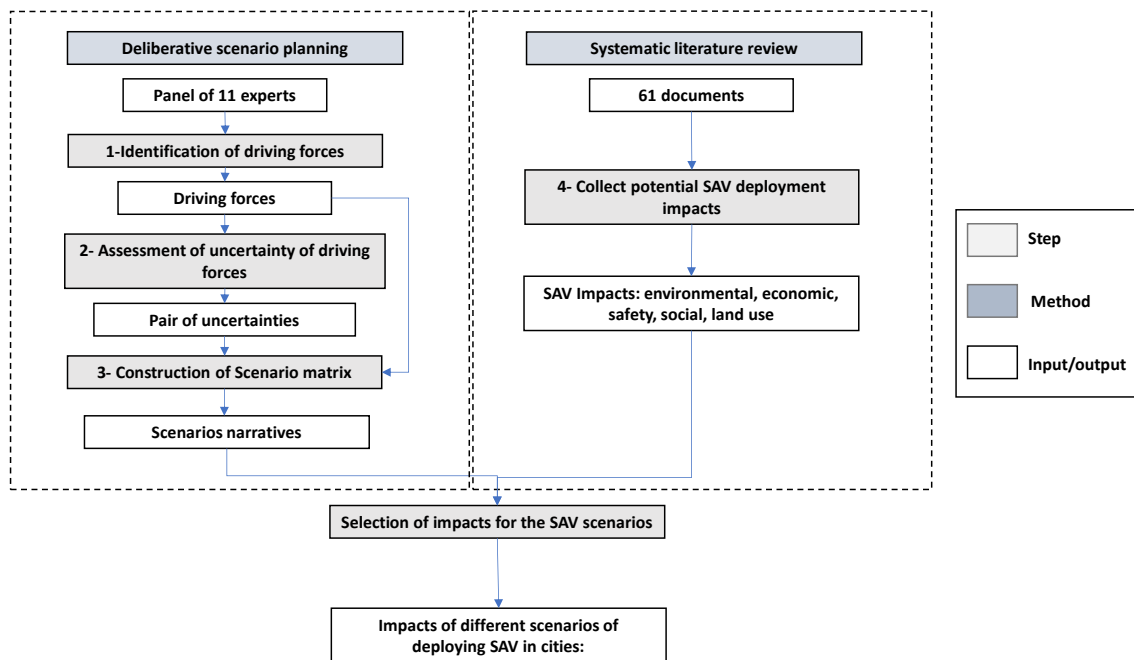


Figure 5: Research Methodology

### 3.3.1 Scenario method

We followed Milakis et al. (2017b) scenario planning steps previously used to study AV deployment in the Netherlands. Based on the ILA, this method explores potential SAV deployment in urban areas.

We assembled an 11-member expert panel from various fields, including sustainable mobility, transport economics, circular economy, consumer psychology, future mobility behaviour, shared mobility solutions, innovation strategies, and PT. This diverse panel comprised four professors and four researchers from universities in France, Germany, and Switzerland, along with three transport operators specializing in PT and digital mobility. The input collection reached data saturation, indicating a sufficient sample size for scenario development and impact assessment. Data saturation means they have gathered ample and diverse information. This completeness ensures robust scenario development and impact assessment.

Further data might not significantly change outcomes, as they have covered a comprehensive spectrum (Saunders et al., 2018). Due to COVID-19, discussions occurred virtually via presentations and workshops. Due to COVID-19, discussions occurred virtually via presentations and workshops (Masclaf et al., 2021).

### Step 1

The panel of experts brainstorms potential driving forces that could influence the deployment of SAV in European cities. These driving forces are grouped into categories following the PESTLE analysis. It is composed of (P)–political (e.g. policy and government support), (E)–economic (e.g. market demand, employment), (S)–social (e.g. changing attitudes, social equity), (T)–technological (e.g. technological advancements, digitalization) (L)-legal (e.g. liability and compliance laws), and (E)-environmental (e.g. emission reduction, energy transitions) forces (Ho, 2014).

### Step 2

Identifying uncertainties is essential for crafting realistic SAV deployment scenarios. Our approach observed the brainstorming process, selected key uncertainties, and validated them with experts. We participated as moderators but guided the process of scenario planning. A subset of these more influential uncertainties was integrated into the scenario matrix. These selected uncertainties shape distinct SAV deployment scenarios, leading to four scenarios with varying uncertainty levels.

### Step 3

We construct coherent and plausible narratives for each scenario based on the potential interactions between the uncertainties. The scenarios are built using selected driving forces. We name and describe the scenarios and then present the stories to the experts to validate them.

### Step 4

Once the scenarios have been validated, we can study each scenario's possible ramifications. Thus, we utilise the systematic literature review to collect potential impacts from other studies. Then, we rely on the experts to select the implications of introducing the SAV in cities for each scenario from the SLR findings. Finally, we continue the narratives by describing the implications of each scenario.

#### 3.3.2 Systematic literature review - potential impacts of SAV

The SLR consists of three stages based on Yigitcanlar et al. (2019): 1-Planning stage defines sources and research aims; 2- Review stage carries the descriptive analysis; 3-



Dissemination stage analysing the findings.

The SLR addresses the following: What are the potential environmental and socio-economic impacts of future deployment scenarios for SAV? This systematic method involves comprehensive data collection, findings synthesis, and evidence-based decision-making it, ideal for assessing SAV impacts in cities and identifying research gaps.

### Planning stage

In this step, we determine the search strategy and strings. The research objective is to determine the proposed deployment scenarios' impacts. Thus, the query keywords defined for the review were attributed to automated vehicles. The search strings include the following terms (or combinations): 'Automated', 'driverless', 'self-driving', 'intelligent', 'autonomous', 'connected', 'robo', and 'shared'. Then, a further assessment checked the documents for the words "impacts", "implications", "outcomes", "effects", or "consequences".

These studies provide insights, methodologies, and data. They draw from a corpus of academic and grey literature collected during the AVENUE project from 2018 to 2022. This database, comprising 1278 files at the study's inception, was stored in an internal cloud repository and largely sourced from Scopus and Web of Science.

### Review stage

We employed inclusion and exclusion criteria covering documents up to 2022. Out of 1278 scanned titles, abstracts, and descriptions, 297 were selected based on keywords aligning with our objectives, including 213 journal articles, 61 reports, and 23 conference proceedings. We excluded non-English, inaccessible (behind a paywall), and duplicate documents, leaving us with 119 eligible files. After evaluation, 61 documents were retained for scenario planning analysis and classification using pattern-matching techniques. Pattern-matching techniques were used to organise the data by identifying recurring themes in the documents, such as the SAV impacts, allowing for structured categorisation. Subsequently, we categorised this literature based on SAV impacts, encompassing environmental, economic, social, safety, and land use impacts, Figure 6.

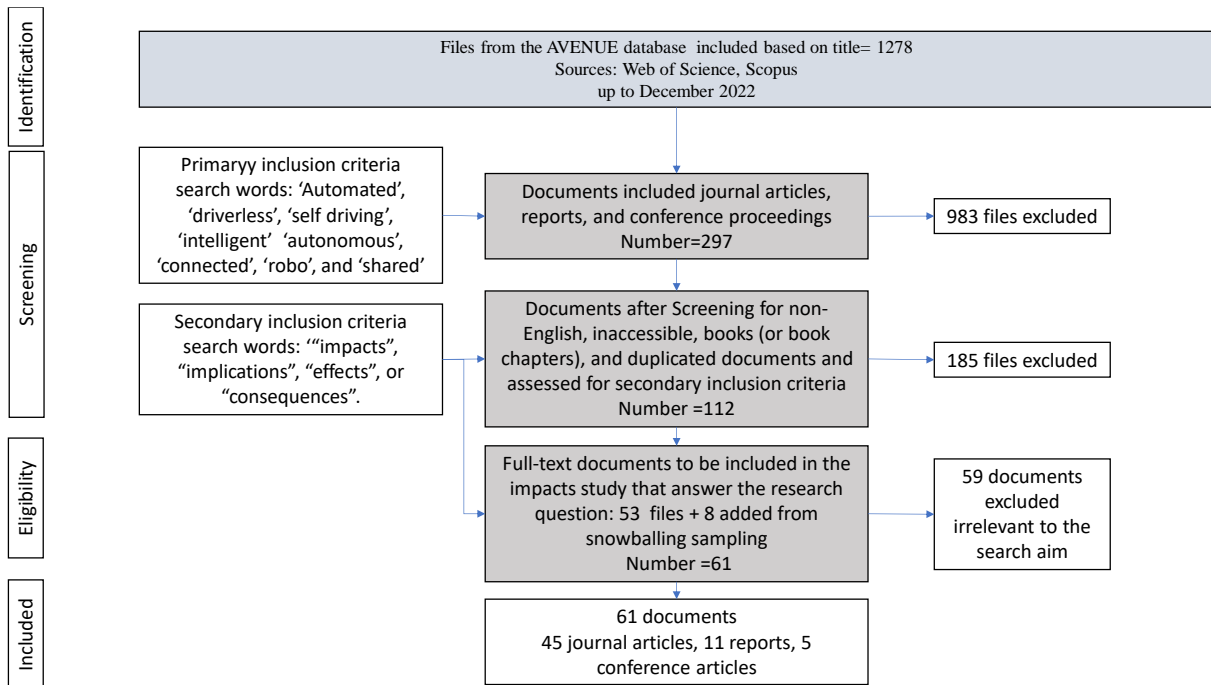


Figure 6: Systematic Literature Review

## Dissemination stage

In this stage, the findings are presented descriptively. The final results present the driving forces and the uncertainties of deployment, resulting in the scenario matrix, the scenario narratives and the associated impacts for each scenario determined through the SLR.

## 3.4 RESULTS

### 3.4.1 The driving forces

The panel focused on the objective of the analysis: plausible deployment forms of SAV in cities and the consequent impacts. The experts identified the driving forces that influenced the introduction of SAV. We then grouped them based on the PESTLE analysis, Figure 7.

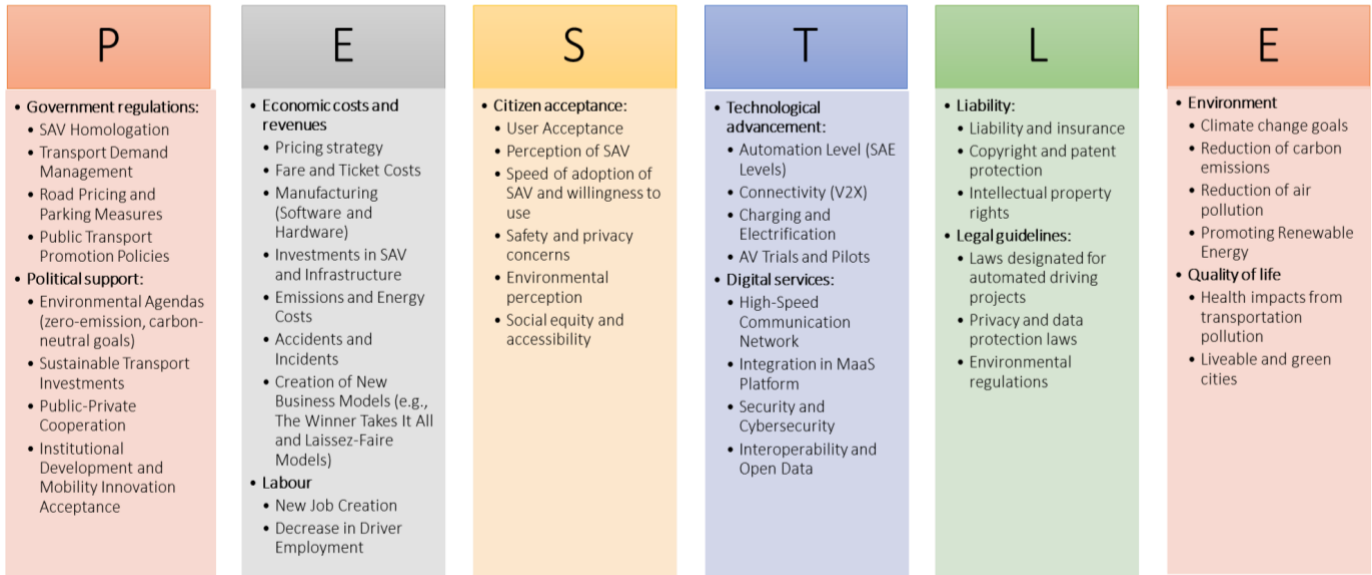


Figure 7: Driving Forces Grouped Using PESTLE

The driving forces identified as significant to our objective of envisioning plausible scenarios for the deployment of SAV in urban areas encompass the following dimensions:

- **Political:** It includes the regulatory environment and political agendas regarding transportation policies.
- **Economic:** Key considerations encompass labour and acquisition costs, pricing models, market acceptance, competition, fuel prices, and transport pricing.
- **Social:** Within this dimension, factors like willingness to pay, user acceptance, mobility preferences, attitudes toward transportation modes, and environmental awareness are crucial.
- **Technology:** Technological advancements in AV technologies, connectivity, data analytics, electrification, navigation systems, and security measures play a pivotal role in SAV efficiency.
- **Legal:** It covers regulatory requirements, liability standards, data protection, consumer protection, intellectual property, and governance structures.
- **Environmental:** It includes Environmental policies, climate goals, and circular economy adoption.

### 3.4.2 Uncertainties and Scenario Matrix

As moderators, we selected uncertainties related to integrating SAV in collaboration with the experts. First, We consulted the experts to assess key driving forces. Then, prioritising those forces deemed most influential based on their fields of expertise, we, along with the experts, tried to group them to define the uncertainties. On the one hand, political factors encompassing governance structures, homologation processes, support for public-private collaborations, and regulatory frameworks were highlighted. Additionally, economic considerations such as investment in AV infrastructure, market competition, pricing strategies, financial incentives, revenue streams, and operational costs were identified as critical factors. Legal aspects like liability and insurance laws, alongside social factors including social acceptance, safety perceptions, and public engagement with SAV operations, were also emphasised. These different factors were grouped because of their high influence on the SAV operation model.

On the other hand, economic factors relating to ride costs, legal factors encompassing road pricing, fuel and parking measures, technological forces like AV trials, high-speed communication networks, interoperability, and open data, as well as social factors such as user acceptance, adoption speed, and accessibility, political forces supporting public transport promotion, endorsement of innovative mobility solutions, and environmental factors contributing to reduced pollution were prioritised. This group was acknowledged as crucial for the integration of SAV within the transport system.

The two groups defined the two key uncertainties: the SAV deployment business model and modal shifts. The business model includes revenue streams, service provision, pricing, vehicles, user experience, user groups, and collaboration. Modal shifts involve changes in transportation preferences, shifting from private vehicle ownership to shared mobility like SAV.

We defined the business model uncertainty as private or public management as follows:

- Private business model: a model where companies like Waymo and Lyft would own and manage a private fleet and provide mobility services through a mobile app or platform. Fares would be market-driven, dependent on factors like demand and distance, with specific service areas and pick-up/drop-off points (Ferdman, 2020).
- Public business model: it integrates SAV into PT systems through public-private collaborations for last-mile solutions. MaaS tools enhance accessibility for all users,

with government oversight ensuring regulations, public funding, and user protection. Pilot projects involve private-public partnerships (Fournier et al., 2023).

To present the modal shift uncertainty,

- Substitution of a specific mode: it involves replacing a particular mode of transport, like polluting vehicles ICEV or outdated buses, with SAV. It focuses on phasing out specific modes within the transportation system.
- Add-on to the existing system: SAV integrates into the transportation system without targeting the replacement of any specific.

To conclude, the limits of the uncertainties are:

1- Business model: private operation - public operation

2- Modal shift: SAV as an add-on - SAV as a substitution

The next step is to create the scenario matrix matrix that combines the two chosen uncertainties, presented in Figure 8.

### **3.4.3 Scenario narratives**

For each scenario, we determine the vehicles used, whether cars or AM, the mobility services offered under the chosen business model, and the replaced modes of transport. Then, we identified the significant key drivers. The identification of significant key drivers was a collaborative process involving expert consultation, as described previously. We engaged experts to assess driving forces critical to SAV deployment based on the scenarios established in the scenario matrix. This helps construct coherent narratives and then describe the impacts using the findings from the SLR, Figure 8.

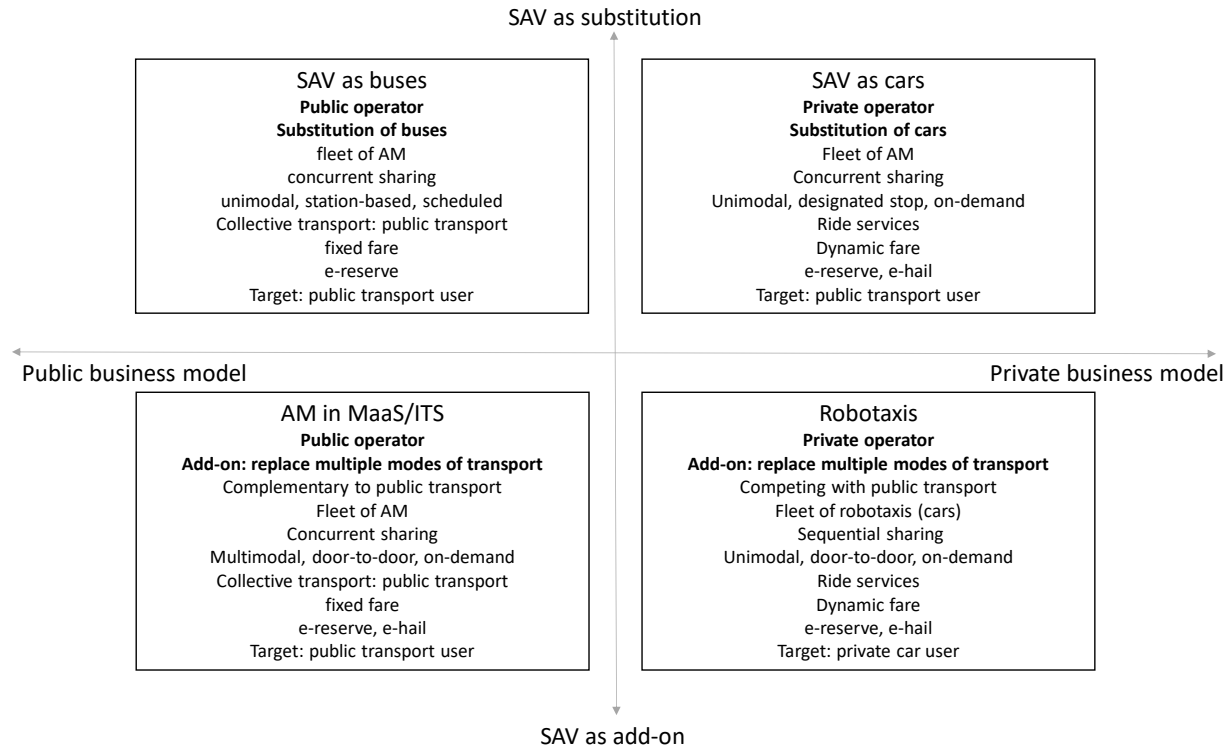


Figure 8: Scenario Matrix For The Deployment Strategies Of Am And Robotaxis

### Scenario 1: SAV as buses

PT operators modernise by using SAV to substitute buses. AM operate in dense urban areas as part of the PT service, following a concurrent sharing model with designated stops and scheduled itineraries to replace traditional buses over time (Shaheen and Cohen, 2019). The fleet provides simple, unimodal trips for a fixed fare. City planners support this strategy due to limited urban spaces and manoeuvrability issues associated with larger buses. Governments are working in tandem with transportation authorities to create regulatory frameworks that promote innovation, accessibility, affordability and user acceptance in PT while also addressing safety standards, data privacy, cybersecurity, and licensing. The main economic motives for replacing traditional buses with AM are lower operation costs, addressing the shortage of bus drivers, and increasing ridership revenues. This transition contributes to environmental targets by reducing greenhouse gas emissions and noise pollution. Technological advancements, such as higher levels of automation, improved sensory capabilities, and AV platooning, enhance fleet management and facilitate the replacement of traditional buses with AM. The services will be most attractive for typical PT users (Whitmore et al., 2022).

## Scenario 2: SAV as cars

Private operators deploy AM as a car substitution model. The fleet provides on-demand and ridesourcing services via digital platforms, connecting passengers with AM (Wali and Khattak, 2022). Operating under a concurrent sharing model, the minibuses provide unimodal trips with online reservations and dynamic fare adjustments based on real-time factors like demand, distance, time, and traffic conditions through data-driven algorithms (Fagnant and Kockelman, 2018). This deployment fills the gap due to ICEV restrictions in densely populated urban areas (Gonzalez et al., 2022). Environmental motives are reducing air and noise pollution and mitigating climate change while promoting sustainable transportation. Legislative measures aimed at a better quality of life and sustainability, congestion management, and urban liveability may be enforced to restrict ICEV (Lebrusán and Toutouh, 2021). Additional legal requirements may be imposed on private operators to ensure compliance with safety and security standards. The economic driving forces behind this scenario include cost reduction through driver elimination, increased utilisation rate by optimising occupancy, and additional revenue stream from the dynamic fare system and data monetisation. Technological factors crucial to the effective deployment of AM include advancements in automated and electric vehicle technology, vehicle-to-X (V2X) communication, and data analytics (Bučko et al., 2021). We envision the services to be targeted to typical car users.

## Scenario 3: Robotaxis

Scenario 3 presents the case where private operators would manage a fleet of cars deployed as robotaxis providing on-demand taxi services. Robotaxis are an add-on to the transportation system. Thus, they would replace different modes of transport, including PT. The vehicles operate under a sequential sharing model, where passengers use the same vehicle consecutively (Winter et al., 2020). Single rides give passengers a more customised travel experience without sharing the car with strangers. As passengers have complete control over the journey experience, this can create a sense of privacy, comfort, and convenience.

The service is facilitated through e-reserve or e-hail (Shaheen and Chan, 2016). The fleet offers door-to-door trips within the city and utilises dynamic fare pricing based on real-time data (Fagnant and Kockelman, 2018). The robotaxis as an add-on to the system would attract different road transport users, thus replacing modal shares of biking,

walking, cars, and PT. However, we envision that the robotaxis option would be mostly attractive to car drivers. This scenario would reflect a laissez-faire model.

Regarding politics and legislation, the government normally adopts a hands-off or a laissez-faire stance. It lets the market forces determine the evolution and expansion of the robotaxis business (Fournier et al., 2023). The economic motives would be cost efficiency, market profitability, and more investments in SAV. The robotaxis deployment could be more attractive for users. As social driving forces, they might be more convenient and private compared to a minibus, thus garnering more user acceptance (Milakis, 2021). Robotaxis private operators might also be more motivated by achieving technological innovations and creating a closed ecosystem to capture the value created.

#### Scenario 4: AM in MaaS/ITS

In this scenario, AM are deployed as part of a MaaS system facilitated through a public-private partnership. Public operators collaborate with established transport and technology corporations to implement an integrated MaaS system. The platform focuses on user convenience, enabling passengers to reserve on-demand, last and first-mile trips for a fixed fare. The AM in MaaS/ITS can also be used as a mobility gap filler. AM in MaaS/ITS generates more precise data through door-to-door possibilities and can improve AM and the transport system (Fournier et al., 2023). AM are further shared for intermodal trips, attracting passengers who would have otherwise walked, biked, or driven, particularly benefiting PT users (UITP, 2019). The public-private partnership generates revenue from passenger fees, advertising, and data monetisation, fostering economic growth and job opportunities in technical support, charging infrastructure management, and maintenance. Technological innovations, including MaaS, Application Programming Interface (API) services, on-demand features, interoperability, ticketing, ride-pooling, and routing algorithms, contribute to the plausibility of this scenario. The political motives driving this scenario involve achieving sustainability and climate change goals, reducing congestion, and providing efficient and accessible mobility solutions. The public-private collaboration demonstrates the government's commitment to promoting technological advancements and effective governance (Amblard, 2018). Governments play a critical role in developing regulations that govern the operation, safety, privacy, liability, and accessibility of AM in the MaaS system. The unique feature of this private-public collaboration lies in its ability to leverage strengths, encourage innovation, manage projects efficiently, share financial risks, and prioritise the larger public interest. This



collaborative strategy maximises the potential for successful and sustainable deployment of automated electric minibuses in a Mobility-as-a-Service system (MaaS Alliance, 2017).

#### **3.4.4 SAV impacts using SLR**

The SAV literature mainly covers 2013-2019, with a peak in 2017-2019 due to increased attention. Limited literature focuses solely on minibuses. Various methods are used: 33 quantitative, 25 qualitative, and 3 mixed. SAV is generally seen as improving road safety, but impacts on the built environment and travel behaviour vary, with emissions and induced demand showing mixed results. Table 1 summarises the major impacts of the SLR, labelled as positive or negative, based on the authors' views.

Table 1: Impacts collected from Systematic literature review

Categorization	Key findings	Causes	References
Environmental	<p>Class.</p> <ul style="list-style-type: none"> <li>• Lower emissions, reducing climate impacts;</li> <li>• Pollutant reduction through energy-efficient operations, especially with renewable energy sources;</li> <li>• Decreased energy consumption using electric vehicles in SAV services;</li> <li>• Improved air quality and public health by reducing greenhouse gas emissions and pollutants like carbon monoxide and volatile organic compounds;</li> <li>• Less local air pollution, even during peak hours;</li> <li>• Reduced noise pollution and resource utilisation in car and road production;</li> <li>• Minimised emissions and noise through optimised velocity profiles;</li> <li>• Eco-driving, platooning, and optimised driving behaviour for increased energy savings;</li> <li>• Reduced deterioration of buildings and roads due to lower emissions;</li> <li>• Efficient material use with lighter and fewer materials;</li> <li>• Integration of sustainable transportation systems with public transport and SAV.</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicle electrification;</li> <li>• SAV powered by renewable energies;</li> <li>• Efficient operation (Optimised vehicle utilisation, efficient routing, traffic management);</li> <li>• More benefits in cases of ridesharing, with higher occupancies;</li> <li>• Modal shift from private vehicles to SAV;</li> <li>• Integration with public transport and Non-Motorised Modes (NMT)</li> </ul>	<p>Fournier et al., 2020; Iclodean et al., 2020; Merlin, 2017; Bösch et al., 2016; Narayanan et al., 2020a; ITF, 2015b; Vleugel and Bal, 2017; Huber et al., 2019; Litman, 2022; Niles, 2019; Zhong et al., 2020; Milakis et al., 2017b; Milakis et al., 2017a; UITP, 2017; Spieser et al., 2014; Tomás et al., 2020; Medina-Tapia and Robusté, 2019; Fagnant and Kockelman, 2014; Alazzawi et al., 2018;</p> <p>Burns et al., 2013; Greenblatt and Saxena, 2015; Townsend, 2014; Kok and et al., 2017; Greenwald and Kornhauser, 2019; Fulton et al., 2017; González-González et al., 2019; Greenblatt and Saxena, 2015; Fulton, 2018; Fagnant and Kockelman, 2015a; Nunes and Hernandez, 2020; Gucwa, 2014; Zachariah et al., 2014; Burghout et al., 2015; ITF, 2015a; Fagnant et al., 2016</p>
	<p>Positive</p> <ul style="list-style-type: none"> <li>• Higher levels of greenhouse gas emissions;</li> <li>• Energy savings offset by energy used from higher speeds and new user groups.</li> </ul>	<ul style="list-style-type: none"> <li>• Induced demand;</li> <li>• The energy source for the electricity grid;</li> <li>• New users;</li> <li>• Low occupancy, single rides and empty trips;</li> <li>• Modal shift from NMT and public transport;</li> <li>• Longer trips to increase profit.</li> </ul>	<p>Alazzawi et al., 2018; Childress et al., 2015b; Wadud et al., 2016; Merlin, 2017; Ross and Guhathakurta, 2017</p>
Economic	<p>Negative</p> <ul style="list-style-type: none"> <li>• Cost savings for passengers;</li> <li>• Reduction of operation costs;</li> <li>• Significant decrease in salary costs;</li> <li>• Reduction in housing development costs;</li> <li>• Electric propulsion halves the fuel cost;</li> <li>• Reduction of congestion costs;</li> <li>• High levels of service at a lower cost;</li> <li>• Achieve significant yearly revenues;</li> <li>• Former parking areas in inner city areas could be used for new economic purposes;</li> </ul>	<p>Positive</p> <ul style="list-style-type: none"> <li>• Operation efficiency;</li> <li>• Dynamic fare system lowering peak demand and reducing user rate of SAV and operation costs;</li> <li>• Ridesharing lowering services cost;</li> <li>• Elimination of expensive garages and on-ground parking;</li> </ul>	<p>Tomás et al., 2020, Bösch et al., 2016; Merlin, 2017; Burns et al., 2013; Greenblatt and Saxena, 2015; Kok and et al., 2017; Litman, 2022; Narayanan et al., 2020a; González-González et al., 2019 ;Mladenovic and McPherson, 2016; Milakis et al., 2017a; Milakis et al., 2017b; Ferdman, 2020; Soteropoulos et al., 2019; Fagnant et al., 2016; Nunes and Hernandez, 2020</p>

Categorization	Key findings	Causes	References
Class.	<ul style="list-style-type: none"> <li>Promoting economic competitiveness and urban vitality.</li> <li>Substantial impact on fixed and variable costs of public transport;</li> <li>Strong economic incentive toward a highly efficient vehicle to cut energy costs;</li> <li>New job opportunities;</li> <li>Positive spillover on local businesses;</li> <li>Land rents rise in the centre but fall on the periphery.</li> </ul>	<ul style="list-style-type: none"> <li>Use of electric energy from renewable resources;</li> <li>Increased accessibility.</li> </ul>	
Social	<ul style="list-style-type: none"> <li>Increased cost for passengers in peak hours due to dynamic fares;</li> <li>No parking revenue;</li> <li>Less profit from public transport.</li> </ul>	<ul style="list-style-type: none"> <li>Changes in demand affecting prices as estimated by dynamic fare systems;</li> <li>No need for parking as vehicles roam;</li> <li>Modal shift from public transport to SAV.</li> </ul>	<p>Kok and et al., 2017; Niles, 2019; Milakis et al., 2017b; Milakis et al., 2017a;</p> <p>ITF, 2015b; Townsend, 2014; Soteropoulos et al., 2019,Merlin, 2017; UITP, 2017;</p>
Social	<ul style="list-style-type: none"> <li>Reduction of car ownership and car use (even during peak hours);</li> <li>Potential increase in high-capacity public transport ridership like trains;</li> <li>Potential increase in the overall public transit ridership and not motorised transport use;</li> <li>“Last-mile” trips in SAV could be longer trips in public transit;</li> <li>Improved perception of the safety of bicycling and subsequently positively influence cycle use.</li> </ul>	<ul style="list-style-type: none"> <li>Convenient and cost-effective SAV transportation;</li> <li>Increased public transport usage with improved access to stations and bus stops;</li> <li>Efficient first-mile/last-mile service for existing transit;</li> <li>Integrated multimodal mobility platform offering MaaS for better transportation options;</li> <li>Improved road safety through SAV deployment and reduced human error;</li> <li>Less human drivers needed:</li> </ul>	<p>Greenwald and Kornhauser, 2019; Iclodean et al., 2020; ITF, 2015b; Merlin, 2017; Milakis et al., 2017b; Bösch et al., 2016; Vleugel and Bal, 2017;</p> <p>Narayanan et al., 2020a; Niles, 2019; Shen et al., 2018; Soteropoulos et al., 2019; (Leich and Bischoff, 2019); Alazzawi et al., 2018; Ainsalu et al., 2018a; Wadud et al., 2016; Fulton et al., 2017;</p> <p>; Greenblatt and Saxena, 2015; ITF, 2015b; Fagnant and Kockelman, 2014; UITP, 2017; Martinez and Viegas, 2017; Nunes and Hernandez, 2020; Burghout et al., 2015; Mladenovic and McPherson, 2016</p>
Social	<ul style="list-style-type: none"> <li>An increase in overall volumes of travel and commuting;</li> <li>A potential drop in the use of high-capacity public transport systems, such as trains, metro, light rail and the bus system;</li> <li>Might negatively influence the use of active modes;</li> <li>No changes in private vehicle ownership;</li> <li>Slowing and complicating the movement of</li> </ul>	<ul style="list-style-type: none"> <li>Increased demand due to improved accessibility, convenience, and shorter travel times;</li> <li>Productive and relaxing travel experience leading to higher usage, especially among young and old passengers;</li> </ul>	<p>ITF, 2015b; Milakis et al., 2017b; Bösch et al., 2016; Merlin, 2017; Narayanan et al., 2020a; Vleugel and Bal, 2017, Niles, 2019; UITP, 2017;Townsend, 2014, Narayanan et al., 2020a; Burns et al., 2013; Greenwald and Kornhauser, 2019; Litman, 2022, González-González et al., 2019; Wadud et al., 2016; Medina-Tapia and Robusté, 2019 ; Fagnant and Kockelman, 2014; Zhang et al., 2015; Zhang and</p>

Categor.	Key findings	Causes	References
Class.	<p>people and goods, including cyclists and pedestrians;</p> <ul style="list-style-type: none"> <li>• Gradually eroding public transport market share;</li> <li>• Creating social injustice.</li> </ul>	<ul style="list-style-type: none"> <li>• Utilisation of MaaS and connectivity driving increased usage;</li> <li>• Potential competition to traditional public transportation.</li> </ul>	<p>Guhathakurta, 2017; Ferdman, 2020; Cordera et al., 2021</p>
Safety	<p>Positive</p> <ul style="list-style-type: none"> <li>• Reduction in the number of accidents, fatalities, and injuries;</li> <li>• Reduction in the severity of collisions;</li> <li>• Overall improved transportation safety due to reduction in accidents externality;</li> <li>• Crashworthiness of the vehicles much less important in the future;</li> <li>• Eliminating the largest cause of car accidents while also outperforming human drivers in perception;</li> <li>• Crash reduction by providing more affordable alternatives to higher-risk drivers, as automation reduces the effects of human errors.</li> </ul>	<ul style="list-style-type: none"> <li>• Better V2X and prediction capabilities</li> </ul>	<p>Iclodean et al., 2020; Medina-Tapia and Robusté, 2019; Litman, 2022; Milakis et al., 2017b; UITP, 2017; Narayanan et al., 2020a; Fournier et al., 2020; ; Burns et al., 2013; Kok and et al., 2017; Alazzawi et al., 2018; Litman, 2022; Wadud et al., 2016 ; Fulton et al., 2017; Greenblatt and Saxena, 2015;Taeihagh and Lim, 2019;ITF, 2015b; ITF, 2015a, 2017, 2018</p>
	<p>Negative</p> <ul style="list-style-type: none"> <li>• Cyberattacks, maliciously controlled vehicles and software vulnerabilities compromising traffic safety benefits;</li> <li>• Crash rates similar to an average driver;</li> <li>• Potential total crashes increase when automated and human-driven vehicles mix;</li> <li>• Behavioural adaptation would lower safety improvements;</li> <li>• Mixed traffic expected to be the reality for at least the next couple of decades, resulting in only limited improvements in traffic safety, Platooning risks such as human drivers joining platoons and increasing crash severity.</li> </ul>	<ul style="list-style-type: none"> <li>• Reliance on software and internet connection;</li> <li>• Mixed traffic with human drivers.</li> </ul>	<p>Litman, 2022; Milakis et al., 2017b</p>
Land use	<p>Positive</p> <ul style="list-style-type: none"> <li>• Significant reduction in parking space, both on-street and off-street parking spaces;</li> <li>• Improving land use (less land needed for parking);</li> <li>• Making a lot of urban space available.</li> </ul>	<ul style="list-style-type: none"> <li>• No need for parking roaming SAV.</li> </ul>	<p>Burns et al., 2013; Spieser et al., 2014; Milakis et al., 2017b; Vleugel and Bal, 2017; Ainsalu et al., 2018a; Alazzawi et al., 2018; Soteropoulos et al., 2019; Fournier et al., 2020; Fulton et al., 2017; González-González et al., 2019; Fulton, 2018; ITF, 2015b; Keeney, 2017; Niles, 2019; Fagnant and Kockelman, 2015a; UITP, 2017; ITF, 2017; Burghout et al., 2015; Zhang et al., 2015; Fagnant et al., 2016; Zhang and Guhathakurta,</p>

Categor. Class.	Key findings	Causes	References
Negative	<ul style="list-style-type: none"> <li>• Increased pavement-rutting damage;</li> <li>• Potential residential and urban sprawl;</li> <li>• Urban land accommodating AV travel;</li> <li>• Dispersed and scattered urban growth pattern;</li> <li>• Risk of overcrowding around transit stations;</li> <li>• Potential urbanisation wave into rural areas.</li> </ul>	<ul style="list-style-type: none"> <li>• Convenient travel options, passenger travel further from workplaces;</li> <li>• New users and empty trips;</li> <li>• Conflict over curb space for pick-up points.</li> </ul>	<p>2017; Cordera et al., 2021</p> <p>Townsend, 2014; Milakis et al., 2017b; Niles, 2019; Spieser et al., 2014; Soteropoulos et al., 2019; Litman, 2022; Lim and Taeihagh, 2018b; Zachariah et al., 2014; Medina-Tapia and Robusté, 2019; Cordera et al., 2021</p>

### 3.4.5 The 4 Scenarios' Impacts

At this stage, we present the findings of the SLR from Table 1 to the panel of experts. They relied on the potential connections between the driving forces, uncertainties, and potential impacts to select adequate consequences for each deployment scenario. Extra attention was paid to highlighting the changes attributed to ridesharing services and their relation to PT. The 11 experts chose scenario-specific impacts deliberately. The moderators seamlessly integrated these into narratives and cited relevant literature sources. Thus, the narrative incorporates the expert opinions.

