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Automated Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D8.6 Economic Impact Assessment



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Acronyms

ADS	<i>Automated Driving Systems</i>	GNSS	<i>Global Navigation Satellite System</i>
AI	<i>Artificial Intelligence</i>	GWP	<i>Global warming potential</i>
AMPT	<i>Automated Minibuses for Public Transport</i>	HARA	<i>Hazard Analysis and Risk Assessment</i>
API	<i>Application Protocol Interface</i>	ICEV	<i>Internal combustion engine vehicle</i>
AV	<i>Automated Vehicle</i>	IPR	<i>Intellectual Property Rights</i>
BES	<i>Business Ecosystem</i>	IT	<i>Information Technology</i>
BMM	<i>Business Modelling Manager</i>	ITF	<i>International Forum of Transportation</i>
CAPEX	<i>Capital Expenditures</i>	ITU	<i>International Telecommunications Union</i>
CAV	<i>Connected and Automated Vehicles</i>	ICEV	<i>internal-combustion engine vehicles-</i>
CB	<i>Consortium Body</i>	KPI	<i>Key Performance Indicators</i>
CERN	<i>European Organization for Nuclear Research</i>	LA	<i>Leading Author</i>
D7.1	<i>Deliverable 7.1</i>	NEEDs	<i>New energy externalities development for sustainability</i>
DC	<i>Demonstration Coordinator</i>	NMVOC	<i>non-methane volatile organic compound</i>
DI	<i>The department of infrastructure</i>	NMT	<i>non-motorised transport</i>
DMP	<i>Data Management Plan</i>	NO	<i>Nitrogen oxides</i>
DWL	<i>deadweight loss</i>	MaaS	<i>Mobility as a service</i>
DSES	<i>Department of Security and Economy Traffic Police</i>	MC	<i>Marginal cost</i>
DTU test track	<i>Technical University of Denmark test track</i>	MEM	<i>Monitoring and Evaluation Manager</i>
EAB	<i>External Advisory Board</i>	MRMT	<i>microrecensements mobilité et transports</i>
EASI-AV [®]	<i>Economic Assessment of Services with Intelligent Automated Vehicles</i>	OCT	<i>General Transport Directorate of the Canton of Geneva</i>
EC	<i>European Commission</i>	ODD	<i>Operational Domain Design</i>
ECSEL	<i>Electronic Components and Systems for European Leadership</i>	OEDR	<i>Object And Event Detection And Response</i>
EM	<i>Exploitation Manager</i>	OFCOM	<i>Federal Office of Communications</i>
EU	<i>European Union</i>	OPEX	<i>Operation Expenditures</i>
EUCAD	<i>European Conference on Connected and Automated Driving</i>	PC	<i>Project Coordinator</i>
F2F	<i>Face to face meeting</i>	PCU	<i>Passenger Car Unit PCU</i>
FEDRO	<i>Federal Roads Office</i>	PEB	<i>Project Executive Board</i>
FEDRO	<i>(Swiss) Federal Roads Office</i>	PGA	<i>Project General Assembly</i>
FOT	<i>(Swiss) Federal Office of Transport</i>	PKM	<i>Person-km</i>
GDPR	<i>General Data Protection Regulation</i>		
GHG	<i>GREENhouse gas</i>		
GIMS	<i>Geneva International Motor Show</i>		

PRM	<i>Persons with Reduced Mobility</i>	UITP	<i>Union Internationale des Transports Publics</i>
PRS	<i>Product related Service</i>		
PSA	<i>Group PSA (PSA Peugeot Citroën)</i>	VAS	<i>Value Added Service</i>
PT	<i>Public Transport</i>	VKm	<i>vehicle kilometre travelled</i>
PTO	<i>Public Transport Operator (French: TPO)</i>	VSL	<i>Value of statistical life</i>
PTS	<i>Public Transportation Services</i>	VOT	<i>Value of time</i>
QRM	<i>Quality and Risk Manager</i>		
QRMB	<i>Quality and Risk Management Board</i>	VOLY	<i>Value-of-statistical life</i>
RN	<i>Risk Number</i>	WP	<i>Work Package</i>
SA	<i>Scientific Advisor</i>	WPL	<i>Work Package Leader</i>
SAE Level	<i>Society of Automotive Engineers Level (Vehicle Autonomy Level)</i>	WTT	<i>WELL-TO-TANK</i>
SAN	<i>Cantonal Vehicle Service</i>		
Sc	<i>Scenario</i>		
Sc01	<i>Reference urban scenario</i>		
Sc02	<i>Reference suburban scenario</i>		
Sc1	<i>Scenario replace all buses</i>		
Sc2	<i>Scenario replace all cars</i>		
Sc3	<i>Scenario robotaxis</i>		
Sc4	<i>Scenario expansion of public transport network</i>		
Sc5	<i>Scenario Targeted expansion</i>		
Sc6	<i>Scenario AM in MaaS</i>		
SDG	<i>Sustainable development goals</i>		
SDK	<i>Software Development Kit</i>		
SMB	<i>Site Management Board</i>		
SoA	<i>State of the Art</i>		
SOTIF	<i>Safety Of The Intended Functionality</i>		
SUMP	<i>Sustainable Urban Mobility Plan</i>		
SWOT	<i>Strengths, Weaknesses, Opportunities, and Threats.</i>		
TCO	<i>Total Cost of Ownership</i>		
TCM	<i>Total Cost of Mobility</i>		
TDM	<i>Transportation Demand management</i>		
TM	<i>Technical Manager</i>		
TPG	<i>Transport Public de Geneve</i>		
TPO	<i>Transport Publique Operateur (engl. PTO)</i>		
TTW	<i>Tank-to-Wheel</i>		

Executive Summary

The AVENUE project aims to design and carry out full scale demonstrations of urban transport automation by deploying fleets of automated minibuses in European cities. Within the project, the Work Package 8 (WP8), task T8.3 aims to evaluate the environmental, economic, and social implications of implemented urban and suburban automated full-scale demonstrators. This deliverable D8.6 deepens the insights presented in the deliverable D8.4 considering the remarks of the internal and external reviewers and presents the final advances of the task within the scope of the project.

The first assessment in this deliverable presents an in-depth analysis of the customer/citizen centered intermodal MassS centered ecosystem scenario (as announced on D8.4). It presents in details the characteristics of this scenario (general description, practice examples, strategic direction, general evaluation, success factors and risks, and the network of possible partners), it also details the scenarios business opportunities, and business strategies (in both contexts of collaboration and competition with public and private MaaS stakeholders), and its business model definition based on such collaborative and competitive approaches.

The next assessment details the business cases for the current AVENUE operating sites by expanding the economic assessment tool EASI-AV[®] presented on D8.4. It presents the on-demand fleet sizing calculations that was incorporated in the tool, thus completing the fleet dimensioning analysis proposed in the project. Furthermore, it expands on the excel version presented on D8.4 by presenting the beta version web version application of the tool, which makes accessing the economic viability of services with automated vehicles available to all.

The final assessment presented on this deliverable goes in-depth on the expected externalities for the cities, by detailed the scenarios planning methodology as well as the 6 selected scenarios (replace all buses, replace all cars, expand the network, targeted expansion of the network, robotaxis, AM in MaaS) are explained. Then, the updates in the externalities categories are introduced. Firstly applying the model in detail to the case study of Geneva, where the mobility behaviour of the city, the results in terms of savings or losses per scenario and their implications are presented and discussed. Second, it is applied to the other 3 cities of AVENUE (Luxembourg, Lyon, and Copenhagen). In a final stage, a comparative analysis is conducted between the cities. At last, section 6 presents the overall conclusions of this deliverable and the next steps to be taken in future projects both micro and macro analysis (scenarios for service and city-levels) help to simulate in which conditions an automated fleet service will create benefits for the community.

1 Introduction

AVENUE aimed to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen and Luxembourg) and 2 replicator cities (Sion and Esch). The AVENUE vision for future public transport in urban and suburban areas is that automated vehicles will ensure safe, rapid, economic, more sustainable and personalised transport for passengers. AVENUE introduces disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress prescheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience as well as the overall quality and value of the service will be introduced, also targeting elderly people, people with disabilities and vulnerable users. Road behaviour, security of the automated vehicles and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period in 2022 the mission is to have demonstrated that automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental and social potential of automated vehicles for both companies and public commuters while assessing the vehicle road behaviour safety.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens. Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport. On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient. On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization. It is recognized that the use and integration of on-demand automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.2 Fully Automated Vehicles

A self-driving car, referred in the AVENUE project as a **Fully Automated Vehicle (AV)**, also referred as Autonomous Vehicle, is a vehicle that is capable of sensing its environment and moving safely with no human input.

The terms *automated vehicles* and *autonomous vehicles* are often used together. Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

- An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required
- "fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In AVENUE we operate **Fully Automated minibuses for public transport**, (previously referred as autonomous shuttles, or autonomous buses), and we refer to them as simply *automated*

minibuses or the AVENUE minibuses. In relation to the SAE levels, the AVENUE project operates SAE Level 4 vehicles.



SAE J3016™ LEVELS OF DRIVING AUTOMATION

		SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?		You <u>are</u> driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You <u>are not</u> driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
		You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
		These are driver support features			These are automated driving features		
What do these features do?		These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features		• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

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Figure 1. Levels of driving automation

1.2.1 Automated vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated in the vehicle and implements the road behaviour of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined by the higher-level view of the overall fleet management.

For micro-navigation automated vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LIDAR, sonar, GNSS, odometry and other types of sensors. Control software and systems, integrated in the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detecting obstacles in the surrounding environment, and choosing the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn etc.

For the Macro-navigation, that is the destination to reach, the automated vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route), or from the remote control service via a dedicated 4/5G communication channel, for a fleet-managed operation. The fleet management system takes into account all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets) and send route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Automated vehicle capabilities in AVENUE

The automated vehicles employed in AVENUE fully and automatically manage the above defined micro-navigation and road behaviour in an open street environment. The vehicles are automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and automatically decide to bypass them or wait behind them, based on the defined policies. For example, with small changes in its route the AVENUE shuttle is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE vehicles are able to handle different complex road situations, such as entering and exiting roundabouts in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).

The shuttles used in the AVENUE project technically can achieve speeds of more than 60Km/h. However, this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control of any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations. An **Intervention Team** is present in the deployment area ready to intervene in case of an incident to any of the minibuses. Table 2 provides an overview of the AVENUE sites and OODs.

	Summary of AVENUE operating sites demonstrators						
	TPG		Holo		Keolis	Sales-Lentz	
	Geneva		Copenhagen	Oslo	Lyon	Luxembourg	
Site	Meyrin	Belle-Idée	Nordhavn	Ormøya	ParcOL	Pfaffental	Contern
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	May 2017	June 2018	June 2018
Start date of trial	July 2018	June 2020	September 2020	December 2019	November 2019	September 2018	September 2018
Type of route	Fixed circular line	Area	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service*	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Fixed route/Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops
Route length	2,1 km	38 hectares	1,3 km	1,6 km	1,3 km	1,2 km	2,3 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Public road	Public road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Speed limit	30 km/h	30 km/h	30 km/h	30 km/h	8 to 10 km/h	30 km/h	50 km/h
Roundabouts	Yes	Yes	No	No	Yes	No	No
Traffic lights	No	No	No	No	Yes	Yes	Yes
Type of service	Fixed line	On demand	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	2	4	2
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes
Number of vehicles	1	3-4	1	2	2	2	1
Timetable	Fixed	On demand	Fixed	Fixed	Fixed	Fixed	Fixed
Operation hours	Monday-Friday (5 days)	Sunday-Saturday (7 days)	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Saturday (6 days)	Tuesday & Thursday Saturday, Sunday & every public holiday	Monday - Friday
Timeframe weekdays	06:30 – 08:30 / 16:00 – 18:15	07:00 – 19:00	10:00 – 18:00	7:30 – 21:30	08:30 – 19:30	12:00 – 20h00	7:00 – 9:00 16:00 – 19:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	08:30 – 19:30	10:00 – 21:00	No Service
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site
Driverless service	No	2021	No	No	No	No	No
Drive area type/ODD	B-Roads	Minor roads/parking	B-Roads/minor roads	B-Roads	B-Roads	B-Roads	B-Roads/parking
Drive area geo/ODD	Straight lines/plane	Straight lines/ plane	Straight lines/ plane	Curves/slopes	Straight Lines/ plane	Straight lines/ plane	Straight lines/ plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	Regulatory	Regulatory	Regulatory
Drive area surface/ODD	Standard surface, Speedbumps	Standard surface, Speedbumps	Standard surface Speedbumps, Roadworks	Frequent Ice, Snow	Standard surface, Potholes	Standard surface	Standard surface

Table 2: Summary of AVENUE operating site (+ODD components)

2 Scope and aim of the economic impact assessment study

The economic assessment is integrated in the WP8 framework and follows the people centric vision of mobility of the EU (German EU Council Presidency 2020) and UITP (UITP 2020). This vision is coherent with the SUMP framework as mobility of people should respect the environment and be inclusive.

The economic assessment framework analyses accordingly business scenario and externalities for several stakeholders like user and potential user, PTOs, cities, and the new business ecosystems is a modular approach for a comprehensive analysis, identification, analysis & evaluation, and planning of businesses for AVENUE. As detailed on D8.4 (p.18-20), the planning modules are defined as follows:

- Analysis of the individual Status Quo Business Scenario ('As-Is Use Case')
- Identification of applicable Future Business Scenarios ('To-Be Use Cases')
- Elaboration of operational Business Cases for the Status Quo Business Scenario
- Economic Analysis of Expected Externalities for cities for Business Scenarios & Use Cases
- Identification of Business Opportunities
- Identification of Business Strategies
- Definition of Business Model Concepts
- Elaboration of operational Business Cases for intended Future Business Scenarios

Thereby, the task's economic assessment follow an evolutionary approached, and are intended as pragmatic guiding suggestions for structuring, analyzing, reflecting and planning of concrete future AVENUE businesses. As shown on D8.4, this methodological sequential approach has been applied to alternative Business Scenarios (BS1– BS4). Together they represent a conceptional Framework of building blocks for further elaborations of strategic business planning focusing the business with Automated Minibuses for Public Transport as shown in (Figure 2):

Owner	Business Scenarios (BS) (relevant for AVENUE)	Design Steps (S)	S1 General Business Characterization	S2 AVENUE Business Opportunities	S3 AVENUE Business Strategies	S4 AVENUE Business Models
		Examples	Bus. Ecosystem Definition, Bus. Potentials, Bus. Perspectives, Examples, etc.	Opp. Description, Opp. Evaluations	Ecosystem Strategies, Market Strategies, Offering Strategies, Competitor Strategies, Customer / Citizen Strategies, Functional Strategies (R&D, Marketing, etc.), Innovation Strategies, etc.	Business Model Canvas (incl. Value Proposition [Values/Benefits, Cost / Time / Performance Benefits, etc.] / Offerings / Innovations / USPs for relevant Stakeholders), Cost Model, Revenue Model, Invest & Finance Model, Customer Model, Delivery Model), SWOT, etc.
ECP	BS 1 TPO Centred Ecosystem (Traditional Approach currently applied at the 6 AVENUE Pilots)	AVENUE – Trad. Approach				(Elaborations based on Business Case Calculator: quantitative business profitability analysis based on an integrated cost/revenue calculation)
HSPF /SAG	BS 2 Automotive Centred Ecosystem	Moia, car2go			<i>Which successful business (vision, goal, strategy, business opportunities, business models) can AVENUE play in each of the four different scenarios?</i>	
HSPF /SAG	BS 3 New Mobility Provider Centred Ecosystem	Uber, UberPool, Lyft-US, blablalines				
HSPF /SAG	BS 4 Customer/ Citizen Centred Intermodal MaaS Ecosystem	MaaS-Global, Clever Shuttle-DB, Moia, Moo-vel, City Mapper, Moovit, Uber				

Figure 2. Conceptional Framework of Strategic Business Planning for AMPT.

In the following sections the Design Modules (Task Building Blocks) determined by Business Scenarios vs. Design Steps within the Economic Assessment Framework are elaborated for the final Business Scenario 4 (Customer/Citizen centered intermodal MaaS ecosystem). They are prepared for being focused and refined to a concrete AVENUE application scenario offered by a likewise concrete tender.

3 Business Scenarios

Since the individual business scenarios (with the exception of the customer/citizen centred intermodal MaaS centred ecosystem scenario) have already been described and discussed in detail in the second iteration economic impact assessment (3.1-3.6), only a brief summary is provided below. After that, however, as already announced in the second iteration, we will then go into detail about the customer/citizen centred intermodal MaaS centred ecosystem scenario.