#### Scenario 1: SAV as buses

Deploying AM to replace buses would have mixed consequences. While initial reductions in congestion can be expected through optimised routing and traffic management, increased road occupancy by multiple AM would slow traffic flow and lead to more congestion.

The environmental repercussions would be higher emissions and energy consumption than normal-sized electric or automated buses (ITF, 2015a). However, compared with diesel buses, using electric powertrains would reduce air pollution and greenhouse gas emissions while improving energy efficiency and reducing noise pollution (Merlin, 2017; Iclodean et al., 2020). With technological advancements and political support, the transition to AM can positively impact the environment.

From an economic perspective, transitioning to AM under a public business model can yield benefits, such as reduced driver expenses and operational costs due to economies of scale (Burns et al., 2013). This model can also have positive spillover effects on the local economy [González-González et al., 2019].

The potential social impacts stemming from the deployment of AM manifest as alterations in travel behaviour, with the possibility of increased commuting, especially among children and older adults. Additionally, the service's convenience has the potential to substitute short-distance trips, which could adversely affect rates of walking and biking (Narayanan et al., 2020a).

Although road safety improvements can be expected, bus involvement in accidents is generally low.

Regarding its impact on land use, incorporating AM could result in a noticeable reduction in the spatial requirements for bus parking facilities. This raises the prospect of expanding urban areas as a potential outcome (Milakis et al., 2017b).

### Scenario 2: SAV as cars

The deployment of AM under a private operator to absorb the modal share of ICEV would have, in general, positive implications. However, we note that private business ownership of the SAV fleet might lead to longer trips to maximise capital returns. This could worsen potential environmental and social impacts (Ferdman, 2020).

As observed in prior studies, adopting an electrically powered fleet promises to diminish emissions and noise pollution while reducing energy consumption (Huber et al., 2019). Regulatory and political measures would be pivotal in compelling private entities to align with climate change objectives, thereby underscoring the potential environmental impacts.

From an economic perspective, the dynamic fare system would guarantee a substantial revenue stream for the private operator. Using the services would lessen the burden of car ownership and expenses, leading to cost savings for users. Developing technology and AM services would also generate employment (Bösch et al., 2016).

As for the social impacts, the convenient services would improve accessibility and access to other transportation options. However, the AM might end up eventually causing a rebound effect of NMT users switching to AM, which might lower the potential environmental benefits and worsen traffic (Vleugel and Bal, 2018). Another contested point is the impact on privately owned cars. We predict that this scenario would lead to a reduction in car ownership since research has proved Low Emission Zones (LEZ) and Pollution Mitigation (PM) strategies would reduce car ownership (Gonzalez et al., 2022).

The safety impacts of replacing cars with AM are lower accident rates (Medina-Tapia and Robusté, 2019). The effect on the physical space is fewer parking spaces in deployment areas, freeing up scarce urban space. The flexible transportation system would push urban planning towards the periphery, hence more urban sprawl.

### Scenario 3: Robotaxis

Our study anticipates several negative impacts associated with the deployment of

robotaxis under private operators, particularly in sequential and laissez-faire models, with implications across various domains.

For the environmental impacts, adopting electric powertrains and optimised operations would reduce emissions and energy consumption (Fagnant and Kockelman, 2014). However, competition with PT could result in distributional effects within the transportation system, leading to negative environmental impacts due to less public and non-motorised transport (Merlin, 2017).

From an economic perspective, robotaxis would offer cost savings for users, reducing car ownership expenses. The private operator would generate revenue, leveraging the dynamic fare system and minimal pricing regulations. Through the creation of a closed ecosystem, the created value can be captured using “the winner takes it all”. Further, these economic changes could seriously affect taxi drivers, potentially leading to job displacement [Nunes and Hernandez, 2020]. On the other hand, the economic incentive to increase revenue and efficiency would drive innovation in AV, creating new business opportunities (Burns et al., 2013; Soteropoulos et al., 2019).

The social impacts of the SAV would preserve an individual motorised mobility paradigm, which would not resolve the system-limited accessibility issues. Ensuring equitable access to robotaxi services is crucial to address social justice concerns and avoid exacerbating transportation disparities since they are operated by a private operator where revenue might be more important (Ferdman, 2020).

Regarding safety, the heterogeneity of vehicle types could compromise the anticipated accident reduction, raising challenges in insurance and liability disputes.

Furthermore, the proliferation of robotaxis would impact pedestrian and cyclist movements, necessitating careful planning (Litman, 2022). Urban planning could become more car-centric, prioritising vehicle accommodation over people-centric design. However, deploying robotaxis may reduce parking spaces (Spieser et al., 2014).

#### Scenario 4: AM in MaaS/ ITS

The introduction of AM in a MaaS system under a public-private business model has positive impacts.

The environmental impact is considered positive because the electric AM would reduce



air pollution and emissions. Moreover, the complementarity of all the means of transport through MaaS completed with AM as mobility gap filler of the transport system enables better use of resources and energy as well as positive externalities.

The economic impacts depend on local market conditions, regulatory frameworks, and collaboration between public and private stakeholders (Burns et al., 2013; Bösch et al., 2016; Soteropoulos et al., 2019). Cost savings for passengers, new business opportunities, and job creation are expected, although there may be disruptions to existing ridership and taxi services. Moreover, the generated data can improve the vehicles' efficiency and flexibility (Fournier et al., 2023).

The social impacts of this scenario are attributed to the mobility gap filler role. It could improve connectivity, accessibility, and inclusivity in the transportation system. Last-mile AM trips also enhance PT access, potentially increasing ridership. However, the convenience of the service (area flexibility and temporal flexibility) could replace not only private cars but also other forms of PT and more walking or biking short-distance trips (rebound effects) (Korbee et al., 2022).

The safety impacts are due to the personalised AM in MaaS/ITS services, which can alleviate traffic congestion and thus improve safety using the complementarity of means of transport (Milakis et al., 2017b),

For the same reason, MaaS-integrated AM optimises land use by reducing the demand for private parking spaces, allowing for alternative urban needs (Zakharenko, 2016).

MaaS-integrated AM could thus be a game-changer, offering safety, flexibility, reliability, and potential benefits for the environment, economy, social equity, safety, and land use (Fournier et al., 2023).

## **3.5 DISCUSSION**

### **3.5.1 General Discussion**

The analysis of innovative mobility solutions, like SAV, uncovers a complex landscape with diverse factors influencing outcomes. Our scenario-based study highlights a crucial aspect of innovative transport planning: recognizing that SAV deployment outcomes depend on specific urban conditions as presented in the form of the driving forces such as the transport infrastructure, the regulatory framework, and environmental agendas, as well as

the uncertainties like the integration of the SAV within the urban transport system. These scenarios reveal a range of potential positive and negative results, emphasizing the uncertainties linked to SAV deployment. As Slaughter (2018) has argued, a comprehensive evaluation of SAV technology within a broader context is essential due to the multifaceted and interconnected nature of its impacts.

However, we can highlight that the true potential of SAV materialises when they are seamlessly integrated with ridesharing and effectively incorporated into existing PT systems. Deployment strategies exemplified in scenarios like "AM in MaaS/ITS", "SAV as buses", and "SAV as cars" demonstrate the capacity to yield favourable impacts, strengthening the transportation ecosystem and aligning with a purpose-driven economic approach (Hurst, 2016; Narayanan et al., 2020a). Conversely, a laissez-faire approach to governing robotaxi deployment may perpetuate individual mobility and weaken PT, potentially exacerbating its negative consequences (Fournier et al., 2020). These findings underscore a critical realisation: the impacts of SAV deployment are intrinsically tied to the specific context and the strategic choices governing deployment scenarios. The quality and direction of these impacts are significantly influenced by factors such as the chosen business model and the degree to which SAV complement existing PT services.

In the case of AM in MaaS/ITS, fostering collaboration between private and public sectors within a MaaS would stimulate innovation, particularly complementarity of the means of transport and facilitate the provision of citizen-centric services (Fournier et al., 2023). Conversely, the private operation of SAV, as shown mostly in the robotaxis scenario without robustly implemented policies, could exacerbate issues such as congestion, pollution, and limited accessibility for all users (Ferdman, 2020).

Similarly, relying solely on public operators may neglect a citizen-centric approach, as public transportation often prioritises broader objectives and transportation goals over individual customer demands and preferences, which could lead to fragmented transportation offers (Donolato, 2023).

Examining the impacts of the scenarios reveals consensus on certain effects of SAV deployment: reduction in parking space requirements (Zakharenko, 2016), safety improvements (Alazzawi et al., 2018; Mueller et al., 2020), and environmental footprint reduction (Huber et al., 2022). These predictions are bolstered by technological

advancements, including higher levels of automation, advanced artificial intelligence to improve AM and the transport system, electric powertrains, and optimised routing and traffic management. Additionally, political and legislative frameworks in cities generally align with mitigating climate change, enhancing safety, and utilising limited urban spaces more efficiently (Gössling, 2020). However, other impacts, such as changes in travel behaviour, economic gains and losses, and land use (excluding parking), present mixed results (Harper et al., 2016; Nikitas et al., 2021). Anticipating passenger reactions to a new mode of transport proves challenging, as subjective preferences play a significant role (Ettema et al., 2016). User acceptance is, therefore, pivotal in determining the social impact of SAV deployment (Korbee et al., 2022). Similarly, predicting changes in land use depends on factors beyond the SAV deployment strategy, such as economic growth (González-González et al., 2019). Economic impacts are highly contingent on user acceptance and land use changes, potentially resulting in operator cost savings but increased unemployment and social costs for cities due to drivers' job losses (Soteropoulos et al., 2019; Nikitas et al., 2021).

To combat the negative impact of induced demand transportation, urban planners and transport operators should focus on studying it as a rebound effect (Harper et al., 2016). Additionally, they must explore alternatives like citizen-centric services in MaaS/ITS and robotaxis to reduce traffic and shift users away from traditional vehicles, thus minimizing induced demand (Fournier et al., 2023). However, these modes could also have unintended consequences if they replace walking and biking or introduce new passengers into the network.

The dichotomy between robotaxis and AM in MaaS/ITS underscores the importance of effective governance and implementing policies that maximise the societal benefits of SAV. Finally, the study provides novel insights by highlighting the substantial influence of specific urban conditions in the form of driving forces on SAV deployment outcomes. It details various scenarios, examining the effects of integrating SAV into systems like MaaS or introducing them as robotaxis. It presents perspectives on the potential advantages of effectively incorporating SAV with public transport systems versus laissez-faire approaches that may exacerbate urban issues like congestion. The research underscores the critical role of strategic decisions, particularly the chosen business model, in shaping SAV's societal and environmental impacts. By outlining diverse scenarios and their implications, the study enhances our understanding of how SAV deployment influences urban environments. It gives a new outlook for experts and policymakers on which driving

forces to address to unlock SAV potential in cities.

### 3.5.2 Limitations

Our study acknowledges several limitations. Predicting outcomes of rapidly evolving technology in a complex system is inherently challenging and subject to biases (Slaughter, 2018). Assessing impacts involves numerous variables like technological advancements, user acceptance, and regulations (Childress et al., 2015b). Existing literature primarily focuses on urban AV deployment. This urban-centric perspective and a preference for robotaxis have constrained our Systematic Literature Review findings (Narayanan et al., 2020a). While our qualitative research benefited from stakeholder and expert insights, it could be further strengthened by environmental assessments through lifecycle sustainability evaluations and mobility behaviour studies using surveys (Huber et al., 2022).

## 3.6 CONCLUSION

In conclusion, our study thoroughly explores four scenarios for SAV introduction in urban environments. We leverage expert insights to estimate environmental and socio-economic impacts in European cities. These scenarios cover a range of deployment approaches, providing insights into their alignment with desired outcomes. Stakeholder involvement mirrors real-world urban policy implementation, fostering diverse contributions to shape the final results. We employ the SLR method to comprehensively overview SAV. This informs our current analysis and future stakeholder collaboration in SAV deployment scenarios. Our analysis highlights the challenge of changing societal mobility behaviors when transitioning from conventional cars to SAV. Achieving this transformation requires concerted efforts to reduce reliance on individual motorised mobility, which may take time. However, it is important to address the potential of automated ride-sharing. Based on our analysis and existing evidence, automated ride-sharing, whether through SAV as cars or as, presents a promising option for replacing private mobility while complementing high-capacity public transport. This approach showcases the potential to not only enhance public transport ridership but also address crucial mobility gaps. Replacing traditional buses with smaller, 15-passenger SAV, seemingly advantageous in theory, raises concerns about potential traffic congestion. Replacing high-capacity buses with smaller vehicles may increase vehicle volumes on the road, complicating traffic management. This leaves us with two promising options: AM

integrated into MaaS/ITS and robotaxis. Robotaxis, as currently configured in our scenario (single rides managed by private operators), essentially replicate the car-centric individual mobility model.

In contrast, AM integrated into MaaS/ITS presents a pragmatic and feasible option for the near future. It not only shows the potential to enhance PT ridership but also offers the capability to optimise PT routes and address critical mobility gaps within urban environments. This alignment with urban and climate objectives positions AM in MaaS/ITS as an attractive and compelling choice for adoption by cities. This study uniquely contributes to smart and sustainable mobility research by assessing the combined impacts of deployment factors. It emphasises that the consequences of SAV deployment depend significantly on specific city conditions. Expert input is crucial for identifying ideal deployment conditions. We recommend more participatory approaches like living labs or multi-stakeholder projects in SAV planning to engage all stakeholders, optimise services, and reduce rebound effects. While AM in MaaS/ITS promises positive impacts in urban areas, we acknowledge that focusing on urban introduction might not capture its full potential. Urban areas typically boast robust PTation systems, potentially leading to rebound effects that reduce other PT ridership and active mobility modal shares. Thus, it might be even more impactful in less densely populated rural areas. Future research would benefit from more holistic assessments of whole transport systems and from including the effects of the introduction of SAV in MaaS / ITS in rural areas. It is expected that the potential for mobility gap filling and replacement of individual mobility is significant there, too.

The results from Chapter 3 address the research question concerning the deployment and potential impacts of SAV in urban areas. The outcomes outline various deployment scenarios and their associated impacts, which form a critical component of the forthcoming Chapter 4 analysis. These scenarios and their calculated externalities serve as a means to validate the qualitative predictions made in this study within this chapter.

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## 4 DEPLOYING SHARED AUTOMATED VEHICLES FOR SUSTAINABLE MOBILITY: EXTERNAL COSTS ASSESSMENT IN LYON-AND GENEVA

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### Abstract

Sustainable mobility is crucial in achieving climate change goals, considering fossil-fuel transportation's significant greenhouse gas emissions. Innovations in vehicles and services offer potential solutions for affordable, accessible, and environmentally friendly transportation. Among these innovations, Shared Automated Vehicles (SAV) are viewed as a disruptive force that could promote sustainable transport. However, their actual impacts remain uncertain and speculative. This study investigates the potential impacts of deploying SAV in diverse scenarios in Lyon and Geneva to unlock their full potential. External cost calculations focusing on emissions, noise exposure, accidents, and congestion effects are employed based on data from the CE Delft handbook of external costs and interdisciplinary research conducted during an H2020 project that tested automated minibuses in public transport. Our findings reveal that deploying SAV to provide shared rides and bridge first and last-mile gaps within a Mobility-as-a-Service system is a viable scenario, garnering user acceptance and leveraging technological advancements. This deployment approach leads to significant reductions in external costs and yields positive impacts on the city. Conversely, a robotaxis scenario, offering single rides, displays minimal reductions in external costs and exacerbates urban traffic congestion.

These results can serve as essential guidance for policymakers, offering insights into the effective deployment of SAV in European cities. By embracing shared mobility models and leveraging technological advancements, cities can harness the full potential of SAV to foster sustainable and efficient transportation systems, contributing to a greener and more accessible urban future.

**Keywords:** External costs, Shared Automated Vehicles, Sustainable mobility

## 4.1 INTRODUCTION

The transport sector's impact on the environment, economy, and urban planning has led to a push for sustainable mobility and net-zero emissions by 2050 (EEA, 2020). Integrating land use and transport complexities, sustainable mobility addresses environmental, social, and economic implications, effectively mitigating negative externalities like congestion and emissions (Banister, 2008; Verma et al., 2015). Research has surged in this domain, exploring transport behaviour, policy, sustainability indicators, and the emergence of transformative technologies like AV (Bahamonde-Birke et al., 2018). However, harnessing the advantages of AV, especially SAV, like automated minibuses and robotaxis, requires a citizen-centric governance approach (Gruel and Stanford, 2016; Jing et al., 2019; Wang et al., 2021). The concept of SAV encompasses sharing goods and services, as explained in Chapter 2. Indeed, SAV could provide affordable on-demand services to provide last-mile solutions, fill mobility gaps, and strengthen public transport.

Our focus lies on automated minibuses and robotaxis. AM provide on-demand, door-to-door, or first/last mile services, accommodating up to 15 passengers through ride-sharing and functioning as a form of micro transit. On the other hand, robotaxis mainly serve as individual transportation, offering on-demand and door-to-door services. Both SAV types operate with electricity and achieve level 5 or 4 automation, according to SAE (2018). The SAV system is expected to encompass management and supervisory control aspects necessary for 24-7 public mobility applications while considering capacity, safety, congestion, and sustainability in mixed-use versus dedicated guideway implementations (Lazarus et al., 2018).

Studying AV deployment's societal and environmental implications is crucial, as they remain uncertain and speculative. While SAV services may compete with public transport, they could foster intermodal travel behaviour and enhance intermodality. However, large-scale SAV deployment remains limited (Krueger et al., 2016), with some pilot sites exploring automated minibuses as a form of SAV. Among these projects, AVENUE aimed to test automated and electric minibuses integrated with public transport in Belgium, France, Denmark, and Luxembourg and two replicator cities, Sion and Esch-Sur-Alzette, in Switzerland (AVENUE, 2018). The objective is to address uncertainty related to SAV deployments, particularly AM and robotaxis. To assess the environmental and societal



impacts, we employ externalities calculations, presenting monetary values to communicate the combined environmental and economic assessments effectively (Girardi et al., 2020)

The primary question this research seeks to answer is: What are the externalities associated with the deployment of SAV?

This study represents one of the first attempts to estimate the external costs associated with introducing SAV. While external costs have been extensively used to assess road transportation (Musso and Rothengatter, 2013; Jochem et al., 2016b; van Essen et al., 2019; Girardi et al., 2020), research on the externalities of automated vehicles remains limited. This study addresses this gap by considering external cost impacts of emissions (air pollution and climate change), noise, accidents, and congestion.

This analysis addresses a gap in the literature by considering transport users' mode choice decisions, specifically the potential modal shift to SAV. It utilises results from a representative survey (n=1816) presented by Korbee et al. (2022) to assess the external cost implications of these shifts in real-life settings. Different SAV deployment scenarios are applied to connect findings to practical contexts.

In conclusion, this research investigates the societal and environmental impacts of SAV deployment in urban settings. Results reveal changes in external costs due to modal shifts to SAV from traditional transportation in Geneva and Lyon, offering valuable insights for policymakers on the viability of SAV deployment in cities.

The paper is structured as follows: The second part presents the conceptual framework of mobility and SAV externalities. The third part outlines the methods and data used for calculating externalities in selected scenarios in Geneva and Lyon, including the marginal costs of buses and cars and values for SAV. Various deployment scenarios and their transport performances are described. The fourth part presents the results, and the final part discusses and concludes the study.

## **4.2 CONCEPTUAL BACKGROUND**

### **4.2.1 External costs of transport**

External costs refer to expenses or benefits incurred by individuals, groups, or society due to economic transactions in which they are not directly involved. These third-party costs

or benefits can result in economic inefficiency, reflecting market failures and inefficient resource allocation (Pigou, 1920; Eriksen, 2000). External costs can be negative, such as pollution, when social costs exceed private costs for transport users, or positive, like infrastructure investments, yielding both private and social benefits (Santos et al., 2010c). An important concept in transportation externalities is marginal external costs, representing the costs incurred when increasing the transport activity of a specific mode by one unit. Despite their significance, transportation decisions often overlook marginal external costs (van Essen et al., 2019). Providing accurate and personalised insights on transportation externalities is challenging due to the diverse nature of mobility behaviour and data limitations at the individual level (Molloy et al., 2021). This study focuses on climate change emissions during energy provision (well-to-tank), air pollution, and climate change emissions during vehicle operation (tank-to-wheel). It also accounts for vehicle production in the vehicle life cycle assessment (Schipper et al., 2001). We distinguish between a well-to-wheel (WTW) and a vehicle Life Cycle Assessment (LCA). While both are considered types of LCA, the WTW focuses on the energy and environmental implications associated with an energy source's complete life cycle. In contrast, vehicle LCA evaluates a vehicle's environmental performance during its entire life cycle, including the production and end-of-life stages (EEA, 2018). LCA is an efficient method for assessing transportation's environmental, social, and economic implications over the transportation system's life cycle (Moslehi & Reddy, 2019).

This study specifically focuses on the short-term<sup>8</sup> direct effects of transport externalities: environmental impacts, congestion, and accidents, as well as indirect effects, energy provision and vehicle manufacturing.

#### 4.2.2 Externalities of SAV

AV's benefits are well-known, particularly in shared forms like SAV (Fagnant and Kockelman, 2015). However, estimating innovation-related externalities, such as SAV, poses considerable challenges. While some predictable transport externalities like congestion and climate change may arise, SAV's novelty might introduce unpredictable ones (Lee, 2022). For example, studies on robotaxi penetration in Berlin and Stuttgart

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<sup>8</sup> Short-run costs consider operating expenses and not infrastructure maintenance and improvement over an extended duration van Essen et al. (2019).

show reductions in accidents, congestion, and air pollution externalities with higher penetration rates. However, integrating these vehicles into the mobility network and user acceptance remain crucial (Fournier et al., 2020). Another study on SAV without ride-sharing in Berlin indicates increased congestion but reduced air pollution and only marginal noise level changes (Kaddoura et al., 2017b).

Despite potential positive impacts on accidents, congestion, safety, and accessibility, SAV may generate new negative consequences, including accidents and privacy concerns due to data use (Ganesh, 2020; P. Lee, 2022). Additionally, SAV replacing human drivers may lead to job losses and adverse social implications (Nikitas et al., 2021). Positive externalities of SAV depend on effective integration into the transportation system through data aggregation, leading to spillover benefits like reliable traffic management, reduced congestion, and pollution (Martens, 2021). Pooled mobility data due partially to SAV connectivity would amplify network externalities where more users would use the transport system (Martens, 2021). However, the extent of rebound effects and increased vehicle usage due to the convenience of SAV is also a contested point (Hymel et al., 2010; Soteropoulos et al., 2019).

The convenience of SAV would create more trips by reaching new categories of users, such as the elderly and children (Soteropoulos et al., 2019). The ease of SAV travel could lead to more trips, longer and more frequent journeys, and risks of empty trips, resulting in increased passenger and vehicle kilometres travelled (Martin, 2019).

### **4.3 METHODOLOGY**

In this study, we seek to estimate the effects of introducing SAV in urban areas under different scenarios, using Geneva and Lyon as examples of typical European cities. The methodology is presented in Figure 9.

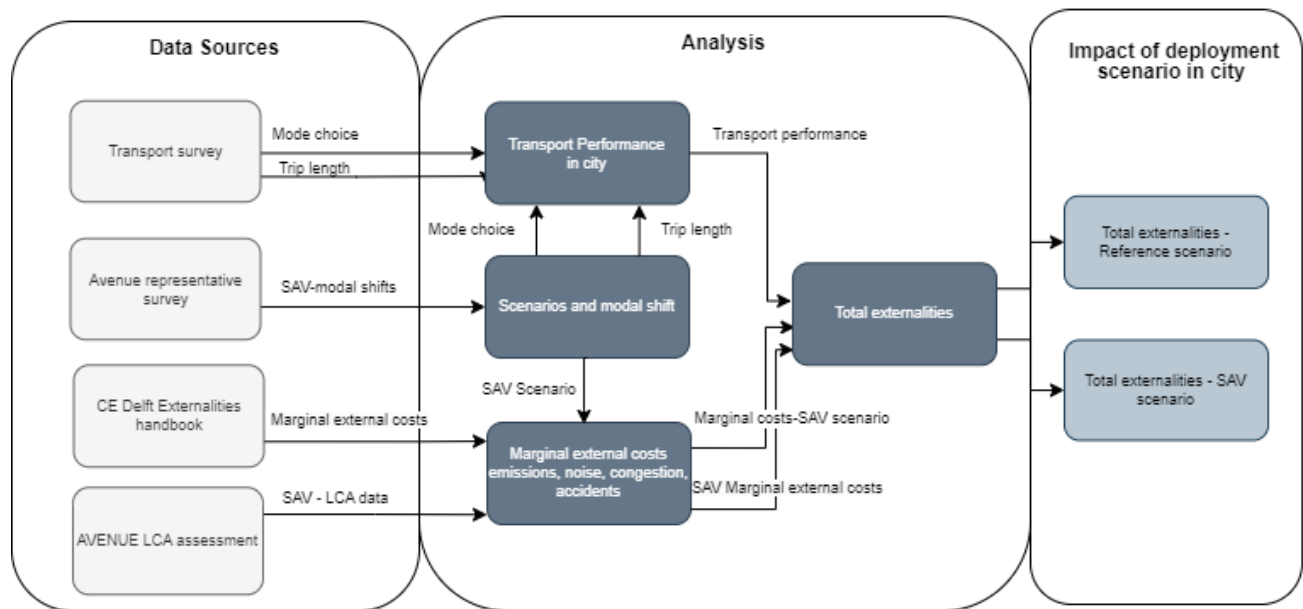


Figure 9: Methodology to Estimate the Impacts of SAV in the City

The analysis comprises three main parts. Firstly, we calculate the transport performance using mode choice and trip length data from travel surveys in Geneva and Lyon (Sytral, 2016; TPG, 2016; Montfort et al., 2019) for the reference scenario. Secondly, we employ scenario and modal shift analysis based on scenarios from (Jaroudi et al., 2021) and a representative survey conducted by AVENUE (Korbee et al., 2023) with a combined sample of 785 respondents from Geneva and Lyon. This step provides mode choice and trip length estimations for SAV deployment scenarios. Thirdly, we estimate marginal external costs using data from CE Delft's externalities handbook (van Essen et al., 2019) and AVENUE LCA research (Huber et al., 2022). Finally, we compute the total externalities for the reference scenario and SAV scenarios, comparing the results to determine positive or negative impacts. The assessment starts with specific assumptions: ICEV, diesel buses, and active modes (walking and biking) are susceptible to substitution by SAV. Private AV deployment is not considered due to financial burdens (Meyer et al., 2017; Janasz, 2018). Electric vehicles (EV) are omitted to focus on SAV impacts in the near future. A speed limit of 30 km per hour is assumed in populated areas while walking and biking are considered to have negligible negative externalities (Keall et al., 2018; Rossi et al., 2020).

Person-km (pkm) is used instead of vehicle-km for transport performance calculations to better reflect SAV's effects on public transport (Greenwald and Kornhauser, 2019). The total transport performance remains identical to the reference scenario by assuming that every pkm on SAV is one pkm less on other modes (Bubeck et al., 2014).

The reference scenario represents the current mobility behaviour and accounts for 2015 transport performance without any AV in the ecosystem. Urban scenarios are distinguished based on city centre characteristics (Yu et al., 2021b). Population growth and socio-demographic changes are not considered to simplify computations (Huss and Honton, 1987).

### 4.3.1 Scenarios and modal shifts

To assess the potential impacts of SAV introduction, we consider scenarios envisioned during the AVENUE project in consultation with experts. These scenarios will likely occur based on factors like technology readiness, policies, governance, and social acceptance. The analysis focuses on four scenarios described by Jaroudi et al. (2021). Three of which pertain to the AM and one to the robotaxis. Please refer to section 3.4.5 (The four scenarios' Impacts) for a more detailed description.

- Scenario 1: "SAV as buses."
- Scenario 2: "SAV as cars."
- Scenario 3: "Robotaxis"
- Scenario 4: "AM in MaaS/ITS"

for scenario 1, the AM modal share equals the modal share of buses. In scenario 2, similarly, the AM modal share is the modal share of ICEV. For scenario 3, Studies by Zhong et al. (2020) and Ward et al. (2019) suggest that robotaxis could capture 7% of bus trips. Clewlow and Mishra (2017) and Heineke et al. (2019) indicate a potential 20% modal shift from ICEV to robotaxis. Furthermore, robotaxis could reduce the modal share of walking trips by 13% (Fournier et al., 2020; Heineke et al., 2019). Finally, for scenario 4, the AM are supported by a MaaS to deliver improved on-demand services that connect the first and last mile and offer seamless travel. Their introduction is intended to support public transport services. They can affect multiple forms of transportation (cars, walking, and biking). In this scenario, the modal shift under consideration is the proportion of trips within an intermodal trip that link to or from a train/tram station. We assume bike commuters to stations would switch to AM, as would those walking over 500m, absorbing 3% of walking trips and 1.7% of biking trips (Gebhardt et al., 2016; Giansoldati et al., 2020; Paydar et al., 2020).

The estimation for the modal shift from ICEV is also based on the large-scale survey. We focus on the rate of the "very willing" answers to the question: "Would you give up your

car if the AM offers a service that bridges the first and last mile?" from the pool of daily car users who inhabit the city centre in Lyon and Geneva. This represents the equivalent of 28% of car trips. We assume bike commuters to stations would switch to AM, as would those walking over 500m, absorbing 3% of walking trips and 1.7% of biking trips (Gebhardt et al., 2016; Giansoldati et al., 2020; Paydar et al., 2020). Figure 15 and Figure 34 show the different modal shares for each scenario for Geneva and Lyon-Villeurbanne.

### 4.3.2 Transport performance and mobility behaviour

Transportation performance measurements forecast, evaluate and monitor the extent to which the transportation system meets established public goals (EPA, 2021). We rely on national microcensus to determine the transport performance in Geneva and Lyon. We describe a baseline scenario for each city. We define the modal split, trip data per mode, fleet size, and population. These numbers would help us determine the transport performance for each mode of transport and the overall road transportation in 2015. These computations are later used to project the transportation performance in each of the four scenarios.

#### Geneva

This research utilises mobility behaviour data from "Microrecensements Mobilité et Transports" (MRMT), a study conducted by the Canton of Geneva's statistics office and Geneva Public Transport (TPG) between 2000 and 2015. The MRMT is part of a Swiss national census with 4,500 participants, providing insights into mobility trends over 15 years. The study includes trip distribution and average daily distance by mode of transportation (Montfort, De Faveri et Bisso 2019) (Figure 10).

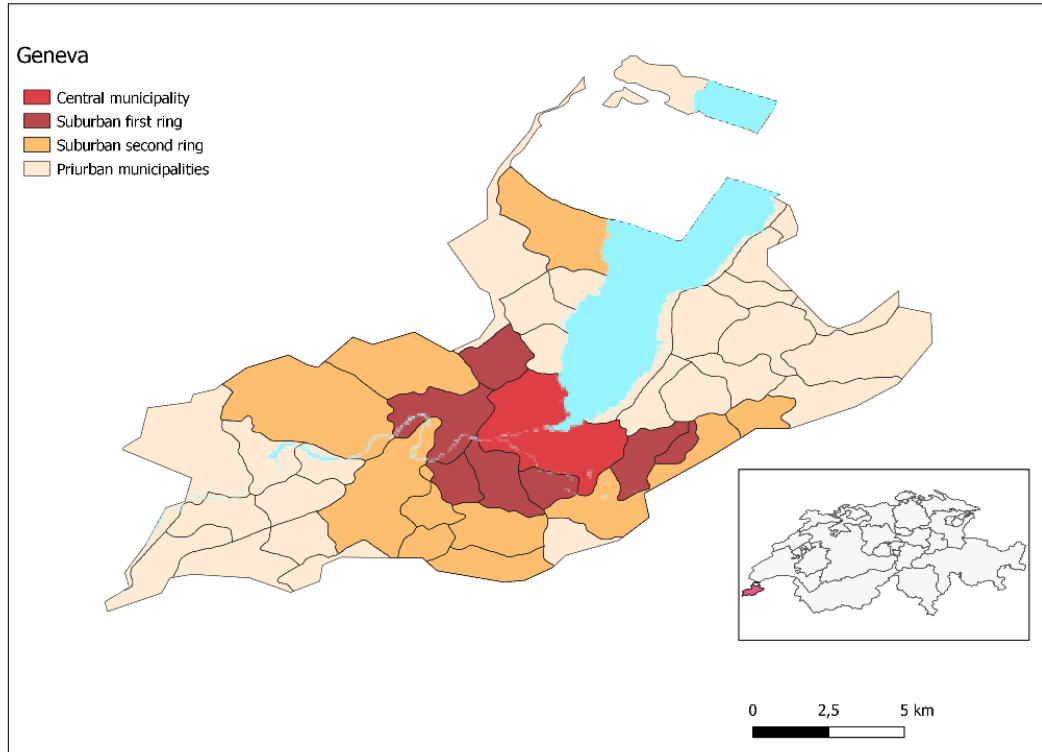


Figure 10: Typological Delimitation Of Geneva (GADM, Copernicus, OCSTAT). (Jaroudi, 2023a)

The baseline scenario is set in the city of Geneva (central municipality in Figure 10), and it would be the comparison point for the urban scenarios. Geneva has a population of 197,376 people and a total area of 15.93 Km<sup>2</sup> (Service de la mensuration officielle, 2005; Rietschin, 2015). The modal split (Figure 11) and the average daily trip number (711,000 trips) are adopted from TPG (2016) and Montfort et al. (2019). Thus, we determine the transportation performance shown in Table 2.

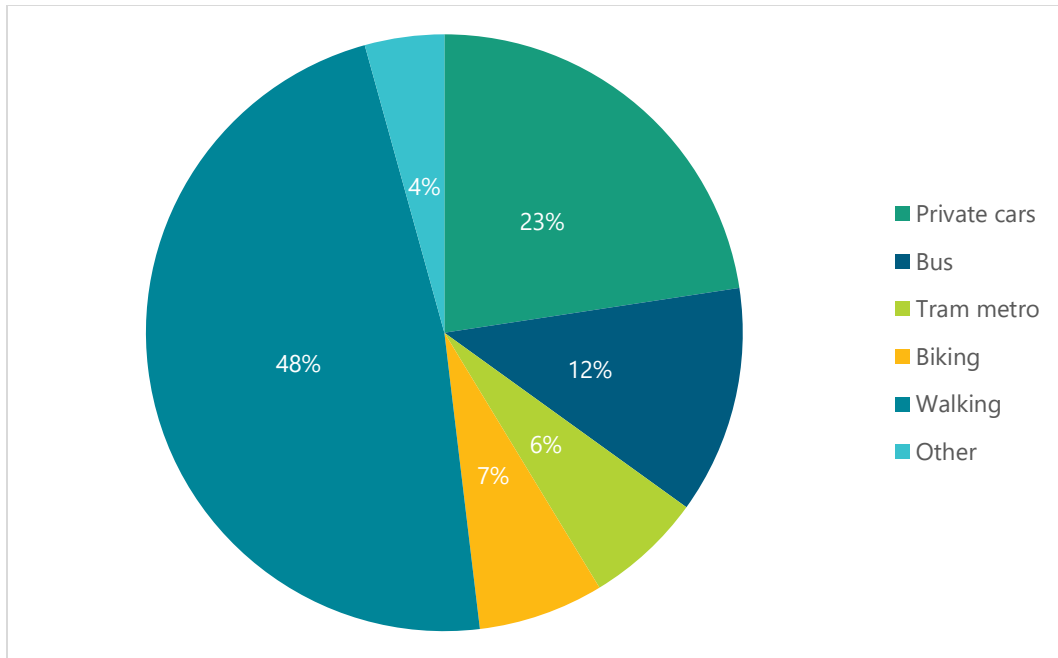


Figure 11: Modal Split - City Of Geneva In 2015 (Montfort et al., 2019)

Table 2. Transport performance per mean of transport, city of Geneva in 2015

Mode of transport	Modal share **	Average daily distance (km)**	Total transport performance in million pkm
Private cars	23%	13.5	972.6
Bus	12%	5.4	389.0
Tram metro*	6%	N/A	N/A
Biking	7%	1.0	72.0
Walking	48%	2.6	187.3
Other	4%	1.0	72.0

\*The analysis focuses on road transportation

\*\* (Montfort et al., 2019)

## Lyon

The statistics on transportation performance and mobility behavior are derived from a mobility survey lead by the "Syndicat mixte des transports pour le Rhône et l'agglomération Lyonnaise" in 2015. The survey had 27,000 participants from the Metropole of Lyon, run every ten years. Our analysis focuses on the Lyon Metropole area composed of Lyon-Villeurbanne, Figure 12, as assessed in the Sytral (2016) mobility



survey.

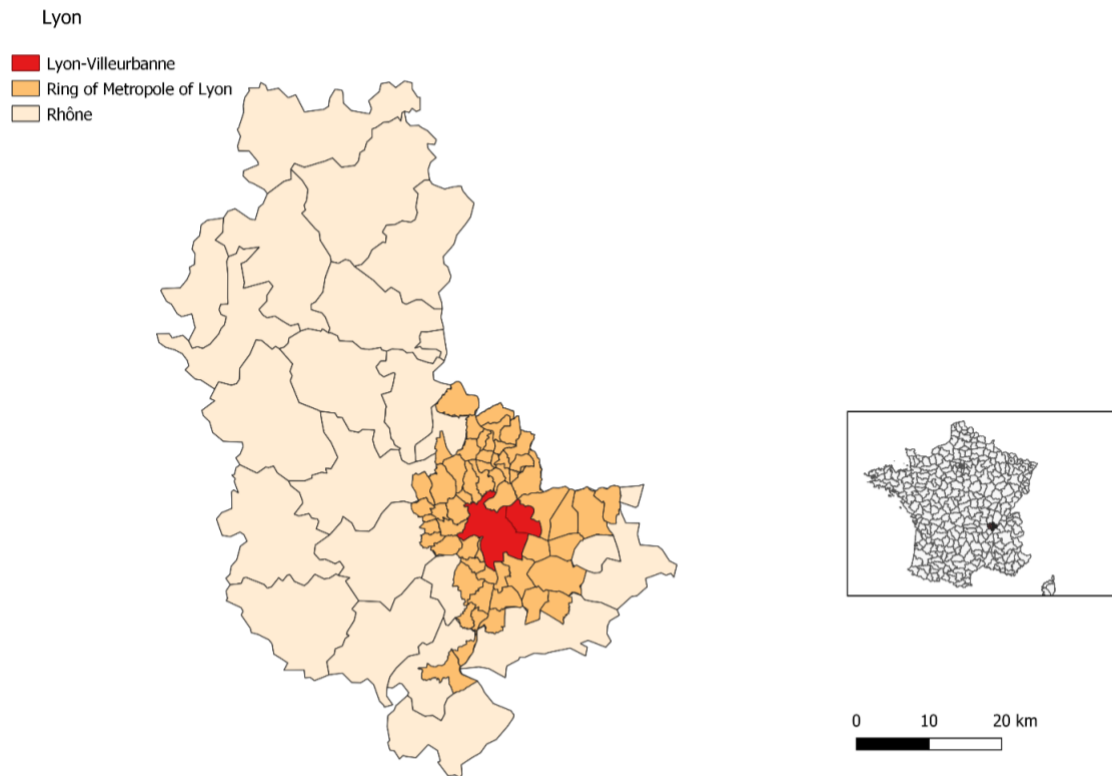


Figure 12: Typological Delimitation Of Lyon, (GADM maps and data, data.gouv.fr, Sytral). (Jaroudi, 2023b)

The baseline study for the transport performance for urban scenarios is set in Lyon-Villeurbanne (the centre of Lyon). Lyon-Villeurbanne has a population of over 500,000 and an area of 47.9 Km<sup>2</sup>. The modal share is presented in Figure 13. The estimated transport performance is in Table 3.

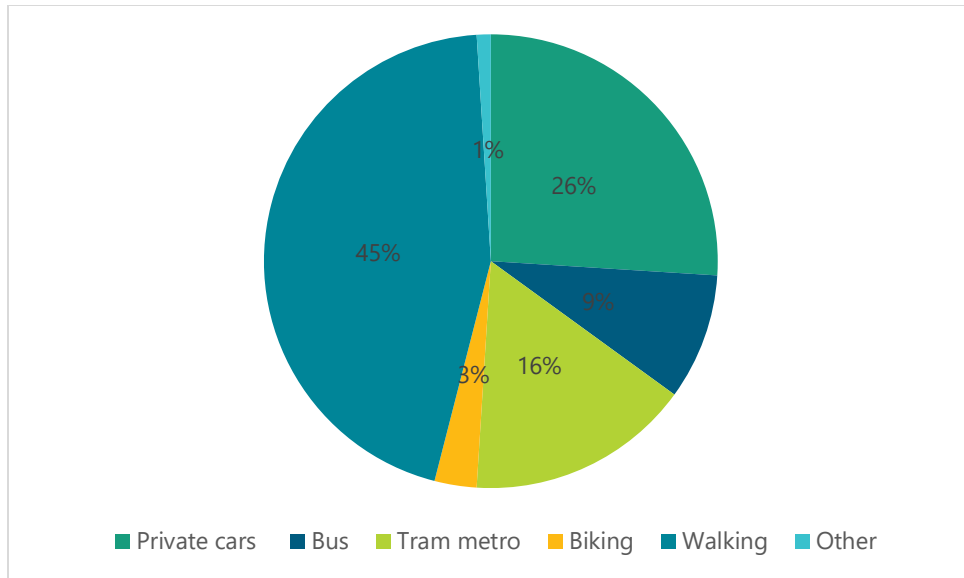


Figure 13: Modal Split - Lyon-Villeurbanne, 2015 (Sytral, 2016)

Table 3. Transport Performance - Lyon-Villeurbanne, 2015

Mode of transport	Modal share*	Average daily distance in km*	Total transport performance in million pkm
Private cars	26%	8.10	1,478.25
Bus	9%	1.22	221.74
Tram metro	16%	N/A	N/A
Biking	3%	0.14	24.64
Walking	45%	0.41	73.91
Other	1%	0.27	49.28

\* (Sytral, 2016)

### 4.3.3 Marginal costs

The assessment relies on the latest values for the EU. These values and the impacts of externalities are presented by van Essen et al. (2019). We start by defining the different marginal costs considered in our study (emissions during wtw and production of vehicles, noise, accidents, and congestion). Then, we present the selected values of the marginal costs for traditional modes of transport. Finally, we present our own estimations for the SAV.

## Impacts and methods

### *Air pollution and climate change Emissions*

The externalities are based on the well-to-tank as well as the production emissions in Figure 14 based on Rose et al. (2013). In this analysis, we do not account for end-of-life emissions because, when assessed separately, it has the least impact on overall life cycle emissions (EEA, 2018; Kemp et al., 2020).

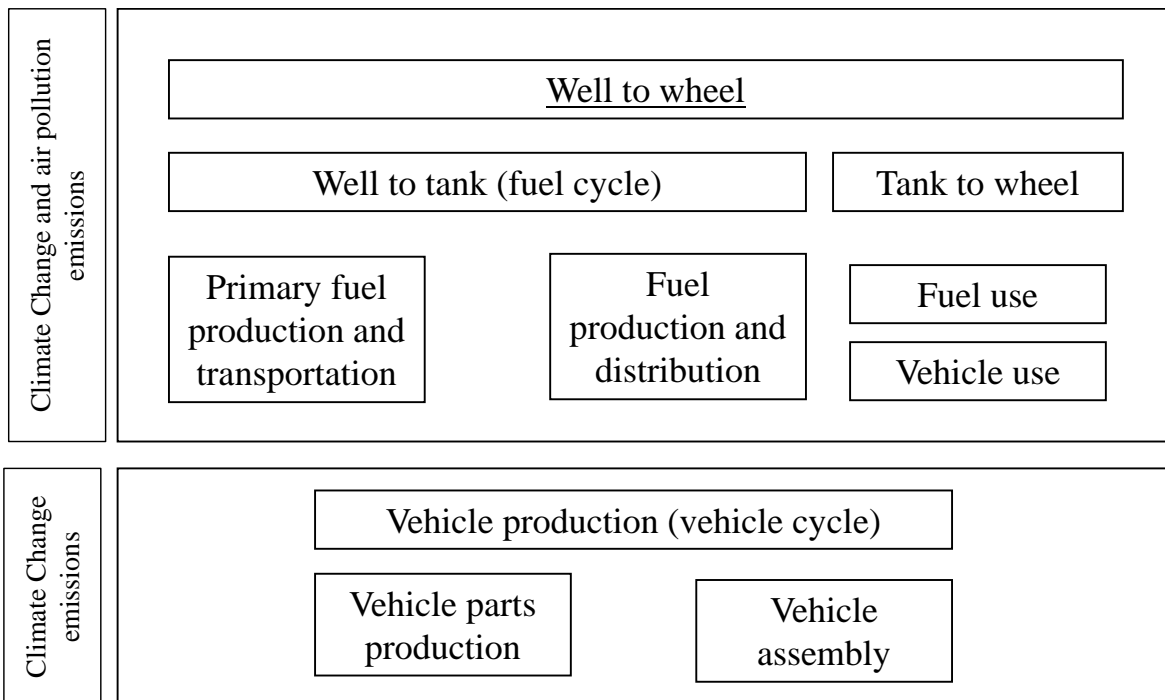


Figure 14: Well-to-wheel and Production Emissions Analyses

### *Well-to-wheel*

A well-to-wheel (wtw) research relies on the whole fuel cycle emissions: The tank-to-wheel (ttw) research addresses the energy (fuel or electricity) consumption and related emissions to operate the vehicle. We account for air pollution emissions such as particulate matter PM<sub>2.5</sub> and PM<sub>10</sub>, nitrogen oxides NO<sub>x</sub>, and sulfur dioxide SO<sub>2</sub>. The impacts are health effects, crop losses, building damage, and biodiversity. We also account for climate change emissions: carbon dioxide CO<sub>2</sub>, nitrous oxide N<sub>2</sub>O, and methane CH<sub>4</sub>. We use Global Warming Potential (GWP) to convert to CO<sub>2e</sub>. The cost estimation relies on the impacts of Sea-level rise, biodiversity loss, water management difficulties, extreme weather conditions, and crop failures. The well-to-tank (wtt) concerns the upstream

process from the fuel (fossil or electricity) extraction to the refuelling station, as Silva et al. (2006) described. The estimation of the wtt externality is for the impacts of the aggregated emissions for air pollution and climate change, which is similar to the wtw emission. The marginal costs per country are available in the Handbook on the external costs of transport per country for road transport (van Essen et al., 2019).

### *Production*

Vehicle manufacturing is a complicated process ranging from raw material extraction to component fabrication (Chester and Horvath, 2009). The estimation of the externality considers climate change emissions (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) following the avoidance approach. We adapt the methodology from Handbook on the external transport costs to estimate the production externality in Appendix B.1 (van Essen et al., 2019). The marginal costs for production are for the EU level.

### *Noise exposure*

Noise exposure is any unwanted sound of varied duration, loudness, or other characteristics that causes bodily or psychological harm. Estimating the externality is based on the annoyances and health effects caused by road traffic noise. These impacts depend on traffic conditions, background noise, time of day, and population. The health side effects include the risk of hypertension, heart disease, stroke, and dementia. The annoyance is expressed in potential irritation, anxiety, and sleep disruption.

### *Accidents*

The marginal external cost includes the costs of traffic accidents not covered by risk-based insurance. It also does not account for accident prevention. According to van Essen et al. (2019), the damage cost approach puts a value on production losses (55% of reduced work capacity of accident victims), and administrative (around 30% of non-medical expenses to assist with the accident), medical (around 50% of the medical expenses of accident victims), and human costs (the victim's pain and suffering in events of injury, and the victim's loss of utility in the event of death). The estimation is based on the value of statistical life (VSL), determined through the Stated Preference approach (SP).

### *Congestion*

Congestion is an inherent commuting cost due to supply and demand dynamics in

transportation. External congestion costs arise from temporary infrastructure constraints, leading to delays, uncertain travel times, additional expenses, and economic activity loss. Estimating marginal costs is complex, but it involves delay and deadweight loss approaches to quantify the value of travel time lost and societal costs resulting from inefficient infrastructure (Russo et al., 2019).

### Traditional road transport marginal costs

The first set of marginal costs for buses and cars that covers the impact of climate change and air pollution emissions (the wtw cycle), accidents, congestion, and noise were taken from the Handbook of External Costs. We work with national values for France and Switzerland for the study of Lyon and Geneva, respectively. In line with van Essen et al. (2019), we set the occupancy factors for cars and buses at 1.6 and 19, respectively. The values are in Table 4. We computed the values for the production emissions in Appendix B.1.

Table 4: Marginal costs for bus and ICEV for Lyon and Geneva in €-cent/pkm

City		Geneva		Lyon		
Mode of transport		ICEV	Bus	ICEV	Bus	
wtw emissions	Aggregated wtw emissions (air pollution + climate change)	0.42	0.19	0.40	0.19	
	ttw emissions	air pollution	0.63	0.76	1.00	1.01
		climate change	1.31	0.44	1.10	0.52
Noise		1.92	0.84	0.38	0.28	
Accidents		1.35	1.62	0.76	0.23	
Production emissions		0.38	0.18	0.38	0.18	

For scenario 3, we set different congestion values to better reflect the deployment context. For the robotaxis scenario, we consider that the roads would be more congested on average due to more vehicles on the road (Table 5).

Table 5: Congestion Marginal Costs for Bus and ICEV in Geneva and Lyon in €-cent/pkm

City	Geneva		Lyon	
vehicle	ICEV	Bus	ICEV	Bus

Scenarios baseline 1, 2, 4	39.30*	6.50	27.50	4.60
Scenario 3	48.50**	8.00	33.90	5.70

\*Social marginal congestion cost €-cent/pkm -other urban road – near capacity<sup>9</sup>

\*\* Social marginal congestion cost €-cent/pkm -other urban road – congested

### Shared Automated Vehicles' marginal costs

We determine the wtw emissions for an AM and robotaxi using Huber et al. (2022) LCA of the AM. The LCA compares the emissions of different vehicles in different use cases. It demonstrates that an AM and robotaxi are comparable to a small electric bus and an electric vehicle. We define AM and Robotaxi's occupancy factor as 6 and 1.2, respectively. We calibre the marginal costs in €-cent/pkm accordingly.

We follow the assumptions made by Fournier et al. (2020) and Arizcuren-Blasco et al. (2023), and considering a slow speed, the motor's noise emissions from braking and revving may be considered insignificant. The marginal cost estimates for accidents were based on the inputs of accident risk per vehicle, costs per causality, and risk elasticity. The formula for calculating the accidents was presented in the Handbook on external transport costs.

$$MC = r (a+b+c)(1+E) - \theta r(a+b)$$

MC = marginal cost

r = risk of the vehicle causing an accident or being in one

a = The costs due to an accident for the person exposed to the risk

b= The costs for the relatives and friends of the person exposed to the risk

c= The costs of the accident to the rest of society

E= The risk elasticity,

---

<sup>9</sup> Over capacity: flow to capacity ratio above 1.2, Congested: flow to capacity ratio between 1.0 and 1.2, and Near capacity: flow to capacity ratio between 0.8 and 1.0.

$\theta v$ = The share of the accident costs that is internal for each vehicle category

The risk (r) of being in an accident is proportional to the number of injuries (or fatalities) and the Vkm travelled. We estimate that the risk values are minimal based on the number of occurrences reported from AVENUE pilot trials relative to the total kilometres driven. We also consider the reporting of accidents in other studies to compute the marginal cost for the robotaxi (Dixit et al., 2016; Filiz, 2020; Petrović et al., 2020). Hence, we conclude that the marginal cost of accidents for SAV, at least in the near future, is zero.

Finally, to determine the congestion, we estimate that the AM congestion externality is equivalent to an urban minibus. In contrast, automated technology reduces overall congestion based on its penetration rate. Both studies by Fournier et al. (2020) and Fagnant and Kockelman (2015a) depict the impact of varying AV penetration rates on congestion reduction. For a value of AV penetration of 10%, 50%, and 90%, the reduction values are 5%, 10%, and 15%. Furthermore, similar to van Essen et al. 's (2019) analysis, we use the Potential Capacity Unit<sup>10</sup> (PCU) to determine the marginal costs of SAV. We account for PCU 1.25 for an AM based on Shalkamy et al. (2015). The robotaxi would have 1 PCU.

All the values are taken on the EU level except those for congestion, see Table 6. We determined the marginal costs of congestion based on the PCU and the marginal costs of an ICEV, as done by van Essen et al. (2019). Thus, the values are represented nationally, as shown in Table 7

Table 6: Marginal Costs for AM and Robotaxi in €-cent/pkm

Mode of transport		AM	robotaxi	
wtw emissions	Aggregated wtt emissions (air pollution+climate change)	0.54	1.11	
	ttw emissions	air pollution	0.05	0.07
		climate change	0	0

---

<sup>10</sup> It is a unit showing a vehicle's impact on a road expressed as the number of equivalent passenger vehicles (Pajecki et al. (2019)).

Noise	0	0
Accidents	0	0
Production emissions	0.3	0.64

Table 7: Marginal Costs for Congestion For AM and Robotaxis in €-cent/pkm

City	Geneva		Lyon	
	AM	Robotaxi	AM	Robotaxi
Scenarios 1, 2, 4	13.10	-	9.17	-
Scenario 3	-	64.67	-	45.20

## 4.4 RESULTS

### 4.4.1 Externalities analysis in Geneva

We start by presenting the potential change in modal shares for the scenarios compared with the reference scenario for urban settings in Figure 15. The overall changes in external costs compared to the base scenario are presented in Figure 16.



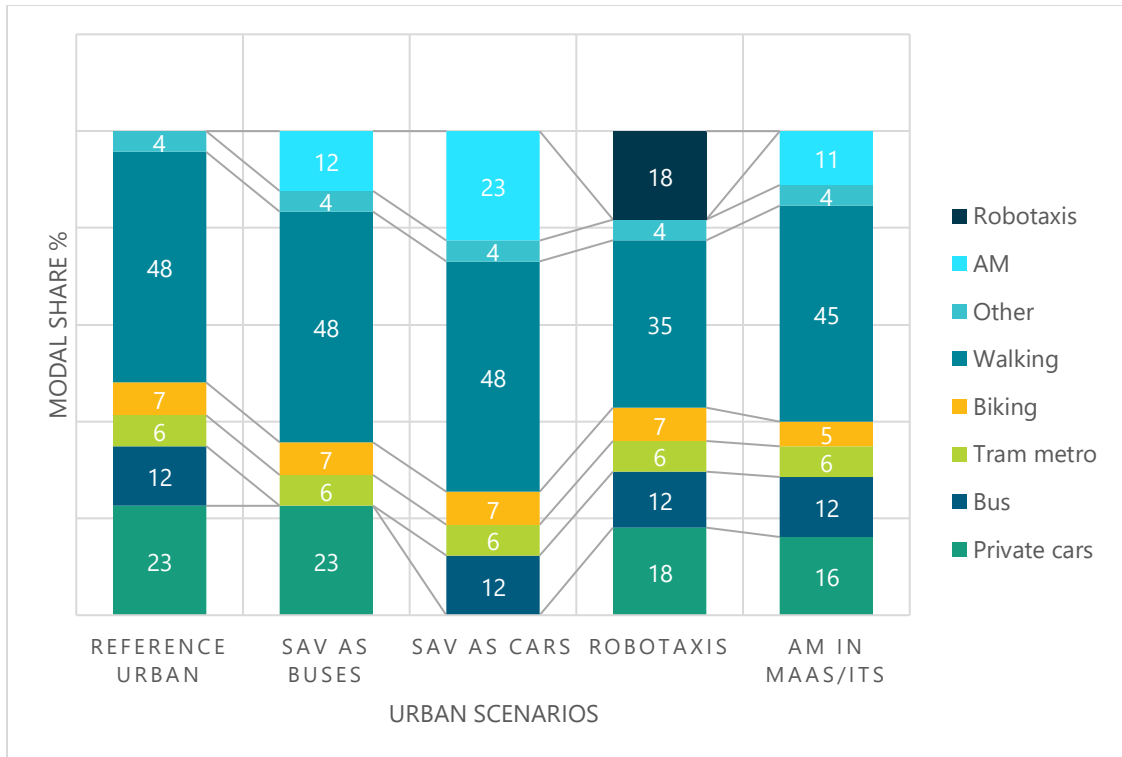


Figure 15: Changes in Modal Shares between The Scenarios and The Reference Scenario

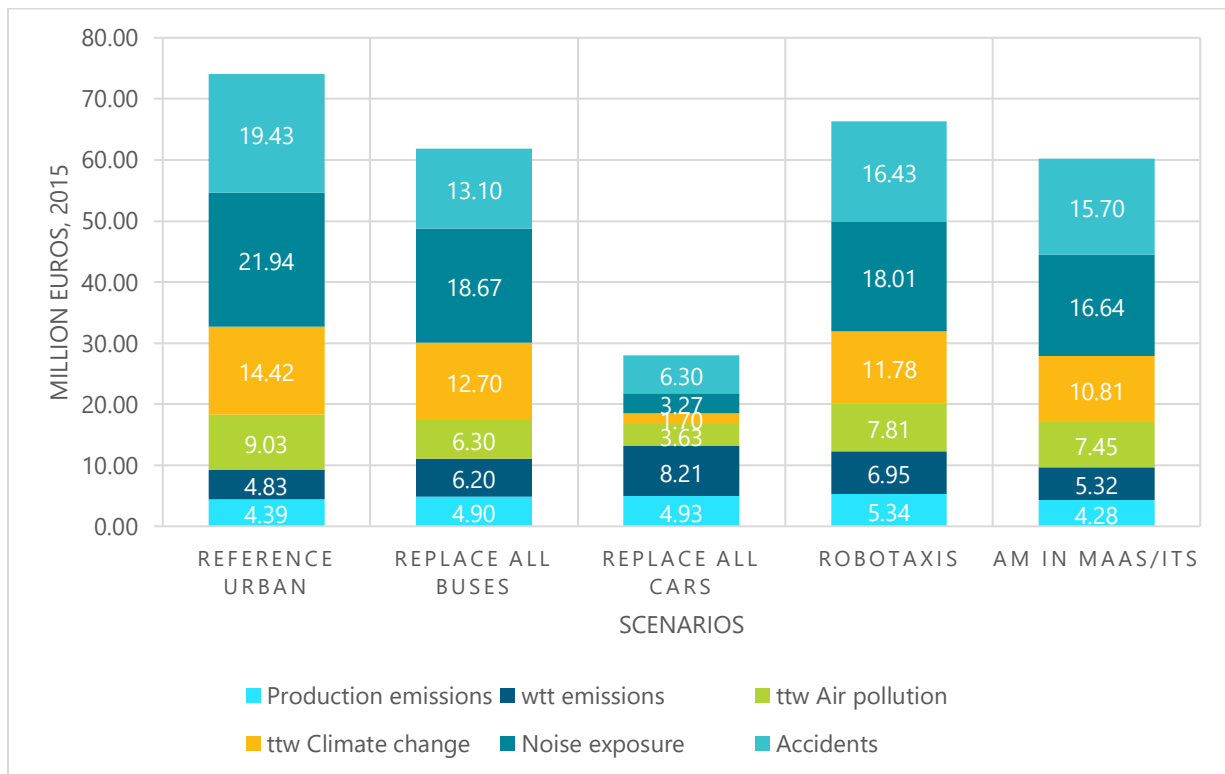


Figure 16: Changes in Externalities Compared to the Reference Scenario Excluding Congestion in Geneva

### Scenario 1: SAV as buses (S1)

The modal share of AM is 12%, replacing diesel buses. We assume that the AM will maintain the average distance of bus trips. Figure 16 and 9 show changes in externalities between the baseline and the SAV as buses scenario, excluding congestion. Our results indicate a 16% decrease in overall external costs without congestion (€12.2 million, 2015) and a 2% increase (€10.9 million, 2015) when considering congestion. This reduction is due to improved traffic management and cooperative driving, leading to fewer accidents (Szűcs and Hézer, 2022) and lower tank-to-wheel emissions from electrification and fleet management (Huber et al., 2022).

Additionally, noise exposure decreases with electric engines (Hua et al., 2021). However, this scenario would lead to an increase in congestion. The fleet would need more vehicles to meet the demand covered by high-occupancy buses that could transport a significant number of passengers, which could worsen the traffic flow (Leich and Bischoff, 2019a). However, the scenario also causes increased congestion, requiring more vehicles to meet demand and potentially worsening traffic flow (Leich & Bischoff, 2019). Furthermore, this deployment strategy leads to increased well-to-tank and production emissions due to battery and electronic component production and fossil-fuel-based energy use (Cox et al., 2018).

### Scenario 2: SAV as cars (S2)

The AM modal share is 22.6%, equivalent to the previous car trip modal share (Figure 15). This deployment results in a substantial reduction of approximately 250 million euros in total external costs for Geneva, accounting for almost half of the projected costs of the road passenger transportation system. Improved traffic management capacity leads to a total congestion external cost of around 200 million euros, compared to the reference scenario's 407 million euros. Figure 8 illustrates the changes in external cost impacts (excluding congestion) between the reference and Scenario 2 (S2), showing a 52% decrease in total external costs. Notably, there is a significant reduction in tank-to-wheel air pollution, climate change emissions, congestion, and noise, mainly attributed to the decrease in the impact of ICEV on urban road transport. This aligns with similar studies showing the positive impacts of automated vehicles with ridesharing replacing ICEV (Fagnant and Kockelman, 2015a). However, similar to the previous scenario, we observe

an increase in well-to-tank and production emissions for similar reasons.

### Scenario 3: Robotaxis (S3)

The robotaxis achieved an 18% modal share, comprising 4.5% from ICEV, 1% from buses, and 13% from walking (Figure 15). Their deployment in the city centre with a laissez-faire outcome leads to a significant increase in external costs. Social and environmental costs rise by approximately 157 million euros, nearly 33% compared to the reference scenario. The main driver of this increase is congestion, estimated at around 650 million euros, up by 210 million euros from the baseline (407 million euros), even considering improved traffic management. This is due to the single-ride nature and low occupancy factor (1.2 for robotaxis vs 1.6 for ICEV), resulting in more empty trips, additional vehicles, and chaotic driving patterns during drop-off and pick-up (Niles, 2019)

Excluding congestion, robotaxi deployment exhibits positive effects with a decrease in total external costs by 8 million euros (10%) (Figure 8). Electrification and automation technologies contribute to reduced noise, accidents, and emissions during vehicle use, resembling previous scenarios. However, the production and provision phases would demand more energy and lead to increased emissions, as observed in the previous scenarios.

### Scenario 4: AM in MaaS/ITS (S4)

The modal share of the AM is 11%, as seen in Figure 15. 6% from ICEV modal share is the equivalent of 28% of car trips (23% based on the survey), 3% from walking, and 1.7% from biking. The deployment of AM within MaaS to support public transport would reduce external costs by 84 million euros. Hence, congestion would still define the bulk of the effects on the transportation system. We register a potential decrease in congestion of around 70 million euros.