3.1 Short recapitalisation from D8.4

In D8.4 we elaborated the business scenarios BS1 to BS3, where automotive and new mobility provider centred business ecosystems have been focused. Completing these scenarios, the last scenario “Mobility as a Service (MaaS)” (BS4) is presented in detail in the following part. Figure 3 shows all four business scenarios and identified refinements in a final framework of Business Ecosystem (BES) Scenarios:

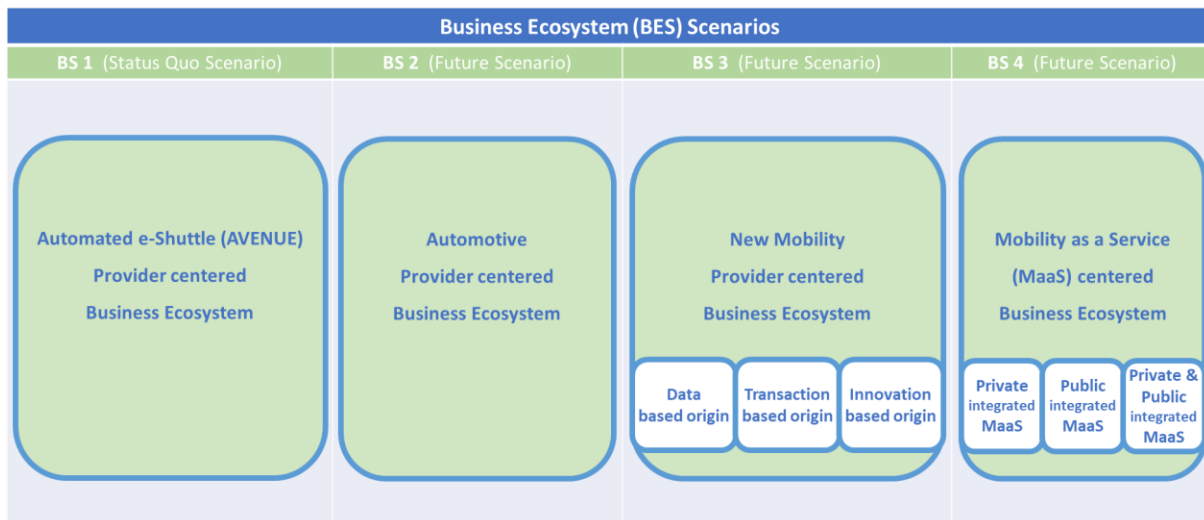


Figure 3. Framework of Business Ecosystem (BES) Scenarios

The business scenarios and sub scenarios displayed in this conceptual grid can be characterized in a preliminary and high-level way by first comparing definitions describing the different background and focus, as well as main differentiating characteristics and emphases (see Figure 4):

Business Ecosystem (BES) Scenarios			
BS 1 (Status Quo Scenario)	BS 2 (Future Scenario)	BS 3 (Future Scenario)	BS 4 (Future Scenario)
Automated e-Shuttle Provider (AVENUE) centered Business Ecosystem	Automotive Provider centered Business Ecosystem	New Mobility Provider centered Business Ecosystem	Mobility as a Service (MaaS) centered Business Ecosystem
- Mix of unimodal and multimodal approaches - Automotive provided centred, new mobility provided centred and MAAS centred business ecosystems (BS 2-4) in embryonal maturity statuses - AVENUE as a consortium of complementary partners for automated e-shuttles tries to develop its own business ecosystem within the developing market situation described above - Financial and resource basis as well as market coverage and customer access are very limited - Currently no integration with other platforms / ecosystems available - Strong competition (e.g. EasyMile, smarter together) with similar platform / ecosystems based on automated e-shuttle innovations	- Automotive Manufacturers become customer-oriented mobility & service providers through product- and market diversification - Existing business models are facing digitalization, connectivity and disruptive innovations in vehicle technologies. - Shift of value creation from automotive (i.e. vehicle) offerings towards usage of user and vehicle data. - Integrated digital service innovations are needed in order to meet changing customer requirements	Digital transformation enables competitors from different industries to appear as new players on the market: - New DATA BASED mobility providers or internal startups from IT-Tech giants diversify their offering portfolio by extending their ecosystems with mobility services - New TRANSACTION BASED mobility providers or transaction platform startups are entering the market with innovative digital mobility services and providing transaction platforms for partners and citizens - New INNOVATION BASED mobility providers or emerging OEMs and automotive technology startups are trying to conquer the market through e-mobility and automated vehicles, which will provide innovative products, solutions, services and infrastructures	- MaaS Providers connect different modalities of transport to intermodal seamless travel chains. - MaaS offerings provide a fully integrated and seamless transport for dedicated passenger journeys, enabled by integrated ticketing concepts, tariff packages and information & communication technologies (ICT) - MaaS systems allow consumers to purchase multimodal mobility services offered by central or distributed mobility providers (TPOs) on a common single platform - Mobility providers and ecosystems from BS1/2/3 are integrated in a complementary & synergetic way

Figure 4. High Level Characterization of Business Ecosystem (BES) Scenarios

The design steps from D8.4, as previously shown in Figure 2, are again the basis for the elaborations for Scenario 4 (MaaS). Figure 5 shows an overview of all eight Business Opportunities / Clusters (BO1-8) which have been evaluated, prioritized, and selected by the in D8.4 presented and used methodologies:

		SWOT Justification of Business Opportunities		MaaS (Mobility as a Service) Ecosystem (BS4)			
				BO 5	BO 6	BO 7	BO 8
BS2	Automotive Centred Ecosystem (BS2)	- Lack of competencies of software - Outsourcing of non-core services - Lack of user-related data of OEMs - Since AVENUE is already testing Automated shuttles, they have more experience from which the OEMs can benefit	Provide Value Added Automated E-Shuttle Services (VAS) to Automotive Centred Mobility Providers				
	New Data Based Ecosystem (BS3.1)	- Lack of competencies in the field of vehicle construction - Since AVENUE is already testing with Automated shuttles, they have more experience (special equipment, placement of sensors, placement of seats) from which new data based mobility providers can benefit	Provide Automated E-Shuttle Solutions to New Data Based Mobility Providers	Automated E-Shuttle Solutions	Provide Automated E-Shuttle Solutions	Provide Automated E-Shuttle Solutions	Provide Automated E-Shuttle Solutions
BS3	New Mobility Provider Centred Ecosystem (BS3)	- Transaction based mobility provider does not offer shuttle solutions so far - AVENUE can earn a share of the driving costs - High level of initial investment required which can be bypassed	Provide Automated E-Shuttle Solutions to New Transaction Based Mobility Providers	as complementary Collaboration Partner	as complementary Collaboration Partner	as Competitor of other E-Shuttle Providers	as Competitor of other E-Shuttle Providers
	New Innovation Based Ecosystem (BS3.1)	- High level of initial investment to build a service network can be bypassed - Complex fleet management can be efficiently handled by AVENUE	Provide Product Related Automated E-Shuttle Services (PRS) to New Innovation Based Mobility Providers	within a Public Sub-Ecosystem (Public PTO as MaaS Integrator)	within a Private Sub-Ecosystem (Private PTO as MaaS Integrator)	within a Public OR Private Sub-Ecosystem (Private PTO OR Public PTO as possible MaaS Integrators)	providing an own (Private) Sub-Ecosystem (Private PTO AND Public PTO as common MaaS Integrators)

Figure 5. Final Overview of Business Ecosystem Opportunities Clusters for Business Scenarios

This conceptual overview about the interdependencies of business scenarios – consisting of most attractive Ecosystems BS2 (Automotive Centred Ecosystem), BS3 (New Mobility Provider Centred Ecosystem) [BS3.1, BS3.2, BS3.3] and BS4 (MaaS Ecosystem) – and the according selected, most promising Business Opportunities (functional Business Opportunities: BO1-BO4 and MaaS Business Opportunities BO5-BO8), the basis for the subsequent elaborations on strategic planning building blocks.

Regarding the high aggregation level of business scenarios and its business opportunities it is important to regard and utilize the subsequent design modules for the business scenarios as rough directional strategic guidelines and recommendation suggestions or motivational examples for further analyses, discussions and refinement focused on the concrete acquisition use case which AVENUE as a potential entrepreneurial provider is facing.

3.2 Business scenario 4: Customer/Citizen Centred Intermodal MaaS centred Ecosystem

Within this chapter all **4 Design Steps for Strategic Business Planning for Business Scenario 4** – mentioned in the conceptional grid (see **Erreur ! Source du renvoi introuvable.**) - are elaborated:

1. AVENUE Business Scenario Characterization,
2. AVENUE Business Opportunity Identification,
3. AVENUE Business Strategies Identification,
4. AVENUE Business Model Definition.

3.2.1 Business Characterization (Business Scenario 4)

The Characterization of Business Scenario 4 is elaborated by the following methods or templates addressing the most relevant issues relevant for the concrete strategic planning:

1. BES General Description and Practice Examples
2. BES Strategic Direction
3. BES General Evaluation
4. BES Success Factors & Risks
5. Typical exemplary Traditional BES – Partner Network

3.2.1.1 BES General Description and Practice Examples

The General Description of the Customer/Citizen Centred Intermodal MaaS centred Ecosystem provides main descriptonal issues of understanding and identified practice examples of typical companies representing the Business Scenario for the Customer/Citizen Centred Intermodal MaaS centred Ecosystem.

The hypothesis for the General Description of this Business Scenario is that the most probable future will be a Customer/Citizen Centred Intermodal MaaS centred Ecosystem where private and public MaaS providers connect different modalities to intermodal seamless travel chains which allows passengers a fully integrated seamless transport for their journey. This multimodality is supported by appropriate multimodal mobility services on a common platform.

The analysis of this Business Scenario shows that today there are already promising MaaS platforms, BES and services from private and public mobility partners and respective MaaS concepts available and partially implemented. But there are still deficits in area-wide application of MaaS concepts due to still embryonal or unclear regulations as well as lacks and gaps of the MaaS BES value chain (e.g. first/last mile gaps, closed e.g. by modalities like AMPT, and often only fragmented ticketing/tariffing and routing systems).

As a general conclusion it can be determined that numerous building blocks (strategies, collaboration and data platforms, services, governance concepts, etc.) of Customer/Citizen Centred Intermodal MaaS centred Ecosystems as a mid – long term scenario are evolving. This scenario can be regarded as the most probable and in terms of customer/passenger centricity desirable solution for the public mobility market.

BES Description	BES Examples
- The idea behind the concept is a fully integrated and seamless transport for dedicated passenger journeys enabled by integrated ticketing concepts, tariff packages and information and communication technologies (ICT) ⁽³⁾ - MaaS systems allow consumers to purchase multi-modal mobility services offered by the same or different mobility provider (TPOs) on a single platform ⁽¹⁾ - The result is the linkage of different modalities of transport to create intermodal travel chains ⁽²⁾ - Mobility providers and ecosystems from BS1/2/3 are integrated in a complementary & synergetic way	- Reach Now (Joint Venture of Daimler & BMW)  - City Mapper  - Moovit (Intel)  - DiDi Chuxing Technology  - Free2Move (PSA Group)  - Whim  - Clever-Shuttle (Deutsche Bahn) 

Figure 6. BES General Description (Business Scenario 4)

3.2.1.2 BES Strategic Direction

The Strategic Direction for the Customer/Citizen Centred Intermodal MaaS centred Ecosystem (BES) analyzes the general strategic orientation (Purpose & Goals and Vision) and characteristic emphases of Business Opportunities, General Strategies and Business Models for this Business Scenario. These issues are the basis for further refinement in the subsequent subchapters of this Business Scenario.

The hypothesis for the Strategic Direction of this Business Scenario is a clear purpose and vision for the public mobility of the future based on customer / citizen centric solutions from private and/or public providers for integrated seamless transport, single platform mobility ecosystems for BES partners, citizens and other stakeholders, as well as an ecosystem of all relevant services necessary therefor.

The analysis of this Business Scenario shows that despite this clear strategic direction there's plenty of room for alternative strategic and operational alternative concepts as well as numerous technical / virtual and business applications which are often in an embryonal phase and still need to be developed.

As a general conclusion it can be determined that this Strategic Direction rapidly needs to be elaborated and driven forward as multiple modalities (e.g. AMPTs), applications, platforms and services as well as data regulations and governance concepts are developing and huge benefits (e.g. customer satisfaction & comfort, travel efficiency, profitability increases) for all stakeholders are expected.

BES Topic	Characterization
BES Purpose	- Offer mobility services to citizens/passengers by same or different provider (TPOs) on a single platform - Make public transport more attractive, more environmentally friendly and cheaper by fast/seamless multimodal transport from A to B - Optimize future mobility demands of passengers (intermodal, personalized, on-demand, customer-specific) (1) (2) - Reduce volume and usage of private transport vehicles (3)
BES Vision	- Provide complex transportation journeys without private vehicles as a single service available on-demand utilizing a multimodal portfolio of transport services (2) - Provide integrated and seamless mobility based on the integration of ticketing concepts, mobility packages and information and communication technologies (ICT) - Adoption and efficient use of multiple transport modes through a single platform
BES Business Opportunities (First Ideas)	- Acceleration of the technological development and rapid market adoption of automated and electric vehicles - Increased customer base by attractive individualized offers - Development of integrated customer service and digital interface for optimized individual journey planning, booking and payment => increased profitability and customer satisfaction - Development of TPO based services for integrated multimodal fleet management and scheduling of vehicles - Establishment of data-based services for passengers and TPOs (analysis apps, management apps, prediction apps)

Figure 7. BES Strategic Direction (Business Scenario 4)

3.2.1.3 BES General Evaluation

For a deeper understanding of the Business Scenario – Customer/Citizen Centred Intermodal MaaS centred Ecosystem it is essential to analyze it by using the SWOT method. In this context the SWOT analysis expresses 4 central business planning relevant factors for scenario stakeholders and business ecosystems:

a. the general opportunities (on a higher abstraction level of concrete business opportunities) provided by this business scenario, b. the general threats within this business scenario, c. the general strengths of business ecosystems or players supported by this business scenario, d. the general weaknesses which business ecosystems or players are facing within this business scenario.

The hypothesis for the General Evaluation of this Business Scenario is that this Customer/Citizen Centred Intermodal MaaS centred Ecosystem provides numerous strengths impacting promising opportunities, but also faces significant weaknesses on technical, organizational and conceptional level as well as threats partially resulting from this.

The analysis of this Business Scenario shows that for example technical (e.g. reliability, security), conceptional / complexity-related or regulatory weaknesses may easily precipitate in decreasing acceptance by potential BES partners or citizens/passengers. Only there are sustainable solutions on a stable maturity level for these challenges the desired benefits can increase exponentially.

As a general conclusion it can be determined that there are still various challenges (weaknesses, threats) on all BES levels to be mastered before the benefits and advantages of ‘Customer/Citizen Centred Intermodal MaaS centred Ecosystems can be successfully harvested.

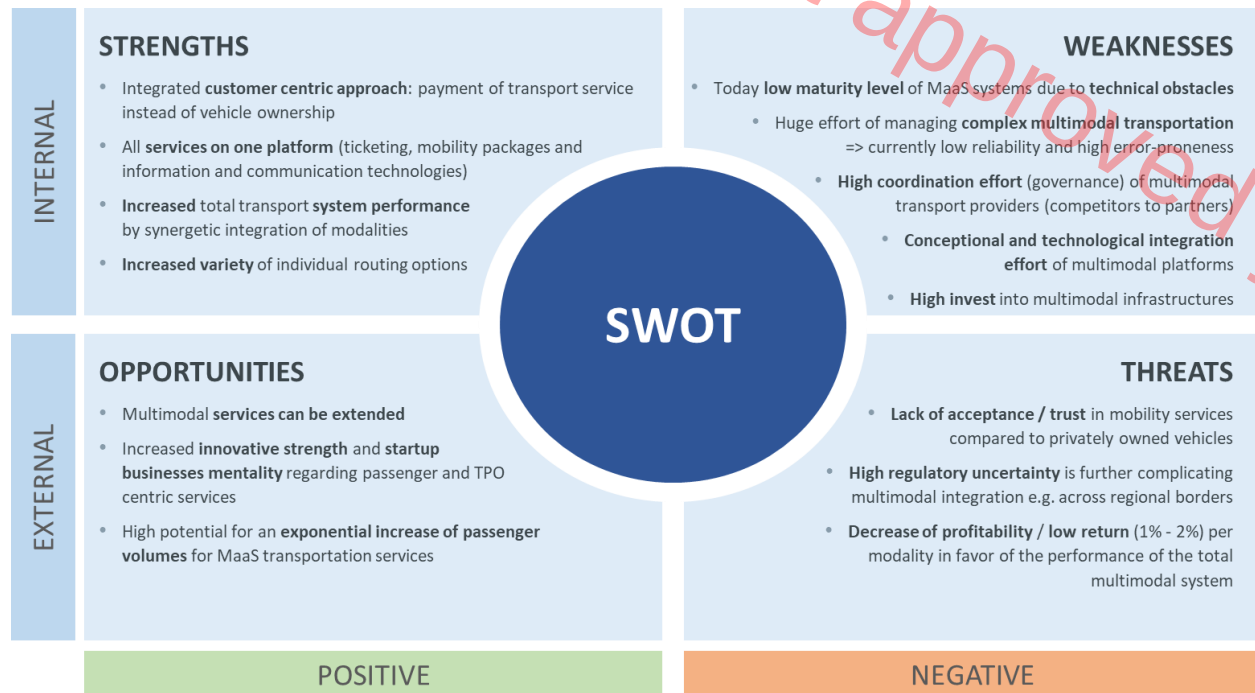


Figure 8. BES General Evaluation (Business Scenario 4)

3.2.1.4 BES Success Factors & Risks

A fundamental focus for strategic planning of business ecosystems is the identification of Success Factors and Risks for entrepreneurial behavior for the setup and management of Business Ecosystems within the Business Scenario of Customer/Citizen Centred Intermodal MaaS centred Ecosystems.

The hypothesis for the Success Factors and Risks of this Business Scenario is that the fulfilment of both: success factors and risks for exploiting the huge business - as well as social, ecological (and in general: innovation) - potentially promised by the MaaS centred Ecosystem approach, is still a complex, difficult, long-term, but nevertheless worthwhile and future-oriented task.

The analysis of this Business Scenario shows that the goals / success factors: citizen-centricity (e.g. paradigm shift from TCO - total-cost-of-ownership to TCM – total cost-of-mobility), or multimodal seamless transport modalities integration, are still highly sophisticated tasks. On the other hand, there are still significant regulatory discussions for data platform access and transparencies or technical risks to be solved.

As a general conclusion it can be determined that it is necessary for this highly innovative and complex Scenario to identify and refine further individual success factors and risks as each one of them can be success critical.

Success Factors	Risks
1. Strictly citizen centric approach => high comfort, broad availability of services, high acceptance 2. Fully integrated transport system => significant benefits compared to unimodal transport systems 3. Full transparency of mobility database at least of public TPOs => high leverage for development of ecosystem due to many startups/innovators	1. High complexity => extremely difficult to manage and prone to errors 2. Risk of not having access to mobility database of private TPOs 3. Regulatory framework is still in development and not clearly defined by government (Regulations on local, regional, country and global level determine success of business model) 4. IT infrastructure is not sufficiently available in many regions 5. Vehicle infrastructure (e.g. charging stations) is still in an embryonal status 6. IT security risks

Figure 9. Success Factors & Risks (Business Scenario 4)

3.2.1.5 Typical exemplary BES – Partner Network

For a pragmatic strategic planning of a business ecosystem within this business scenario it is beneficial to have an idea of an archetypical model of a partner network as an exemplary structure of a Business Ecosystem represented by typical ecosystem partners as well as the central ecosystem lead partner (as ecosystem management platform owner) shaping and orchestrating this Business Ecosystem.

3.2.1.5.1 Typical exemplary BES – Partner Network – Private Mobility Provider as Integrator

The hypothesis for the Partner Network - **Private Mobility Provider as Integrator** within this Business Scenario is that there is a MaaS platform BES existing with a Private Mobility Provider as owner and orchestrator of BES partners and interactions, increasing their business with usage of public & private platform data and thus providing seamless intermodal transportation.