The changes in the other categories are shown in Figure 16. The AM in MaaS/ITS would reduce the harmful impacts of accidents, noise exposure and wtt emissions. We also predict an increase in the wtt emissions. Finally, we summarise the results in Table 8.

Table 8: Summary of Total External Costs Changes in Geneva

	Modal share in %	With congestion	Without congestion
--	---------------------	-----------------	--------------------

		million €	million €
SAV as Buses	12	+10.95	-12.2
SAV as Cars	23	-251.93	-41.86
Robotaxis	18	+156.65	-7.73
AM in MaaS/ITS	11	-84.29	-13.84

+ Increase in external costs  
- Decrease in external costs

#### 4.4.2 Externalities analysis in Lyon

Following the analysis demonstrated for Geneva, we present the total external costs for the four scenarios in Table 9. For more detailed figures, check Appendix B.2.

Table 9: Summary of Total External Costs Changes in Lyon

	Modal share %	With congestion, million € <sub>2015</sub>	Without congestion, million € <sub>2015</sub>
SAV as Buses	9 %	+5.74	-3.37
SAV as Cars	26 %	-324.08	-46.29
Robotaxis	19 %	+132.48	-6.24
AM in MaaS/ITS	12%	-90.21	-12.98

+ Increase in external costs  
- Decrease in external costs

Similarly, "SAV as Buses" and "Robotaxis " lead to an increase in external costs caused mainly by congestion. Thus, the two scenarios would worsen the impacts of the road passenger transport system. The highest reduction in external costs is attributed to "SAV as Buses". AM in MaaS/ITS leads to results similar to those in Geneva.

## 4.5 DISCUSSION

We present figures (Figure 18 and Figure 17) displaying the changes in external costs across various scenarios for Geneva and Lyon. Urban areas, like the city of Geneva, with its higher population density (12,500 inhabitants/Km<sup>2</sup>) and 711,000 daily trips, have more short-distance trips in smaller areas.

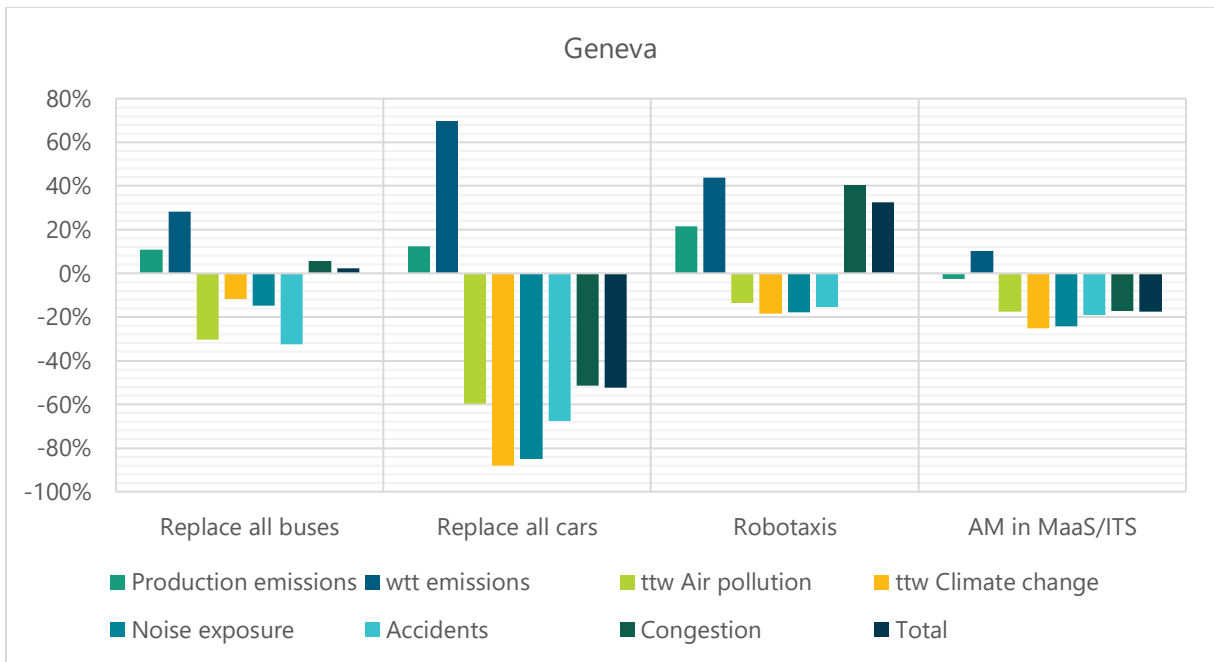


Figure 17: External Costs Changes in the Different Scenarios for Geneva

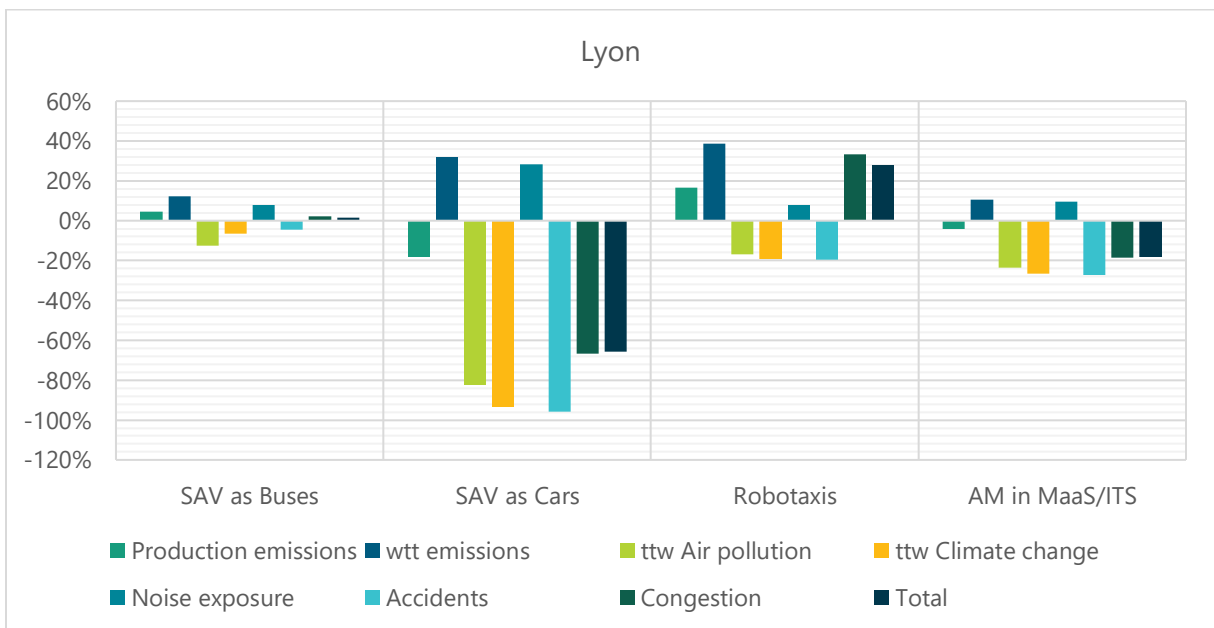


Figure 18: External Costs Changes in The Different Scenarios For Lyon

The two scenarios with the highest external costs were "Robotaxis" and "SAV as Buses." The first is designed to rival public transportation, while the second is geared to modernise the bus service. Both show that replacing existing public transit without a

planned strategy (or with a laissez-faire approach) will exacerbate the impact of AV deployment in cities and reduce their potential advantages to the environment and society.

The findings of the bus replacement scenario reflect the simulation of replacing buses with shared AV in Helsinki (ITF, 2017). As a result, it is not advised to replace all buses with AM, but rather to target bus trips during off-peak hours, as in scenario 4, where bus service is supported with AM on-demand.

The robotaxis exacerbates the transportation system's inadequacies. It encourages an individual mobility paradigm shown over time to be harmful to the city and the environment. Numerous studies have suggested that the robotaxis should be used with a ridesharing service, reducing external costs while supporting the public transportation network.

Alternatively, the scenario "SAV as Cars" substantially reduces external costs in both cities. This is consistent with most urban plans that encourage limiting car use to make a city more livable. However, limiting car access in urban sites might be challenging, especially in the near future, since it highly depends on people's acceptance of the technology and willingness to give up their cars (ITF, 2015b, 2017; Duarte and Ratti, 2018; McCallum, 2020).

In our baseline scenario, we observe significant variations in the marginal external costs between Lyon and Geneva. For instance, the noise value for ICEV is 1.92 €-cent/pkm in Geneva and 0.38 €-cent/pkm in Lyon, while the congestion value is 39.3 €-cent/pkm in Geneva and 27.5 €-cent/pkm in Lyon. These values were estimated using van Essen et al.'s (2019) externalities handbook. Such differences can be attributed to factors such as population density, urbanization patterns, and congestion exposure levels. Moreover, variations in willingness to pay and perceived value of time (depending on the trip purpose and distance) between the two countries were also considered in estimating the aforementioned marginal costs.

Considering the congestion externality, "AM in MaaS/ITS" becomes a viable deployment scenario. MaaS might minimise environmental degradation on a larger scale while increasing AM efficiency, even if it absorbs some active mobility methods. It might be part of an on-demand and door-to-door service offered throughout Geneva and Lyon to eliminate long-distance automobile trips and increase access to mobility hubs. While "AM

in MaaS" is a user-centric approach pull strategy, "SAV as cars" relies on push and pull policies under a transport demand management strategy to limit cars in the city.

By delving more into the externalities categories, congestion is the decisive factor in validating if a scenario would have a positive or negative impact. The estimation is based on transport pricing and the value of time. For the "SAV as buses" scenario, buses usually circulate on dedicated lanes. Thus, replacing them with AM would potentially disrupt traffic flow. Similarly, robotaxis providing single rides would worsen the congestion, especially in mixed traffic with human drivers (ITF, 2015b). The impacts of congestion are closely tied to worsening air pollution, climate change, and the quality of life in cities. Our estimations for congestion externalities mimic the results of Jochem et al. (2016a) and Sovacool et al. (2021) as the highest potential cost.

We register potential reductions in accidents, noise exposure, and emissions during the ttw phase external costs for our scenarios. This implies that deploying SAV, whether AM or robotaxis, would positively impact accident rates, air pollution and climate change emissions. Nevertheless, external emissions costs during the wtt and production phases could increase. Indeed, the production of electricity for battery charging could be highly energy- and GHG-intensive, which leads to an important environmental burden, as proved by Del Pero et al. (2018).

The model's limitations include challenges in monetising congestion due to reliance on an EU-level study for national marginal costs. Using national-level costs for city-level assessments may limit accuracy, and estimating accidents' marginal costs with AV-human interaction is complex and evolving. Future research should consider positive externalities from data use and explore AV impact on land use for a more comprehensive analysis.

This study presents potential future scenarios based on current data and observations, but its quantitative extrapolation is limited. User acceptance plays a crucial role in reducing car trips and ownership. A representative survey indicates that approximately 45% of car drivers are 'willing' or 'very willing' to give up their cars if an AM first and last-mile service is available (Korbee et al., 2023). However, attitudes may not necessarily translate into behavioural changes once the AM in MaaS/ITS service is implemented.

## **4.6 CONCLUSION**

In conclusion, this study provides valuable insights into the recommended deployment

strategy for sustainable development in European cities. The results highlight the significance of time, delays, and congestion in achieving positive impacts with AM. Moreover, contextual factors, such as population density and mobility habits, play a crucial role in determining the shift from ICEV to AM in MaaS/ITS or robotaxis.

User acceptance emerges as a critical factor in promoting a paradigm shift towards intermodal and customised public transport. Integrating AM into an Intelligent Transportation System and offering services that meet passengers' needs can increase acceptance and reduce reliance on ICEV. The "AM in MaaS/ITS" scenario presents a grounded approach to introducing AM gradually, initially filling mobility gaps and gradually replacing individual mobility, potentially without coercive policies.

In contrast, the robotaxis scenario could increase externalities, compete with public transport, and raise concerns about congestion and pollution. Addressing the potential positive impact on access and accessibility is crucial, but challenges related to digital access, vehicle customisation, and adoption uncertainties must be considered to ensure social inclusion.

To accompany the deployment towards sustainable mobility, policymakers and urban planners should integrate AM in MaaS/ITS with SUMP. The planning process should include governance structure changes, stakeholder collaboration, and citizen involvement. Internalising external costs and directing policy revenues towards implementing ITS can further support the long-term integration of AM and AV in the public transport network. The focus on AM in MaaS/ITS may make a coercive strategy unnecessary and promote a citizen-centric approach to mobility.

In conclusion, this study lays the foundations for effective policy measures and emphasises a system-based approach to road automation, contributing to a more sustainable and inclusive transportation future. The analysis of four scenarios indicates that while replacing all cars in urban areas would yield the best environmental and societal results, challenges persist in eliminating ICEV due to user acceptance. Consequently, the introduction of AM in MaaS/ITS emerges as a reliable scenario for AV deployment in cities. This chapter addresses how to calculate externalities for shared electric vehicles and their impact on cities, aligning with prior assumptions about AM in MaaS/ITS positive impacts. It partially answers how these calculations can guide smart mobility deployment for sustainable urban development. Further exploration of this scenario: AM in MaaS/ITS



potential to foster sustainable urban development and recommendations for SAV deployment will be detailed in Chapter 5.

The analysis of externalities laid the groundwork for advocating AM in MaaS/ITS over the other scenarios. While it ranked second to SAV as Cars, the latter demands high user acceptance and strict push measures to limit ICEV use. Favouring AM in MaaS/ITS, we foresee its efficiency as a pull strategy, positively impacting congestion, noise, air pollution, and climate change, confirmed in this chapter and aligned with prior findings in Chapter 3. The following chapter shifts to examining how SAV introduction in cities as AM in MaaS/ITS aligns with sustainable urban development policies in Geneva and Lyon-Villeurbanne. It seeks to provide policy recommendations for SAV introduction, emphasizing alignment with Sustainable Development Goals. Investigating how AM in MaaS/ITS aligns with Sustainable Urban Development and SDGs, this analysis highlights its potential to drive sustainable urban development and achieve SDGs through policy documents and Integrative Propositional Analysis in Lyon and Geneva. The shift from scenario comparison to city comparison is set to provide a more targeted and context-specific analysis. While scenario comparisons offer a broad understanding of theoretical outcomes through the external costs and scenario impacts, analyzing specific cities allows for a more practical and detailed examination of how these scenarios align with the unique policies, infrastructure, and needs of those locations.

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## 5 LEVERAGING SUSTAINABLE URBAN DEVELOPMENT THROUGH AM IN MAAS/ITS: A COMPARATIVE POLICY ANALYSIS OF GENEVA AND LYON

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### **Abstract**

The role of transport in advancing Sustainable Development Goals (SDGs) necessitates collaborative efforts to address its challenges. A paradigm shift in Mobility, particularly the introduction of Smart mobility like Shared Automated Vehicles (SAV), is presented as a disruptive innovation that could resolve these issues given the right conditions. SAV, self-driving vehicles navigating with limited human control, offer configurations like Automated Minibuses (AM) integrated into Mobility as a Service system (MaaS) and Intelligent Transport Systems (ITS), promising significant impacts on transportation systems and cities. This study investigates if AM in MaaS/ITS as a form of smart mobility aligns with Sustainable Urban Development (SUD) and the SDGs, using policy document analysis, Integrative Propositional Analysis (IPA), and case studies in Geneva and Lyon. The analysis highlights policy recommendations, leverage points, and impacts, suggesting transformative potential for SUD. Leveraging AM in MaaS/ITS aligns with SDGs, reducing noise pollution, accidents, emissions, and congestion while enhancing public-private collaboration and intermodal transport. Policy recommendations stress the importance of developing smart mobility infrastructure, ensuring fair mobility access, engaging stakeholders, and leveraging digital tools to improve intermodal mobility. The study positions AM in MaaS/ITS as a force driving sustainable urban development in line with SDGs, urging strategic alignment with city policies and global sustainability objectives.

## 5.1 INTRODUCTION

Transport plays a pivotal role in advancing various Sustainable Development Goals, posing challenges that demand collaborative efforts to mitigate its impacts (European Economic and Social Committee, 2018). A shift in the mobility paradigm is imperative to address these challenges. Innovations such as AV are presented as a disruptive paradigm that could solve these issues if introduced under the right conditions (Nemoto, 2022). Mackay and Metcalfe (2002) define disruptive innovation as *"new technologies with characteristics that are initially unfamiliar to producers and consumers, which may also require a major evolution of institutions and infrastructures, and which have the potential to disrupt market structures and lead to changes in behaviours"* (Nicolai and Le Boennec, 2018)

AV are self-driving vehicles equipped with advanced technologies allowing them to navigate and operate without or with limited direct human control (SAE, 2018). They offer various configurations, including automated minibuses seamlessly integrated into public transport and Mobility as a Service system (UITP, 2017). Deploying AM to complement public transport within MaaS/ITS can provide passengers with seamless, intermodal trips through digital platforms (Fournier et al., 2023). This strategy has the potential for significant impacts on both transportation systems and cities, offering sustainable, accessible, affordable, and environmentally friendly solutions.

AM in MaaS/ITS aligns with the smart mobility concept, characterised by an innovative and technologically advanced approach to urban transportation. Smart mobility integrates digital technologies, data-driven solutions, and sustainable practices to enhance the efficiency, accessibility, and sustainability of transportation systems in urban areas (Biyik et al., 2021).

The primary research objective of this thesis focuses on examining how SAV deployment could bolster sustainable urban development. Initially, scenario planning outlined four SAV deployment scenarios and their potential impacts. Subsequently, externalities calculations were utilised to validate the qualitative analysis of the scenarios and select one scenario from the four described. The chosen scenario AM in MaaS/ITS not only exhibited a significant reduction in external costs but also demonstrated practicality based on user acceptance and feasibility within a realistic time frame. This particular scenario already showcases positive impacts on land use, safety, economy, environment, and



society while notably reducing negative external costs like noise, congestion, air pollution, and climate change. To bolster this analysis, the real-life case studies of Geneva and Lyon were incorporated to investigate the potential connection between the scenario's impacts and the cities' policy targets for sustainable urban development. This connection would demonstrate how the deployment of this scenario aligns with and contributes to achieving the cities' sustainable urban development objectives. This chapter investigates whether AM in MaaS/ITS. A smart and sustainable mobility strategy can achieve Sustainable Development Goals aligned with the SDGs. To achieve this, a comprehensive understanding of SUD is essential. SUD is a strategic approach to city planning aiming for resilient, equitable urban environments while minimising negative environmental impacts. It seeks to create livable, inclusive cities that meet the needs of present and future generations (European Commission, 2019).

The central research question explores how smart mobility, specifically AM in MaaS/ITS, could foster SUD in cities and what the recommendations are for deploying AM in cities. The chapter employs policy document analysis, IPA, and case studies. Policy document analysis provides a holistic understanding of the strategic sustainable mobility and urban development goals of case study cities (Geneva and Lyon-Villeurbanne) and how they align with AM in MaaS/ITS potential impacts and the SDGs. It includes policy framework analysis, cross-impact analysis, comparative policy analysis, and policy recommendations (Rozhenkova et al., 2019). Case studies ground the analysis, providing evidence-based insights into the relationship between AM in MaaS/ITS impacts, sustainable mobility, and urban development.

Based on Interdisciplinary Studies (IS), the IPA addresses the challenge of synthesising theories across disciplines. It offers a tangible and visual mapping approach to facilitate the integration of theories, specifically focusing on the relationship between AM in MaaS/ITS impacts, sustainable mobility, and sustainable development within the SDGs framework (Wallis, 2013). This research aims to fill a significant gap in understanding the potential of smart mobility, such as AM in MaaS/ITS, as a transformative force for urban sustainability. The study's added value lies in utilising policy analysis and case studies to provide valuable insights for policymakers and urban planners.

The paper follows a structured format, including a brief literature review on key concepts (Section 2), methodology (Section 3), findings (Section 4), discussion (Section 5), and a concluding section (Section 6).

## 5.2 CONCEPTUAL BACKGROUND

### 5.2.1 Smart Mobility

#### What is smart mobility?

Here, smart mobility is presented briefly. A more in-depth analysis is presented in Chapter 2, section 2.4.2). Smart mobility could be identified in three components (Biyik et al., 2021). Firstly, it shifts from vehicle ownership to 'usership,' as seen in car-sharing and MaaS. The MaaS concept is frequently characterised as a single platform that digitally integrates trip planning, booking, and delivery into a seamless travel management solution (Wong et al., 2020). Secondly, it emphasises the value of ITS and digital technologies. As an advanced application, ITS relies on real-time data and technologies such as traffic control and V2X to improve overall mobility (European Parliament, 2010; Yu et al., 2021). Lastly, it envisions a 'citizen-centric' transport system where traditional mode boundaries blur, facilitated by integrated mobility platforms (Docherty et al., 2018).

Smart mobility, in an alternative definition, is described as the integration of advanced technologies and innovative strategies to enhance urban transportation systems, ensuring efficient, safe, and sustainable travel experiences (Nicolăi and Le Boennec, 2018). Transitioning to Smart Mobility models promises multiple benefits, fostering societal enhancements and economic and industrial advancements through a technologically advanced transportation network (Láinez, 2022). Current mobility systems often suffer from key vulnerabilities, including inefficient road network utilisation, lack of transport mode coordination, and underutilisation of emerging technologies. The increasing importance of smart mobility in the daily management of urban areas is geared toward improving residents' quality of life by establishing efficient transportation systems (Simonofski et al., 2023).

#### SAV as a form of smart mobility

Láinez (2022) analysis shows a wide presence of initiative projects of smart mobility located in the EU, North America, and Asia. In the context of smart mobility initiatives, introducing SAV offers a compelling solution. SAV are key disruptive technologies, as defined in this chapter's introduction, that offer improved transportation monitoring, safety, and efficiency, aligning with the smart mobility framework (Cassandras, 2017). SAV is a broad term encompassing the convergence of automated driving technology with

various sharing modes and services. This encompasses shared vehicle fleets (including automated minibuses and robotaxis), ridesharing services, on-demand options, and door-to-door mobility solutions (Gruel and Stanford, 2016; Jing et al., 2019; Wang et al., 2021). SAV leverages open API and open data, which are prerequisites for the interoperability and intermodality to offer user-centric services within the smart mobility framework. These services aim to bridge mobility gaps and facilitate a shift from traditional car ownership models to a more sustainable paradigm that emphasises active mobility and public transportation (Stocker and Shaheen, 2017; Fournier et al., 2023)(Stocker and Shaheen, 2017; Fournier et al., 2022). Emerging Automated driving technologies are seen as catalysts for advancing smart and SUM initiatives. However, there is limited empirical evidence on how SAV contribute to smart urban mobility (Golbabaei et al., 2021). Studies such as Nemoto et al. (2023b) explore the potential of SAV, such as AM, in European cities' public transport systems. It identifies crucial factors for promoting SUM strategies in urban cities by introducing smart mobility forms like the SAV. It demonstrates potential as a new mobility alternative, enhancing transport networks and aiding cities in achieving sustainable mobility under specific conditions. Recommendations include deploying AM to fill genuine mobility gaps, implementing policy measures to incentivise public transport-centred mobility, fostering citizen participation in planning, assessing present and future performance, and emphasizing institutional cooperation for successful deployment aligned with sustainable goals.

Additionally, within the realm of cities and urban planning, smart mobility can contribute significantly to sustainable urban development, specifically in the form of SAV. Urban mobility is a crucial element of an integrated city strategy (Bıyık et al., 2021).

## 5.2.2 Sustainable Urban Development

### What is sustainable urban development?

SUD is a city's deliberate planning and management to meet its citizens' economic, employment, and well-being needs while prioritising environmental and health considerations. It seeks to minimise air and water pollution and encourages green spaces and leisure opportunities. Additionally, SUD involves citizen engagement in addressing urban challenges and embraces bottom-up sustainable planning and management, aiming to benefit all residents in the city (Basiri et al., 2017).

These pillars/goals align with the goals of smart mobility, especially in terms of user-

centric and citizen-engagement green mobility. Even more, the effects of the SAV deployment relate directly and indirectly to environmental, social, and economic goals.

SUD serves as a contemporary paradigm for mitigating environmental externalities (an in-depth definition of externalities is present in Chapter 2, section 2.2), stemming from pervasive human activities (Yigitcanlar and Teriman, 2015). The analysis of externalities supports SUD by demonstrating the hidden costs and benefits of road transportation. This analysis helps guide policymakers to create effective policies, allocate resources wisely, prioritise sustainable solutions, and raise public awareness.

The EU's approach to sustainable and integrated urban development can be summarised by several key principles: promoting a strategic vision for urban development, targeting cities of all sizes, fostering multi-level governance and multi-stakeholder involvement, encouraging cross-sectoral collaboration, leveraging diverse funding sources, and emphasising result-oriented logic with robust monitoring and evaluation frameworks (European Commission, 2019). SUD strategies fall into three main categories: specific districts or neighbourhoods within a city, entire cities or suburbs, and functional areas involving multiple municipalities. In the 2014-2020 period, most strategies focused on cities or suburbs (45%), followed by districts (31%) and functional areas (20%) (European Commission, 2019). The prevalence of SUD strategies focusing on cities is driven by the global demographic shift that occurred in 2008 when urban populations surpassed rural populations, and this trend is expected to continue through 2050. It highlights the growing importance of SUD strategies in urban areas, where population density, resource management, and environmental sustainability are crucial challenges to address (United Nations, 2023b).

#### – SUD and the SDGs

SUD strategies relate closely to the SDGs, 17 global goals and 169 targets covering various social, economic, and environmental aspects to reach sustainable development nationally and globally by 2030. Urban planners leverage these goals to achieve sustainable development. SDG 11 is a goal closely related to sustainable urban development and mobility. The latest UN progress report states that in 2022, only 50% of the world's urban population had easy access to public transportation, with ongoing urban sprawl, air pollution, and limited public spaces in cities. The report shows that in 2022, around 40% of urban areas are not served by public transport in European and North American cities.

In fact, the UN emphasises the urgent need for cities to integrate motorised transportation with active mobility via SUMP, infrastructure and policies (United Nations, 2016b, 2023c).

### 5.2.3 Relationship between Smart Mobility and Sustainable Urban Development

Smart mobility could play a vital role in achieving SUD since both share common goals and interconnections. On one hand, urbanisation patterns and transport planning mutually influence each other (González-González et al., 2019). On the other, smart mobility and SUD utilise innovations to reduce negative externalities, enhance residents' and users' quality of life, and shift away from a car-centric development model. In fact, reducing car reliance, traffic congestion, emissions, and environmental impacts is crucial for SUD. Recent years have seen technology and innovation play a pivotal role in achieving this synergy with smart mobility like SAV, which is progressively becoming part of cities' transportation strategies (Cugurullo et al., 2020, 2021). Explorations into smart mobility, encompassing automation and shared services, have been scrutinised as specialised initiatives with the capacity to disrupt established socio-technical systems (Manders et al., 2018). Manders et al. (2018) noted that isolated urban trials of automated vehicles have yet to demonstrate a clear contribution to SUD. Nevertheless, integrated with electric vehicles and MaaS, they hold promise in addressing sustainability challenges within urban settings.

Despite the expectation that smart mobility, including SAV, will bolster SUD, it is crucial to acknowledge the significant roles of city and transport planning in shaping urban futures in the age of automated driving. However, evidence from trials in various countries suggests significant gaps between the visions of SAV futures and local planning goals (Acheampong et al., 2023).

The amalgamation of smart mobility, exemplified by SAV, as electric vehicles accompanied by MaaS and ITS, is poised to yield a spectrum of benefits. These include reducing emissions, addressing climate change and mitigating urban pollution (Huber et al., 2019). Additionally, the system's ability to optimise resource utilisation, employ dynamic routing, and alleviate traffic congestion results in an efficient transportation network (Fagnant and Kockelman, 2015a).

## 5.3 METHODOLOGY

### 5.3.1 Background

In this chapter, we explore how SAV can contribute to SUD. We employ the SDGs framework to guide our analysis and establish a solid foundation for our research. Many cities have set ambitious climate goals to align with the SDGs by 2030, using SDG indicators to monitor their progress (Sanchez Rodriguez et al., 2018). By incorporating the SDGs framework into our analysis, we link SAV's estimated impacts and externalities to SUD. Our study centres around a deployment scenario featuring automated minibuses integrated into MaaS within an ITS in both Geneva and Lyon-Villeurbanne. We identify mobility-related policies aligned with our anticipated impacts (Figure 19) and SDGs goals. Geneva and Lyon-Villeurbanne serve as our case studies, chosen due to their previous inclusion in the AVENUE project's impact analysis, providing valuable empirical data and insights (AVENUE, 2017). This data consists of the impacts and externalities of the SAV deployment in these two cities, including quantifying these impacts into externalities (Jaroudi et al., 2021). In Geneva, based on the external costs analysis, the introduction of SAV in the form of SAV in MaaS is predicted to result in a 24% reduction in noise externalities, a 17% decrease in congestion, a 35% cut in overall emissions, and a 19% reduction in accidents. Additionally, there is an anticipated modal shift, with a 6.4% decrease in car usage, a 1.7% reduction in biking, and a 3% decrease in walking. While in Lyon-Villeurbanne, our analysis forecasts reductions in externalities, including a 27% drop in accidents, a 19% decrease in congestion, and a significant 43% reduction in emissions.

By systematically examining these impacts in the specific urban contexts of Geneva and Lyon-Villeurbanne, our study provides valuable insights into the potential benefits of integrating SAV into urban transportation systems while also addressing sustainability goals.

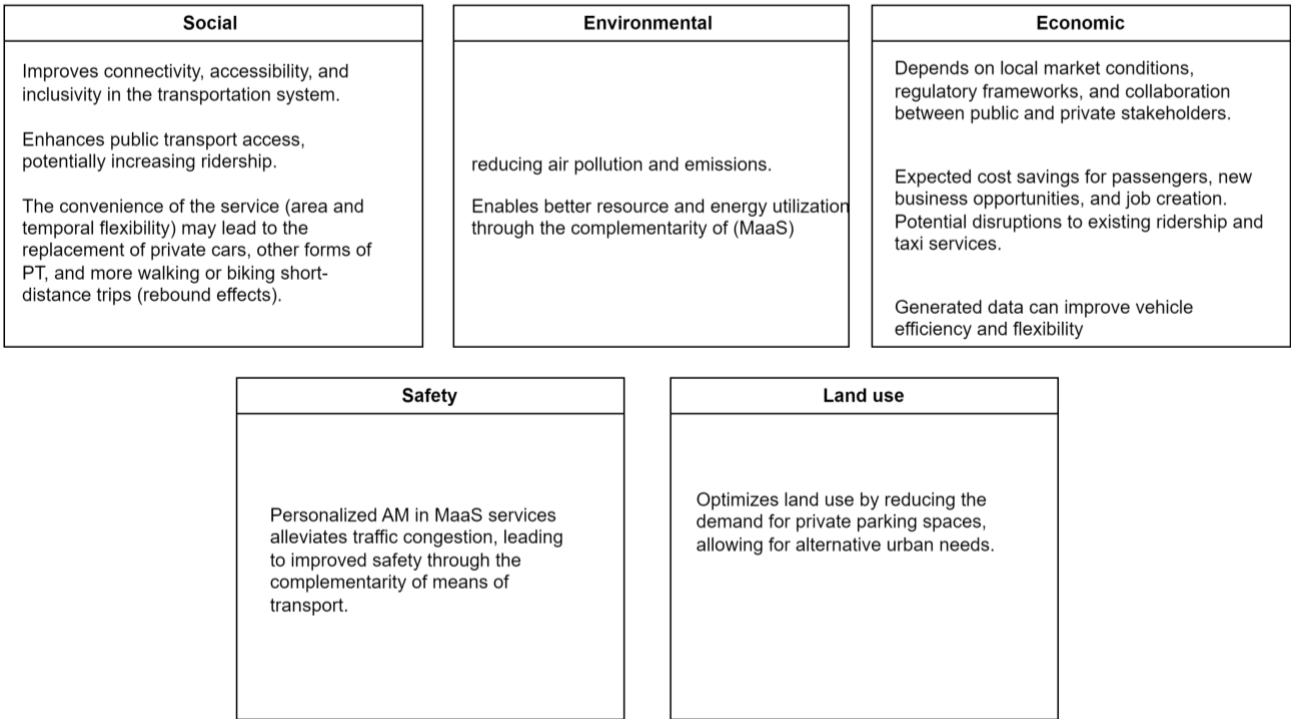


Figure 19: Impacts of AM in MaaS/ITS - Summary of Impacts from Chapter 3

### 5.3.2 Data Collection-Policy documents

To obtain the most relevant documents, we conducted a documentary analysis. The documents were collected from official websites, including government sites, local government platforms, and governmental reports (Shaw et al., 2004). This study encompasses various policy documents across different periods. For instance, in the case of Geneva, our analysis extended to three editions of the municipality's climate and energy strategy from 2009 to 2025 (Ville de Genève, 2009, 2014, 2018). Specific sections within these documents were extracted, focusing on elements pertaining to sustainable mobility.

Our data collection focused on public policies at the local level, specifically from the Geneva municipality and the municipalities of Lyon and Villeurbanne. We collected a total of 11 documents for Geneva and 7 for Lyon-Villeurbanne, encompassing 32 policies for Geneva and 26 for Lyon-Villeurbanne. A list of the documents is presented in Appendix D.1. These documents predominantly consisted of climate and energy plans and traffic-related regulations and policies, spanning both old and new versions, mostly establishing goals for 2030. The data were analysed using our defined policy analysis framework to facilitate the systematic capture of the document contents (Shaw et al., 2004).

### 5.3.3 Policy Analysis Process

As defined by Wee (2022), policy analysis involves examining and advising in the context of public policymaking, encompassing activities, methodologies, and tools. We utilised the Integrative Propositional Analysis methodology, rooted in extensive research on integrative complexity, complexity theory, and systems thinking<sup>11</sup>. It employs both quantitative and qualitative analyses to discern the underlying structure of plans, measuring their "Breadth" in terms of the number of concepts and their "Depth" in terms of interconnectedness or coherence (Wright and Wallis, 2015). The use of IPA while evaluating the policy documents helps identify SUM and SUD goals that AM in MaaS/ITS deployment could contribute to achieving. By measuring the Breadth, it uncovers the range of ideas and strategies within policies, revealing the scope of considerations. Assessing the Depth highlights how these concepts connect, unveiling the complexity and interrelations within policies and the proposed deployment strategy. This helps identify goals aligned with AM in MaaS/ITS deployment strategies for sustainable urban mobility and development. A summary of the process is in Figure 20. The results from Chapter 4 were used to select the deployment scenario of AM in MaaS/ITS (from the four SAV deployment scenarios: SAV as cars, SAV as buses, SAV as robotaxis. and AM in MaaS/ITS). The impact assessment of the scenarios from Chapter 3 was used to study the policy targets of SUD in both cities and the alignment with the SDGs.

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<sup>11</sup> Complexity Theory studies the interactions and relationships between various components within a system, focusing on the emergence of complex behaviors from simple interactions and non-linear dynamics Manson (2001) .



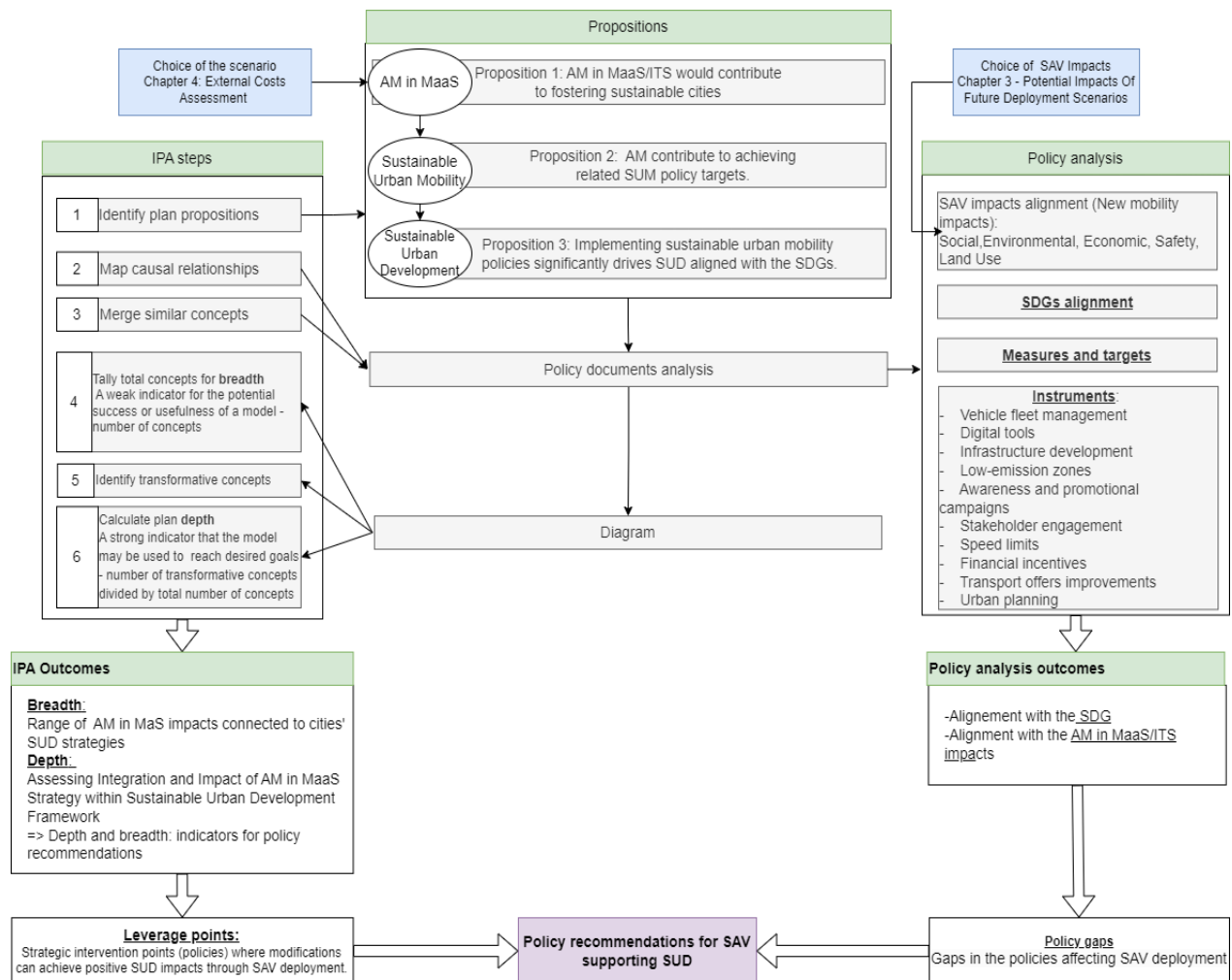


Figure 20: The IPA and policy analysis process and outcomes

IPA follows a 6-step process:

- (1) Identify plan propositions,
- (2) Map causal relationships between proposition concepts.
- (3) Merge similar concepts into an overarching diagram,
- (4) Tally total concepts for plan Breadth (the total number of distinct concepts present in the plan),
- (5) Identify and count transformative concepts (where numerous arrows converge),
- (6) Calculate plan Depth by dividing transformative concepts by the total number of concepts. In this context, depth serves as a gauge of the "systemic nature" of the conceptual system (Wallis, 2016).

Based on the 1<sup>st</sup> step, three propositions are introduced.

- (1) The first proposition: MaaS/ITS would contribute to fostering sustainable cities.
- (2) The second proposition: Each impact category and external cost impact of AM significantly contributes to achieving the corresponding SUM policy targets.
- (3) The third proposition: Implementing sustainable urban mobility policies plays a pivotal role in advancing SUD aligned with the SDGs, Figure 21.

In Figure 20, the blue boxes represent transformative concepts. They are designated as such because multiple arrows converge towards them, underscoring their pivotal role in various propositions, as explained in step 5.

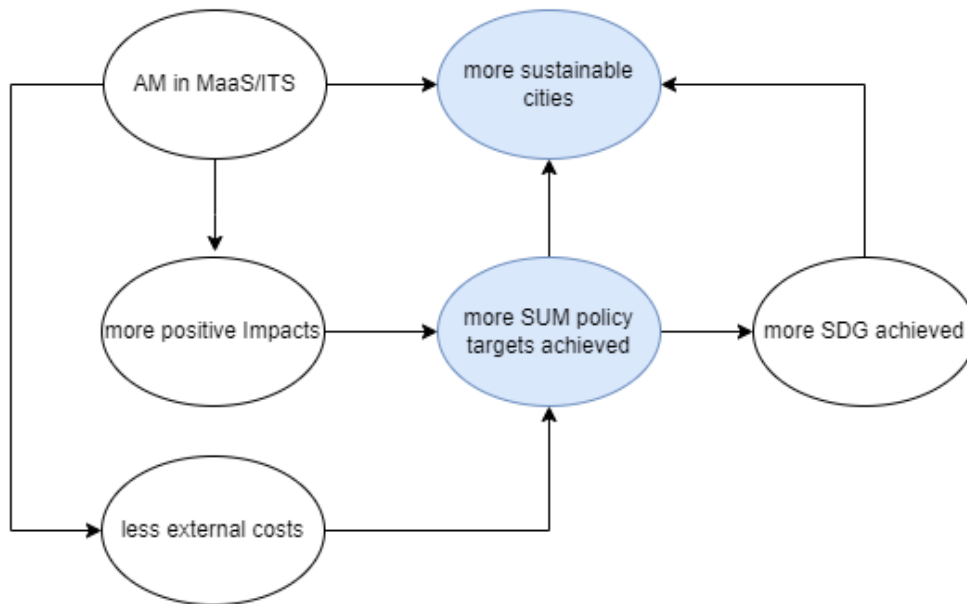


Figure 21: IPA diagram

In Figure 21, the diagram presents a simplified version of the diagram in Appendix D.3, which is further developed in the results section. The diagram represents the second and third steps in the IPA. Steps 4, 5, and 6 are included in the results section.

We designed a policy analysis framework to address the causal relationships and concepts as defined in step 2 in more detail. This also provided the basis for the diagram mentioned previously. Each policy text was classified in the first stage based on its targets, measures and instruments. According to Hettiarachchi and Kshourad (2019), a policy instrument refers to the methods employed by public authorities to advance specific policies to attain predetermined objectives. We aligned them with the SDGs in the second stage by investigating the relative targets and indicators. In the third stage, we relied on the ITF (2023) and FTA (2020) new mobility systems framework and their regional impact.

Accordingly, these impacts are grouped as environmental, economic, social, safety, and land use.

- Social Impact: Covering aspects related to accessibility and travel behaviour
- Environmental Impact: Encompassing policies to reduce emissions, improve energy efficiency, and mitigate noise pollution.
- Economic Impact: Classifying policies with economic implications, including investments, job creation, payment and ticketing systems, as well as financial incentives.
- Safety Impact: Focusing on policies related to accident prevention, reducing injuries, and overall risk management.
- Land Use Impact: Addressing policies that pertain to urban sprawl, zoning regulations, and sustainable land use in urban planning.

We identified various policy instruments to implement these strategies, and they were grouped and coded as follows, adapted from VTPI (2013):

- Vehicle fleet management (fleet renewal, electric and fuel-efficient vehicle adoption, support for low-emission engines).
- Digital tools (platforms, apps, and ticketing systems).
- Infrastructure development (sound-absorbing road surfaces, cycling paths, charging points).
- Low-emission zones (parking restrictions, circulation bans).
- Awareness and promotional campaigns (marketing, training, certifications).
- Stakeholder engagement (collaboration with private and public partners).
- Speed limits (traffic calming measures, zone-specific speeds).
- Financial incentives (subsidies, grants, loans, support for bikers, public transport, taxi fares, and mobility-related businesses).
- Transport offers improvements (seamless and multimodal services, sharing options).
- Urban planning (mobility plans, green spaces, mobility hubs, urban density, mixed land use, green corridors).

The study has provided insights into the contributions of these policies to the overarching global sustainability agenda, as reflected in the SDGs, along with their associated targets and indicators. By consistently addressing the SDGs in our methodology and integrating them into our analysis, we aimed to establish a structured and coherent framework for examining the relationship between smart mobility, SUD, and the SDGs in both Geneva and Lyon-Villeurbanne (A. Pernestål et al., 2020). Our analysis showed there is a focus on the following SDGs:

Table 10: The related SDGs analysed based on (United Nations, 2015)

SDG	Title	Targets	Indicators
11	Make cities and human settlements inclusive, safe, resilient and sustainable.	11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons	11.2.1 Proportion of the population that has convenient access to public transport by sex, age and persons with disabilities
		11.3 By 2030, enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.1 Ratio of Land Consumption Rate to a population growth rate
		11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities
13	Take urgent action to combat climate change and its impacts.	13.2 Integrate climate change measures into national policies, strategies and planning  Indicator 13.2.2: Total greenhouse gas emissions per year	
		13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	13.1.1 The extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed
3	Ensure healthy lives and promote well-being for all at all ages,	3.6: halve the number of global deaths and injuries from road traffic accidents	3.6.1 Death rate due to road traffic injuries
		3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.1 Mortality rate attributed to household and ambient air pollution
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	4.7: By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development	4.7.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed
7	Ensure access to affordable, reliable, sustainable and modern energy for all	7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.2 Proportion of population with primary reliance on clean fuels and technology
		7.2 By 2030, increase substantially the share of	7.2.1 Renewable energy

		renewable energy in the global energy mix	share in the total final energy consumption
8	Promote sustained, inclusive, sustainable economic growth, full and productive employment, and decent work for all.	8.2: Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value-added and labour-intensive sectors	8.2.1 Annual growth rate of real GDP per employed person
		8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value	8.5.1 Average hourly earnings of employees by sex, age, occupation and persons with disabilities
9	Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.	9.1: Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all	9.1.2: Passenger and freight volumes by mode of transport
		9.4: By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities	9.4.1: CO2 emission per unit of value added

Eventually, the study aims to establish the connection between the AM in MaaS/ITS as a form of smart mobility and their impacts and how these impacts would correlate with SUD policies.

### 5.3.4 Comparative Policy Analysis and Policy Recommendations

The comparative analysis aims to understand the specific objectives of mobility policies in Geneva and Lyon-Villeurbanne within distinct impact categories. A comparative city policy would help fulfil the SDGs. This comparative data on city-level policies would aid in addressing questions about strategies such as the AM in MaaS/ITS's potential to enhance access to sustainable, safe, and affordable mobility (Rozhenkova et al., 2019). We seek to explore each city's sustainable mobility priorities, unique approaches to leveraging the SDGs framework for policy formulation and urban planning, and how the SDGs targets align with policy objectives and their ensuing impacts. The comparison investigated how the AM in MaaS/ITS deployment would align in both cities and extract insights on how it could contribute to their SUD goals.

The results include policy recommendations addressing identified weaknesses revealed through comparative policy analysis (Fagnant and Kockelman, 2015a). This is based on insights and data generated from the analysis, encompassing qualitative impacts of SAV deployment, externalities calculations, and policy analysis. The data is crucial in translating

analytical outcomes into actionable policy recommendations, focusing on integrating smart, safe, reliable, and environmentally friendly shared automated vehicles. This translation process is vital, ensuring that the research significantly improves urban transportation systems and fosters sustainable urban development.

In summary, our methodology adopts a holistic approach by leveraging the SDGs framework, integrating empirical data from Geneva and Lyon-Villeurbanne as case studies, and employing rigorous policy analysis. This approach allows for a comprehensive examination of SAV impacts on SUD. By aligning policy instruments with sustainability objectives, conducting comparative analyses, and providing recommendations, our methodology offers a framework for understanding and enhancing the integration of SAV as AM in MaaS/ITS into urban transportation systems to promote sustainable urban development.

## 5.4 RESULTS

### 5.4.1 Key Insights

In this part, we focus on the IPA results and steps, which address the documents analysed collectively to better address the integration of the deployment scenario within SUD strategies in a European city.

Drawing from the methodology outlined in the IPA's steps, the following results are presented: Step 4, which tallies the total concepts for plan Breadth (reflecting the overall number of distinct concepts within the plan), Step 5, dedicated to identifying and quantifying transformative concepts, and Step 6, aimed at calculating plan Depth to assess the systemic nature of the conceptual framework (Wallis, 2016), see Figure 20. For the IPA, all the documents for both Geneva and Lyon Villeurbann were analysed together. We identified the repeating targets and impacts, and we merged them whenever feasible, as outlined in step 3 of the IPA, Figure 20. The diagram was constructed by summarising recurring key goals identified across various impact categories (economic, social, environmental, land use, safety) analysed in the documents. A detailed analysis of the documents and the different classifications is included in Appendix D.2. The arrows illustrate the alignment of the impacts of AM in MaaS/ITS with the corresponding economic, social, environmental, land use, and safety policy targets. Notably, when multiple arrows converge on the same concept, it signifies transformative concepts, as outlined in Appendix D.3. The diagram exhibits 38 distinct circles, representing various concepts extracted from both cities' policy analysis—examples include noise reduction,

decreased car use, use of more efficient vehicles, and heightened awareness of sustainable mobility. These circles signify the breadth, denoting the diversity of AM in MaaS/ITS impacts linked to SUD targets within the documents, representing step 4 of the IPA.

Among these concepts, 16 concepts were identified as transformative concepts, encompassing ideas like emissions reduction, enhanced traffic management, and alignment with SDG 11. In step 5 of the IPA, transformative concepts emerge as pivotal ideas resulting from the deployment's various impacts. For example, the economic impact of AM in MaaS/ITS leads to cost savings for passengers, which enhances accessibility. Likewise, the scenario's social impact improves connectivity, accessibility, and inclusivity, all contributing to bolstering accessibility—a crucial transformative concept aligned with the social targets of SUD policies. Refer to Figure 19 for details. Therefore, increasing accessibility stands as a transformative concept within the social objectives of SUD policies. In step 6 of the IPA, dividing the breadth by transformative concepts unveils the depth of the plan. This depth signifies how thoroughly these impacts integrate into the analysed SUD policies. It illustrates the alignment between the deployment strategy of AM in MaaS/ITS and the cities' policy frameworks.

Fewer concepts in a plan signify focused goals, while more transformative concepts indicate greater effectiveness. AM in MaaS/ITS contributes to SUD through policy targets and SDGs. Merging breadth and transformative concepts creates a deeper, more effective plan, requiring policies that amplify AM's impact on urban sustainability goals. The resulting IPA diagram in Appendix D.3 shows the breadth of the plan is 38. The transformative concepts are 16. Transformative concepts of the studied strategy denote critical components that wield significant influence over the entire system (Wallis 2016). The detailed analysis of the collective policy documents for Geneva and Lyon-Villeurbanne indicated the key targets as transformative concepts such as accessibility, car use/car ownership, transition to electromobility and efficient fuel engines, emissions, collaboration with stakeholders, urban density and mixed-land use, and traffic management. Our proposed scenario AM in MaaS/ ITS has impacts, external cost reductions, and modal shifts aligned with the targets. Thus, our scenario would contribute to achieving these goals. The other layer is the alignment with the SDGs. The analysis shows that SDG11, SDG 13, SDG 3, SDG 7, and SDG 4 align with the policy targets and as a consequence, our scenario would also help achieve them and thus achieve the SUD goals.

The depth estimation (transformative concepts=16, devised by the breadth of the plan=38) shows a value of 0.42. The value of 0.42 is considered moderate but focuses on key concepts and could be further increased through policy recommendations (Wallis 2016). The value shows moderate potential for the deployment of SAV in the form of AM in MaaS/ITS to achieve SUD and SDGs. Thus, the results demonstrate the need for policy recommendations to better enhance the alignment of the scenarios and the desired goals of SUD.

The subsequent policy analysis connected AM in MaaS/ITS impacts with city SUD targets, identifying alignment and gaps in policy. This process, highlighting transformative concepts, informs valuable policy recommendations. Its goal is to facilitate seamless AM deployment, ensuring sustainable urban development objectives. Analyzing the diagram and policy documents identifies "leverage points"—key concepts with the potential for significant systemic change (Wallis, 2016). Red circles in Appendix D.3 represent selected points, with more connections to other concepts, indicating their pivotal role. These points include:

- (1) Decreasing car modal share
- (2) Increasing public transport modal share
- (3) Increasing the use of more efficient vehicles (e.g. electric vehicles)
- (4) Reducing emissions.

Focusing on these pivotal points triggers positive systemic changes, initiating feedback loops that amplify AM in MaaS/ITS impacts, contributing to SDG targets. These feedback loops, as defined by Wallis (2016), magnify specific effects within the system. One crucial point involves promoting shifts toward public transport and discouraging car use. The deployment strategy of AM in MaaS/ITS, supported by modal share and externalities analyses, demonstrates its potential to reduce car usage, enhance public transport, and reduce air pollution and climate change emissions. Strengthening these leverage points through policy recommendations is crucial to align AM in MaaS/ITS with city SUD policies further.

#### 5.4.2 SUD Policy Analysis of Geneva

The City of Geneva promotes sustainability through administrative programs, policies, and actions, addressing energy, climate, waste, water, planning, mobility, and biodiversity in its environmental commitments (City of Geneva, 2023). The city follows a Municipal



Master Plan, revised every 10-15 years, based on eight key principles: balanced urban development, affordable housing, diversity in populations and services, sustainable mobility, social and environmental commitments, international attractiveness, and active involvement in its growth (Ville de Genève, 2022b). The city employs a monitoring system to assess policy progress, exemplified by evaluations for the 2020 Municipal Plan initiated in 2009 (Ville de Genève, 2009, 2020b). By 2018, positive assessments were achieved for the cycling paths project and moderate assessments for pedestrian zones. The 2009 Municipal Plan remains effective, and a new plan is scheduled for 2024. Mobility is a key priority overseen by the State of Geneva (Ville de Genève, 2014). The analysis of the documents highlighted that the local authorities prioritise environmental targets as well as travel behaviour in policymaking, Figure 22.

The mobility policies enacted in Geneva align with the SDGs framework, particularly SDG 11, focusing on sustainable cities. Around half the policies analysed showed a direct association with this SDG, Figure 23. The measures undertaken by the city align with target SDG 11.2, which stipulates include access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons (Ville de Genève, 2022b, 2023b). Furthermore, Geneva's mobility policies exhibit a comprehensive approach to sustainability by considering other relevant SDG indicators, including SDG 11.2.1, aligned with access to public transport, and SDG 11.6.2, targeting air quality improvements in urban areas (Eltis, 2016; Ville de Genève, 2022b).

The findings also demonstrate a strong synergy with SDG 13 (Climate Action) and SDG 3 (Good Health and Well-Being) (Ville de Genève, 2018). For instance, SDG 13.2.2, which focuses on total annual greenhouse gas emissions, resonates with Geneva's efforts to reduce its carbon footprint. Likewise, SDG 3.9.1, which pertains to the mortality rate attributed to household and ambient air pollution, underscores the city's dedication to improving the well-being and health of its residents by minimising pollution-related risks (United Nations, 2015; Ville de Genève, 2023a). The alignment with SDG 11 also corresponds to the SECAP outlined in Chapter 2.

The policy analysis, see appendix D.1, reveals a predominant reliance within the city's sustainable mobility agenda on key policy instruments, including infrastructure development (24% of all policy analysed), urban planning initiatives(16%), awareness

campaigns (14%), and improving the transport offer (14%), Figure 24. Notably, the infrastructure policy component encompasses strategic initiatives, including the expansion of the cycling network, the reduction of road gauges, the implementation of sound-absorbing surfaces on roadways, and the creation of new footpaths (Ville de Genève, 2020c, 2021, 2022a). Urban planning initiatives focused on increasing centrality around mobility hubs and redesigning space for pedestrians and bikers (Ville de Genève, 2020a, 2022b, 2023a). The awareness campaign included training and certification programs for public transport drivers, media campaigns to encourage residents to adopt more environmentally friendly transport choices, as well as educational campaigns for children and students to promote cycling, Figure 24 (Ville de Genève, 2022b). A summary of the policy instruments is presented in Table 11.

Table 11: Summary of Policy Instruments in Geneva

Policy Instrument	Description
Vehicle Management Fleet	Fleet Renewal: Strategies to renew the vehicle fleet based on environmental criteria.
	Electric and Fuel-Efficient Vehicle Adoption: Encouraging the adoption of electric and fuel-efficient vehicles.
	Support for Low-Emission Engines: Promoting and supporting the use of low-emission engine technologies.
Digital Tools	Platforms, Apps, and Ticketing Systems: Development and utilization of digital platforms, apps, and ticketing systems for efficient mobility services
Infrastructure Development	Sound-Absorbing Road Surfaces: Implementation of surfaces to reduce road noise.
	Cycling Paths and Facilities: Expansion and enhancement of cycling paths, parking, and biking facilities.
	Charging Points: Installation and promotion of charging points for electric vehicles.
Low-Emission Zones	Parking Restrictions: Regulations and restrictions aimed at low-emission vehicles in certain zones.
	Circulation Bans: Bans on certain vehicles or traffic in specific zones to reduce emissions.
Awareness and Promotional Campaigns	Marketing Initiatives: Campaigns and events promoting sustainable mobility options.
	Training Programs: Educational initiatives and certifications encouraging environmentally friendly practices
Stakeholder Engagement	Collaboration with Partners: Engagement with private and public partners for mobility initiatives.

Speed Limits	Traffic Calming Measures: Implementing measures to calm traffic flow and reduce speeds.
	Zone-Specific Speeds: Setting speed limits specific to different zones for safety and noise reduction.
Financial Incentives	Subsidies, Grants, Loans: Financial support for various sustainable mobility initiatives.
	Support for Bikers and Public Transport: Specific financial support for bikers, public transport, taxi fares, and mobility-related businesses.
Transport Improvements	Offers Seamless and Multimodal Services: Development and promotion of integrated transport services.
	Sharing Options: Encouraging shared transportation modes for increased efficiency.
Urban Planning	Mobility Plans: Planning and implementation of urban mobility strategies.
	Green Spaces and Mobility Hubs: Development and integration of green spaces, mobility hubs, and mixed land-use planning.
	Urban Density and Green Corridors: Strategies focusing on urban density, green corridors, and mixed land use.

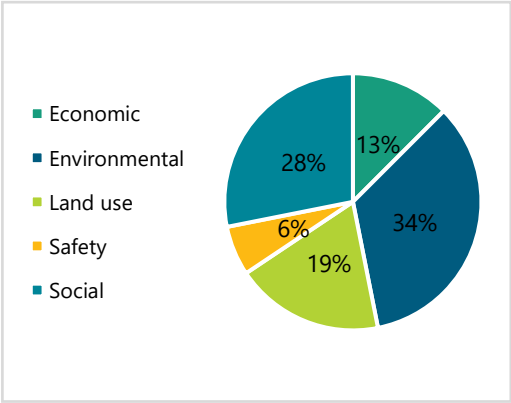


Figure 22: Distribution of policy emphasis by impact in Geneva

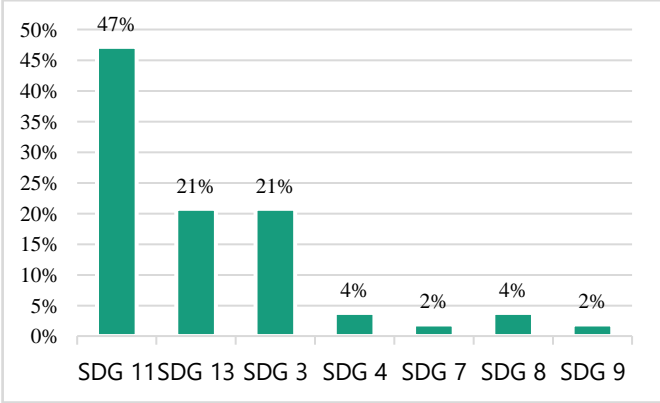


Figure 23: Alignment of Geneva's mobility policies with sustainable development goals

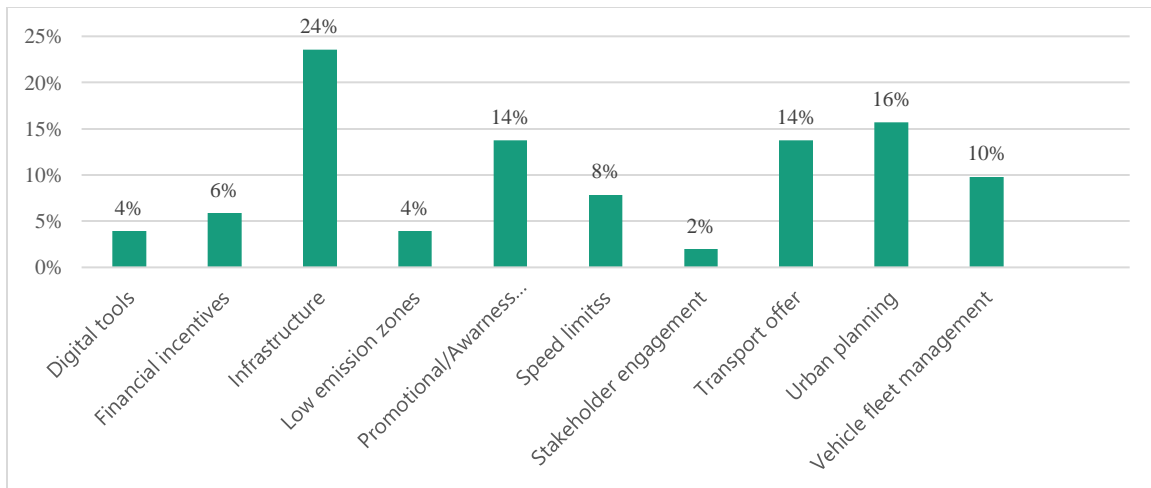


Figure 24: Policy instruments and their distribution in Geneva's sustainable mobility strategy

### 5.4.3 SUD Policy analysis of Lyon-Villeurbanne

In the face of global climate challenges, the issue of transportation has emerged as a significant concern for the city of Lyon-Villeurbanne. In response, encouraging active mobility has become crucial, representing viable alternatives to individual car usage (Ville de Lyon, 2022b). The city has already made significant strides, achieving a 45% Walking modal share, becoming the primary mode of transportation in the Lyon-Villeurbanne area (Ville de Lyon, 2023a). The Villeurbanne municipality's climate strategy aims to build a city that secures mobility for all road users, promoting complementarity between different modes of transportation. It prioritises protection for pedestrians, cyclists, drivers, and public transit users (Sytral, 2016; Villeurbanne, 2020).

The analysis demonstrates that Lyon-Villeurbanne's policy aligns with social impacts related to the introduction of SAV (Lyon Smart Community, 2017), Figure 25. It emphasises the transition from individual motorised transportation to active mobility and public transport. Secondly, the city's mobility policies mostly align with economic and social goals. The policies implemented seek to promote environmentally friendly transportation, focusing on reducing air and noise pollution while minimising energy consumption in the transport sector (Ville de Lyon, 2019, 2022c, 2023b). The analysis of the policies shows that Lyon-Villeurbanne aims to promote a low-carbon industry that relies on financial support to encourage innovative and environmentally friendly entrepreneurship. It also aims to improve its ticketing system and digital tools, such as multimodal platforms (Villeurbanne, 2020; Ville de Lyon, 2021, 2022a). However, while policies centre on influencing travel behaviour as a social aspect, there exists a gap in addressing social

equity. The document analysis revealed a few key points: support for vulnerable populations, improvement in accessibility for PRM, and efforts to enhance access to roads and public transport. However, it also highlighted the limited attention given to social equity. Accessibility issues receive comparatively less attention than environmental and economic goals within these policies (Fandio et al., 2020).

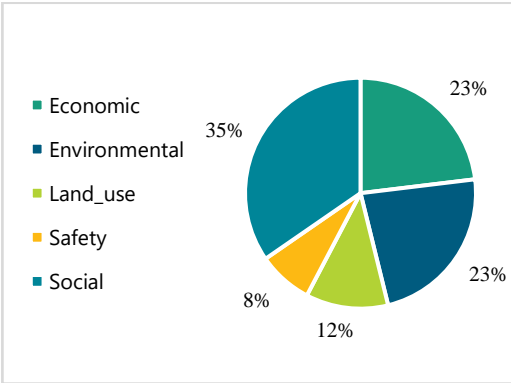


Figure 25: Distribution of policy emphasis by impact in Lyon-Villeurbanne

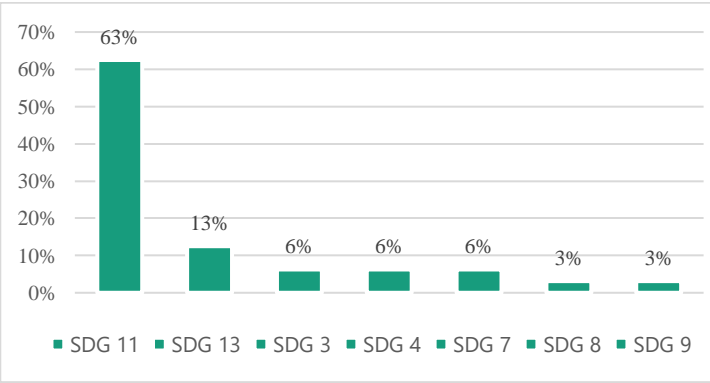


Figure 26: Distribution of policy emphasis by impact in Lyon-Villeurbanne

The policies are primarily aligned with SDG 11. More than 60% of the analysed policies were directly connected to SDG 11 compared to the other SDG (only 3% related to SDG 8, Decent Work and Economic Growth, and SDG 9, Industry, Innovation, and Infrastructure), Figure 26. Additionally, they draw upon a selection of related indicators, notably SDG 11.2.1 (indicator for the urban population experiencing adverse impacts of both ambient and household air pollution) and SDG 11.6.2 (indicator for annual mean levels of fine particulate matter in cities) (United Nations, 2023a) Lyon-Villeurbanne's policy approach encompasses several facets, including infrastructure development (22% of all policies analysed), low-emission zones (12%), and improving the transport offer (12%) (Villeurbanne, 2020; Ville de Lyon, 2021, 2022a) as presented in Figure 27 and Table 12.