The analysis of this Business Scenario shows that the Private Mobility Provider (private TPO) as MaaS BES Integrator orchestrates ecosystem partners like: Automotive Service Providers, other private TPOs, public TPOs, IT infrastructure services providers, and others. AMPT solution providers can engage in various ways in this MaaS BES depending on the offering they contribute (e.g. either as supplier of private or public TPO or as partner for components, services etc.).

As a general conclusion it can be determined that this is a scenario with clear advantages and preferences and thus a strong position for the Private Mobility Provider as Integrator (hiding own BES data and utilizing public TPO data).

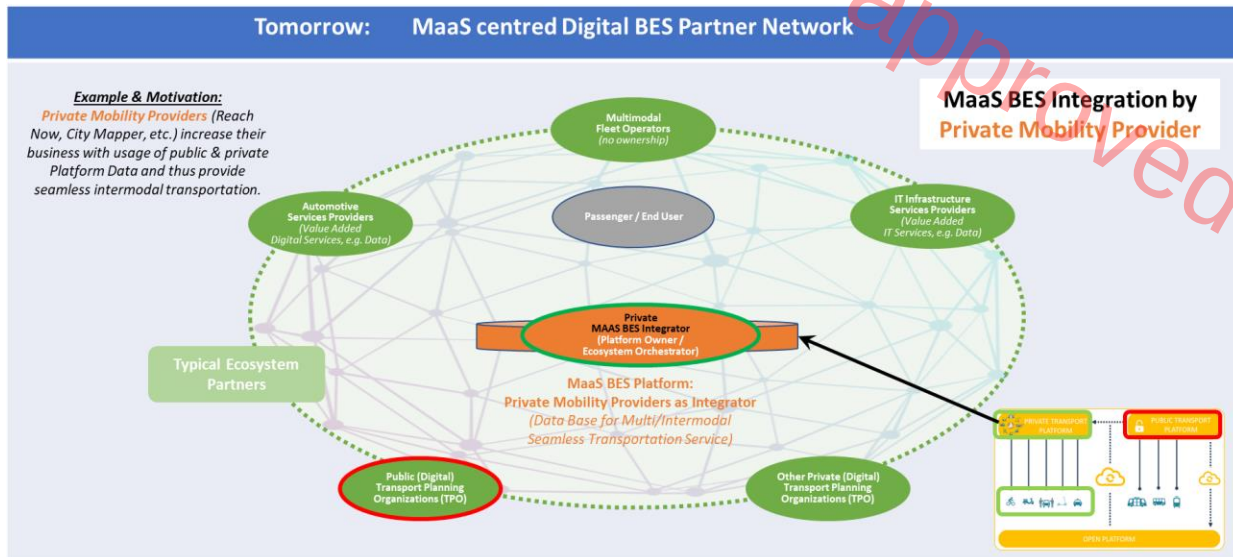


Figure 10. Typical exemplary BES – Partner Network – MaaS BES Integration by Private Mobility Provider (Business Scenario 4)

3.2.1.5.2 Typical exemplary BES – Partner Network – Public Mobility Provider as Integrator

The analysis of this Business Scenario shows that the Public Mobility Provider (public TPO) as MaaS BES Integrator orchestrates ecosystem partners like: Automotive Service Providers, other private TPOs, public TPOs, IT infrastructure services providers, and others. AMPT solution providers can engage in various ways in this MaaS BES depending on the offering they contribute (e.g. either as supplier of private or public TPO or as partner for components, services etc.).

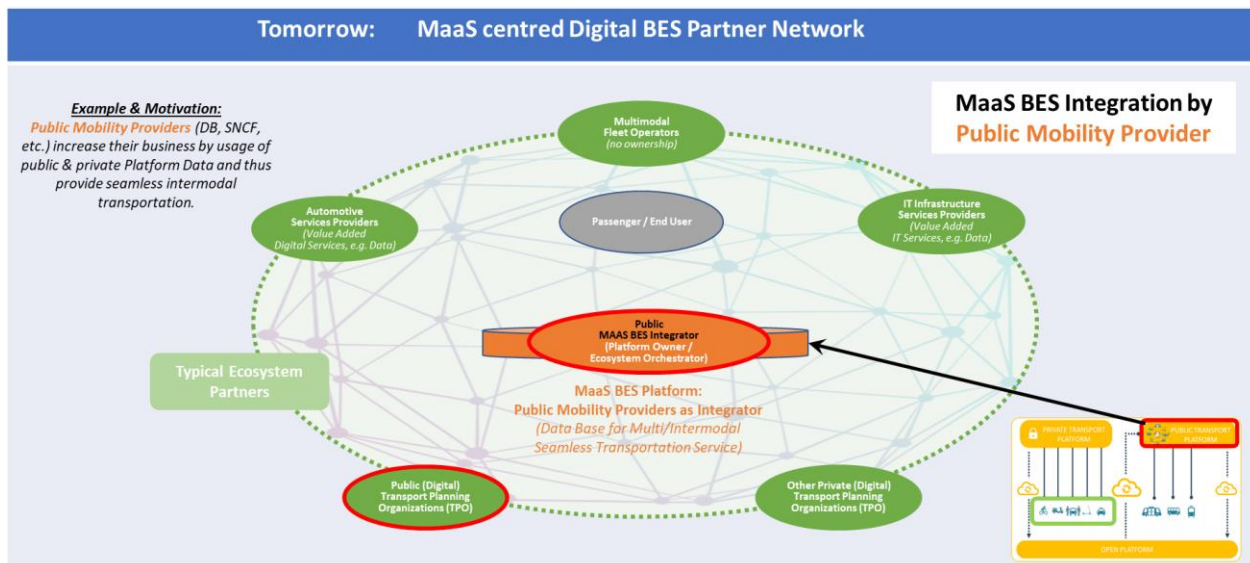


Figure 11. Typical exemplary BES – Partner Network – MaaS BES Integration by Public Mobility Provider (Business Scenario 4)

As a general conclusion it can be determined that this is a scenario with clear advantages and preferences and thus a strong position for the Public Mobility Provider as Integrator (providing own TPO and BES data and utilizing private TPO data).

3.2.1.5.3 Typical exemplary BES – Partner Network – Private & Public Mobility Providers as Integrator

The analysis of this Business Scenario shows that Private and Public Mobility Providers (private & public TPOs) as MaaS BES Integrators orchestrate together ecosystem partners like: Automotive Service Providers, other private TPOs, other public TPOs, IT infrastructure services providers, and others. AMPT solution providers can engage in various ways in this MaaS BES depending on the offering they contribute (e.g. either as supplier of private or public TPO or as partner for components, services etc.).

As a general conclusion it can be determined that this is a scenario with a balanced and thus 'democratic' or collaborative position for the Private and Public Mobility Providers as common Integrators (both providing TPO and BES data and utilizing TPO data).

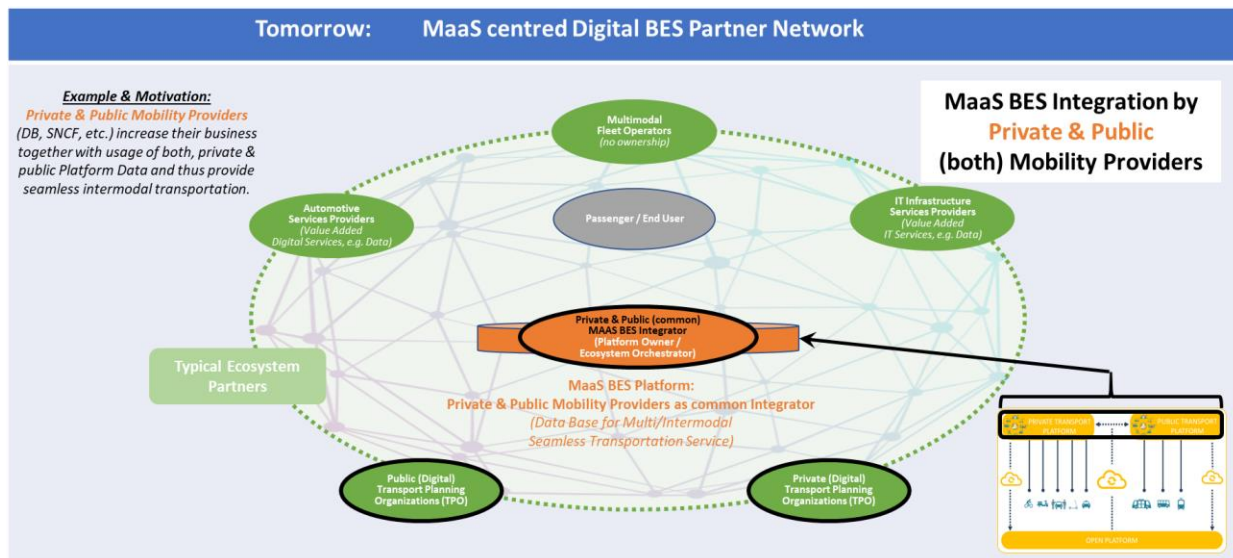


Figure 12. Typical exemplary BES – Partner Network – MaaS BES Integration by Private & Public Mobility Provider (Business Scenario 4)

3.2.1.5.4 Typical exemplary BES – Partner Network – AVENUE (Private) as Own Mobility Provider

The analysis of this Business Scenario shows that **AVENUE (Private) as Own Mobility Provider** (private TPO) as MaaS BES Integrators orchestrate ecosystem partners like: AVENUE Digital PRS and VAS Service Providers, other private TPOs, public TPOs, infrastructure providers, distributors and others. AVENUE as AMPT solution provider can design this MaaS BES to its own needs and wishes.

As a general conclusion it can be determined that this is a scenario with a strong position for AVENUE as a private Mobility Providers and Integrator (generating own TPO and BES data).

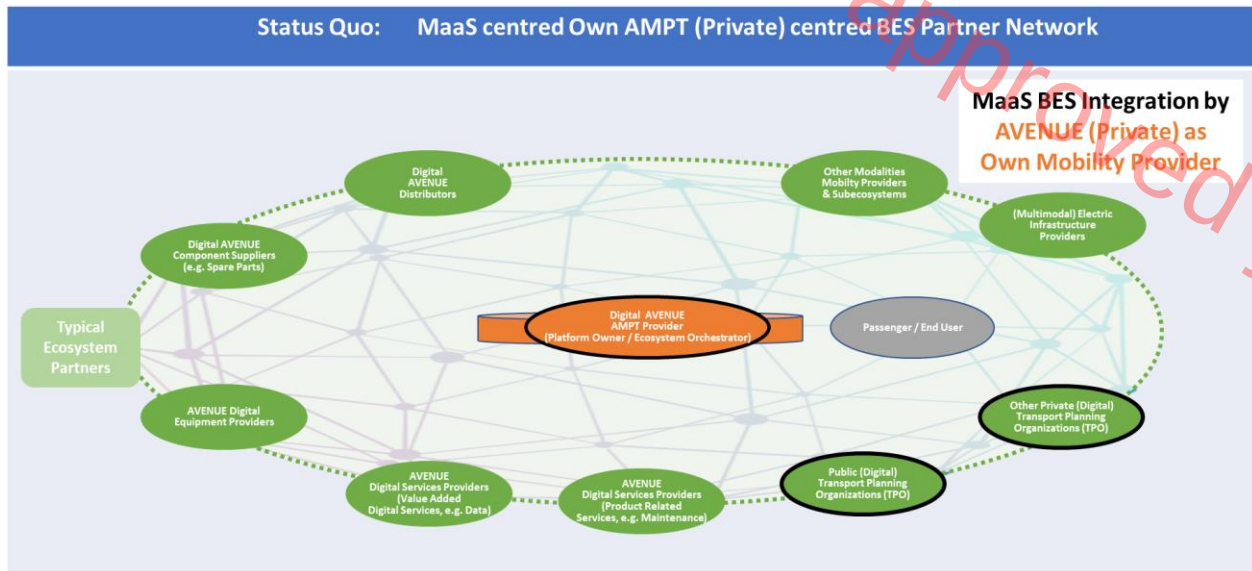


Figure 13. Typical exemplary BES – Partner Network – MaaS BES Integration by AMPT (AVENUE) Provider (Business Scenario 4)

3.2.2 Business Opportunities (Business Scenario 4)

The most promising Business Opportunities BO5, BO6, BO7 and BO8 for this Business Scenario has been characterized by a 'staircase' of sequential core questions:

3.2.2.1 Business Opportunity – Collaboration with Public MaaS Sub-BES

The hypothesis for the Business Opportunity – **Collaboration with Public MaaS Sub-BES** of this Business Scenario is that it can be very attractive for AMPT solution providers due to the fact that this is a relatively safe position with competition only at call for public tenders and very advantageous in niche markets or small market segments.

The analysis of this Business Scenario shows that AMPT solution providers can generally apply its whole solution portfolio to the Public MaaS Sub-BES and intensify its partner and niche position by specialization. As a general conclusion it can be determined that this is a very attractive Business Opportunity with long-term perspectives.



Figure 14. Business Opportunity Staircase – Collaboration with Public MaaS Sub-BES (Business Scenario 4)

3.2.2.2 Business Opportunity – Collaboration with Private MaaS Sub-BES

The hypothesis for the Business Opportunity – **Collaboration with Private MaaS Sub-BES** of this Business Scenario is that it can be as well very attractive for AMPT solution providers due to the fact that the AMPT providers can create themselves a close relationship position with the Private MaaS orchestrator by specializing on complementary offerings or complementing the offering of other partners by trustful relationship and high quality performance e.g. in niche markets or small market segments.

The analysis of this Business Scenario shows that AMPT solution providers can generally apply its solution portfolio to the Private MaaS Sub-BES and intensify its partner and niche position by complementary specialization and high performance.

As a general conclusion it can be determined that this is also a very attractive Business Opportunity with long-term perspectives.



Figure 15. Business Opportunity Staircase – Collaboration with Private MaaS Sub-BES (Business Scenario 4)

3.2.2.3 Business Opportunity – Competition within Public (A) or Private (B) MaaS Sub-BES

The hypothesis for the Business Opportunity – **Competition within Public (A) or Private (B) MaaS Sub-BES** within this Business Scenario is that it can be a very competitive situation for AMPT solution providers to be one among other AMPT solution partners within a Public (A) or Private (B) MaaS Sub-BES which requires dedicated AMPT competition or innovation strategies for achieving significant USPs.

The analysis of this Business Scenario shows that AMPT solution providers can generally apply its solution portfolio to the Public (A) or Private (B) MaaS Sub-BES but have to compete with other AMPT solution providers by defining promising USP focused strategies in competition (e.g. cost/performance/outpacing/etc. leadership), technical and business innovation, markets, etc.. As a general conclusion it can be determined that this – born from necessity - is also a challenging Business Opportunity characterized by innovation pressure and striving for sustainable competition advantages (USPs).

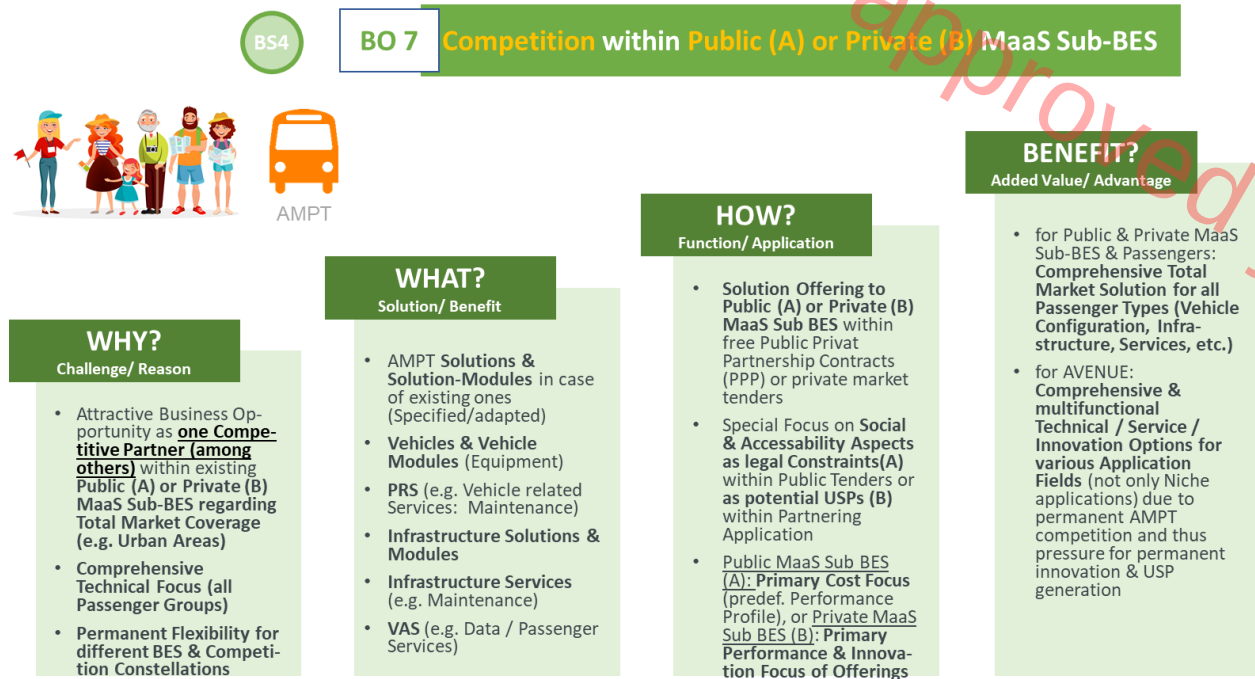


Figure 16. Business Opportunity Staircase – Competition with Public or Private MaaS Sub-BES (Business Scenario 4)

3.2.2.4 Business Opportunity – Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES

The hypothesis for the Business Opportunity – **Competition / Own (Private MaaS BES with other (Private & Public) MaaS Sub-BES)** within this Business Scenario is that it can be a very competitive and challenging but nevertheless attractive situation for AMPT solution providers to be one among other competitor AMPT solution partners within a common Private (A) & Private (B) orchestrated MaaS Sub-BES and building up an Own MaaS Sub-BES.

The analysis of this Business Scenario shows that AMPT solution providers aim to conquer the whole AMPT market in a combative way to be autarcic, preserve comprehensive technical focus and permanent flexibility towards competitors.

As a general conclusion it can be determined that this entrepreneurial behavior and strategy is characterized by permanent and increasing technical and business innovation and and striving for permanent market success and expansion.