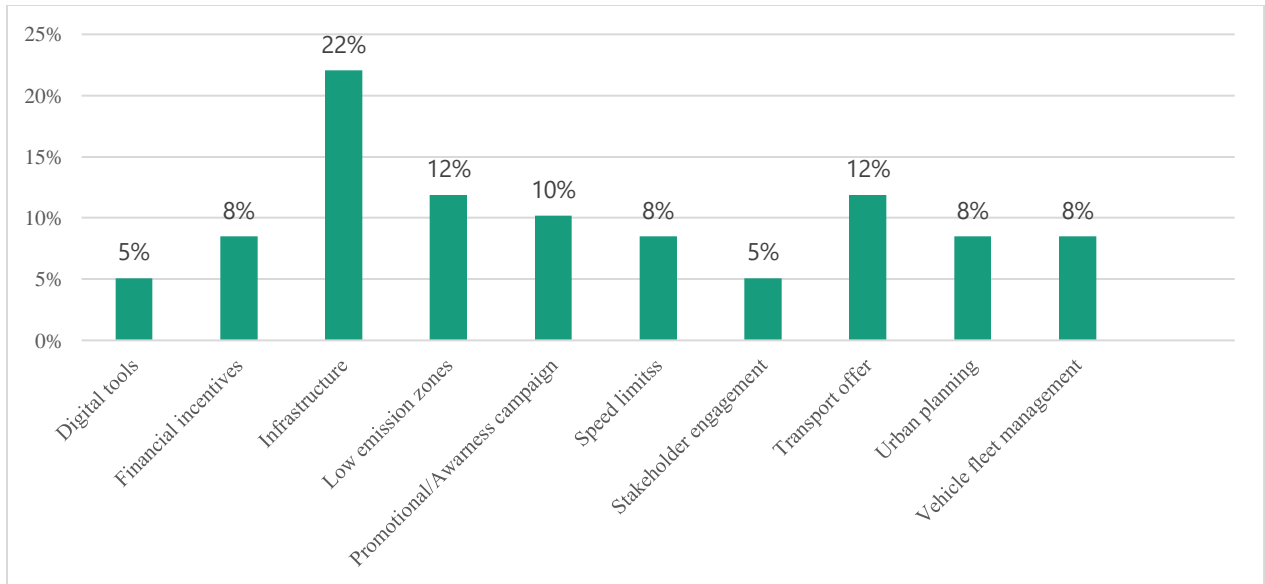


Figure 27: Policy instruments and their distribution in Lyon-Villeurbanne's sustainable mobility strategy

Table 12: Summary of Policy Instrument in Lyon-Villeurbanne

Policy Instrument	Description
Vehicle Fleet Management	Vehicle Renewal Support for Less Polluting Vehicles
Digital Tools	Sustainable Mobility at Work Digital Platform Renewal of Ticketing Systems Multimodal Information Master Plan Digital Information Tools
Infrastructure Development	Cycling Paths Charging Points Urban Public Transport Infrastructure Development New Train Stations Secure Bike Parking Bicycle Racks
Low-Emission Zones	Parking Restrictions Circulation Bans Reform of Paid Parking Bans on Polluting Vehicles Increase in Low-Emission Public Transport
Awareness and Promotional Campaigns	Communication Plans for Road Usage Active Modes of Transport Communication Plan Mobility Improvement Awareness for Public Workers Kids' Bike Safety Certification
Stakeholder Engagement	Collaboration with Over 100 Organizations Admin Mobility Plan with Employee Workshops Leading a Socio-Economic Player Network
Speed Limits	Traffic Calming Measures Zone-Specific Speed Limits
Financial Incentives	Subsidies to Clusters Grants, Loans Support for Bikers Support for Public Transport, Taxi Fares

	Support for Mobility Businesses
Transport Offers Improvements	Seamless and Multimodal Services Sharing Options Improvements in PRM Accessibility Passenger Safety Enhancements Better Connections to Neighboring Areas
Urban Planning	Mobility Plans Green Spaces Mobility Hubs Urban Density Mixed Land Use Green Corridors

#### 5.4.4 Comparative Policy Analysis (Geneva and Lyon-Villeurbanne)

Both cities, Lyon-Villeurbanne and Geneva, have adopted similar mobility policies as an integral component of their sustainable development planning. Lyon-Villeurbanne's primary focus of these strategies is to drive social impact by encouraging residents to transition from individual motorised vehicles to active mobility and public transport (35% of policies analysed compared to 28% in Geneva). This shift is designed to reduce traffic congestion, enhance accessibility, and promote healthier, more sustainable modes of transportation. Lyon-Villeurbanne's second focus is economic targets within its mobility strategy (23% of policies analysed compared to 13% in Geneva). This approach involves motivating its workforce to adopt sustainable mobility options, equipping them with digital tools to implement mobility initiatives effectively, and investing in innovative, low-carbon mobility businesses. By doing so, the city aims to stimulate economic growth, create jobs in the mobility sector, and foster innovation. Lyon-Villeurbanne also leverages financial incentives to modernise its ticketing system and actively promotes collaboration with private stakeholders, forging partnerships that further advance sustainable mobility. Its environmental goals under its sustainable mobility strategy focused mainly on air quality and low carbon mobility, Figure 28.

Meanwhile, Geneva prioritises environmental goals by curbing emissions, mitigating noise pollution, and increasing energy efficiency in the transportation sector (34% of policies analysed compared to 23%). In the second place, Geneva focuses on social impacts again, focusing on mobility behaviour and pushing for biking as a cornerstone of its strategy. Lyon-Villeurbanne policy analysis focuses on economic and environmental policies, Figure 28. Conversely, Geneva's mobility policies prioritise land use impacts (19% of policies analysed compared to 12% in Lyon-Villeurbanne). These policies are designed to reduce

the need for extensive parking infrastructure, promote mixed land use, and encourage the development of centralised areas and mobility hubs. These measures aim to optimise land usage, reduce urban sprawl, and create more walkable, connected, and efficient urban spaces.

Geneve's focus on land use impacts aligns with the envisioned outcomes of SAV deployment, where the city anticipates achieving more sustainable and economically efficient land utilisation. Thus, it effectively reduces travel distances, car usage, and ownership (Nemoto et al., 2023). This also aligns with the AM in the MaaS/ITS scenario, which aims to curtail car travel for short trips within city centres. The AM deployment involves providing convenient connections to mobility hubs as first and last-mile solutions, promoting the use of cars and bicycles by passengers for their urban journeys (Fournier et al., 2023).

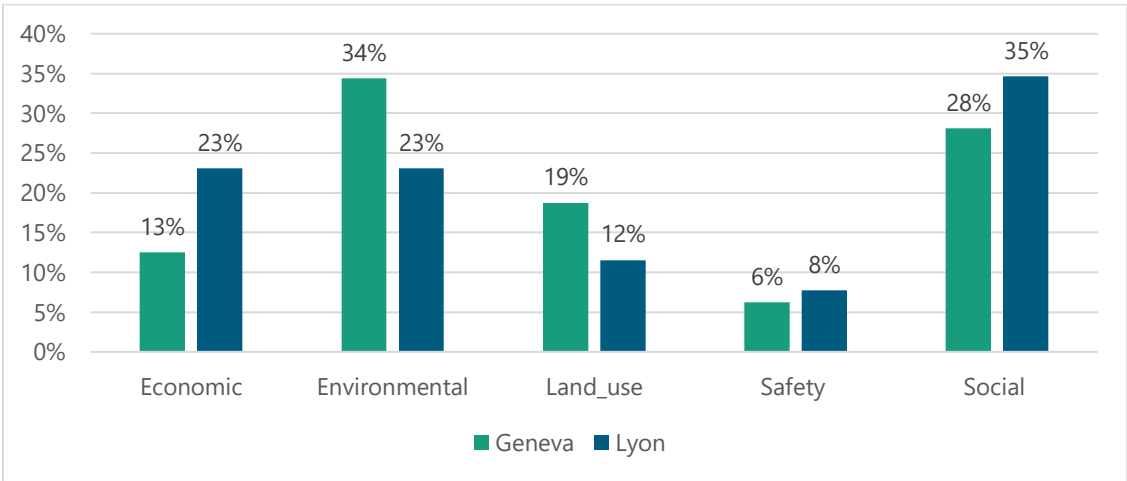


Figure 28: Comparing Policy Emphasis by Impact in Lyon-Villeurbanne and Geneva

In both city cases, most mobility policies analysed correspond to the SDG 11 objectives, reflecting a strong alignment with urban sustainability goals. Additionally, Geneva's policies exhibit compatibility with SDG 13 (Climate Action) and SDG 3 (Good Health and Well-being), whereas Lyon-Villeurbann's policies are more closely associated with SDG 13 and to a lesser degree SDG 3, 4, and 7, Figure 29. Furthermore, for both cities, mobility policies demonstrate alignment with specific SDG indicators, including SDG 11.2, SDG 11.3.1, SDG 13.2.2, and SDG 13.3.1, emphasising their commitment to sustainable and climate-resilient urban development.



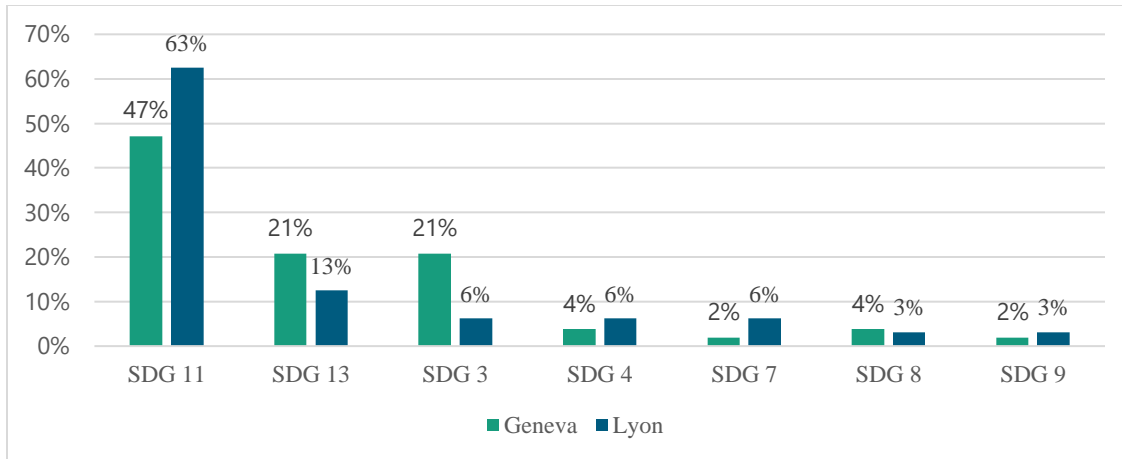


Figure 29: Comparing Policy Emphasis by Impact in Lyon-Villeurbanne and Geneva

Regarding the choice of policy instruments, both cities rely on infrastructure development as a primary approach. Geneva places the least emphasis on digital tools, low-emission zones, and stakeholder engagement (4%, 4%, and 2% of the policies analysed, respectively), with a greater focus on promotional and awareness campaigns, urban planning, and expanding the public transport offering (14%, 16%, and 14% respectively). Lyon-Villeurbanne employs low-emission zones and improving the transport offer as essential tools to achieve its sustainable mobility goals (12% each). Lyon-Villeurbanne is also not utilising tools like stakeholder engagement and digital tools to reach its mobility goals (5% each); see Figure 30.

In the context of comparative policy analysis, we observe that Geneva's policies, with their specific targets, display alignment with various social impacts. Notably, these policies also resonate with SDG 11, SDG 13, SDG 3, and SDG 4. In contrast, Lyon-Villeurbanne's policy alignment primarily centres around SDG 11, with a narrower focus. This pattern is consistent across the spectrum of impact areas. Geneva's mobility policies encompass a broader range of SDGs, addressing multiple goals within each impact category, Figure 31. In contrast, Lyon-Villeurbanne's approach is characterised by a more focused approach, with fewer SDGs targeted per impact area, Figure 32.

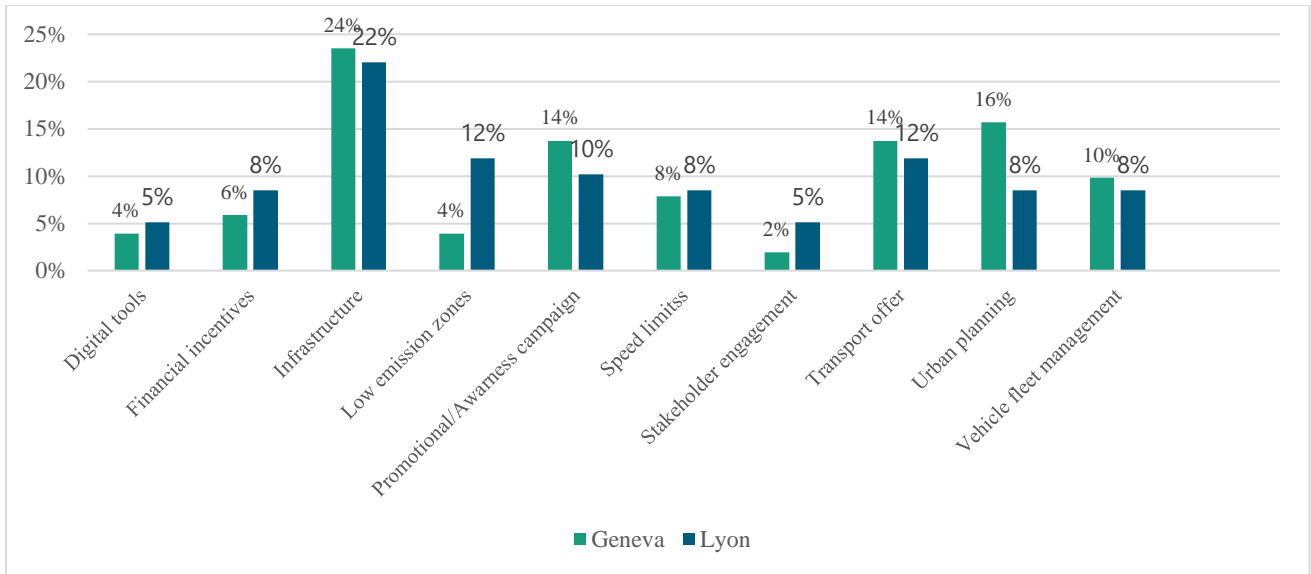


Figure 30: Comparison of policy instruments and their distribution between Geneva and Lyon-Villeurbanne

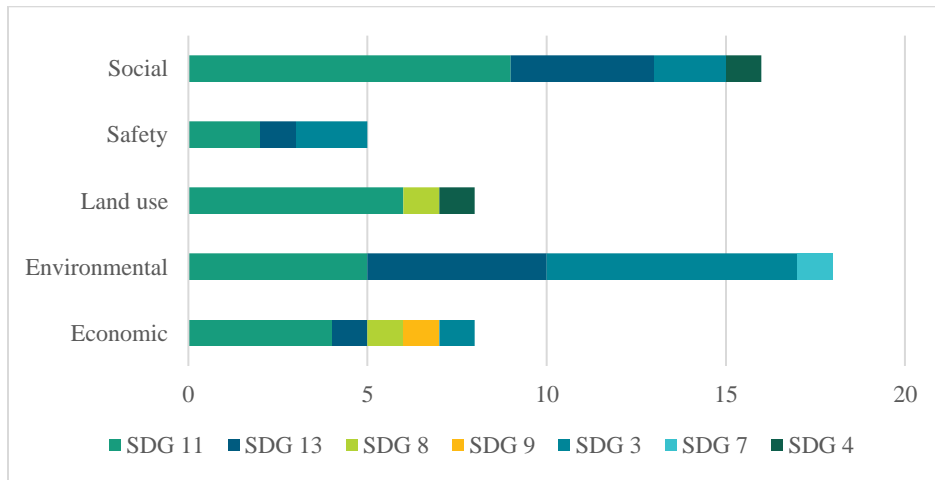


Figure 31: Distribution of SDGs focus per policy impact group in Geneva

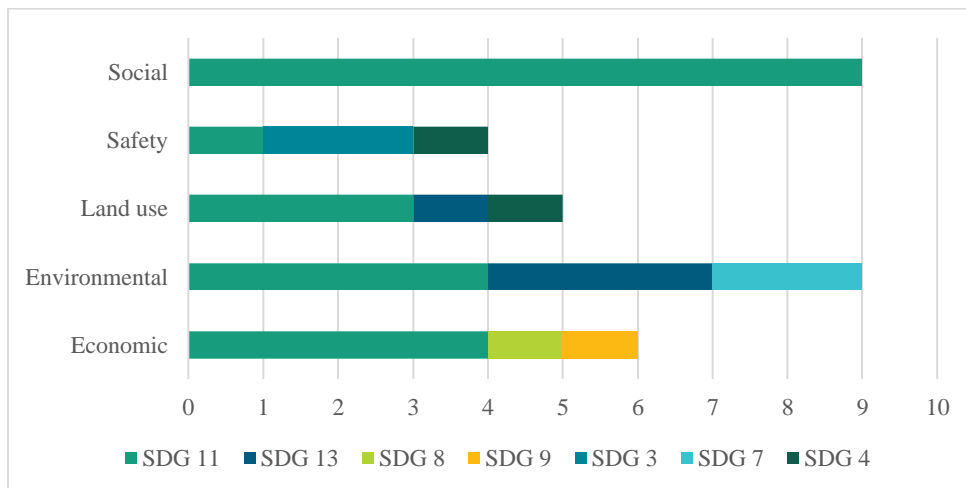


Figure 32: Distribution of SDGs focus per policy impact group in Lon-Villeurbanne

Despite being the least emphasised aspect in both Geneva's and Lyon-Villeurbanne's mobility policies, safety remains a priority through speed restrictions that reduce accidents, noise, and pollution while influencing residents' travel behaviour (Rossi et al., 2020).

## 5.5 DISCUSSION

### 5.5.1 Cross-Impact Assessment

To answer the question of how AM in MaaS/ITS can foster SUD, the results of the analysis highlight the need for aligned policy recommendations targeting key concepts in the strategy presented in the policy documents and the IPA diagram.

Exploring the implications of deploying AM in MaaS/ITS uncovers transformative concepts for SUD. Strengthening policy recommendations for MaaS/ITS is crucial for cultivating these transformative concepts, aligning scenario impacts with sustainable urban mobility and SUD targets, and enriching the plan's depth ( $>0.42$ ). The results provide an understanding of how SAV deployment aligns with policies related to sustainable urban development in both cities. The integration of AM in MaaS/ITS aligns with SDGs by reducing car dependency and complementing public transport, which resonates with SDG 11 and specifically targets SDG 11.2. This synergy is further emphasised in the results of the IPA, identifying two pivotal leverage points as discussed in the results section.

External cost analysis indicates notable reductions in accidents, as shown in Chapter 4 results, aligning with SDG 11 and SDG 3 and targeting SDG 3.6 and SDG 11.2. AM in MaaS/ITS contributes to emissions reduction, aligning with SDG 13, SDG 11, and SDG 3, targeting SDG 13.2, SDG 11.6, and SDG 3.9. Congruent with economic policies, private-public cooperation aligns with SDGs 9 and 8, targeting SDGs 9.2 and 8.5 (United Nations, 2023a). Addressing congestion, AM in MaaS/ITS contributes to environmental benefits, increased productivity, and economic revenues, aligning with SDG 11 and targeting SDG 11.2 (Huber et al., 2019). Changing travel behaviour aligns with SDG 11, targeting SDG 11.2, emphasising the pivotal role of AM in MaaS/ITS in advancing urban sustainability (Korbee et al., 2023; United Nations, 2023a).

The policy analysis revealed that both cities heavily rely on infrastructure as a primary

policy instrument to pursue SUD goals and SDGs. In Geneva, 24% of the policies analyzed emphasised infrastructure, while in Lyon-Villeurbanne, it was 22%. However, notably absent in these policies was any mention of developing new infrastructure tailored to emerging smart mobility solutions like AM or SAV.

The comparative policy analysis revealed that both cities underutilised digital tools and stakeholder engagement as policy instruments. These technologies can enhance access to intermodal transport options (Jonuschat et al., 2015). Smart mobility forms providing personalised services, such as AM in MaaS/ITS, are geared towards addressing environmental concerns and social inequalities. However, their incorporation into policy documents remains limited. The lack of specific objectives and vague representations of smart mobility hinder their effective implementation. This raises questions about the adequacy of current planning tools to accommodate innovative and new modes of transport and urges a rethinking of planning strategies for better integration into policy frameworks (Castex et al., 2017). Furthermore, prioritising stakeholder engagement offers a citizen-centric approach, motivating private stakeholders to innovate and collaborate with local authorities, ultimately achieving affordable, sustainable, and clean transport for all. Techniques like living labs and participatory workshops have effectively engaged stakeholders (Mück et al., 2019)

The implementation of AM in MaaS/ITS synergises with SDG, reducing car usage and linking to mobility hubs, aligning with SDG 11 and its target SDG 11.2. External cost analysis indicates notable reductions in accidents, as shown in Chapter 4, externalities calculations. See Figures 17 and 18, aligning with SDG 11 and SDG 3 and targeting SDG 3.6 and SDG 11.2. AM in MaaS/ITS contributes to emissions reduction, aligning with SDG 13, SDG 11, and SDG 3, targeting SDG 13.2, SDG 11.6, and SDG 3.9. Congruent with economic policies, private-public cooperation aligns with SDGs 9 and 8, targeting SDGs 9.2 and 8.5 (United Nations, 2023a). Addressing congestion, AM in MaaS/ITS contributes to environmental benefits, increased productivity, and economic revenues, aligning with SDG 11 and targeting SDG 11.2 (Huber et al., 2019). Changing travel behaviour aligns with SDG 11, targeting SDG 11.2, emphasising the pivotal role of AM in MaaS/ITS in advancing urban sustainability (Korbee et al., 2023; United Nations, 2023a).

### 5.5.2 Policy Recommendation: Enhancing Smart Mobility for Sustainable Urban Development

The deployment of SAV in urban areas should adhere to carefully defined conditions and

considerations. Our selection of the AM in MaaS/ITS scenario was supported by qualitative impact analysis within a deliberative scenario planning process, as well as externalities calculations based on a transport behaviour survey (Korbee et al., 2023)

Our study underscores the potential reduction of external costs caused by introducing smart mobility like the AM in MaaS/ITS, as demonstrated in our case studies of Geneva and Lyon-Villeurbanne, which significantly contributes to these cities' sustainable urban development and mobility strategies. The integration of SAV in general, and the AM in specific, is pivotal for strengthening public-private collaboration and industry involvement while reducing car ownership, lowering emissions, and enhancing safety (Fagnant and Kockelman, 2015a; Narayanan et al., 2020a). Policy recommendations for advancing AM in MaaS/ITS for sustainable urban development stem from identified leverage points found in previous chapters. These leverage points include reducing car modal share, increasing public transport usage, adopting efficient vehicles, and cutting emissions. These aspects were extensively discussed in the scenario analysis (Chapter 4, section 4.3.1), environmental impact studies (Chapter 3), and externalities analysis (Chapter 4). The alignment of these recommendations with policy gaps observed in Lyon-Villeurbanne and Geneva, such as limited attention to social equity and vague representations hindering implementation, guides these suggestions. Lyon-Villeurbanne's focus on vulnerable populations underscores policy directions emphasizing equitable mobility access.

The chosen policies closely align with these leverage points and identified gaps. They emphasise smart mobility infrastructure, tackling the lack of tailored infrastructure for smart solutions. Stakeholder engagement initiatives resonate with the need to increase public transport usage and address social equity gaps. A recommendation for digital transformation echoes leverage points related to public transport, efficient vehicle usage, and emission reduction. It also addresses the lack of specific objectives hindering smart mobility implementation, contributing to bridging these identified gaps. These policies aim to bridge these gaps, enhancing accessibility, reducing environmental impacts, and integrating new transport modes like AM in MaaS/ITS for urban sustainability. They focus on infrastructure development, stakeholder engagement, equitable access, and digital transformation, ultimately mitigating externalities such as noise, accidents, congestion, and emissions. These policies amplify scenario impacts, enhancing accessibility, connectivity, emission reduction, energy usage, economic savings, safety, and land use efficiency. Figure 33 shows the summary of the policies and their relation to the leverage

points, key impacts, and results from Figure 19, as well as policy gaps from the results.

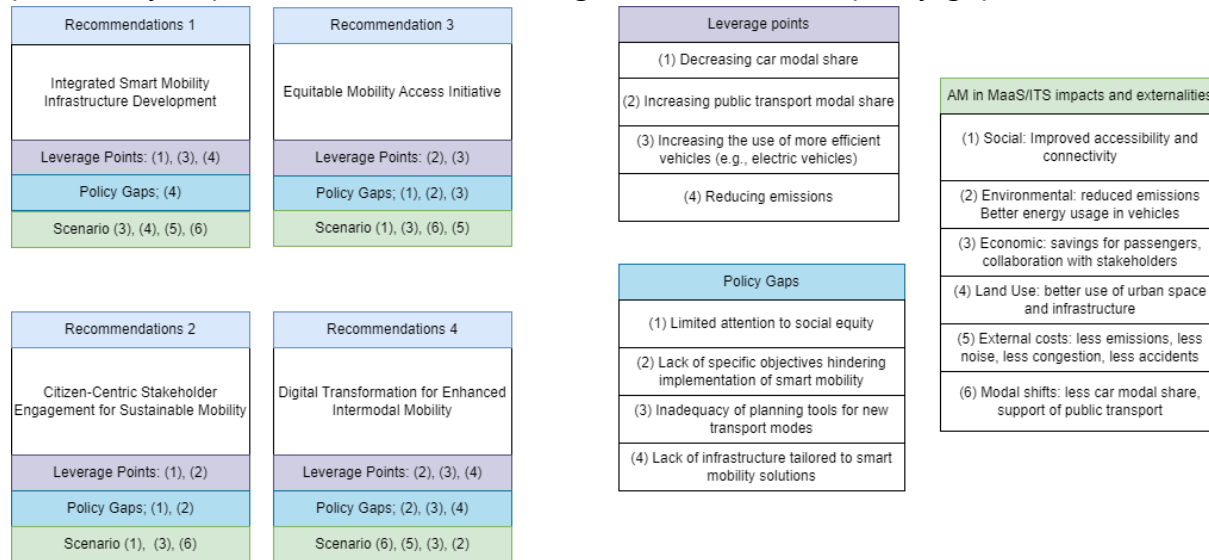


Figure 33: Policy recommendation for AM in MaaS/ITS to support SUD

### Recommendation 1 - Integrated Smart Mobility Infrastructure Development

Objective: Upgrade urban infrastructure and digital platforms to support emerging smart mobility solutions like AM in MaaS.

Measures:

- Implement adaptable urban zoning policies to accommodate evolving AM technology.
- Cultivate public-private collaborations to finance and establish smart infrastructure, such as charging stations' exclusive lanes and multimodal platforms to book intermodal trips, ensuring seamless integration with AM in MaaS systems.

### Recommendation 2 - Citizen-Centric Stakeholder Engagement for Sustainable Mobility

Objective: Prioritise stakeholder engagement to ensure citizen-centric, sustainable, and clean transport solutions.

Measures:

- Create collaborative forums like living labs and communal workshops engaging residents, businesses, and authorities in AM in MaaS/ITS deliberations and planning.
- Motivate private entities with incentives or grants to foster innovation and

collaboration in sustainable transport initiatives.

- Introduce feedback systems integrating public opinions and preferences into AM in MaaS/ITS policy and planning.

### Recommendation 3 - Equitable Mobility Access Initiative

Objective: Enhance accessibility, particularly for vulnerable populations and PRM.

Measures:

- Allocate dedicated resources within the AM in the MaaS deployment framework to enhance infrastructure, including ramps and accessible pathways for PRM.
- Implement targeted subsidy schemes specifically designed for AM in MaaS/ITS providers to offer discounted services to underserved communities.
- Establish community-centred programs within the AM in MaaS/ITS strategy to address distinct accessibility challenges and ensure inclusivity in transportation options.

### Recommendation 4 - Digital Transformation for Enhanced Intermodal Mobility

Objective:

To develop and implement a comprehensive digital infrastructure strategy aimed at promoting intermodal transportation options through multimodal platform platforms and increasing public transport utilization while reducing individual car usage within the framework of AM in MaaS/ITS deployment.

Measures:

- Develop user-friendly digital platforms integrating various transportation modes for route planning, real-time schedules, and seamless payments across services.
- Create a unified digital ticketing system enabling purchases for diverse transport modes through a single app, encouraging public transit use.
- Utilise platform data for informed urban planning, adapting and improving transit services based on user behaviour and demand.

In summary, cities should embrace the integration of SAV and AM in MaaS/ITS, bolstered by supportive infrastructure, to advance sustainable urban development and mobility

while improving accessibility, reducing environmental impact, and enhancing the overall quality of urban life.

### 5.5.3 Limitations

The policy analysis within the study could have been more robust by incorporating comprehensive evaluation mechanisms and performance indicators used by Geneva and Lyon-Villeurbanne to measure the effectiveness of their mobility initiatives. While the analysis heavily drew from the cities' climate strategies, it missed valuable perspectives that could have been gleaned from interviews with policymakers and thorough scrutiny of regulatory documents. Additionally, focusing solely on Lyon-Villeurbanne as a unified entity limited the depth of insights that could have emerged from separately examining these neighbouring cities. A more thorough exploration of regional and national policies could have shed light on clearer governance mechanisms, aiding local authorities in tailoring context-specific implementations for their respective areas. The IPA methodology faces limitations due to reliance on available data, potential biases in policy selection, complexity in interpreting interrelated impacts, unpredictable external factors, and challenges in quantifying qualitative effects.

## 5.6 CONCLUSION

In conclusion, our study establishes a robust connection between the implementation of AM in MaaS/ ITS in Geneva and Lyon-Villeurbanne and the overarching policies of these municipalities. Both cities prioritise sustainability within the UN Sustainable Development Goals framework, albeit with distinct emphases. Geneva strongly focuses on environmental targets, employing key instruments such as infrastructure development and urban planning. Conversely, Lyon-Villeurbanne directs its efforts toward social targets, emphasising modal shifts to active mobility facilitated by infrastructure development, improved transport offerings, and low-emission zones.

Our analysis underscores the substantial potential of AM in MaaS/ITS to significantly contribute to urban sustainability and align with the diverse objectives of the SDGs. The comparative policy analysis reveals that enhancing awareness for sustainable and safe mobility, coupled with modal shifts towards active mobility and public transport (as shown in the results section of this chapter), stands as key cornerstones for ensuring the success of AM deployment in achieving sustainable development in cities as demonstrated in the cities targets to promote active mobilities and public transport shown in the results of this



chapter.

Moreover, our findings advocate for clear, well-defined policy conditions supported by comprehensive qualitative impact analysis and externalities calculations.

In conclusion, the comprehensive assessment conducted highlights four pivotal recommendations essential for steering urban centres toward sustainable and smart mobility solutions. These recommendations encompass various facets, beginning with the imperative need to enhance urban infrastructure for accommodating emerging smart mobility solutions, emphasizing the significance of stakeholder engagement in sustainable transport planning. Furthermore, the focus on equitable mobility access and the development of a robust digital infrastructure strategy for diverse transportation options were identified as critical pillars for fostering inclusive, efficient, and environmentally conscious urban mobility. Implementing these recommendations not only addresses present challenges but also sets a strong foundation for resilient and future-ready urban transport systems. Additionally, exploring governance aspects and aligning local regulations with regional and European policies could further illuminate the complex dynamics of sustainable cities.

To conclude, our study positions AM in MaaS/ITS as a transformative force of smart mobility that, when strategically aligned with city policies and global sustainability objectives, has the potential to drive sustainable urban development in line with the SDGs framework. The analysis focuses on urban areas. However, the deployment of the SAV would be more beneficial for suburban and rural areas due to the lack of adequate public transport and longer distances travelled. This is addressed further in the following chapter.

The fifth chapter delved into how the chosen scenario, evaluated through an externalities assessment, contributes to fostering sustainable urban development. The adoption of AM in MaaS/ITS represents a proactive strategy that cities can leverage to attain their sustainability goals and, ultimately, meet their targets for sustainable development. An analysis of a scenario similar to the AM in MaaS/ITS in suburban areas is included in Appendix C.

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## 6 DISCUSSION

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The thesis centres on reshaping urban transportation through smart mobility solutions, notably AM, for sustainable urban development in European cities. Essential to this exploration is the often-underestimated understanding of externalities linked to these innovations. This chapter synthesises discussions from various sections, addressing the deployment, impacts, and calculated externalities of AM. It aims to unravel the intricate relationship between externalities, deployment strategies, and their role in sustainable urban development. Transitioning, it explores pivotal urban planning strategies and extends focus to SAV (robotaxis and AM) deployment beyond Europe, including the potential benefits in suburban and rural areas.

### 6.1 EXPLORING DEPLOYMENT SCENARIOS AND EXTERNALITIES OF SMART AUTOMATED VEHICLES

In the chapter "Potential impacts of future deployment scenarios of SAV", the deliberative process engaged experts to envision deploying innovative smart mobility technologies, notably AM, within urban environments. This research focused on the contextual circumstances surrounding deployment scenarios, examining a spectrum of likely scenarios, ranging from reducing car modal shares to the prevalent concept of robotaxis providing customised passenger services. A critical aspect was evaluating the relationship between these scenarios and public transport, analysing AM as a replacement for conventional buses and as a complement bridging first and last-mile trips, shedding light on safety, economic, environmental, land use, and societal impacts. Results strongly advocate reducing car modal shares as the most beneficial approach. Robotaxis present potential adverse effects and induce demand, posing challenges. The preferred scenario, identified through initial qualitative assessments, emerged as AM in MaaS/ITS, a pragmatic choice aligning with European cities' future. It is predicted to substantially benefit the transport system, public transport, and society. It is forecasted to reduce emissions, noise, accidents, and parking needs, as shown in the externalities calculations in Chapter 4, while fostering economic growth and accessibility, facilitating modal shifts toward public transport, especially for long-distance rail trips, as shown in chapter 3 of the qualitative impacts analysis.

Validating this choice involved a deep dive into externalities, which is crucial for



quantitative impact assessment and providing a comprehensible framework for policymakers and stakeholders. While extensive research on transport externalities exists, its application to SAV remains limited, particularly in the case of SAV like AM (Meshulam et al., 2024). The Chapter: "Deploying Shared Automated Vehicles for Sustainable Mobility: External Costs Assessment in Lyon and Geneva" in the thesis utilised CE Delft's EU external costs of road passenger transport as a foundation, augmented by a survey within the AVENUE project and literature review to estimate potential modal shifts across envisioned scenarios. Case studies of Lyon and Geneva, coupled with LCA evaluations from AVENUE, grounded the analysis, fortifying its evidential base. Notably, it aligned with expert opinions and systematic literature reviews while dispelling uncertainties, especially regarding congestion and environmental emissions. Demonstrating the AM in MaaS/ITS's prowess, the analysis showcases significant reductions in external costs, emphasising its viability over alternatives. As shown in Chapter 4, in Geneva, according to the analysis of external costs, the integration of SAV within MaaS is expected to yield a 24% decline in noise-related impacts, a 17% alleviation in traffic congestion, a 35% decrease in overall emissions, and a 19% reduction in accidents.

Furthermore, an estimated shift in transportation modes is foreseen, with a projected 6.4% decrease in car usage, a 1.7% reduction in biking, and a 3% decrease in walking. Conversely, in Lyon-Villeurbanne, the analysis anticipates reductions in various external impacts, notably a 27% decrease in accidents, a 19% alleviation in congestion, and a substantial 43% reduction in emissions. Nonetheless, challenges persist in persuading complete car relinquishment, highlighting the convenience of seamless first and last-mile services.

Drawing from scenario planning, externalities calculations, systemic literature review, and survey analysis, the policy analysis recommends integrating SAV. This strategy aims to address negative externalities while capitalising on potential positive impacts, detailed in the chapter titled "Leveraging Sustainable Urban Development through AM in MaaS/ITS: A Comparative Policy Analysis of Geneva and Lyon". It aligns with Lyon and Geneva's climate policies within the SDGs framework, specifically targeting SDG 11 and 13, aligning policies with the potential impact levels defined in scenario planning and SDG objectives. Geneva prioritised environmental goals, focusing on cutting emissions and noise pollution. Meanwhile, Lyon took a more social approach to alter mobility habits and promote shifts away from cars towards active mobility and public transport. Our research highlighted gaps in city roadmaps for sustainable urban development, notably the

oversight of crucial digital tools like AI, MaaS, and ITS, which are pivotal for sustainability agendas. This oversight raises concerns, potentially resulting in unregulated robotaxi introductions and insufficient infrastructure. Additionally, there was a lack of emphasis on engaging stakeholders and citizens in sustainable urban mobility planning. Although Lyon showed initiatives to incentivise private businesses towards sustainable mobility, citizen engagement in the decision-making process remained limited.

Our recommendations stress the importance of adapting infrastructure to accommodate these innovations. We underscore the need for a contextual roadmap to maximise benefits from AM's chosen deployment strategy in MaaS/ITS. Engaging citizens and key stakeholders is vital to avoid adopting 'winner takes all' or 'laissez-faire' models, ensuring a more inclusive and practical approach to sustainable urban mobility, as shown in Chapter 5's policy recommendations. It is also important to focus on increasing the modal shares of active mobility and public transport by deploying the AM in MaaS/ITS as a pull approach within a broader Transit-oriented development strategy by ensuring that the AM in MaaS/ITS connects to mobility hubs in a mixed land use strategy where passengers could walk or bike for shorter distances. The assumption made in Chapter 4 modal shifts is that the AM in MaaS/ITS would absorb long walking distances of more than 500 m to train/metro stations. Therefore, AM in MaaS/ITS would provide a mobility gap solution rather than an alternative for all active mobility modal shares (Gebhardt et al., 2016; Giansoldati et al., 2020; Paydar et al., 2020). Integrating mobility within sustainable urban development emerges as imperative, leveraging innovations to propel sustainable practices within transportation systems and cities, ensuring positive impacts and reduced external costs while potentially generating positive externalities.

## **6.2 LIMITATIONS**

Some of the research within this thesis was conducted as part of the H2020 AVENUE project, contributing to a comprehensive EU initiative that links interdisciplinary studies with various related research endeavours. This involved diverse investigations, including surveys on social acceptance of AM in Lyon, Geneva, Luxembourg, and Copenhagen (Korbee et al., 2023), LCA evaluations of AM and robotaxis (Huber et al., 2019), sustainability indicators (Nemoto et al., 2021), and the exploration of business models for AM deployment (Fournier et al., 2023). Additionally, it granted access to essential data, experts, and stakeholders, forming foundational elements for this thesis. Further limitations specific to this analysis are detailed in chapters 3, 4, and 5. In this section, we

provide a brief reintroduction to these constraints.

### Scenario Planning and its Impact on Transport Planning

Predicting outcomes in complex systems, as noted by Slaughter (2018), poses significant challenges. Acknowledging several limitations, the hybrid meeting formats during the pandemic may have hindered the exchange of ideas. Focusing solely on uncertainties might overlook potential outcomes beyond the business model and AM integration in the transport system. Relying on the Systemic Literature Review from the AVENUE literature database that was collected throughout the project's four years may introduce bias.

### Externalities Assessment

Monetising congestion and accidents encounter challenges due to reliance on large-scale EU-level studies for national marginal costs as shown in the CE Delft (2019a) study. Estimating accidents might be overly optimistic, considering that AV technology is still being tested, and the potential shift in accident rates with larger-scale deployment alongside human drivers remains uncertain. Downscaling inputs like speed-flow functions, demand curves, and Value-of-Time (VOT) poses a challenge for smaller cities, necessitating a sensitivity analysis for more robust results. Using national-level costs in city-level assessments might limit accuracy, particularly concerning air pollution. Future research should consider positive externalities from transport data. Understanding induced traffic, increased vehicle demand, and behavioural changes is vital to fully comprehend AM's effects and potential rebound effects. A simulation considering increases in Vkm could capture the full spectrum of SAV external costs (Fagnant & Kockelman, 2018).

### Policy Analysis

The study's policy analysis could have integrated evaluation mechanisms and indicators implemented by Geneva and Lyon-Villeurbanne to track the success of mobility initiatives. Relying heavily on policies from the cities' climate strategy, it lacked insights from policymakers' interviews and regulatory documents. Analysing Lyon-Villeurbanne as one entity limited the nuanced insights that could have been observed from separately analysing the neighbouring cities. Furthermore, a deeper exploration of regional and national policies would have provided more evident governance mechanisms for local

authorities' context-based implementation.

## **6.3 FUTURE RESEARCH**

### **6.3.1 AM in Transit-Oriented Development**

The introduction of AM in MaaS/ITS requires robust urban planning strategies. Transit-oriented development (TOD) is an urban planning approach that emphasises the creation of communities and infrastructure designed to maximise access to public transportation (Liang et al., 2020). It integrates land-use and transport planning to enhance sustainable transit by concentrating urban growth around transit hubs and optimising transport services. Critical aspects encompass improving transit access, densifying station areas, and diversifying functional zones for successful TOD projects (Ibraeva et al., 2020). According to Knowles et al. (2020), the principles of TOD include Density, Diversity, Design, Distance, Destination, and Demand management. Density highlights compact urban living, Diversity indicates mixed land use, and Design emphasises pedestrian-friendly layouts (Calthorpe, 1993). Distance underscores proximity to mobility hubs, Destination emphasises accessibility and walking distance, while Demand management. Transport demand management encompasses enhancing the transport offer, financial incentives, land use management, and implementation programs (VTPI, 2013).

Urban infrastructure plays a vital role in shaping sustainable cities. The integration of AM within TOD can significantly improve urban sustainability. Diverse preferences for AM and TOD have emerged, showing a preference for transit-oriented communities when AM improve efficiency. This integration could extend the reach of transit stations and increase land availability for other purposes (Lu et al., 2017). A collaborative USA-Sweden project, "TOD, Mobility Hubs, and SAV," aims to reduce car dependency in the suburbs. Merging urban design, TOD, mobility hubs, and SAV transforms public spaces dynamically. Using electric AM, it plans to simulate accessibility impacts, evaluate inclusive mobility, and create an urban design handbook. This guide targets the effective integration of shared mobility systems at city transport hubs. (VINNOVA, 2023).

The integration of AM in MaaS/ITS within TOD harbours significant potential for urban mobility and sustainability. It amplifies connectivity to mobility hubs, effectively addressing first and last-mile challenges. This comprehensive approach enhances the MaaS system, retrofits public transport, and promotes active mobility, presenting a promising solution to reduce congestion, emissions, and reliance on personal vehicles.

### 6.3.2 Robotaxis vs Automated Minibuses: City Impacts and Global Perspectives

AM offer on-demand, door-to-door, or first/last mile services, facilitating ride-sharing for up to 15 passengers, essentially operating as micro transit. Conversely, robotaxis primarily cater to individual transportation needs, providing on-demand and door-to-door services. Robotaxis have garnered more research attention than automated minibuses (Fagnant and Kockelman, 2015a; Narayanan et al., 2020b).

The preference between these options varies across regions. Factors such as urban density, innovation approaches, and public acceptance play a pivotal role in shaping these preferences (Fagnant and Kockelman, 2015a). Studies show a higher acceptance of AM in European cities. For instance, in France, a study reveals a higher preference (59%) for AM over robotaxis (41%) (Vedecom, 2019). Meanwhile, car-oriented cities in the USA lean towards robotaxis (Cervero, 2017). In fact, Babones et al. (2019) highlight Americans' reluctance to use minibuses, making robotaxis a more viable choice in this context. In the US, public transit is often linked with serving lower-income groups, whereas in Europe, it is more widely accepted. Exploiting US advantages in regions lacking public transit could be valuable, especially in cities designed around roads. AM in MaaS/ITS might make more sense in US cities, while in Europe, existing public transit could limit its potential areas (Institute for Transportation and Development Policy, 2019; Basu and Ferreira, 2021).

The International Transport Forum suggests that while microtransit services are suitable for medium-sized cities, robotaxis may significantly replace individual motorised vehicles in metropolitan areas (International Transport Forum, 2015; Cervero, 2017). Therefore, robotaxis may be more operationally feasible and beneficial in American and Chinese cities.

Robotaxis, offering personalised and flexible services compared to other SAV, adapts to personal travel needs. Moreover, tech companies favour robotaxis due to their high profit potential in private-operated fleets, coupled with fewer regulations in the USA and China compared to the stricter EU policies (Schneider, 2023). Without adequate policies, private companies like Waymo could wield Intellectual Monopoly Capitalism by locking in exclusive technology rights to robotaxis and its data. This control, augmented by network effects, could generate 'information rents' (positive externalities due to exclusive access to extensive user data)—enhancing their closed ecosystem and dominance in the robotaxi industry. This dominance becomes more prominent considering the potentially lower

operational costs of robotaxis (improved vehicle utilization and absence of drivers), coupled with the anticipated high user acceptance. However, it is crucial to note that while these advantages exist, they might come with higher external costs (Niles, 2019; Salladarre et al., 2021). Avoiding such a scenario is crucial to ensure fair market access and prevent monopolistic control in emerging transportation sectors (Durand and Milberg, 2020)

In the American context, San Francisco is currently testing robotaxis, notably run by Waymo, without comprehensive regulation. Niles (2019) emphasises the impact of government incentives on the behaviour of commercial fleet operators. Operators often prioritise sales and market share in a less regulated market, potentially compromising accessibility. Policies using incentives strive to balance achieving high ridership and ensuring equitable access across various regions and social groups (Fournier et al., 2023). While AM is often seen as ideal for first or last-mile travel, robotaxis are perceived to offer a broader range of destinations, albeit at a higher cost for users (Salladarre et al., 2021). This convenience may increase congestion and compromise public transport, potentially impacting affordability and accessibility (Bhumbl and Samuel, 2023). Ride-hailing services in the US, including robotaxis, have been linked to reduced public transport use and increased car ownership, a trend similarly observed with providers like Uber and Lyft. This competition between private services and public transit could reshape traditional transportation models, prompting shifts in public transport strategies to adapt to evolving market dynamics (Niles, 2019). Robotaxis, likely privately operated and in competition with public transport, differ from AM in MaaS, which complements public transport by filling mobility gaps and requires effective transport policies to avoid eroding public transport services due to the convenience and affordability of on-demand services (Krueger et al. 2016)

In China, rapid urbanisation increases the need to meet transport needs quickly and efficiently. According to the OECD and European Commission (2020), China had 41% in 2020 of its population living in cities, as opposed to only 29% in 1975. China is even predicted to deliver automated vehicle technology faster than other regions (Pizzuto et al., 2019; Zhou and Xu, 2023). Baidu, a Chinese tech company, has already commenced robotaxi testing in ten cities, alongside trials of AM models (Xu and Fan, 2019; CBS, 2022). The high acceptance of SAV raises hopes for their successful integration into transportation systems. However, concerns raised by Lim and Taihagh (2018a) regarding integrating AV in transportation services point to surveillance and cybersecurity risks. These concerns are particularly relevant given China's proposed 'Social Credit System,'

raising worries about threats to individual freedoms and democratic processes (Creemers, 2018). China has responded by amending personal data privacy and cybersecurity laws (Ramsey and Wootliff, 2017).

This emphasises the urgent need for regional governance mechanisms ensuring that SAV deployment prioritises passenger service, enhances transportation systems, and contributes to sustainable urban development. Preventing misuse of profit motives or surveillance is crucial to maintaining citizen engagement and upholding democratic values while balancing sustainability goals.

### 6.3.3 Prospects of AM in Suburban and Rural Contexts

AM in urban areas promises positive impacts, yet its potential could extend far beyond cities, especially due to inefficient public transport (Velaga et al., 2012). Suburban and rural areas, often overlooked in discussions, hold substantial promise for AM deployment. With their unique blend of urban convenience and rural landscapes, the suburbs present opportunities for AM to improve transportation. Additionally, rural regions, marked by distinct challenges and sparse infrastructure, stand to benefit significantly from AM's safety and mobility advancements. In general,

the effectiveness of similar services in enhancing accessibility to suburban and rural areas remains uncertain and requires thorough analysis to ensure its potential impact is accurately understood and addressed (Castex, 2017).

This discussion explores how AM could reshape suburban and rural landscapes, highlighting their potential beyond urban boundaries. Suburban areas, classified by the OECD (2017) as having a lower density than cities but higher than rural areas, often face challenges connecting with urban centres due to higher rates of motorisation and longer-distance commuting (Wappelhorst, 2021). Suburban areas also connect to the Functional Urban Area, which includes an urban area and the commuter zone that surrounds it, which is another important factor. These regions consist of densely populated areas and adjacent commuter zones that are less populated with a strong labour market connection to the city (Dijkstrai et al., 2019)

Our analysis, mirroring the AM in MaaS/ITS scenario (included in Appendix C), highlights substantial positive impacts in suburban areas around Geneva and Lyon, particularly in reducing emissions, noise, congestion, and accidents. SAV are expected to profoundly

influence suburban regions, reshaping the perception of travel time, alleviating congestion, enhancing safety measures, transforming parking requirements, and influencing urban design (Swan, 2019). Research indicates that fulfilling travel demands through SAV in suburban areas could necessitate up to 4 vehicles per 1000 residents, leading to a considerable reduction in car ownership rates (Gandomani et al., 2022).

Transitioning from suburban to rural areas exposes a distinct landscape in transportation and mobility. Rural regions, delineated by the OECD (2017) as having populations of fewer than 15,000 and lower population density (less than 150 residents per km<sup>2</sup>), present unique challenges in the realm of transportation (Eurostat, 2023). Here, the advantages of SAV become more crucial as safety and mobility benefits take precedence over urban settings. Unlike urban environments, rural areas frequently lack accessible and alternative transportation options. This scarcity often makes walking or biking unfeasible for essential journeys (Ek et al., 2021). In these rural landscapes, access to destinations and alternative transportation is often limited, rendering walking or biking impractical for necessary trips. Despite potential efficiency gains being less pronounced in rural settings, the potential impact on safety and mobility for rural residents could be significant (Dowds et al., 2020). Projects such as ULTIMO seek to test the deployment of AM in MaaS/ITS in rural areas (ULTIMO, 2023).

Rural areas may face constraints in ride-sharing due to lower density, potentially resulting in limited ride-sharers and a higher potential for empty rides (Bischoff et al., 2017). Elevated rates of fatal accidents, dependence on ICEV, and a more significant proportion of older residents and individuals with disabilities underscore the need for tailored, door-to-door, on-demand solutions to ensure efficiency and accessibility in rural transportation (Mörner, 2019; Dowds et al., 2020; Imhof et al., 2020). However, concerns regarding the feasibility of deploying SAV in rural areas persist due to uncertainties surrounding existing infrastructure's ability to support such technology (Vedecom, 2019; Salladarre et al., 2021).

Mörner (2019) model proposes ride-sharing services similar to AM as a feasible substitute for fixed-route public transport in rural areas, despite the relatively low current demand. This adaptable service could increase ridership without overshadowing existing public transport services (Stocker and Shaheen, 2017). Nonetheless, implementing AM in rural environments necessitates nuanced policy frameworks recognising the unique needs, challenges, and infrastructure differences from urban settings. Factors like road conditions, population density, transportation demands, and accessibility requirements in



rural regions demand a thoughtful and specific policy approach for SAV deployment (Imhof et al., 2020).

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## 7 CONCLUSION

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Utilising Methodological Triangulation, the research combined scenario planning, systemic literature review, and externalities calculations to explore deploying smart mobility solutions, specifically automated electric minibuses, to achieve sustainable urban development in European cities. This approach, merging both quantitative and qualitative methodologies, aimed to comprehensively understand the implications of deploying Shared Automated Vehicles on transportation systems and urban landscapes. This holistic analysis led to the selection of the most realistic and advantageous scenario: AM in MaaS/ITS. Through a thorough systemic literature review and a deliberative process centred on context-based deployment external cost calculations, this scenario emerged as highly impactful across various dimensions—social, environmental, land use, safety, and economic.

This thesis serves as an extensive investigation into the intricate dynamics of urban mobility externalities and the potential ramifications arising from the advent of SAV, particularly AM. It aims to answer the question: "How can externalities help determine ways to deploy smart mobility like electric Shared Automated Vehicles to achieve sustainable urban development in European cities?". Thus, the thesis investigates various scenarios of SAV deployment, leveraging data from the H2020 project AVENUE, which focused on introducing AM in European cities' public transport systems. It emphasises the pivotal role of stakeholder engagement and expert insights in navigating the integration of smart mobility solutions in urban settings. It conducts detailed scenario analyses for SAV introduction, presenting deployment of SAV as cars, as buses, as robotaxis, and as AM in MaaS/ ITS and their economic, environmental, social, land use, and safety impacts. This research aims to answer the following questions: "How could shared automated vehicles be deployed, and what are the potential impacts on sustainable cities?"

Through a Systematic Literature Review, the thesis comprehensively assessed the potential impacts of these deployment scenarios. For instance, in Scenario 1, replacing buses with SAV initially alleviates congestion, albeit potentially increasing traffic later. Moreover, transitioning to SAV could yield economic benefits by reducing operational costs due to no human drivers and efficient V2X technologies, though altering travel behaviour might affect short-distance travel patterns. In Scenario 2, deploying SAV under private operators could decrease emissions and energy consumption, offering economic

advantages and potentially reducing car ownership. However, it may prompt a shift from other transportation modes to SAV, influencing traffic and environmental outcomes. Considering Scenario 3, robotaxis present promising reductions in emissions and energy use. Yet, competition with public transport might negatively impact the environment, increase external costs congestion, affect traditional taxi services, and raise job displacement concerns. Ensuring equitable access becomes crucial, and challenges in mixed traffic with human drivers pose safety considerations. Lastly, Scenario 4 introduces SAV in MaaS, projecting positive impacts on air pollution reduction, job creation, and enhanced vehicle efficiency. However, its potential to replace other transport modes raises concerns about accessibility and may alter land use by reducing private parking needs. Throughout these scenarios, the thesis underscores the intricate trade-offs and different impacts tied to the deployment of SAV in diverse urban settings. It accentuates the challenges and opportunities inherent in various SAV models, particularly championing the integration of AM in MaaS/ITS as a pragmatic, urban-centric solution.

To corroborate the viability of these scenarios, an in-depth analysis of externalities was conducted, leveraging large-scale surveys and literature reviews to estimate potential modal shifts resulting from the four deployment scenarios. This analysis sought to answer the question: "How should the externalities of shared electric vehicles and their impact on cities be calculated?" Each scenario underwent a thorough examination of external costs in road transport alongside baseline scenarios, using Lyon-Villeurbanne and Geneva as case studies aligned with the AVENUE project. This comprehensive approach enabled the thesis to outline changes in total external costs attributed to SAV deployment. It explores different deployment scenarios and assesses the externalities of SAV, such as emissions, noise, accidents, and congestion. The research addresses the research gap related to externalities associated with them.

The analysis supported the previous qualitative impact assessment, underscoring the potential of AM in MaaS/ITS as a promising strategy for introducing SAV in urban landscapes. These strategic integrations supported by SUMP and TOD ideally not only support public transport but also address critical concerns regarding noise, congestion, greenhouse gas emissions, and air pollution.

The comprehensive assessment of policies conducted highlights four pivotal recommendations essential for steering urban centres toward sustainable and smart mobility solutions by using the deployment of AM in MaaS/ITS in Lyon Villeurbanne, and

Geneva. This research addresses the question: "What are the recommendations for SAV deployment in cities?"

These recommendations cover a range of aspects related to improving urban infrastructure to accommodate emerging smart mobility solutions. They emphasise the significance of engaging stakeholders in sustainable transport planning and focus on providing equitable access to mobility options. Developing a robust digital infrastructure strategy for diverse transportation options is also critical for fostering inclusive, efficient, and environmentally conscious urban mobility. Implementing these recommendations not only addresses present challenges but also lays a strong foundation for resilient and future-ready urban transport systems.

Furthermore, exploring governance aspects and aligning local regulations with regional and European policies could further illuminate the complex dynamics of sustainable cities. Thus, it addresses the question of what recommendations there are for deploying SAV in cities. The outcome is a better understanding of how SAV deployment aligns with policies related to sustainable urban development through case studies and policy recommendations for introducing SAV in urban public transport automation, with a focus on aligning with SDG.

The thesis addresses the main research question. It achieves this by leveraging external costs to select an optimal deployment strategy for SAV: AM in MaaS/ITS. Additionally, it investigates how this strategy aligns with the sustainable urban development goals and SDGs agendas of European cities and then proposes policy recommendations to support the deployment to reach these goals.

This thesis conducts a thorough evaluation of SAV in the context of sustainable urban development. It addresses gaps in existing research that often only focuses on specific impacts or technological aspects of AV deployment. By using an interdisciplinary approach that combines qualitative and quantitative methodologies, it provides a comprehensive assessment across various scenarios. The study engages experts and stakeholders to anticipate implications at the city level and align with sustainable development goals. Notably, the thesis introduces a novel contribution by intricately assessing SAV externalities, shedding light on specific marginal costs exclusive to SAV, thus bridging a critical gap in comprehending the total external costs associated with different vehicle types and impact categories.



In conclusion, this thesis highlights the transformative potential of AM in MaaS/ITS as a tool for propelling sustainable urban development. Its synchronization with city policies and global sustainability targets underscores its pivotal role in cultivating resilient and environmentally conscious urban ecosystems. Further research diversifying its purview to encompass heterogeneous settings promises invaluable insights into fortifying transportation networks and furthering sustainable urban development aligned with the SDGs framework.

The findings consolidate a compelling narrative for adopting AM in MaaS/ITS as a transformative force poised to reshape urban mobility paradigms, foster sustainable urban development, and propel cities towards a more inclusive, efficient, and environmentally conscious future. As the deployment of SAV in its different forms continues to evolve, future research endeavours should extend beyond European cities, delving into suburban and rural environments alongside diverse urban landscapes such as American cities, especially for AM, to comprehensively examine user acceptance and regulatory implications, fostering a deeper understanding beyond the European context.

## APPENDICES

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## APPENDIX A

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SAE	Automation level	Description
SAE 0	No Automation	The human driver performs all tasks
SAE 1	Driver Assistance	Automation assists with specific tasks. The human driver remains in control.
SAE 2	Partial Automation	Automation oversees both steering and acceleration, necessitating the human driver's engagement to monitor the surroundings.
SAE 3	Conditional Automation	Automation can handle the majority of driving tasks, requiring the human driver to be prepared for system-initiated intervention.
SAE 4	High Automation	The system autonomously manages all driving tasks in specific conditions, yet a human driver can intervene if necessary.
SAE 5	Full Automation	The system performs all driving tasks in all conditions without requiring human intervention.

## APPENDIX B

### Appendix B.1: Production calculations

The marginal cost of production (€ – cent/pkm)  $\equiv$   $\frac{\text{total emissions of CO}_2\text{e during production (tCO}_2\text{e)}}{\text{expected lifetime mileage (km)} \times \text{the average occupancy}} \times 100 \times \text{central short – run value (€/tCO}_2\text{e)}$

The central short-run climate avoidance value (up to 2030) is 100 €/tCO<sub>2</sub>e. Also, the average occupancy factors are based on van Essen et al. (2019). The total emissions and expected lifetime mileage values for ICEV and Electric Vehicles (EV) are extracted from the ecoinvent database (ecoinvent, 2020), a life cycle inventory database and those for the bus were taken from Chester et Horvath (2009); see Table 13.

Table 13. Data Used to Determine the Production Marginal Cost Estimation

Vehicle	Bus	ICEV	AM	robotaxi
Lifetime mileage (km)	402 336	200 000	140 000	200 000
Total emissions (tCO <sub>2</sub> e)	140.00	12.11*	21.35	15.43
occupancy	19.00	1.60	5.00	1.20
Marginal cost in €-cent/pkm	0.18	0.38	0.30	0.64

### Appendix B.2: Lyon Villeurbanne

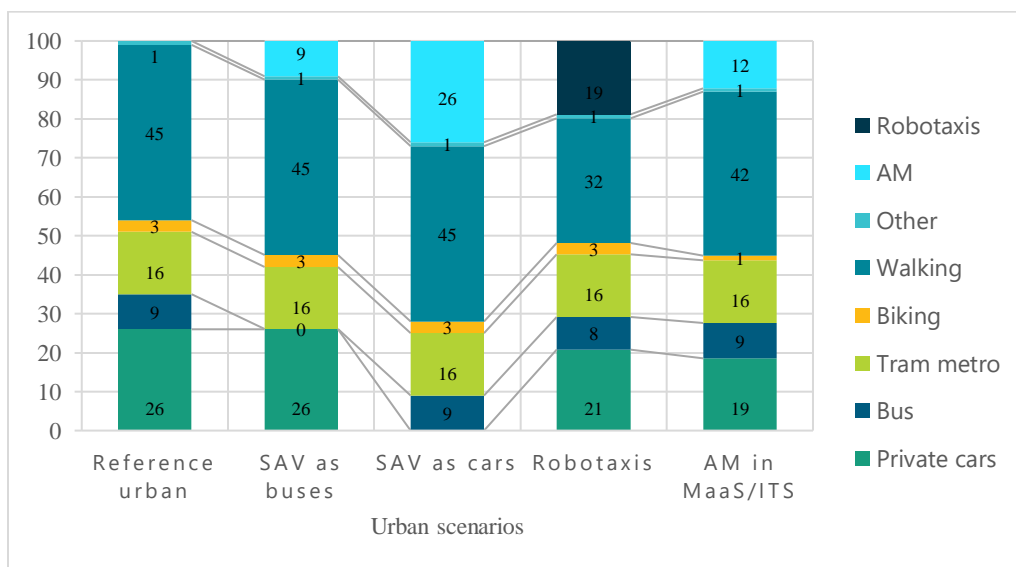


Figure 34: Changes in modal shares in % between the urban scenarios and the reference scenarios in Lyon

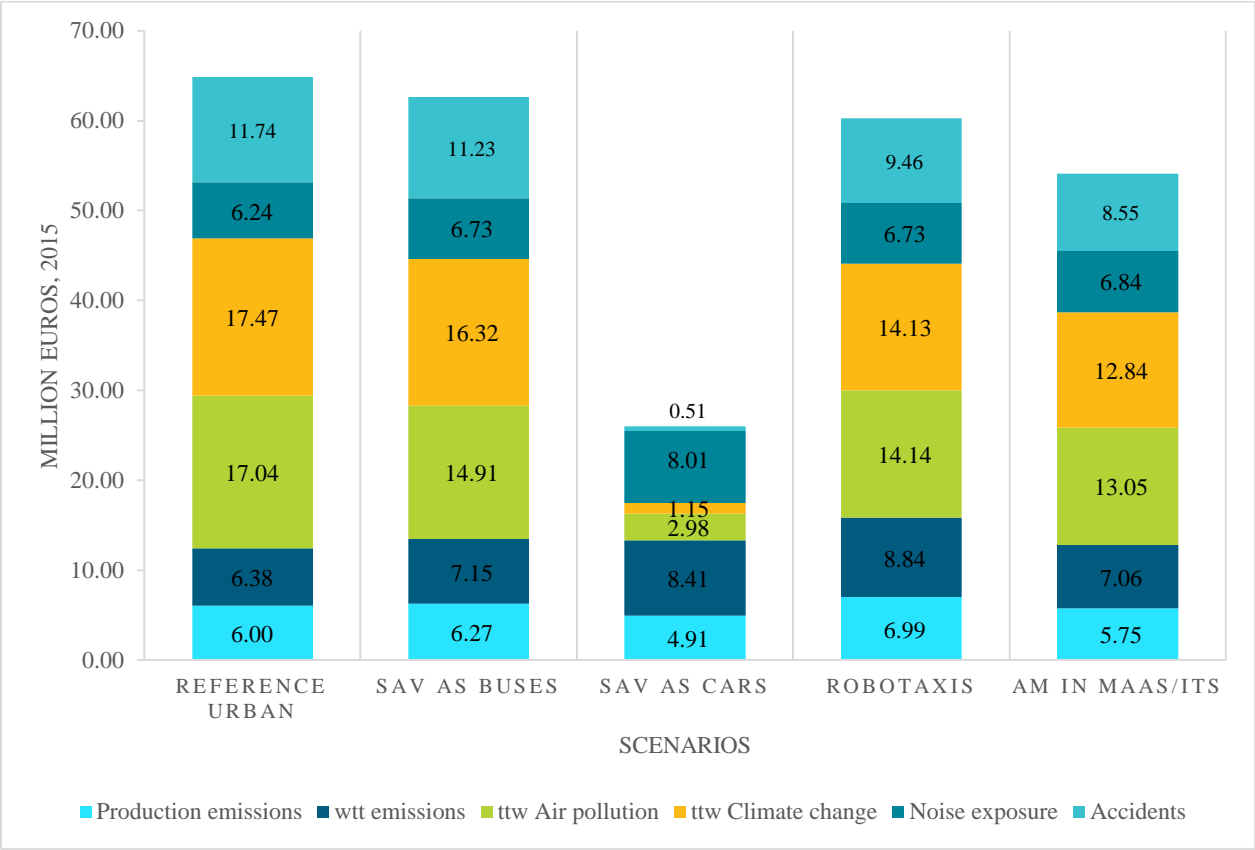


Figure 35: Changes in externalities in the urban scenarios compared to the base scenario, excluding congestion in Lyon

## APPENDIX C

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### Scenario 4: AM in Maas/ITS in suburban areas

#### Background

AM are deployed to support public transportation in low-density areas such as villages and suburban areas where the PT offer is limited. The service provided by the AM is seamless intermodal trips. The policies enabling the expansion of the transportation network with AM are drafted to increase accessibility, reduce reliance on individual vehicles, and replace the low-occupancy bus routes.

#### Expected Impacts

AM deployment in suburban areas would positively affect traffic; the seamless services would improve road capacity, easing congestion, especially during peak hours. In general, waiting times are reduced by increasing the number of AM to serve the residents of these areas and compensate for the shortage of transport connections to long-distance PT. The scenario is expected to improve the efficiency and frequency of public road transport services. It reduces big-sized buses circulation when the travel demand could be met with smaller vehicles. Similarly to previous scenarios, more delays and uncertainty due to vehicle dispatching are expected.

Moreover, the AM deployment would lead to a reduction in car ownership and a slightly induced demand as more people would use the AM rather than walk or drive. Replacing low-demand bus routes would provide more efficient services that might increase the use of other public transport due to intermodal trips. The environmental impact is positive: less noise, emissions, and pollution. Improving the public transport network outside densely populated areas would make them more attractive to inhabitants. Thus, it would increase urban sprawl and attract more people to these areas away from city centres. The effects on the infrastructure are the reduction in road space and the development of more mobility hubs to accommodate seamless and intermodal trips.