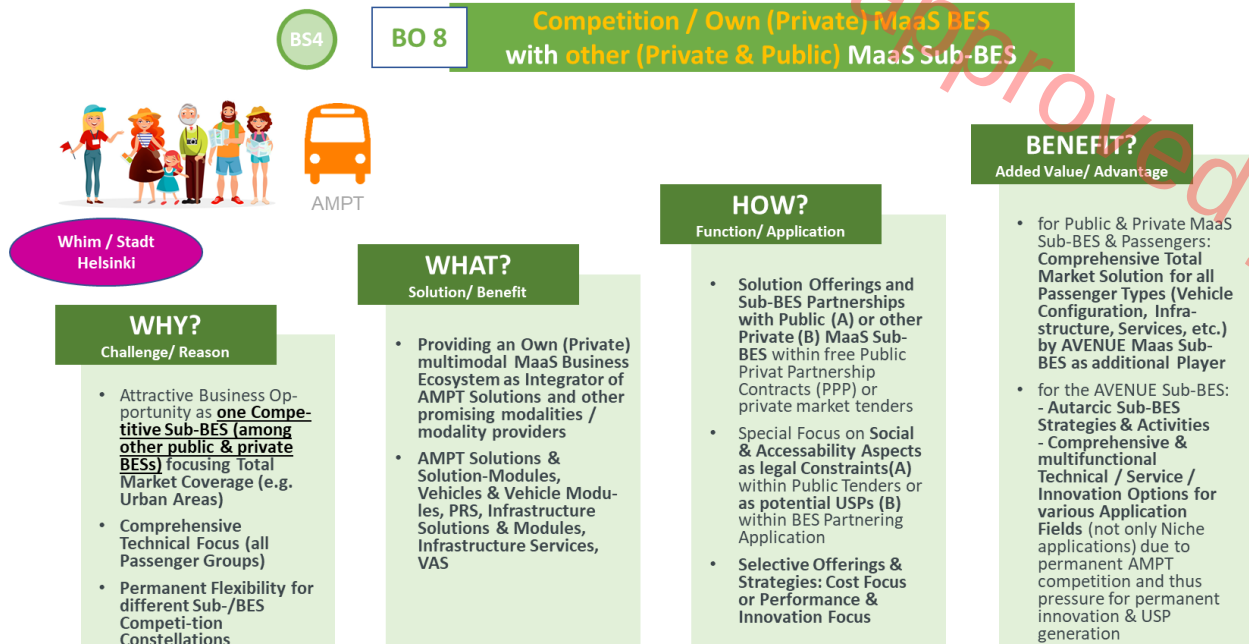


Figure 17. Business Opportunity Staircase – Competition / Own (Private) MaaS Sub-BES (Business Scenario 4)

3.2.3 Business Strategies (Business Scenario 4)

The typical and most promising Business Strategies for the most promising Business Opportunities BO5, BO6, BO7, BO8 within this Business Scenario has been identified by a sequence of strategic core issues that are most relevant for the further definition of future business models. These strategy categories are focused on the typical building blocks of a business model canvas, and additionally highlighting the core innovation strategies relevant for successful conduction of these businesses.

3.2.3.1 Business Strategies – Collaboration with Public MaaS Sub-BES

The hypothesis for the Business Strategies – **Collaboration with Public MaaS Sub-BES** of this Business Scenario is generally that AMPT technology, solution and business strategies are consequently aligned and integrated with the technology, solution and business strategies of the Public MaaS Provider in every facet of the offering portfolio and business model modules.

The analysis of this Business Scenario shows for example that AMPT solution and solution module strategies are consequently specified and adapted to those of the Public MaaS provider in order to utilize this very attractive Business Opportunity with long-term perspectives.

As a general conclusion it can be determined that a consequent strategic alignment to the needs and strategies of Public MaaS Sub-BES orchestrator can be very beneficial in case of success, but also contain a dangerous risk in case of failure.

BS4

BO 5

Collaboration with Public MaaS Sub-BES

ID	BES Strategy Category	Vision / Strategic Goal	Recommended Strategies	Strategy Justification
VO	Value / Offering (Product/Solution/Service) Strategies	Provide offering portfolio strictly compatible with public MaaS provider	• AMPT solutions & solution-modules in case of existing ones (Specified/adapted) • Vehicles & vehicle modules (Equipment) • PRS (e.g. Vehicle related services: maintenance) • Infrastructure solutions & modules • Infrastructure services (e.g. Maintenance) • VAS (e.g. Data / Passenger Services)	Need for complete offering portfolio within MaaS Sub-BES
MC	Market / Customer Group Strategies	Strong orientation / alignment at public MaaS provider (complementary or synchronously)	Focus core partnership with public MaaS integrator in case of public MaaS BES	Long term business stability
CA	Competition & Competition Advantage/USPs Strategies	Leading public transport specific USP position	Generation of USPs in social & accessibility & security/safety aspects/features	Free-of-competition market in predefined areas of responsibility after contracting
SD	Distribution & Sales Channel Strategies (incl. Partnering)	Win public tenders	Public Private Partnership Contracts (PPP)	Secure, long term contracts in a highly subsidized sector
RD	R&D/Production & Technology/Competency Strategies (incl. Partnering)	Long term partnership by common / coordinated (complementary or same) technology R&D	Development of social & accessibility & security/safety (People/Data) focused products / VAS / PRS, focus on robust & functional product features & services PRS/VAS & technologies	Main emphasis of public transportation on social & accessibility & security/safety
FI	Financing & Invest Strategies	Long term partnership by common (complementary or same) technology invest	Invest in social & Accessibility & security/safety technologies/features/offers	Main emphasis of public transportation on social & accessibility & security/safety
CO	Cost Strategies	Cost Leadership	Target Costing Strategy (Primary Cost Focus or Low Cost Strategy (predefined Performance Profile))	Inherent to public tender contracts
RE	Revenue Strategies	Long term partnership by common revenues	Common tariff & ticket sales strategy with Public MaaS Provider	Long term business stability
TI	Offering/Technology Innovation Strategies	Leadership in public transportation quality	Strong focus on public PTO adapted improvements and innovations in service and technologies	Long term technology leadership in public transportation for AMPTs
BI	Business/Marketing Innovation Strategies	Successful integration with public MaaS integrator business strategies & models	Strong collaboration (strong adaption to public integrator)	Long term business stability

Figure 18. Business Strategies Table - Collaboration with Public MaaS Sub-BES (Business Scenario 4)

3.2.3.2 Business Strategies – Collaboration with Private MaaS Sub-BES

The hypothesis for the Business Strategies – **Collaboration with Private MaaS Sub-BES** of this Business Scenario is generally that AMPT technology, solution and business strategies are consequently aligned and integrated with the technology, solution and business strategies of the Private MaaS Provider in every facet of the offering portfolio and business model modules.

The analysis of this Business Scenario shows for example that AMPT solution and solution module strategies are – similar to the collaboration with Public MaaS Sub-BES - consequently specified and adapted to those of the Private MaaS provider in order utilize this very attractive Business Opportunity with long-term perspectives.

As a general conclusion it can be determined that a consequent strategic alignment to the needs and strategies of Private MaaS Sub-BES orchestrator can be – similar to the collaboration with Public MaaS Sub-BES - very beneficial in case of success, but also contain a dangerous risk in case of failure.

BS4

BO 6

Collaboration with Private MaaS Sub-BES

ID	BES Strategy Category	Vision / Strategic Goal	Recommended Strategies	Strategy Justification
VO	Value / Offering (Product/Solution/Service) Strategies	Provide offering portfolio strictly compatible with private MaaS provider	• AMPT solutions & solution-modules in case of existing ones (Specified/adapted) • Vehicles & vehicle modules (Equipment) • PRS (e.g. Vehicle related Services: Maintenance) • Infrastructure solutions & modules • Infrastructure services (e.g. Maintenance) • VAS (e.g. Data / Passenger services)	Need for complete offering portfolio within MaaS Sub-BES
MC	Market / Customer Group Strategies	Strong orientation / alignment at private MaaS Provider (complementary or synchronously)	Focus core partnership with private MaaS integrator	Long term business stability
CA	Competition & Competition Advantage/USPs Strategies	Reach a leading USP position specific for public Transport	Generation of USPs in social & accessibility & security/safety aspects/features	Pushing competitors out of the market
SD	Distribution & Sales Channel Strategies (incl. Partnering)	Prevail over competitors who want to enter the ecosystem	Utilize distribution and sales channels of private MaaS Sub-BES	Secure, long term contracts in a highly subsidized sector
RD	R&D/Production & Technology/Competency Strategies (incl. Partnering)	Long term partnership by common / coordinated (complementary or same) technology R&D	Development of social & accessibility & security/safety (People/Data) focused products / VAS / PRS, focus on robust & functional product features & services PRS/VAS & technologies	Main emphasis of Public Transportation on Social & Accessibility & Security/Safety
FI	Financing & Invest Strategies	Long term partnership by common (complementary or same) technology invest	Invest in social & accessibility & security/safety technologies/features/offers	Main emphasis of public transportation on social & accessibility & security/safety
CO	Cost Strategies	Balanced cost performance leadership	Optimized performance cost performance strategy	Achieving a competitive advantage against competitors
RE	Revenue Strategies	Long term partnership by common revenues	Common Tariff & Ticket Sales Strategy with private MaaS Provider	Long term business stability
TI	Offering/Technology Innovation Strategies	Leadership in public transportation quality	Strong focus on public PTO adapted improvements and innovations in service and technologies	Long term technology leadership in public transportation for AMPTs
BI	Business/Marketing Innovation Strategies	Successful integration with private MaaS integrator business strategies & models	Strong collaboration (strong adaption to private integrator)	Long term Business stability

Figure 19. Business Strategies Table - Collaboration with Private MaaS Sub-BES (Business Scenario 4)

3.2.3.3 Business Strategies – Competition within Public (A) or Private (B) MaaS Sub-BES

The hypothesis for the Business Strategies – Competition within Public (A) or Private (B) MaaS Sub-BES of this Business Scenario is generally that AMPT MaaS are one among other AMPT solution partners within a Public (A) or Private (B) MaaS Sub-BES and thus enhanced AMPT strategies for competitive advantages (USPs) and technical / business innovations as well as dedicated adaption to the strategies

Public (A) or Private (B) MaaS Integrator in every facet of the offering portfolio and business model modules are necessary.

The analysis of this Business Scenario shows for example that AMPT solution and solution module strategies could be focusing especially USPs in social & accessibility or security & safety aspects / features as well as collaborative & flexible innovation strategies complementary to the integrator innovation strategies.

As a general conclusion it can be determined that strong USP focus towards the respective competitors within Public (A) or Private (B) MaaS Sub-BES as well as emphases on innovation strategies and integrator alignment are success factors in this business opportunity.

BS4

BO 7 Competition within Public (A) or Private (B) MaaS Sub-BES

ID	BES Strategy Category	Vision / Strategic Goal	Recommended Strategies	Strategy Justification
VO	Value / Offering (Product/Solution/Service) Strategies	Provide offering portfolio which is strictly compatible with public or private MaaS provider	• AMPT solutions & solution-modules in case of existing ones (Specified/adapted) • Vehicles & vehicle modules (Equipment) • PRS (e.g. Vehicle related Services: Maintenance) • Infrastructure solutions & modules • Infrastructure Services (e.g. Maintenance) • VAS (e.g. Data / Passenger Services)	Need for complete offering portfolio within MaaS Sub-BES
MC	Market / Customer Group Strategies	Strong orientation / alignment at public or private MaaS provider (complementarily or synchronously)	- Focus core partnership with privat MaaS integrator in case of private MaaS BES - Focus core partnership with public MaaS integrator in case of public MaaS BES	Long term business stability
CA	Competition & Competition Advantage/USPs Strategies	Achieve leading public transport specific USP position	Extremely strong focus on USPs in social & accessibility & security/safety aspects/features	- High competition among BES partners as well as private and/or public BES - Improved market position in already integrated BES
SD	Distribution & Sales Channel Strategies (incl. Partnering)	- Win public tenders - Prevail over competitors who want to enter the ecosystem	- public private Partnership Contracts (PPP) in case of public MaaS BES - Focus core partnership with privat MaaS integrator in case of private MaaS BES	Secure, long term contracts in a highly subsidized sector
RD	R&D/Production & Technology/Competency Strategies (incl. Partnering)	Long term partnership by common / coordinated (complementary or same) technology R&D	Development of social & accessibility & security/safety (People/Data) focused products / VAS / PRS, focus on robust & functional product features & services PRS/VAS & technologies	Main emphasis of public Transportation on Social & Accessibility & Security/Safety
FI	Financing & Invest Strategies	Long term partnership by common (complementary or same) technology invest	Invest in social & accessibility & security/safety technologies/features/offerings	Main emphasis of public transportation on social & accessibility & security/safety
CO	Cost Strategies	Cost Leadership	Target Costing Strategy (Primary Cost Focus or Low Cost Strategy (predefined Performance Profile)	Achieving a competitive advantage against competitors (and competitive integrator BES)
RE	Revenue Strategies	Long term partnership by common revenues	Common tariff & ticket sales strategy with public or private MaaS provider	Long term business stability
TI	Offering/Technology Innovation Strategies	Leadership in public transportation quality achieve position as innovation leader for offerings/technologies	Strong focus on public PTO adapted improvements and innovations in service and technologies High flexibility and innovativeness in offerings and technologies due to high competition	Achieve significant offering and technology USPs in public transportation for AMPTs
BI	Business/Marketing Innovation Strategies	Successful integration with public or private MaaS integrator business strategies & models Achieve position as innovation leader for business models and marketing	Strong collaboration (strong adaption to public or private integrator) Strong competition to the other private or public integrator High flexibility and innovativeness in business models and marketing issues due to high competition	Achieve significant business models and marketing USPs in public transportation for AMPTs

Figure 20. Business Strategies Table - Competition with Public or Private MaaS Sub-BES (Business Scenario 4)

3.2.3.4 Business Strategies – Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES

The hypothesis for the Business Strategies – Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES of this Business Scenario is generally that AMPT MaaS are one among other AMPT solution partners within a Public (A) or Private (B) MaaS Sub-BES, but striving for building up an Own MaaS Sub-BES.

The analysis of this Business Scenario that dedicated entrepreneurial AMPT strategies for development of an own (private) multimodal MaaS BES as integrator (orchestrator) of AMPT solutions and other promising modalities and offerings (services, infrastructures, etc.) together with innovation / development strategies for achieving competitive advantages (USPs) are necessary.

As a general conclusion it can be determined that strategies for entrepreneurial technology and business innovations for building up an own MaaS BES as well as simultaneous competition focused USP strategies are the focus of this strategy concept.

BS4

BO 8

**Competition / Own (Private) MaaS BES
with other (Private & Public) MaaS Sub-BES**

ID	BES Strategy Category	Vision / Strategic Goal	Recommended Strategies	Strategy Justification
VO	Value / Offering (Product/Solution/Service) Strategies	Provide multimodal offering portfolio with AMPT as core business Provide multimodal seamless transportation for passengers Run successfully multimodal BES with complementary mobility partners	- Development of an own (Private) multimodal MaaS Business Ecosystem as integrator of AMPT solutions and other promising modalities / modality providers - Development of an own platform and services for MaaS BES - Further development of AMPT solutions & solution-modules as core modality of the MaaS BES	Attractive Business Opportunity for own MaaS BES Available partners and competences for a complete multimodal offering portfolio
MC	Market / Customer Group Strategies	Successful collaboration with complementary MaaS BES partners for seamless multimodal transportation	Provide attractive MaaS BES for potential partners Focus on markets and customers (private and public PTOs) for multimodal transportation	Multimodal seamless transportation as holistic business opportunity
CA	Competition & Competition Advantage/USPs Strategies	Leading USP position for multimodal transport Leadership in MaaS BES Leadership in multimodal transportation technologies and offerings	Generation of dedicated USPs for multimodal transportation Generation of dedicated USPs for MaaS BES within high competition with other MaaS BES Generation of USPs in social & accessibility & security/safety aspects/features	Future trend in competition is the success of complete BES Future trend in passenger behavior is multimodal seamless transportation
SD	Distribution & Sales Channel Strategies (incl. Partnering)	Long term contracts in a highly competitive sector	Focus on private and public tenders with MaaS BES offerings and solutions	Secure, long term businesses and sales channels
RD	R&D/Production & Technology/Competency Strategies (incl. Partnering)	Long term successful R&D/Production/Development partnerships within MaaS BES	R&D and technology innovation for platforms and platform services Development of BES networks and tools Further development and innovation in AMPT offerings and solutions	Basic requirements for MaaS BES development
FI	Financing & Invest Strategies	High profitability of own MaaS BES	Invest in AMPT businesses / Platform development / MaaS BES development Finance from various business revenues from MaaS BES and AMPT Offerings/Solutions businesses	Main emphasis on success factors for MaaS BES
CO	Cost Strategies	Costs are covered by revenues by far (high profitability)	Cost strategy is depending on individual priorities of MaaS BES maturity level / evolution status	Reasonable cost expenditures for necessary MaaS BES development tasks
RE	Revenue Strategies	Maximum accessible revenues in highly competitive MaaS markets	Focus on revenues of AMPT business, MaaS BES partner business as well as public and private PTO tenders	High revenue volumes existing at multimodal MaaS markets
TI	Offering/Technology Innovation Strategies	Leadership in multimodal seamless MaaS BES offerings/solutions/technologies	Innovation focus on AMPT offering technology/solutions Innovation focus on MaaS BES platforms and services Innovation focus on collaborative MaaS BES transportation offerings	Basic requirement for the success of AMPT business, MaaS BES development and multimodal transportation
BI	Business/Marketing Innovation Strategies	Leadership in multimodal seamless MaaS BES businesses and marketing concepts	Innovation focus on AMPT business concept Innovation focus on integrated MaaS BES business concepts	Basic requirement for the success of MaaS and AMPT business

Figure 21. Business Strategies Table – Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES (Business Scenario 4)

3.2.4 Business Models (Business Scenario 4)

The typical Business Models BO5, BO6, BO7, BO8 (characterized by its complementary systemically interacting modules and its integrating logical story) for this Business Scenario derived from and guided by the previously identified Business Strategies have been defined based on the business model canvas template defined in chapter 3.2.

Using these exemplary and suggested business models is important to notice that they have to be regarded as business model categories, aggregating multiple business model subtypes for each module mentioned and suggested from the literature (e.g. St. Gallen Business Model Navigator and others¹):

3.2.4.1 Business Model and Business Model Story – Collaboration with Public MaaS Sub-BES

The hypothesis for the Business Model – **Collaboration with Public MaaS Sub-BES** of this Business Scenario is that the guiding collaborative and synergetic strategy approach leads to a reciprocal alignment and integration of all business model modules with those of the Public MaaS Integrator in every facet of the offering portfolio.

The analysis of this Business Scenario shows that all modules of the business model from Public MaaS Sub-BES are impacting and integrated with the corresponding modules of the AMPT business model. Besides solution alignments (value proposition module), especially close

¹ <https://www.alexandria.unisg.ch/224941/7/Business%20Model%20Navigator%20working%20paper.pdf>

collaborations in the delivery and customer module (e.g. common solution development processes, common marketing and sales activities) are relevant for partnership and business success.

As a general conclusion it can be determined that a consequent integration of AMPT business models with those from Public MaaS Sub-BES integrators are the key for a successful BES partnership.

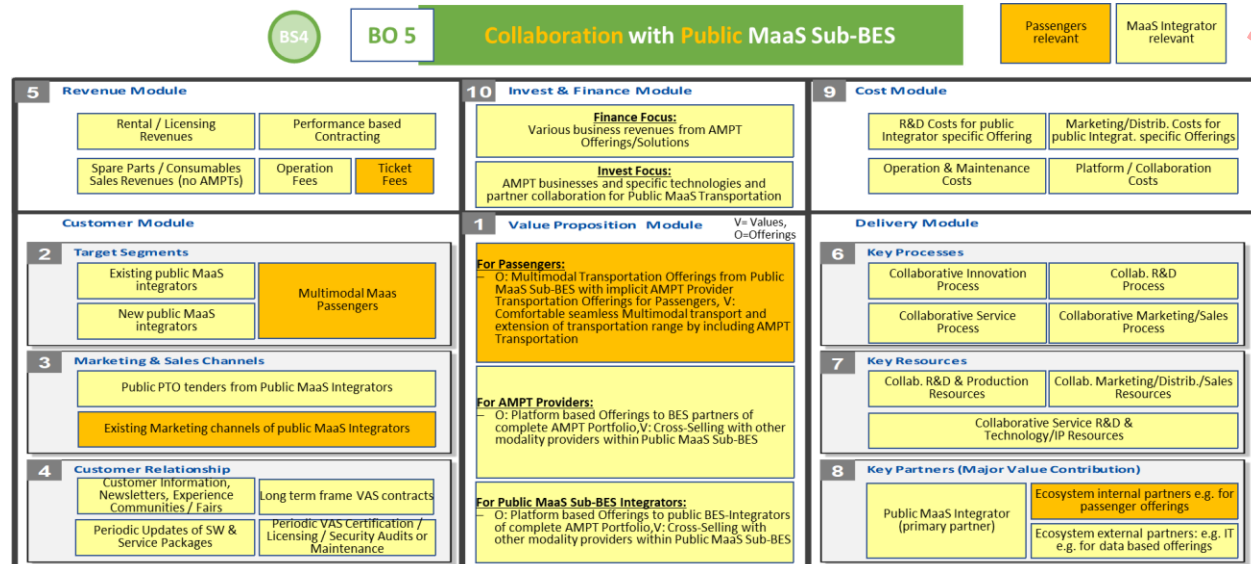


Figure 22. Business Model - Collaboration with Public MaaS Sub-BES (Business Scenario 4)

The hypothesis for the Business Model Story – **Collaboration with Public MaaS Sub-BES** of this Business Scenario is that a successful Win-Win collaboration of an AMPT provider within a Public MaaS Bus-BES is not only based on the alignment of AMPT business model modules (offerings, processes, innovations, etc.) with those of the Public MaaS Bus-BES integrator but also with the reciprocal alignment and integration of all business model modules.

The analysis of this Business Scenario shows that all modules of the business model from the Public MaaS Sub-BES are impacting and integrated (e.g. multimodal transportation offering portfolio complementation) with the corresponding modules of the AMPT business model.

As a general conclusion it can be determined that a consequent integration of AMPT business models with those from Public MaaS Bus-BES are the key for a successful BES collaboration / partnership.

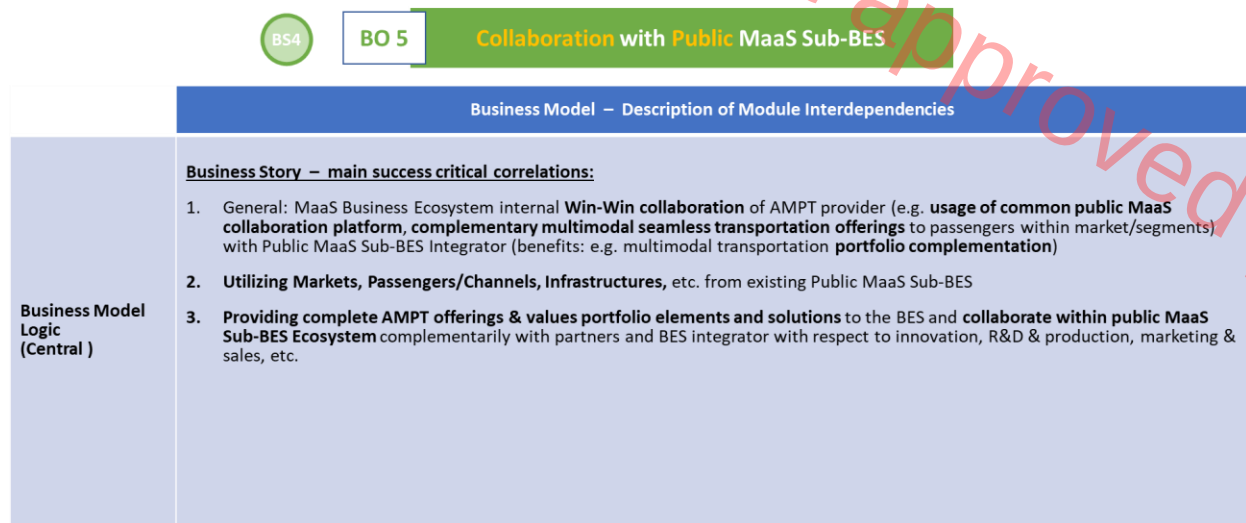


Figure 23. Business Model Story - Collaboration with Public MaaS Sub-BES (Business Scenario 4)

3.2.4.2 Business Model and Business Model Story – Collaboration with Private MaaS Sub-BES

The hypothesis for the Business Model – **Collaboration with Private MaaS Sub-BES** of this Business Scenario is – analog to the previous ‘Collaboration with Public MaaS Sub-BES’ - that the guiding collaborative and synergetic strategy approach leads to a reciprocal alignment and integration of all business model modules with those of the Private MaaS Integrator in every facet of the offering portfolio.

The analysis of this Business Scenario shows that all modules of the business model from Private MaaS Sub-BES are impacting and integrated with the corresponding modules of the AMPT business model. Besides solution alignments (value proposition module) especially close collaborations in the delivery and customer module (e.g. common solution development processes, common marketing and sales activities) are relevant for partnership and business success.

As a general conclusion it can be determined that a consequent integration of AMPT business models with those from Private MaaS Sub-BES integrators are the key for a successful BES partnership. The generally elaborated Business Model for ‘Collaboration with PRIVATE MaaS Sub-BES’ for a MaaS centred BES is represented in the following:

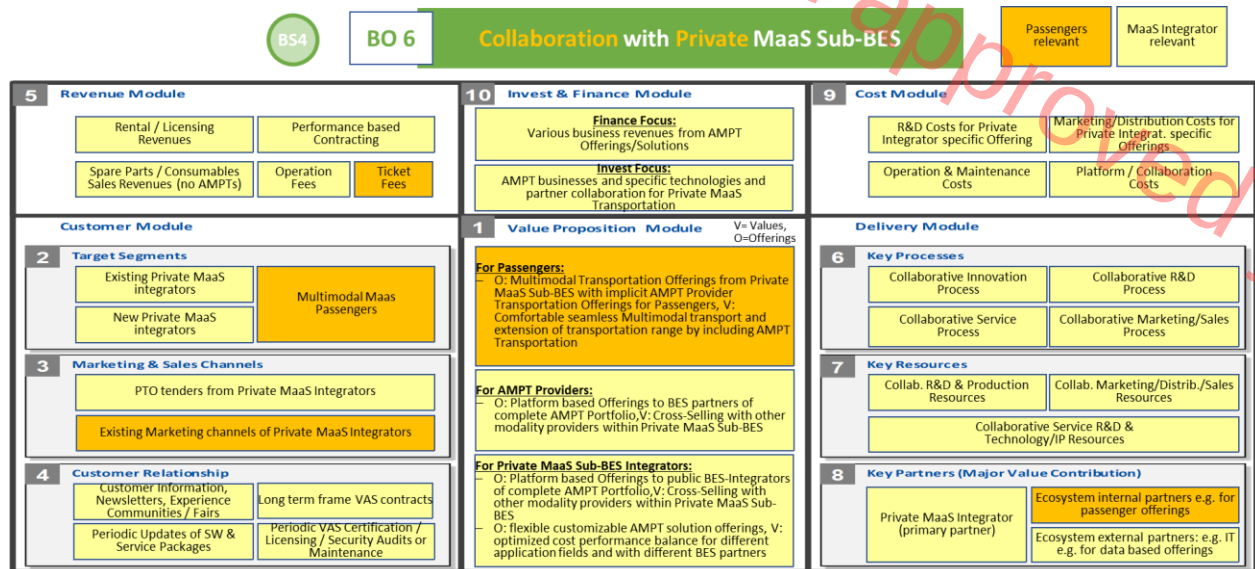


Figure 24. Business Model - Collaboration with Private MaaS Sub-BES (Business Scenario 4)

The hypothesis for the Business Model Story – **Collaboration with Private MaaS Sub-BES** of this Business Scenario is that - analogue to the collaboration with Public MaaS Sub-BES - a successful Win-Win collaboration of an AMPT provider within a Private MaaS Bus-BES is not only based on the alignment of AMPT business model modules (offerings, processes, innovations, etc.) with those of the Private MaaS Bus-BES integrator but also with the reciprocal alignment and integration of all business model modules.

The analysis of this Business Scenario shows that all modules of the business model from the Private MaaS Sub-BES are impacting and integrated (e.g. multimodal transportation offering portfolio complementation) with the corresponding modules of the AMPT business model.

As a general conclusion it can be determined that a consequent integration of AMPT business models with those from Private MaaS Bus-BES are the key for a successful BES collaboration / partnership.

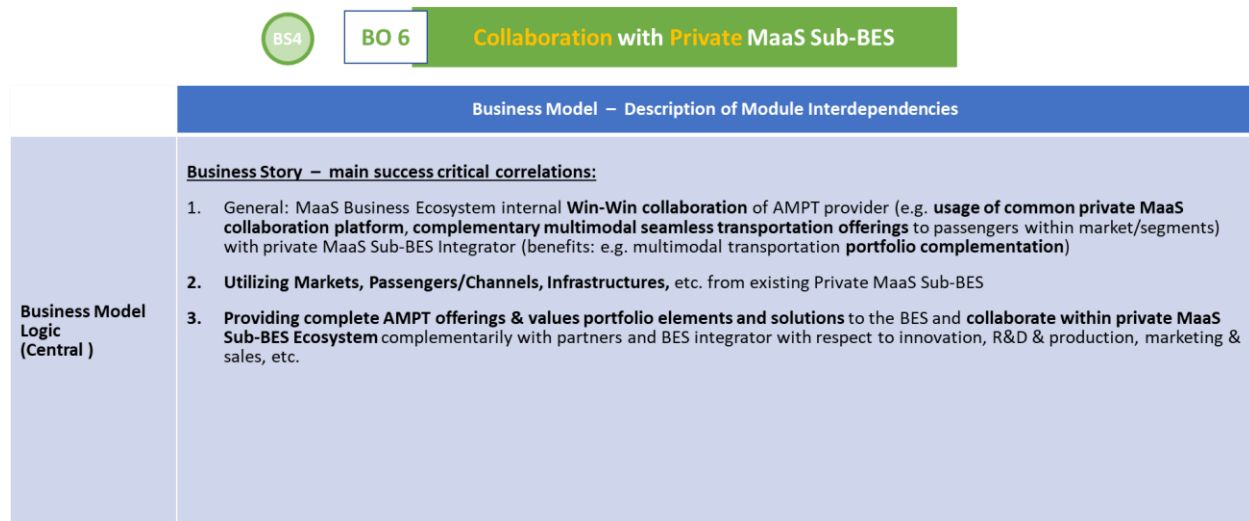


Figure 25. Business Model Story - Collaboration with Private MaaS Sub-BES (Business Scenario 4)

3.2.4.3 Business Model and Business Model Story – Competition with Public (A) or Private (B) MaaS Sub-BES

The hypothesis for the Business Model – **Competition with Public (A) or Private (B) MaaS Sub-BES** of this Business Scenario is that the competitive strategy approach with other AMPT providers within Public (A) or Private (B) MaaS Sub-BES leads to a strong emphasis on technical / business innovation and USP generation of all business model modules towards AMPT competitors and simultaneously to a close business model module alignment with the respective Public (A) or Private (A) MaaS Integrator in every facet of the offering portfolio.

The analysis of this Business Scenario shows that strong innovative and especially USP-driven / competitive AMPT transportation offerings have to be developed and provided to customers (Value / Delivery / Customer modules) and at the same time a clear alignment and integration of all modules with those of Public (A) or Private (B) MaaS Sub-BES are focused.

As a general conclusion it can be determined that both general AMPT strategies and emphases have to be implemented into the AMPT business model and its modules: the competitive (innovation / USP) focus as well as the alignment / integration focus. The generally elaborated Business Model for ‘Competition with PUBLIC or PRIVATE MaaS Sub-BES’ for a MaaS centred BES is represented in the following:

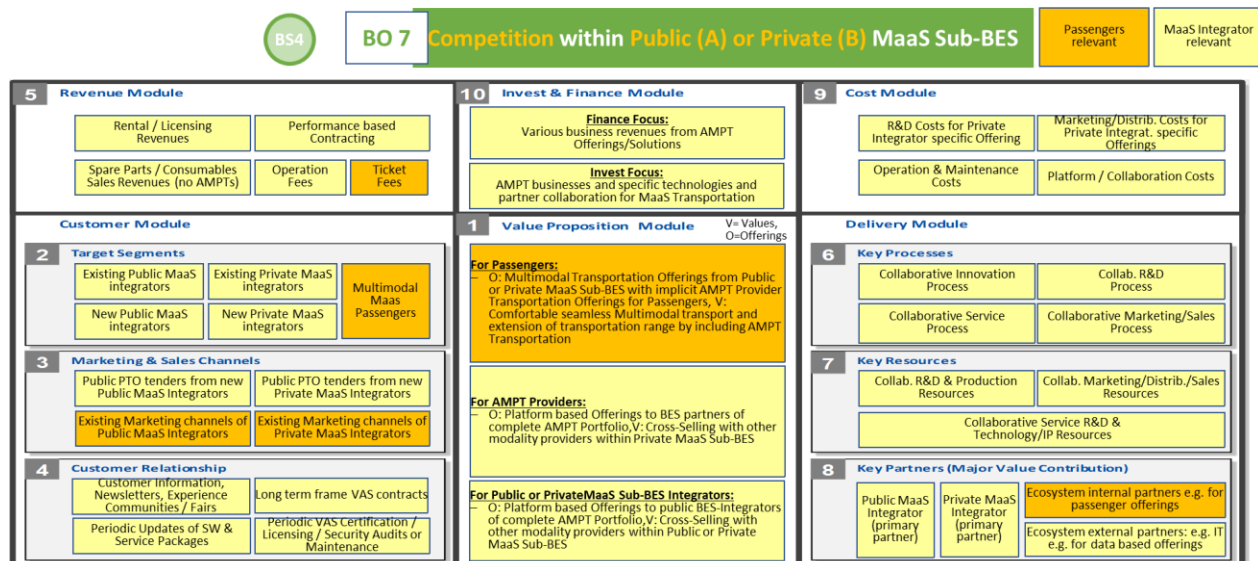


Figure 26. Business Model - Competition with Public or Private MaaS Sub-BES (Business Scenario 4)

The hypothesis for the Business Model Story – **Competition with Public (A) or Private (B) MaaS Sub-BES** of this Business Scenario is that competition with other AMPT providers within a public (A) or private (B) MaaS Sub-BES requires strong innovations and USPs in every module of the business model as well as a strong alignment with the business model modules of the AMPTs (regarding offerings, processes, etc.) with those of the Public (A) or Private (B) MaaS Sub-BES integrator.

The analysis of this Business Scenario shows that all modules of the business models from the Public (A) or Private (B) MaaS Sub-BES are impacting and integrated (e.g. multimodal transportation offering portfolio complementation) with the corresponding modules of the AMPT business model, but each one of the modules have to strive for innovative USPs as well as total business models as USPs.

As a general conclusion it can be determined that a consequent integration of AMPT business models with those from Public (A) or Private (B) MaaS Bus-BES and simultaneously competition orientation within these are the key for a successful BES collaboration / partnership.

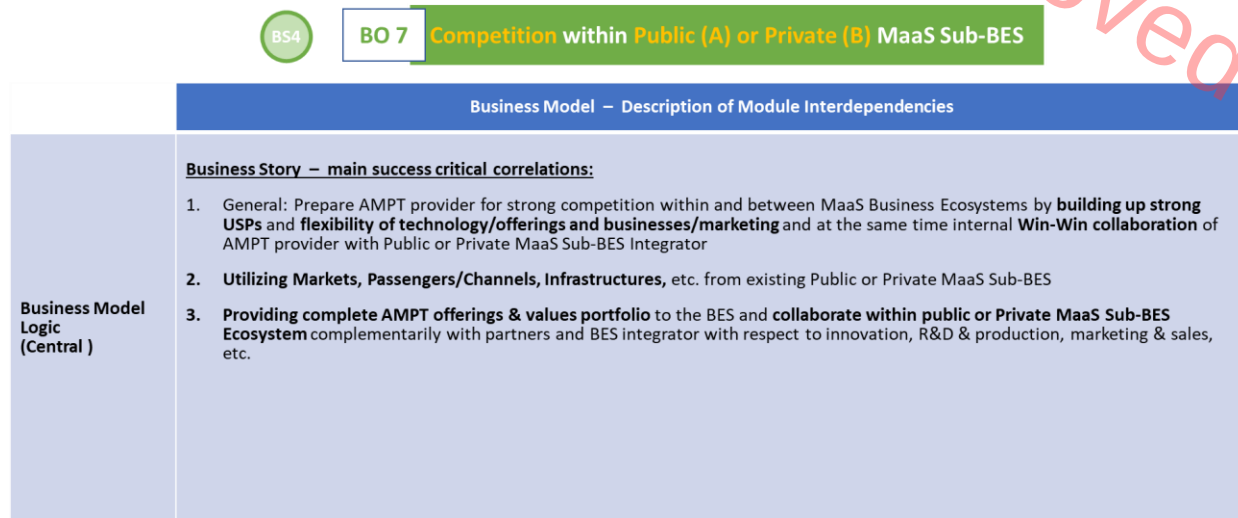


Figure 27. Business Model Story - Competition with Public or Private MaaS Sub-BES (Business Scenario 4)

3.2.4.4 Business Model and Business Model Story – Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES

The hypothesis for the Business Model – **Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES** of this Business Scenario is that the combined entrepreneurial approach and the competitive strategy with other Private & Public MaaS Sub-BES are success relevant for AMPT offering providers.