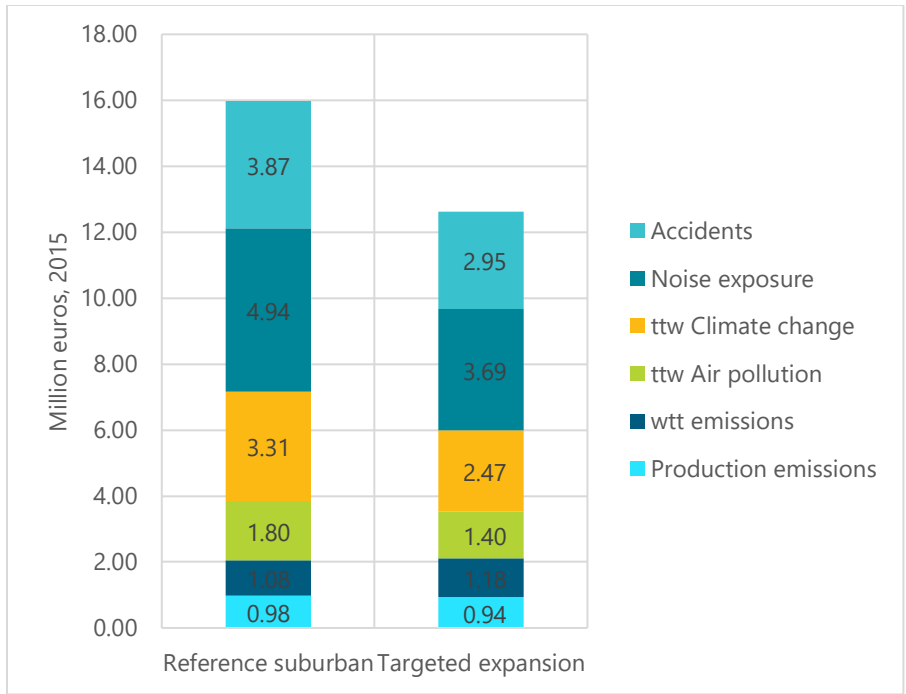


Figure 36: Changes in external costs in the Geneva suburban scenario

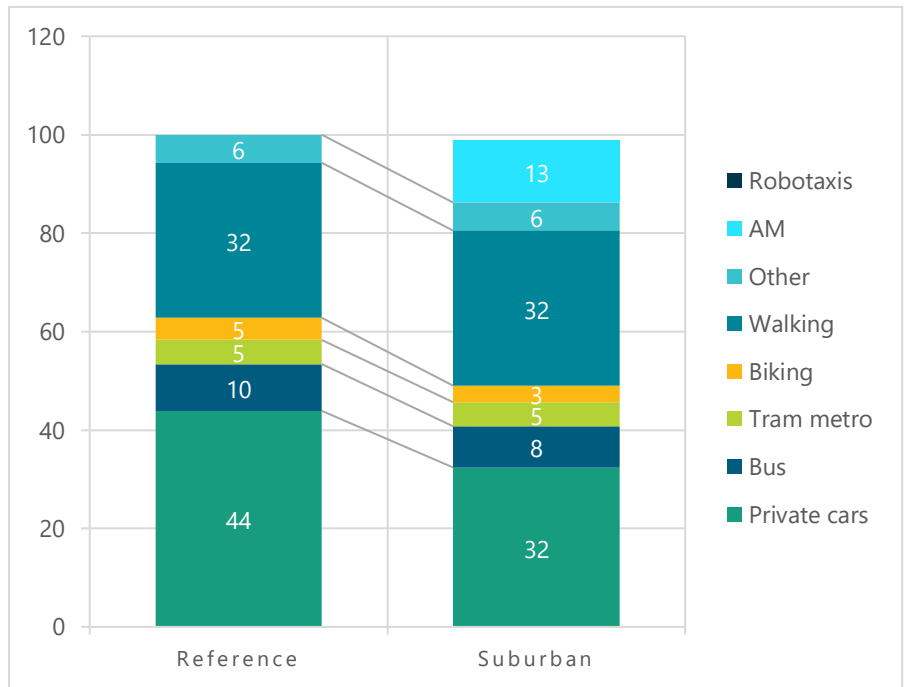


Figure 37: Changes in modal shares in the Geneva-suburban scenario



Figure 38: Changes In Modal Shares In Lyon-suburban Scenario

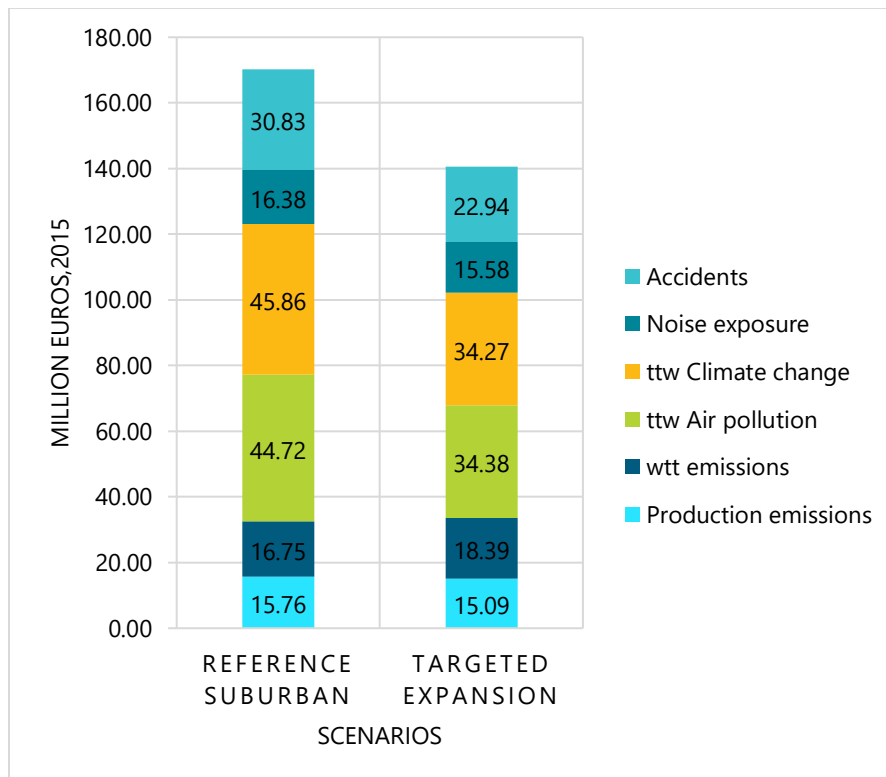


Figure 39: Changes In External Costs In Lyon Suburban Scenarios





## APPENDIX D

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### Appendix D.1

Table 14: Document List For Policy Analysis

<u>Geneve</u>	
1	Energy and Climate Policy - City of Geneva (2009-2013)
2	Climat Strategy - 2022
3	Implementation of Speed Strategy in Line with OPB Standards - Regulatory Daytime Speeds
4	Climate and Environmental Issues
5	Energy and Climate Policy Action Plan (2014-2018)
6	The City Adapts and Reduces Road Noise
7	Climate and Environment Action Programme - Department of Culture and Digital Transition
8	Administrative Council of the City of Geneva Legislature Program 2020-2025
9	Municipal Commitments and Actions in Favor of Sustainable Development
10	Climate Strategy for the City of Geneva - Immediate Actions 2021
11	Municipal Plan Sustainable Development of the City Center - 2020
<u>Lyon and Villeurbanne</u>	
1	Lyon in Transition
2	Climat Plan - Air Quality, Energy-Progress Report 2021-Low Carbon Industry
3	Territorial Climate, Air, and Energy Plan 2030
4	Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility
5	The 30 km/h city: everyone benefits
6	Reduce air pollution with the LEZ
7	Lyon à vélo



## Appendix D.2

Table 15: Analysis of policy documents

Policy name (official)	Policy description				Policy description	SDG
	Responsible institution(s)	Main policy objective	Secondary	Type of policy instrument		
ENERGY AND CLIMATE POLICY ACTION PLAN action 19 2014 - 2018	City of Geneva	Economic	service offer, social: modal shift, economic	Stakeholder engagement Transport offer Promotional/awareness campaign	Target: <b>Improve the level of service</b> offered as part of the transport package, in order to encourage employees to <b>use more environmentally-friendly means of transport</b> when travelling on business  Measure: Redefine project management. Identify the key players. Redefine the tasks and services within the transport package. <b>Promote the Transport Package</b> within departments. <b>Promote the use of the soft mobility</b> offered to employees.	SDG 11 SDG 9 SDG 13
Climat strategy_ Axe 3:Urban mobility- Goal 15	City of Geneva	Environmental	emissions	Transport offer Urban planning	Target: Establish an ambitious mobility plan for the municipal administration ( <b>zero direct emissions</b> by 2030) Action: Develop an exemplary administrative mobility plan	SDG 3 SDG 11 SDG 13
Implementation of speed strategy in line with OPB standards - Regulatory daytime speeds	City of Geneva	Environmental	noise	Speed limits	Target: reduce noise pollution  Measure: <b>speed reduction</b> from 50km/h to 30km/h reduces <b>noise pollution</b> by 3dB(A), which is equivalent to halving road <b>traffic</b> . Action:	SDG11
Climate and environmental issues: urgent measures and a paradigm shift	City of Geneva	Environmental	Emissions, Social: modal shift-car use/ownership	?	<b>limiting travel</b> for people and materials - <b>carbon offsetting</b> of travel	SDG 7 SDG 13
ENERGY AND CLIMATE POLICY ACTION PLAN action 17_2014 - 2018	City of Geneva	Environmental	Emissions, Social: modal shift-car use/ownership	Vehicle fleet management Promotional/awareness campaign	Target: implement a plan of <b>vehicle management</b> policy - <b>environmental aspects</b>  Measure: reduce the number of vehicles and encourage the development of active mobility	SDG 3
ENERGY AND CLIMATE POLICY ACTION PLAN- action 22_ 2014 - 2018	City of Geneva	Environmental	Noise	Transport offer	Target: A significant proportion of the population still lives in areas with excessive <b>noise</b> emissions.  Measure 1: An action plan has been drawn up by the SAM. The city must meet its legal obligations. Measure 2: Apply the <b>Federal Noise Abatement Ordinance</b> OPB strategy. Implement the Remediation Plan.	SDG 3

	Policy description					
THE CITY ADAPTS AND REDUCES ROAD NOISE	City of Geneva	Environmental	noise	Infrastructure	Target: reduce road noise Measure: Installation of a new sound-absorbing surface on the roadway	SDG 3
Climate and environment action programme Department of Culture and Digital Transition,	City of Geneva	Environmental	noise	Infrastructure Speed limits	Measure: introduce a general 30 km/h speed limit throughout the commune, in compliance with the Noise Abatement Ordinance, create 20 km/h and 30 km/h meeting zones and install noise-absorbing road surfaces,	SDG 3
Energy and climate policy of the City of Geneva action 22_ 2009 - 2013	City of Geneva	Environmental	emissions, noise, quality of life modal shift-car use/ownership, accessibility	Urban planning Low emission zones	Target: Reducing motorised traffic in the city in order to meet environmental protection objectives, particularly noise and air pollution. Improving the quality of life in the city by reducing the nuisance of motorised traffic while maintaining or even increasing accessibility. Implementation of the mobility strategy defined in the Municipal Master Plan  Measure 1: Reduce commuter parking. Measure 2: Reclaim public space. Measure 3: Cleaning up OPB and Opair. Measure 4: Enhance public spaces.	SDG 3 SDG 11
Energy and climate policy of the City of Geneva action_18 2009 - 2013	City of Geneva	Environmental	modal shift-active mobility car-ownership	Promotional/awareness campaign	Target: Reduce the climate impact of the Administration's transport. Clean up the municipal vehicle fleet. Action: Encouraging soft mobility for employees Training professional drivers	SDG 3 SDG 11 SDG 13
Energy and climate policy of the City of Geneva action_18 2009 - 2013	City of Geneva	Environmental	modal-shift-active mobility, car ownership, economic	Vehicle fleet management	Target: Drawing up a general strategy for cleaning up the fleet and a renewal strategy based on environmental criteria.  Measure 1: The refurbishment plan and renewal strategy must also strike a balance between the needs of services in terms of service and the resources to be deployed. It must define the pace of renewal in line with the economic effort required. The renewal strategy must aim to reduce the number of vehicles and encourage the development of soft mobility.	SDG 13
ENERGY AND CLIMATE POLICY ACTION PLAN action 21_ 2014 - 2018	City of Geneva	Land Use	Land use: mixed land use	Urban planning digital tools transport offer	Target: Create a strong central area around the future Eaux-Vives station (CEVA): Measure: create a multimodal platform connecting to the transport network and active mobility facilities, create a cultural facility	SDG 4 SDG 8 SDG 11
ENERGY AND CLIMATE POLICY ACTION PLAN- action 24_ 2014 - 2018	City of Geneva	Land Use	modal shift- active mobility	infrastructure	Target: Develop and increase biking facilities (parking and paths) Measure: achieve 155 km of bike lanes	SDG 11

	Policy description					
Energy and climate policy of the City of Geneva action 8 2009 - 2013	City of Geneva	Land Use	mixed land use modal shift_active mobility multimodal offer	Digital tools Urban planning	Target: increase urban density and mixed land use and transport hubs Measure: create a multimodal platform connected to soft mobility and simulate housing and commercial development	SDG 11
Energy and climate policy of the City of Geneva action_23 2009 - 2013	City of Geneva	Land Use	modal shift- active modes, accessibility	Infrastructure	Target: The Pedestrian Master Plan (PDCP) sets out the guidelines for a 15-year pedestrian mobility policy.  Measure 1 Creating new footpaths, squares and pedestrian crossings. Make existing facilities accessible to people with reduced mobility— particular emphasis on vulnerable groups (schoolchildren and the elderly).	SDG 11
Energy and climate policy of the City of Geneva 2009 - 2013	City of Geneva	Land Use	modal shift-active modes	Infrastructure	Target: Improving parking facilities for cyclists. Action: Drawing up a master plan for cycle parking (2009)	SDG 11
ENERGY AND CLIMATE POLICY ACTION PLAN action 23_ 2014 - 2018	City of Geneva	Safety	speed, economy	Infrastructure Speed limits	Target: pursue the development of 30 km/h zones in the city centre  Measure:1 Eliminate "black spots" for cyclists and pedestrians in developed areas. Measure 2: Implementation of 30 km/h zones in accordance with the Municipal Master Plan.	SDG 3 SDG 11
Energy and climate policy of the City of Geneva action 21_ 2009 - 2013	City of Geneva	Safety	environmental	Promotional/awareness campaign	Target: Ongoing training for professional drivers Action: Implement a training project on road safety and environmentally friendly driving. Train 100% of the administration's professional drivers by 2014 Comply with the OACP's legal obligation. Include training in the municipal administration's ongoing training catalogue. Update knowledge of road safety and eco-friendly driving.	SDG 3 SDG 11 SDG 13
Climat strategy_ Axe 3:Urban mobility- Goal 11	City of Geneva	Social	modal shift-car use/ownership	Urban planning Infrastructure	Target: aims to reduce the number of kilometres travelled by motorised individual transport by 50% by 2030. It places particular emphasis on shorter-distance journeys (under 10 km), for which a 75% reduction is targeted Trips.  Measure 1: Increase the amount of public space dedicated to active mobility, green spaces and recreational uses by converting, without compensation, half of all surface parking spaces in the hyper centre and one-third of spaces in residential areas Measure 2: Reduce roadway gauges	SDG 11
Climat strategy_ Axe 3:Urban mobility- Goal 12	City of Geneva	Social	modal shift-active mobility, safety	Infrastructure Urban planning	Target: Reinforce the modal shift towards active mobility to achieve one-fifth (20%) of distances travelled by 2030 Action1: Develop pedestrian zones and systematically create meeting	SDG 11

		Policy description				
Climat strategy_ Axe 3:Urban mobility- Goal 13					<p>zones around schools, cycles, colleges, universities, sports and health centres, in order to make and health centres, in order to make travel safer and calmer and to encourage modal shift</p> <p>Action 2: Expand the cycling network and make it safer by systematically eliminating black spots</p>	
	City of Geneva	Economic	modal shift-public transport, accessibility economic	Financial incentives Transport offer Speed limits	<p>Target: Develop an affordable, efficient and flexible public transport</p> <p>Measure 1: Reduce the price of the TPG annual season ticket for modest and through the creation of a "Grand compte territoire".</p> <p>Measure 2: Increase the commercial speed of the TPG by systematically giving public transport priority at junctions and by distancing certain stops.</p> <p>Measure 3: Develop an integrated mobility offer that complements public transport public transport by expanding car-sharing services, reinforcing home delivery services and subsidizing cab fares for the elderly.</p>	SDG 3 SDG 11
Climat strategy_ Axe 3:Urban mobility- Goal 14	City of Geneva	Environmental	Emissions	Infrastructure Transport offer Vehicle fleet management	<p>Target: Support the transition of the remaining individual motorised mobility to electromobility to reach 50% of the fleet</p> <p>Measure 1: Support the proportionate installation of recharging points in private underground parking lots on private land for residents and develop them in a way that is calibrated for professionals and people with reduced mobility.</p> <p>Measure 2: Renew the City of Geneva's fleet of vehicles and equipment by acquiring models with low-CO<sub>2</sub> propulsion, with the aim of achieving, by 2030, 50% of the fleet in electric form</p>	SDG 11 SDG 13
Administrative Council of the City of Geneva Legislature Program 2020-2025	City of Geneva	Social	Social: modal shift-active mobility, public transport	Vehicle fleet management Infrastructure Transport offer	<p>Target: Supporting and encouraging soft mobility and the use of public transport through the development of safe infrastructures</p> <p>Action: Reduce CO<sub>2</sub> emissions from the City of Geneva's vehicle fleet by generating fewer trips and making the use of non-polluting vehicles compulsory</p>	SDG 11 SDG 13
Municipal commitments and actions in favour of sustainable development	City of Geneva	Social	Active mobility	Infrastructure	Action: 123 additional kilometres of bike paths built between 2010 and 2017	SDG 11 SDG 13
Climate strategy for the City of Geneva - Immediate actions 2021 -	City of Geneva	Social	Active mobility,	Promotional/awareness campaign	"Cycling in all weathers" Poster campaign to promote cycling Continuation of cycle facilities COVID Examples of projects: Favon, Coulouvrenière, Terreau du temple, avenues du Mail and de Champel.	SDG 11 SDG 13

	Policy description					
ENERGY AND CLIMATE POLICY ACTION PLAN action 18_2014 - 2018	City of Geneva	Social	modal shift- active mobility	Promotional/awareness campaign	Target: implement procedure for bike and electric bike use and share Measure: appoint public representatives, promote the use of bikes, and provide training	SDG 4 SDG 11 SDG 13
ENERGY AND CLIMATE POLICY ACTION PLAN action 25_2014 - 2018	City of Geneva	Social	Active modes	Financial incentives	Target: Promote soft mobility Measure 1: Provision of bicycles (subsidy to Genève-roule). Measure 2: Organisation of events (subsidy to Pro Vélo Genève). Measure 3: Publication of a cycle map. On-site public information.	SDG 3 SDG 11
Energy and climate policy of the City of Geneva action 19_2009 - 2013	City of Geneva	Social	modal shift- active mobility	Vehicle fleet management Financial incentives	Target: Continue to develop the bicycle and electric bicycle offer Improve the level of service offered as part of the transport package. Measure: The purchase of bicycles and electric bikes should be systematically included in the new request for credit relating to the renewal of vehicles. Support the test project for a self-service electrically-assisted bicycle system for the administration.	SDG 11
Energy and climate policy of the City of Geneva action 20_2009 - 2013	City of Geneva	Economic	modal-shift	Promotional/awareness campaign	Target: Relaunching and strengthening the transport package Action: Encourage employees to adopt more environmentally friendly forms of mobility when travelling on business	SDG 11
Municipal plan sustainable development of the city centre - 2020 - one job per resident	City of Geneva	Economic	Employment	Urban planning	Objective: to keep people living in the city centre of the conurbation Measure: to correct the imbalance by creating one new home for every new job	SDG 11 SDG 8
Municipal plan sustainable development of the city centre - 2020 - less traffic	City of Geneva	Land Use	Employment	Urban planning	Objective: mixed land use to reduce congestion Measure: +3,600 housing units in the city of Geneva by 2020	SDG 11
Municipal Plan Sustainable Development of the City Center - 2020 -responsible mobility	City of Geneva	Social	accessibility, environmental quality of life, public health, noise pollution	Low emission zones Transport offer Infrastructure	Objective: reconciling accessibility, public health and quality of life by reducing road noise in accordance with federal requirements Measures - help reduce individual motorised traffic - rationalise parking - Help increase the modal share of public transport. - strengthen soft mobility networks	SDG 11

	Policy description			
Policy name (official)	Responsible institution(s)	Main policy objective	Secondary	Type of policy instrument
Lyon in transition	Lyon	economic	Promotional/awareness campaign	public workers-improve mobility



	Policy description				
Climat plan- air quality, energy-progress report 2021-Low carbon industry-action 4	Lyon	Economic	public-private cooperation innovation	Financial incentives Digital tools Urban planning Stakeholder engagement	Target: Promote the low-carbon industry Measure 1: It brings together more than 100 organisations with specific expertise in the active and low-carbon mobility sector. Lyon Metropole's financial support of almost €400,000 in subsidies to competitiveness clusters and clusters (Axelera, CARA, Techtera, Tenerrdis, Cluster Lumière, Cluster MAD) has been consolidated in order to support innovation and business development serving the region's transition and job creation in the chemical-environmental, textiles, mobility, energy and lighting sectors. Measure 2 The sustainable mobility at work digital platform will help employers implement mobility initiatives.
Climat plan- air quality, energy-progress report 2021-Low carbon industry-action 4	Lyon	Economic	public-private cooperation employment	Stakeholder engagement	Federate and lead a network of over 100 socio-economic players throughout the value chain. - Developing structuring projects that encourage the creation of local jobs that cannot be relocated.
TERRITORIAL CLIMATE, AIR AND ENERGY PLAN 2030-action 13 Better multimodal seamless travel	Lyon	Economic	ticketing	Infrastructure Digital tools	Target: Make it easier for residents to combine different modes of transport Measures: new train stations, 40M euros for renewal of ticketing system, Multimodal information master plan (online information and signage on the ground) Ú Digital information tools, better wifi in train stations, multimodal ticketing system, park and go, surveys
Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility	Villeurbanne	Economic	modal shift-active mobility economic	Stakeholder engagement	Administration Mobility Plan:  Collaboratively develop the plan with employees through dedicated workshops. Expand the City's fleet of bicycles and electric bicycles, encouraging their use for professional travel.
The 30 km/h city: everyone benefits	Lyon	Environmental	Noise	Speed limits	The 30 km/h limit is the norm on most roads. The 50 km/h limit (or even 70 km/h in exceptional cases) becomes an exception.
Reduce air pollution with the LEZ	Lyon	Environmental	emission	Low emission zones	reform of paid parking to reduce air quality
Lyon in transition	Lyon	Environmental	energy reduction modal shift-car ownership	Vehicle fleet management	The objective of reducing energy consumption by 30% between 2000 and 2030 corresponds to reducing energy consumption by 20% between 2013 and 2030 through energy-saving and energy-efficiency measures. measure: Reducing mobility by car and changing motorised vehicles
Lyon in transition	Lyon	Environmental	air quality modal shift_car ownership_active mobility	Transport offer	To improve air quality, the Lyon Metropolitan Area committed to reducing polluting vehicle traffic by developing soft mobility and public transport.

	Policy description				
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system	Lyon	Environmental	modal shift_public transport, active mobility, car ownership, fleet renewal	Transport offer Low emission zones Vehicle fleet management	Target: A LOW-CARBON MOBILITY SYSTEM Measure 1: Linking transport modes together more effectively Measure 2: Develop active modes of transport Measure 3: Improving the performance and attractiveness of public transport Measure 4: Reducing the use of cars and their place in public spaces Measure 5: Supporting the deployment of low-emission engines
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system-reduce car use and parking action18	Lyon	Land Use	low emissions	Low emission zones Vehicle fleet management Infrastructure	Low Emission Zone (ZFE), which bans the circulation and parking of the most polluting goods transport vehicles in most of the arrondissements of Lyon, Villeurbanne Less polluting buses-1000 electric and hydrogen charging stations
TERRITORIAL CLIMATE, AIR AND ENERGY PLAN 2030-action 18 supports environmentally friendly vehicles	Lyon	Environmental	Environmental	Low emission zones Financial incentives Vehicle fleet management Infrastructure	objective: Diversifying the energy sources used for motorised transport Measures: low emission zones, grants to buy less polluting vehicles, renewal of public fleet, encouragement to set up car charging stations, electric and hydrogen,
Lyon in transition	Lyon	Safety	safety, accessibility	Promotional/awareness campaign	kids on bikes-safety certification for kids to raise awareness about kids pedestrian, biking and road safety
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system-develop active mobility, action14	Lyon	Safety	Land use, pedestrian safety	InfrastructureUrban planning	The Pedestrian Plan will expand actions to improve the comfort and safety of pedestrian walkways.
Lyon à vélo	Lyon	Social	modal shift- active mobility	Promotional/awareness campaign	communication plan on how to use roads-bike use and walking
Lyon in transition	Lyon	Social	modal shift- active mobility car sharing	Vehicle fleet management	increase car sharing for public workers, increase the use of bikes
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system-develop active mobility, action14	Lyon	Social	modal shift-active modes	Financial incentives Infrastructure	Target: bike project called Les Voies Lyonnaises The use of bicycles has accelerated sharply since 2020, with a 25% increase in traffic. It is being encouraged by a number of measures, including the development of secure parking, the renewal of assistance for the purchase of bicycles, and the loan of 10,000 reconditioned Free Velo 'v bicycles to young students on grants or integration schemes. In 2021, the development of the cycle network will continue, with an increase from 930 km to 1,100 km of facilities and lanes developed between the end of 2019 and the end of 2021 (PCAET target: 1,200 km developed by 2022)

	Policy description				
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system-improve public transport action15	Lyon	Economic		Infrastructure Financial incentives	The development of urban public transport infrastructure continued between 2019 and 2021: Destinations 2026 commit investment of €2.55 billion,
Climat plan- air quality, energy-progress report 2021 low-carbon mobility system-Low emission zones action18	Lyon	Land Use	Modal-shift-car use and use-parking	Infrastructure Speed limits awareness campaigns digital tools Transport offer	Reserved lanes for car-pooling and public transport have been developed. speed limit zones Increase users of carsharing initiatives. Increase users of digital platforms for carsharing and bike-sharing
TERRITORIAL CLIMATE, AIR AND ENERGY PLAN 2030-action 14 better active modes	Lyon	Social	modal shift-active modes accessibility	Infrastructure Promotional/awareness campaign Low emission zones Speed limits	Target: Increase the proportion of journeys made by bicycle by a factor of 4 and increase the already high proportion of journeys made on foot Measures: integrating active modes of transport into urban projects (guide to pedestrian facilities, municipal walking diagnostics, guide to the design of cycle facilities, etc.) Development of facilities (pedestrian, cycle) - lanes, parking, doubling of traffic calming zones to reach 470 km by 2020, 60 km of bus lanes open to cycles, etc. Ú Development of cycle services (cycle stations, long-term hire offer, vélo', purchase subsidies, etc.) Ú Awareness-raising / mobilisation ("active modes of transport" communication plan) Ú Support for vulnerable sections of the population and improvement of active modes of transport links in urban policy neighbourhoods (axis 6 of the PDU) Ú Support for vulnerable groups and improvement of active modes of transport links in urban policy neighbourhoods (axis 6 of the PDU) ...) Ú Raising awareness/mobilisation ("active modes" communication plan) Ú Supporting vulnerable groups and improving active mode links in urban neighbourhoods (priority 6 of the PDU)
TERRITORIAL CLIMATE, AIR AND ENERGY PLAN 2030-action 15 improve public transport	Lyon	Social	modal shift-public transport accessibility	Infrastructure Financial incentives Transport offer	Objective: increase public transport modal shares measures: infrastructure development: metro and train lines, bus lanes Improve financial resources for the agency responsible for mobility. Improve rail hubs Improve bus route performance. Improve PRM accessibility and passenger safety, and improve connections to neighbouring areas.
TERRITORIAL CLIMATE, AIR AND ENERGY PLAN 2030-action 16 regulate car use	Lyon	Social	modal shift-car use	Infrastructure Speed limits Urban planning	Objective: Reduce the proportion of journeys made by car Measures: increase awareness, electric charging infrastructure, subsidies to renew cars, lower speed, increase low-speed zones, optimise road network,

Policy description					
Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility				Low emission zones Promotional/awareness campaign	and sharing of public spaces, control of street parking, optimisation of underground parking, parking zones, communication ad promotional campaigns, carsharing, incentives for car-sharing, multimodal travel card, increase access to roads and public transport
	Villeurbanne	Social	modal shift-active mobility, safety,	Urban planning Infrastructure	Target: Promoting Walking  Develop a city-wide calming and safety strategy, focusing on creating pedestrian-friendly environments, including quality urban furniture, signage, and bicycle racks. Implement a school mobility plan. Pedestrianise the Gratte-Ciel district to contribute to the calming of the city centre. Create green corridors that facilitate pedestrian movement.
Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility	Villeurbanne	Land Use		Infrastructure Transport offer Promotional/awareness campaign	Cycling Promotion and Infrastructure Development: Increase the availability of secure bike parking and bicycle racks near public facilities. Support and expand repair workshops, bicycle schools, and mobility actors. Back the deployment of the Metropolitan Express Bike Network (REV). Continue infrastructure development to ensure cycling continuity, particularly on the axes of the Active Mobility Action Plan (PAMA). Implement sustainable mobility packages for municipal staff. Support the deployment of shared bicycles (traditional and electric). Roll out the "Savoir Rouler à Vélo" (Learning to Ride a Bike) program in schools.
Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility	Villeurbanne	Social	modal shift-active mobility, safety,	Infrastructure Low emission zones transport offer Urban planning Speed limits	Automobile Traffic:  Promote a shift in mobility by securing active modes of transportation. Reconfigure roads based on accident statistics. Enhance the visibility of all pedestrian crossings by 2026 (LOM Law). Implement a strategy for controlling obstructive parking and create a dedicated enforcement brigade. Transition to a "Calm City" model (or "City 30"). Enforce a 30 km/h speed limit throughout the city, except for key thorough fares, where a 50 km/h limit will be exceptionally maintained. Support changes in travel practices as part of the implementation of the Low Emission Zone (ZFE) and promote alternatives to individual car use. Expand paid parking to limit commuter travel (objective: double the number of paid parking spaces by 2030). Develop car-sharing programs with multiple operators. Support parking space-sharing initiatives.

Policy description					
Villeurbanne En Actions Our Ecological Transition Plan 2021-2026 - Mobility	Villeurbanne	Social	modal shift-public transport	Transport offer	<p>Public Transportation:</p> <p>Facilitate ongoing discussions regarding new public transportation lines T6, T9, and the Central-East Line.</p> <p>Assist Sytral during construction and the creation of temporary park-and-ride facilities.</p> <p>Support Sytral in reorganizing bus routes following the introduction of new tram and Central-East Line services, especially C17, 7, and 37.</p>

Appendix D.3

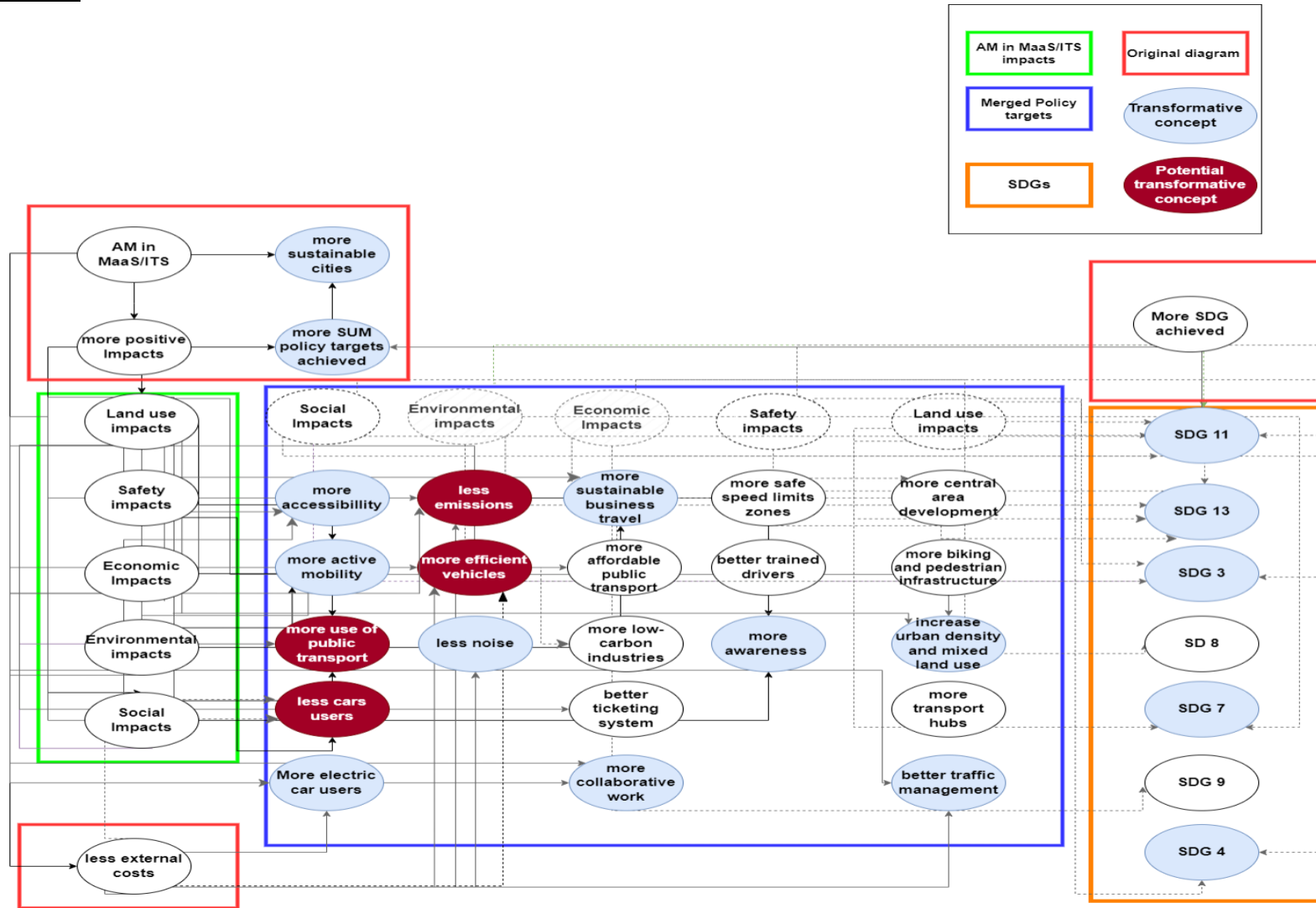


Figure 40: Extended IPA Diagram - AM in MaaS/ITS impacts alignment with SUD targets