The analysis of this Business Scenario shows that AMPT providers have to develop and provide (delivery & customer module) - besides AMPT offerings - also platforms and platform values (value proposition module) to their potential private and public MaaS BES participants, who themselves have to provide multimodal transportation offerings and solutions to the MaaS BES. Additionally, the whole entrepreneurial Own / AMPT MaaS BES has to focus offering / technology / business innovations and USPs focusing the existing competition with other (private and public) MaaS Sub-BES.

As a general conclusion it can be determined that both AMPT strategies and emphases have to be implemented into this AMPT business model and its modules: a. the entrepreneurial MaaS BES focus, and b. the competitive (innovation / USP) focus with other (private and public) MaaS Sub-BES. The generally elaborated Business Model for ‘Competition / Own (Private) MaaS BES with other (PRIVATE & PUBLIC) MaaS Sub-BES’ for a MaaS centred BES is represented in the following:

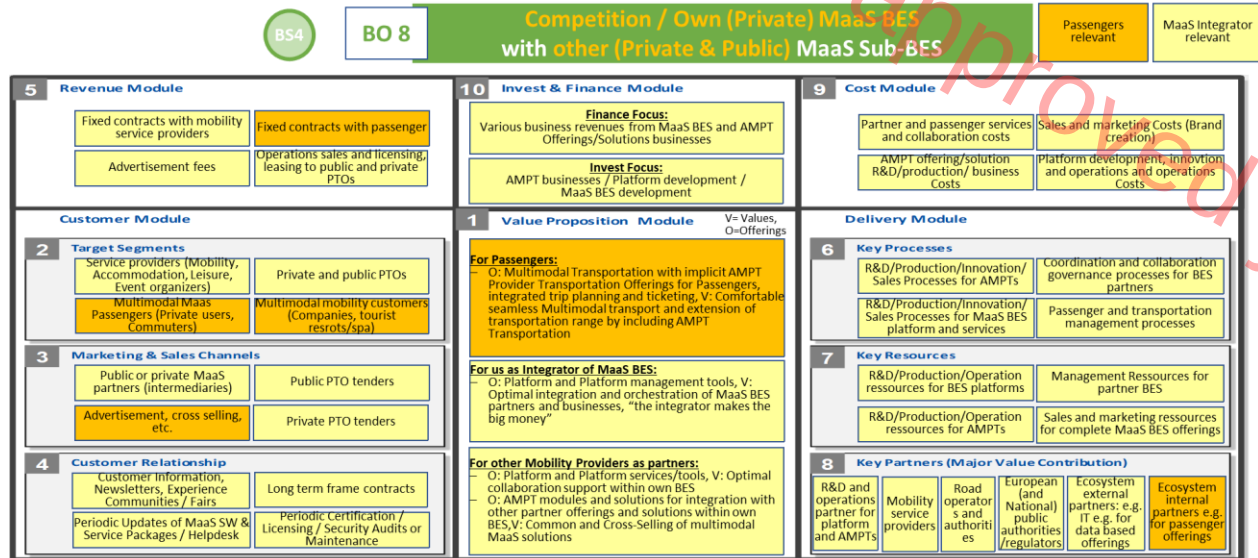


Figure 28. Business Model - Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES (Business Scenario 4)

The hypothesis for the Business Model Story – **Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES** of this Business Scenario is that competition with other AMPT providers or other (private & public) MaaS Sub-BES requires innovative and strong complementary BES partners with USPs for every module of the business model as well as a flexible and efficient BES platform and network management system.

The analysis of this Business Scenario shows that all modules of the own (private) MaaS BES business model require technological and/or business USP's and a consistent business story for the AMPT as well as for the total MaaS BES business model.

As a general conclusion it can be determined that a consistent and powerful business model story for the AMPT business as well as for the whole own (private) MaaS BES is required and is the key for entrepreneurial success with a MaaS BES.

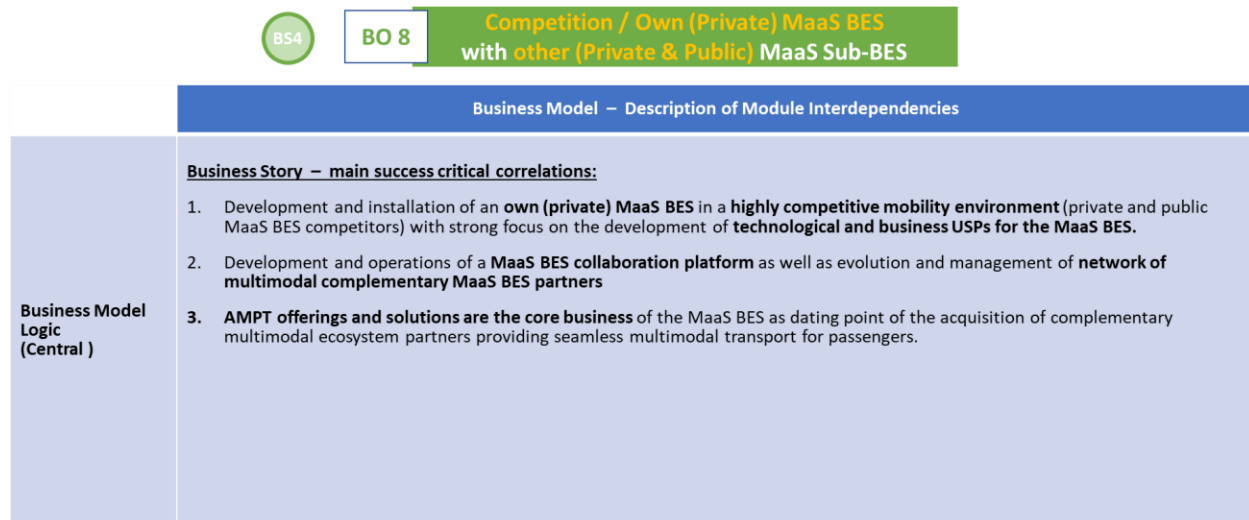


Figure 29. Business Model Story - Competition / Own (Private) MaaS BES with other (Private & Public) MaaS Sub-BES (Business Scenario 4)

3.3 Final Remarks on Business Scenarios

For the practical application of the elaborated results on all **4 Design Steps for Strategic Business Planning for the Business Scenarios BS2, BS3, BS4** – it is recommended for a future AVENUE entrepreneur to identify and analyze the concrete focus use case adapting these Design Steps as a systematic guide and identify, analyze and select the business scenarios, business opportunities, business strategies and business models suggested stepwise iteratively for relevance. On each Design Step level further iterative adaption, discussion and refinement processes have to be conducted and decisions have to be made before a final strategic business planning concept for the concrete use case can be compiled and implemented.

4 Business Cases for Scenario 1 (AVENUE demonstrators and pilots)

4.1 Recapitulation from D8.4

In the previous (second) iteration of the economic deliverable (D8.4), Antonialli et al. (2021) presented the preliminary Excel version of the **EASI-AV**® simulation tool to access, at the local level, the economic impact of services with Automated Shuttles for Collective Transport. Further details on how the tool was conceived can also be found on (Antonialli, Mira-Bonnardel, Bulteau, 2021).

The **E**conomic **A**ssessment of **S**ervices with **I**ntelligent **A**utomated **V**ehicles simulation tool (EASI-AV®) was designed with the objective of helping policy makers in cities, regions, Public Transport Operators (PTOs), and even others interested stakeholders that may wish to implement services with Automated Shuttles (e.g.: private corporate sites or university/hospital campuses).

The tool aims to evaluate the economic impact of different implementation scenarios - supply-pushed or demand-pulled strategy, for both fixed road sites (as the Avenue sites of Lyon, Luxembourg, and Copenhagen) or geofenced on-demand service (as Geneva's Belle Idée site) – offering a comparison between an automated service and any other transport mode.

The preliminary version of EASI-AV® detailed on D8.4., was designed using a spreadsheet software with manual data entry and automated calculation of results, allowing for:

- Service contextualization.
- Fixed route fleet size dimensioning.
- Total cost of ownership assessment.
- Local externalities assessment.

Figure 30, depicts D8.4's global results from the AVENUE demonstrator sites based on the simulation outcomes from EASI-AV®.

	Luxembourg (Sales-Lentz)		Geneva (TPG)	Copenhagen/Oslo (Holo)		Lyon (Keolis)	AVERAGE
	<u>Pfaffenthal</u>	<u>Contern</u>	<u>Meyrin</u>	<u>Nordhavn</u>	<u>Ormøya</u>	<u>Décines</u>	<u>Avenue</u>
CAPEX							
Single shuttle	346.250,00 €	346.250,00 €	333.000,00 €	472.000,00 €	472.000,00 €	1.070.000,00 €	506.583,33 €
Fleet total	626.950,00 €	346.250,00 €	621.000,00 €	472.000,00 €	784.000,00 €	1.520.000,00 €	728.366,67 €
OPEX							
Single shuttle	124.166,96 €	81.033,48 €	274.860,00 €	239.000,00 €	357.075,97 €	259.286,00 €	222.570,40 €
Fleet total	243.533,92 €	81.033,48 €	547.720,00 €	239.000,00 €	676.951,94 €	488.572,00 €	379.468,56 €
KPIs**							
Cost passenger/km	0,98 €	0,40 €	2,18 €	0,84 €	0,81 €	0,73 €	0,99 €
Cost shuttle/km	14,66 €	6,03 €	32,77 €	12,58 €	12,14 €	10,95 €	14,86 €

Figure 30. Total Cost of Ownership of the AVENUE service calculated on EASI-AV®

** Values comprise the Total Cost of Ownership considering the CAPEX, OPEX and Local externalities.

At the time of writing D8.4, EASI-AV[®] was still being finalized. The tool's on-demand fleet size calculation was still being developed as well as the final part of the service's breakeven calculation and business model economic feasibility. At last, a web application version of the tool was being developed to make it widely accessible and easier to use when compared to the Excel spreadsheet version. Over the next subsections these elements are presented and detailed.

4.2 On-demand fleet size dimensioning

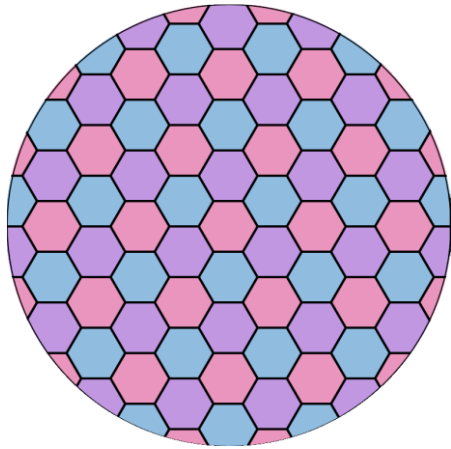
Differently from traditional fixed route buses, on-demand services do not need to follow fixed routes nor a fixed schedule. The service generally consists of vehicles that are smaller than traditional buses, and on less densely populated areas than cities (Alessandrini et al., 2015). Hence, calculating the ideal fleet size has proven a challenge for PTOs and city transport authorities. Mulley et al. (2012) precisely detail the many difficulties faced by these services, such as legal barriers to be overcome, as well as economic, practical, and social constraints for these services' implementation.

Indeed, problems of implementation can also lead to high operating costs, which make the practice difficult to maintain as rentable. But as AVENUE's Belle Idée site has been showing us, with technical improvements, and changing habits, on-demand services will gain strength in the coming years.

However, it is impossible to give an exact dimensioning without carrying out simulations directly of the area to be covered (urban center, peri urban area, rural area, etc.). Indeed, the geometry of the roads, but especially the spatial distribution of the users and the variability of the demand are data that are difficult to access. If such data are available, the studies carried out by Bruni, Guerriero and Beraldi (2014), and Chevrier et al. (2012) can be quite useful to create a simulation adapted to the geometry of the city. However, these studies present generalist models, simulating fleets for large territories (e.g., a city) and not for a more precise service or area with a limited number of vehicles (as is the case with the AVENUE project and other precise demonstrations). In this regard, with the aid of Enzo Gennari and Antoine Zurcher (3rd year engineering students from École Centrale Lyon), we have developed an algorithm to dimension the ideal fleet size for automated on-demand public transport services. As it is not our scope to describe the architecture of the model in this deliverable, full details of how the model was built and tested can be found in the working paper Gennari and Zurcher (2022, in press). In general terms, the proposed model considers as input variables:

- Surface area of the service (in km²).
- Average number of users per day.
- Average vehicle speed (in km/h).
- Maximum passenger capacity of the vehicle.
- Average waiting time for the vehicle (in minutes).
- Maximum distance to walk to a bus stop (in meters).

Given the difficulty of obtaining and processing complex data regarding the geometry of the cities and service implementation areas, the model starts from the simplified premise of a circular geometry (Balac, Hörl & Axhausen, 2020), which is divided into hexagons where at each one's center a hypothetical bus stop is represented (Figure 31).



$$N_{stops} = \frac{2S}{3\sqrt{3} \cdot d_{stops}}$$

Where:

S = surface area of the service (km²)

d_{stops} = maximum walking distance to a stop (meters)

Figure 31. Hexagonal tiling of on-demand service area and foreseen stops

Source: adapted from Genarri & Zurcher (2022, in press).

As such, based on the geometry of the problem, the model takes into account the following intermediate calculation variables (by referencing the study proposed by Chevrier et al. 2012):

- Number of stops.
- Average distance of journeys.
- Route deviation coefficient.
- Proportion of stops served.

Passenger demand is modeled by the sum of two poisson distributions, one for each daily transport peak (morning and evening), as done in (Winter et al., 2018). Once these calculations are done, the algorithm starts the modeling of the fleet size considering a single vehicle/day. The passenger flow (boarding and deboarding) is calculated keeping in mind the proportion of the demand that cannot board once capacity is reached. If, during the day, a portion of passengers had to wait longer than the accepted waiting time, one extra vehicle is added to the simulation. This pattern goes on until there are enough buses to cover all the demand, without the waiting time exceeding acceptable threshold.

In order to test the robustness of the model, we Applied it to three cities of different sizes: Écully, Aix-les-Bains and Mulhouse, all in France. As detailed in Table 1, the results fleet size calculation yielded in 7 full size buses (100 passengers) for Écully, 10 for Aix-les-Bains and 22 for Mulhouse. Such results are consistent with the size of the cities and their respective populations, thus validating the proposed model.

Table 1. EASI-AV[®] on-demand fleet size calculation outcomes

City	Écully	Aix-les-Bains	Mulhouse
Surface (km ²)	8.45	12.62	22.18
Number of users	1800	2900	10800
Service speed (km/h)	25	25	25
Vehicle capacity	100	100	100
Waiting time (min)	30	30	30
Distance to stops (meters)	500	500	500
Number of stops	13	19	34
Journey's avg. distance (km)	1.6	2.1	2.6
Fleet size	7	10	22

Source: adapted from Genarri & Zurcher (2022, in press).

An important feature of this model for on-demand fleet sizing is that it allows a precise result to be obtained using simple and generic variables, thus being easy for any interested actor to use to

simulate this type of service fleet. Thus, this model is suitable for those who do not have the means or the know-how to make a full full-fledged simulation to dimension a network of automated vehicles.

Thus, despite the simplifications and generalizations necessary to create the model, the results prove to be satisfactory and allow decision-makers to continue with the assessment of costs (CAPEX, OPEX and local externalities) and simulation of revenue sources. The next subsection details and exemplifies the current web version of EASI-AV[®], comprising the on-demand fleet size dimensioning.

4.3 EASI-AV[®] web application

In this subsection, we present the beta testing web version of the EASI-AV[®] calculation tool, which can be accessed on the AVENUE project website via the link : <https://h2020-avenue.eu/avenue-economic-calculator/>. We point out that at the time of writing, the version is on beta, still requires some improvements and corrections. However, the tool is already partially operational and allows decision-makers to perform economic simulations and make decisions about the implementation of services with automated vehicles for public transport.

As with the Excel version presented in deliverable D8.4, the web version of the tool is divided into tabs, each containing a specific analysis. Thus, it is possible for the user to perform the calculations in sequential order, or choose the analysis that best suits her/his needs.

Figure 32 presents the welcome screen of the web version of EASI-AV[®]. At the top of the page the calculation tabs are presented, giving the user the flexibility to choose which analysis to perform. In the center of the screen, there is an introductory text, explaining in detail the functionalities and operation of the tool. We emphasize here that each analysis is accompanied by a respective explanatory text, thus, the tool is presented in a simple and clear way, allowing users to perform their analyses autonomously, without depending on specific knowledge and external instructions. Finally, at the bottom of the screen, an option to save/open .JSON files can be seen. This functionality was included in the tool to allow users to save and continue their analysis at a future point in time.

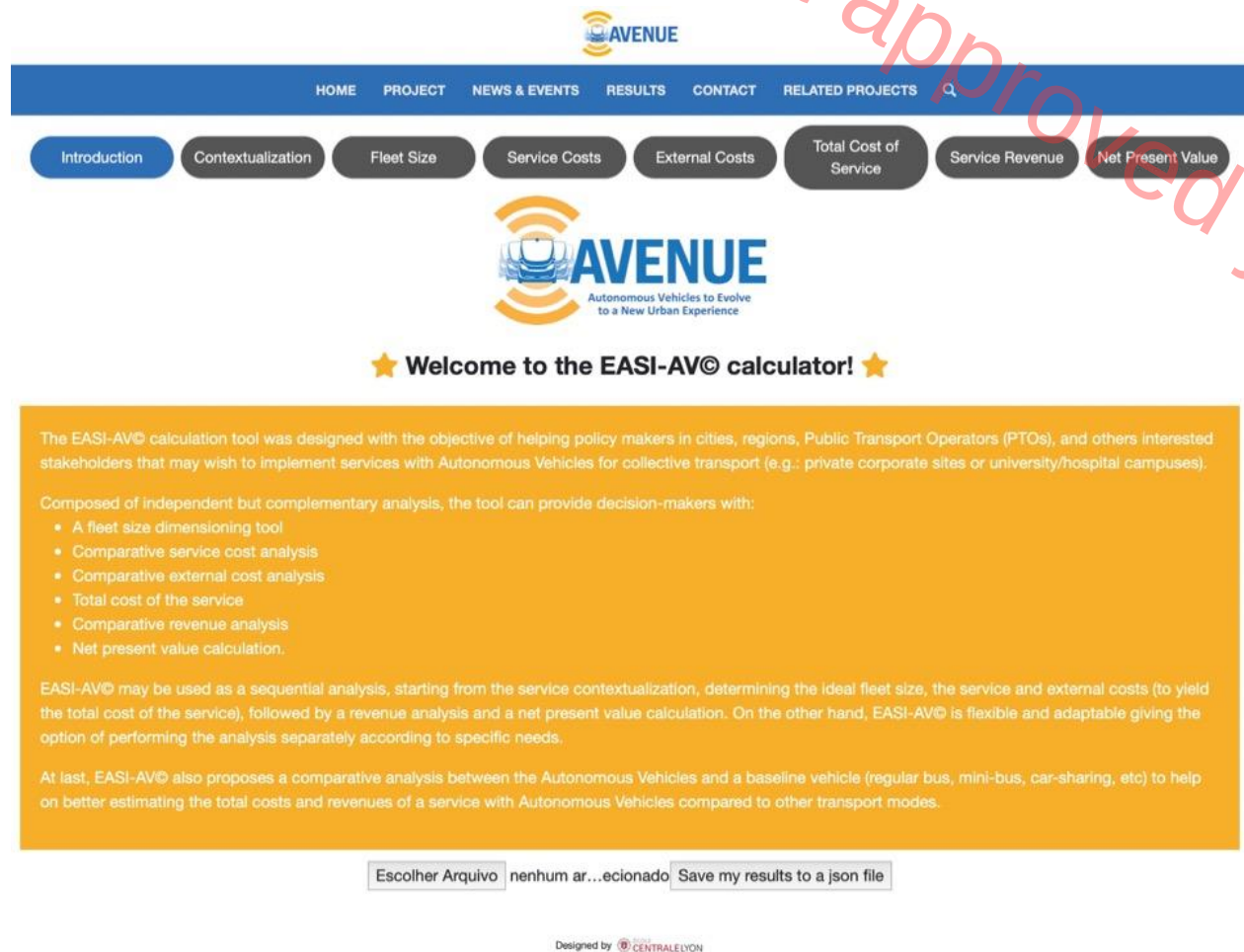


Figure 32. EASI-AV© web application - welcome screen

Source : <https://h2020-avenue.eu/avenue-economic-calculator/>

4.3.1 EASI-AV©: Service contextualization

As with the excel version presented in D8.4, the first tab to be completed concerns the contextualization of the service, with the aim of building more accurate businesses scenarios and allowing decision makers to have a holistic view of the service to be implemented.

As depicted in Figure 33 (with hypothetical data for the Belle-Idée pilot site), EASI-AV© helps to properly frame the territorial typology (urban, peri-urban, rural environments), the zoning (residential, commercial, industrial or mixed areas), define the public transport supply (whether or not public transport services are existent in the area) as well as the area's population density by asking the overall size (km²) and the population in the area. The data entered here is automatically considered by the software for the subsequent analyses.

Framing the territory helps to design the service since population flows schedule differently in a residential area compared to a commercial one. Also, service supply strategies are different in urban or rural areas likewise business model innovations.

Introduction Contextualization **Fleet Size** Service Costs External Costs Total Cost of Service Service Revenue Net Present Value

The purpose of this section is to provide a qualitative overview of the service to be implemented.

Contextualization

» Is there already public transport services being offered in the area where the vehicle will operate?	☐ Yes ☒ No	✓
» What is the environment where the service will be deployed?	☐ Urban ☒ Peri-urban ☐ Rural	✓
» What is the zoning to be served by the service in such environment?	☐ Residential ☒ Commercial ☐ Industrial ☐ Touristic ☐ Mixed	✓
» What is the average extension of the area to be served by the service?	0.38 km ²	✓
» How many workers and consumers are in the area?	1600 workers and consumers	✓

Wonderful! Let's jump to the next tab.

[Fleet Size >>](#)

[Save my results to a json file](#)

Designed by  CENTRALELYON

Figure 33. EASI-AV[®] web application – contextualization page

4.3.2 EASI-AV[®]: Fleet size dimensioning

Once the context is defined, the next step is to dimension the fleet size for the envisioned service. Such fleet sizing is a crucial step because it directly impacts the investment costs and operating costs of the service, so a good assessment of the number of vehicles required helps optimize the total costs.

The excel version presented in D8.4 only described the fixed-route services fleet sizing option, however, the current web version of the tool incorporates the on-demand services fleet sizing option (as detailed in section 4.2).

Figure 34, presents the input variables for fleet sizing for the fixed-route services option (for further details and examples for this calculation model, please refer to D8.4 pages 68-70). Figure 35, on the other hand, presents the input variables for fleet sizing for the on-demand services option. As an example, we have completed it hypothetical data for the Belle-Idée site.

Once all the input data is completed, simply advance to the results page (shown in Figure 36), which displays not only the estimated fleet size for the service (2 automated shuttles), but also other useful indicators for the operators, such as: estimated maximum distance of a journey; average route deviation time per vehicle; average total travel time per journey; estimated total kilometers traveled by each vehicle per day, month, and year.

Introduction Contextualization **Fleet Size** Service Costs External Costs Total Cost of Service Service Revenue Net Present Value

» How will the fleet be used? ☒ Traditional (fixed route) ☐ On demand ☒

Please provide some General Parameters to begin the calculation ✖

» What is the average ONE-WAY route length?	km	✖
» What is the depot distance from the operating site?	km	✖
» What is the number of vehicle's stops/stations?	stops/stations	✖
» What is the average duration of a stop?	min	✖
» What is the average expected speed?	km/h	✖
» What is the average layover time?	min	✖
» What is the vehicle's capacity?	passengers	✖
» What is the vehicle's battery autonomy (in min to run on a single charge)?	min	✖
» What is the vehicle's charging time?	min	✖

Save my results to a json file

Designed by  CENTRALE LYONFigure 34. EASI-AV[®] web application – fleet size dimensioning fixed route, data entry

Introduction Contextualization **Fleet Size** Service Costs External Costs Total Cost of Service Service Revenue Net Present Value

» How will the fleet be used? ☐ Traditional (fixed route) ☒ On demand ☒

Please provide some General Parameters to begin the calculation ✔

» What is the number of passengers expected for peak hours?	100 passengers	✔
» What is the average expected speed?	20 km/h	✔
» What is the average expected passenger wait time?	15 min	✔
» What is the vehicle's capacity?	15 passengers	✔
» What are the operating hours of the service (number of HOURS per day)?	13 hours per day	✔
» What is the number of working days per month?	28 days	✔

Previous Next

Save my results to a json file

Designed by  CENTRALE LYONFigure 35. EASI-AV[®] web application – fleet size dimensioning on-demand route, data entry

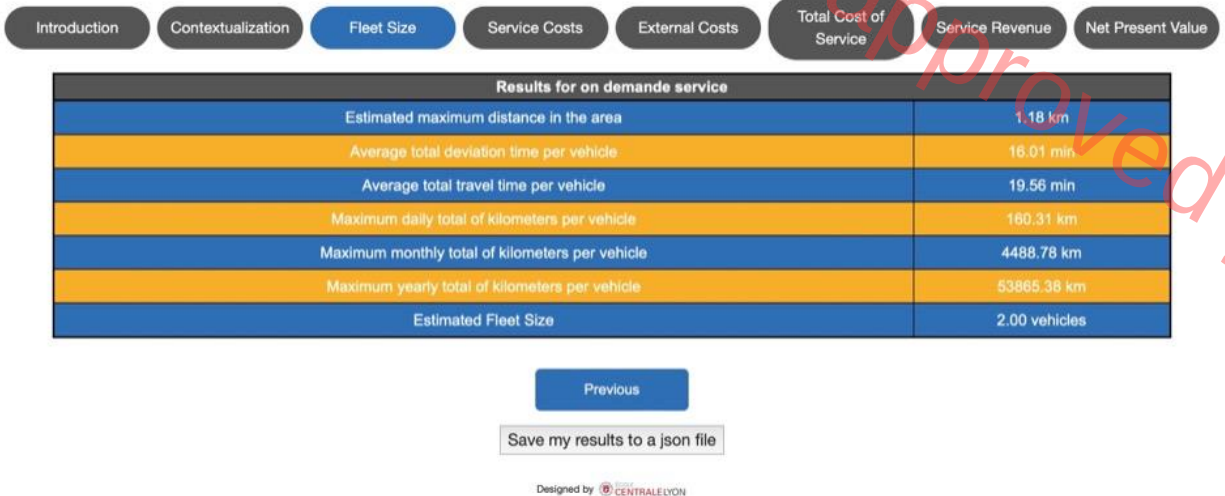


Figure 36. EASI-AV[®] web application – fleet size dimensioning on-demand route, results

4.3.3 EASI-AV[®]: Service costs

Once estimated the fleet size, the investments, and operating costs for implementing the services can be calculated. Thereby, the service costs evaluation may be used as a follow up of the fleet size dimensioning), however, as shown on Figure 37 (completed with hypothetical data for the Belle-Idée site), if the fleet size is already known, the tool also allows the possibility to carry out the TCO comparison by simply entering the fleet size that the users seek to evaluate.

In this step, the user is required to fill in some other important data regarding the general functioning of the service, such as: the expected service-life of the vehicle, and whether the service would require onboard operators (safety drivers) and/or external supervisors. For the time being, the European legal framework requires the presence of a safety driver onboard the shuttles, but as legislation evolves, EASI-AV[®] gives users the flexibility to simulate scenarios with or without these staff members, which in turn, directly impact the service's operating costs.

As can be further observed on Figure 37, this step of data entry also requires the user to fill in data for a comparative analysis with a baseline vehicle of their choosing (different buses options, carsharing, private car, etc.). This is an extra layer of information to assist decision makers on indeed making an informed decision by comparing the total cost of the services of the automated shuttles with their human-driven counterpart of their choosing.

Once this preliminary data is filled in, the next data entry steps regard information about the investment costs (or CAPEX), the operating costs (OPEX) for both the baseline vehicle and the automated shuttle. Figure 38 and Figure 39, illustrates these variables on the web application of EASI-AV[®]. As for the excel version presented on D8.4 (pages 70-74), these data entry elements allow the user to choose if the cost variable applies to a single vehicle or the entire fleet (both for the baseline vehicle and the automated shuttle). In addition, we've given the user the option to use generic cost values for the automated shuttle in case he/she has no estimates in mind. Such generic costs were calculated as the average values among all AVENUE demonstrator sites.

Introduction
Contextualization
Fleet Size
Service Costs
External Costs
Total Cost of Service
Service Revenue
Net Present Value

As a reminder :

	Demand Scenario 1	Demand Scenario 2	Demand Scenario 3	Supply	On Demand service	Manual Entry
Fleet Size For The autonomous Vehicle	not calculated yet	not calculated yet	not calculated yet	not calculated yet	2	no value given

General Parameters

» Indicate how the fleet size was calculated:
 ☐ S1
☐ S2
☐ S3
☐ Supply
☒ On demand
☐ Enter a value manually
✓

» Indicate the estimated lifetime of a vehicle:
 5 Years
✓

» Are onboard safety drivers required for the operations of the service?
 ☒ Yes
☐ No
✓

» Number of onboard safety drivers needed for the full operation of ONE vehicle:
 1 Safety Drivers
✓

» Are offboard supervisors required for the operations of the service?
 ☐ Yes
☒ No
✓

» Comparative analysis with human driven transit vehicles (baseline bus):

☐ 12 meters Internal Combustion Engine bus
 ☐ 12 meters Electric bus
☐ 6 meters Internal Combustion Engine bus
☒ 6 meters Electric bus
☐ Carsharing
☐ Private Car
☐ Other
✓

» Capacity of the selected vehicle:
 30 persons
✓

» Occupancy of the selected vehicle:
 70 %
✓

» Indicate the number of drivers needed for a full day operations of the service for one vehicle:
 2 drivers
✓

» Indicate the estimated lifetime of the vehicle:
 15 Years
✓

Previous
Next

Save my results to a json file

Designed by CENTRALE LYON

Figure 37. EASI-AV[®] web application – service costs, data entry – general parameters

Introduction Contextualization Fleet Size **Service Costs** External Costs Total Cost of Service Service Revenue Net Present Value

CAPEX

ev6

Provide the different costs for the BaseLine vehicle and indicate for each if its calculate for a single vehicle or for the entire fleet.

>> Feasibility Study	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Commision Cost	0 €	✓	>> ☒ Single ☐ Entire	✓
>> Vehicle Aquisition	150000 €	✓	>> ☒ Single ☐ Entire	✓
>> Infrastructure Work	45000 €	✓	>> ☐ Single ☒ Entire	✓
>> Certification and Standardization	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Additionale Services	0 €	✓	>> ☐ Single ☒ Entire	✓

Autonomous Vehicle

Provide the different cost for the autonomous vehicle and indicate for each if its calculate for a single vehicle or for the entire fleet. Your can use Generic cost as an example.

>> Select the button to use generic cost : ☐ Use generic cost ☒ Fill data Manually ✓

>> Feasibility Study	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Commision Cost	25000 €	✓	>> ☒ Single ☐ Entire	✓
>> Vehicle Aquisition	26000 €	✓	>> ☒ Single ☐ Entire	✓
>> Infrastructure Work	45000 €	✓	>> ☐ Single ☒ Entire	✓
>> Certification and Standardization	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Additionale Services	0 €	✓	>> ☐ Single ☒ Entire	✓

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Save my results to a json file

Designed by  CENTRALE LYON

Figure 38. EASI-AV[®] web application – service costs, data entry – CAPEX

Introduction Contextualization Fleet Size **Service Costs** External Costs Total Cost of Service Service Revenue Net Present Value

OPEX

All values to be entered here should be yearly values

ev6

Provide the different costs of the OPEX for the BaseLine vehicle and indicate for each if its calculate for a single vehicle or for the entire fleet.

>> Personnel - drivers salary	90000 €	✓	>> ☒ Single ☐ Entire	✓
>> Insurance	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Taxes and Fees	11400 €	✓	>> ☒ Single ☐ Entire	✓
>> Maintenance	10000 €	✓	>> ☒ Single ☐ Entire	✓
>> additional Services	800 €	✓	>> ☒ Single ☐ Entire	✓
>> Energy Consumption	4500 €	✓	>> ☒ Single ☐ Entire	✓
>> Cleaning	2500 €	✓	>> ☒ Single ☐ Entire	✓
>> Advertising	1000 €	✓	>> ☐ Single ☒ Entire	✓
>> Hidden Costs	1000 €	✓	>> ☒ Single ☐ Entire	✓

Autonomous Vehicle

>> Select the button to use generic cost : ☐ Use generic cost ☒ Fill data Manually ✓

Provide the different costs of the OPEX for the Autonomous vehicle and indicate for each if its calculate for a single vehicle or for the entire fleet. You can use generic costs as an example.

>> Personnel - drivers salary	90000 €	✓	>> ☒ Single ☐ Entire	✓
>> Insurance	1500 €	✓	>> ☒ Single ☐ Entire	✓
>> Taxes and Fees	19760 €	✓	>> ☒ Single ☐ Entire	✓
>> Maintenance	39600 €	✓	>> ☒ Single ☐ Entire	✓
>> additional Services	25000 €	✓	>> ☒ Single ☐ Entire	✓
>> Energy Consumption	4500 €	✓	>> ☒ Single ☐ Entire	✓
>> Cleaning	2500 €	✓	>> ☒ Single ☐ Entire	✓
>> Advertising	1000 €	✓	>> ☐ Single ☒ Entire	✓
>> Hidden Costs	1000 €	✓	>> ☒ Single ☐ Entire	✓

Previous Next

Save my results to a json file

Designed by CENTRALE LYON

Figure 39. EASI-AV[®] web application – service costs, data entry – OPEX

Once all these elements for the TCO comparison data entry are completed, results will be automatically displayed on the next tab of tool. Figure 67 – with hypothetical data for the Belle-Idée site – illustrates the OPEX portion of the results in a graphic manner (via pie charts) and in detailed tables, allowing the user to easily compare the results for the baseline vehicle that they chose, and for the automated shuttle.

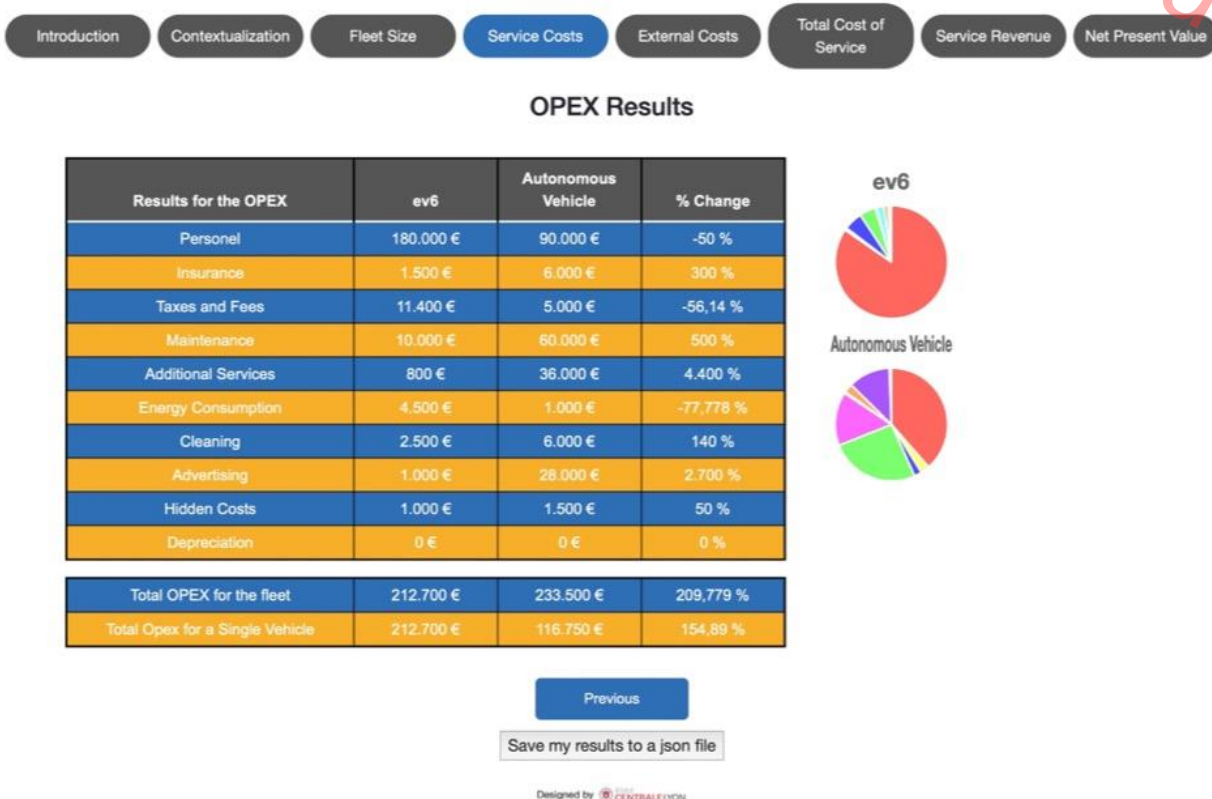


Figure 40. EASI-AV[®] web application – service costs, results – OPEX

4.3.4 EASI-AV[®]: Local external costs

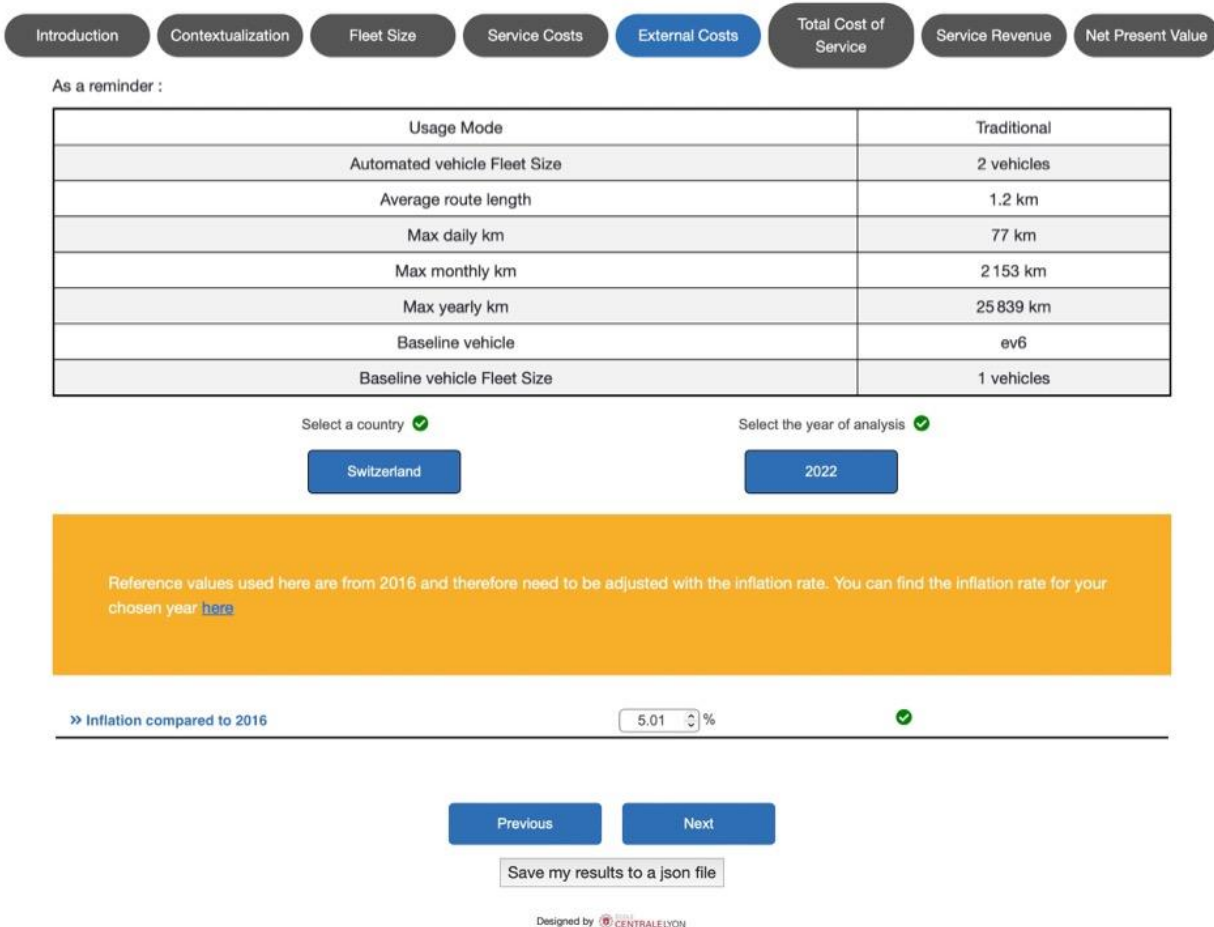
The next analysis from the tool is the calculation of local external costs. An external cost (or externality) occurs when producing or consuming a good or service imposes a cost (negative effect) upon a third party (e.g., on the local environment of the AVENUE testing sites). External transportation costs are costs generated by transport users and not paid by them but by the society as a whole (mainly in form of taxes and governmental fees), and as defined by the 2019 Delft “Handbook on the External Costs of Transport” (European Commission, 2019), the most common externalities generated by transport are: congestion, air pollution, climate change, accidents, noise but also up- and down-stream processes, costs for nature and landscape or additional costs in urban areas.

The aim of this analysis is to provide decisions makers with an overview of the most pressing local external costs of implementing a new mobility service with automated shuttles, those being: accident, air pollution, noise, and congestion costs. A complete and in-depth analysis on external costs for the AVENUE services is provided by HSPF on the macro-analysis calculation (detailed on section 5 of this present deliverable).

For EASI-AV[®], the calculations for local external costs are based on secondary data available on the annex Excel file from the “Delft Handbook on the external costs of transport” (European Commission, 2019) and relate to local externalities for: cars (gasoline and diesel), buses and coaches (diesel) and several types of trucks, for each member country of the European Union.

Since automated shuttles are not listed on the handbook, we opted to take the reference value for buses and make the needed adaptations and data extrapolations for the autonomous shuttles (for further details on how these adaptations were carried out, please refer to D8.4 p.75).

Figure 41, presents the external costs data entry elements for the web application with hypothetical data for the Belle-Idée site. In here the data completion is very straightforward, the user must simply choose the country of analysis from the list, the year of analysis and the inflation rate compared to 2016 (since the reference values from the handbook were collected on that year). If the inflation value is unknown, the user can click on the link shown in the bottom of the page to calculate it.



The interface shows a navigation bar with tabs: Introduction, Contextualization, Fleet Size, Service Costs, **External Costs**, Total Cost of Service, Service Revenue, and Net Present Value. Below the tabs, a reminder table lists reference values for a traditional vehicle. Below the table, users select a country (Switzerland) and a year of analysis (2022). A yellow box contains a note about inflation adjustment with a link. At the bottom, the inflation rate is set to 5.01%, and there are buttons for Previous, Next, and Save my results to a json file. The footer credits CENTRALELYON.

Usage Mode	Traditional
Automated vehicle Fleet Size	2 vehicles
Average route length	1.2 km
Max daily km	77 km
Max monthly km	2 153 km
Max yearly km	25 839 km
Baseline vehicle	ev6
Baseline vehicle Fleet Size	1 vehicles

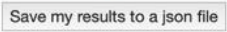
Select a country  

Select the year of analysis  

Reference values used here are from 2016 and therefore need to be adjusted with the inflation rate. You can find the inflation rate for your chosen year [here](#)

» Inflation compared to 2016 % 



Designed by  CENTRALELYON

Figure 41. EASI-AV[®] web application – local external costs, data entry

Similarly, to the service cost analysis, the results here (Figure 42) are given both for the baseline vehicle and for the automated shuttle, allowing decision makers to compare the overall accidents, air pollution, noise, and congestion costs for the service to be implemented. The results also provide relevant KPIs such as the local external cost per passenger and per vehicle/km for both the baseline vehicle and the shuttle as well as the daily, monthly, and yearly local external costs for both types of vehicles.



Figure 42. EASI-AV[®] web application – local external costs, results

4.3.5 EASI-AV[®]: Total cost of service

Once the cost of the service (CAPEX and OPEX) as well as the local external costs have been calculated, the next tab of the tool automatically provides the user with the total cost value for the service (Figure 42). Indicators such as cost per passenger/km and cost per vehicle/km are provided for both the automated shuttle and the baseline vehicle, as well as the relative percentage of the difference between the two types of vehicles. Finally, overall results at the daily, monthly and yearly level are also shown.

Based on this set of results, the user is able to make more accurate decisions about which type of service to implement. Furthermore, being fully customizable, the EASI-AV[®] tool allows users to return to the previous tabs to simulate other input values if they so desire.

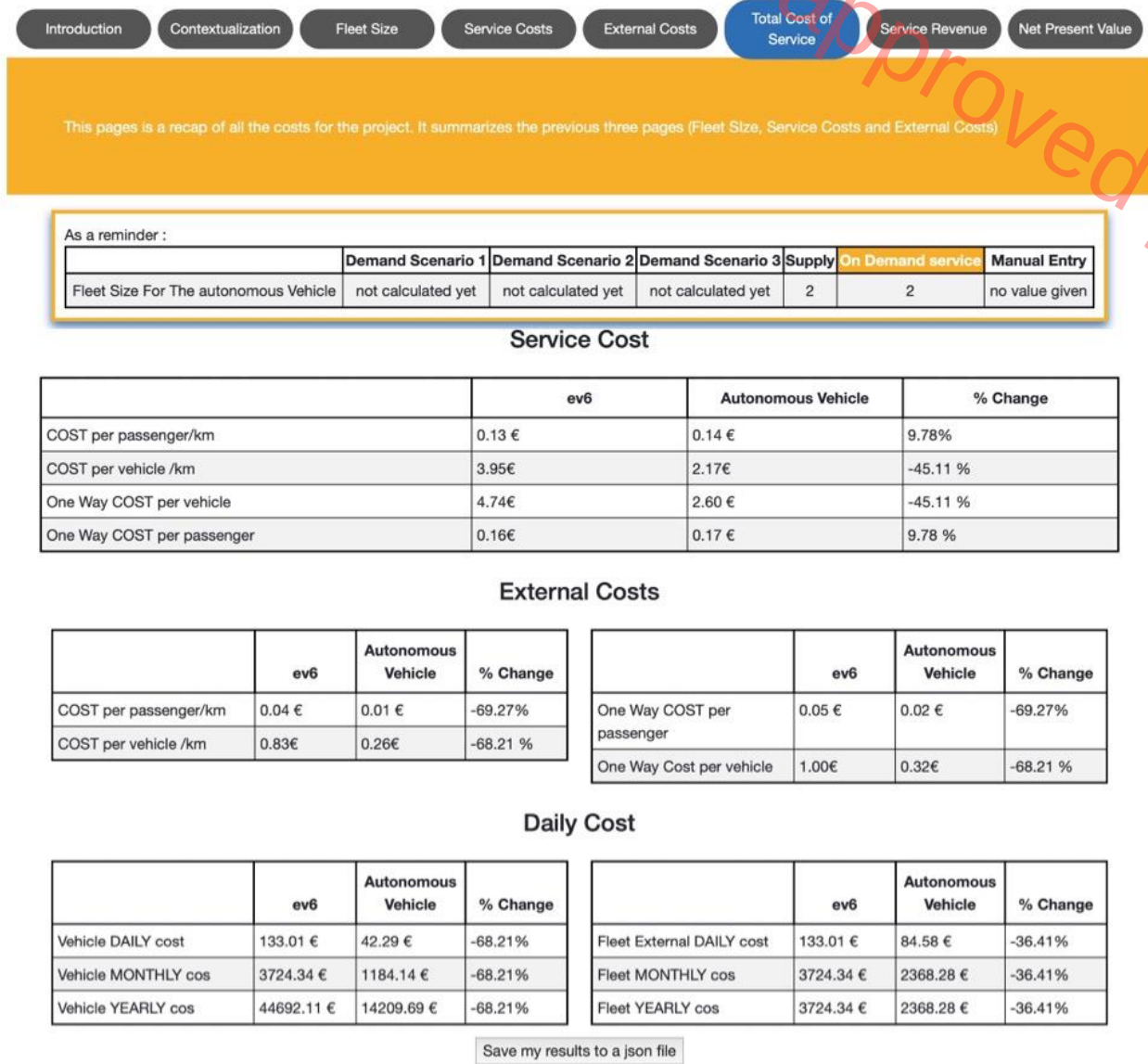


Figure 43. EASI-AV[®] web application – total service costs, results

4.3.5 EASI-AV[®]: Service revenue

Once the total costs for the implementation of the services have been estimated, the EASI-AV[®] tool also gives users the possibility to simulate some complementary revenue sources (Figure 44), such as: advertising from third party companies; subsidies, data commercialization, among others.

Introduction Contextualization Fleet Size Service Costs External Costs Total Cost of Service **Service Revenue** Net Present Value

As a reminder :

	Demand Scenario 1	Demand Scenario 2	Demand Scenario 3	Supply	On Demand service	Manual Entry
Fleet Size For The autonomous Vehicle	not calculated yet	not calculated yet	not calculated yet	2	2	no value given

» Would you like to display publicity on the vehicle ? ☒ Yes ☐ No ✓

» The contract will be annual or monthly ☐ Annual ☒ Monthly ✓

» How much will you be paid per vehicle? 1500 € ✓

Revenue Advertising : 3.000 €/month
Revenue Advertising : 36.000 €/year

» Do you have fundings by public ? ☒ Yes ☐ No ✓

» How often do you receive fundings ? ☐ Once at beginning ☒ Annual ☐ Monthly ✓

» How much will you be paid ? 100000 € ✓

Revenue Fundings : 8.333,333 €/month
Revenue Fundings : 100.000 €/year

» Are you going to commercialise the data you get from your service ? ☐ Yes ☒ No ✓

Total Revenue Service : 136.000 €/year

Figure 44. EASI-AV[®] web application – service revenue, data entry – array of revenue sources

Furthermore, once the need for an onboard supervisor is no longer mandatory, a peculiarity to be considered for automated vehicles is their flexibility for off-peak times. Thus, (as show on Figure 45), the tool also allows users to simulate different complementary services for the vehicle at times of low demand, thus generating additional revenue.

Introduction Contextualization Fleet Size Service Costs External Costs **Total Cost of Service** **Service Revenue** Net Present Value

>> Remaining Off Peak Hours : 14

>> Would you like to offer the courier service ? ☒ Yes ☐ No ☒

>> How many hours will this service be used per day? (if you want the service to use several vehicles, please multiply the number of hours by the number of vehicles) 0 hours ☒

>> How many packages you will manage per hour ? package per hour ☐

Enter the price of a delivered package regarding its size

>> Small (< 35x25x15cm) € ☐

>> Medium (<70x50x30cm) € ☐

>> Big (>70x50x30cm) € ☐

Enter the proportion of packages delivered

>> Small (< 35x25x15cm) 60 % ☒

>> Medium (<70x50x30cm) 30 % ☒

>> Big (>70x50x30cm) 10 % ☒

>> Would you like to offer the grocery delivery service ? ☒ Yes ☐ No ☒

>> How many hours will this service be used per day? (if you want the service to use several vehicles, please multiply the number of hours by the number of vehicles) 0 hours ☒

>> What is the price of one delivery ? € ☐

>> How many deliveries will you do per hour ? deliveries per hour ☐

>> Would you like to offer the vehicle privatization service ? ☒ Yes ☐ No ☒

>> How many hours will this service be used per day? (if you want the service to use several vehicles, please multiply the number of hours by the number of vehicles) 0 hours ☒

>> Which will be the price of one hour privatization? € ☐

>> Would you like to offer the on demand overnight transportation service ? ☒ Yes ☐ No ☒

>> How many hours will this service be used per day? 0 hours ☒

>> How many simple trips will be doing the service per hour? (Estimated - can be a decimal number) trips per hour ☐

>> What will be the percentage increase compared to a day ticket ? % ☐

>> Which is your estimated occupancy rate? % ☐

>> Would you like to offer the medical service during the off-peak hours? ☒ Yes ☐ No ☒

>> How many hours will this service be used per day? (if you want the service to use several vehicles, please multiply the number of hours by the number of vehicles) 0 hours ☐

>> How many simple trips will be doing the service per hour? (Estimated - can be a decimal number) Trips per hour ☐

>> Which will be the price per passenger for this service? € ☐

>> Which is your estimated occupancy rate? % ☐

Save my results to a json file

Figure 45. EASI-AV[®] web application – service revenue, data entry – complementary revenue sources

4.3.5 EASI-AV[®]: Net present value

Once the total costs of the service and the sources of revenue have been estimated, the tool gives the user the option to calculate the Net Present Value (NPV) of the service. It should be noted that the NPV is the difference between the present value of cash inflows and the present value of cash outflows over a time-period. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project.

As shown in Figure 46, EASI-AV allows the calculation of NPV by three different options. That is, the user can consider the evolution of costs and revenues as constant (option 1), can consider these values varying (option 2), or, if preferred, can enter the values manually for each year.



» Please select an option

☐ Constant revenues and constant costs
☐ Constant variation of revenues and costs
☒ Manual entry of revenues and costs

Context

» For what time frame do you want to calculate the NPV? 5 years

» What will be the estimated discount rate? 0 %

Enter data manually

» CAPEX

Years	1	2	3	4	5
Estimated Revenues					
OPEX					
External Costs					

As a reminder :

CAPEX: No value €	Estimated Revenues: 982 720 €	Opex: 233 500 €	External costs: 13 633 €
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Save my results to a json file

Designed by CENTRALE LYON

Figure 46. EASI-AV[®] web application – net present value calculation

At last, it is worth emphasizing that these last two tabs of the application (revenue sources and NPV) still requires further work. More attention is needed to better define the possible sources of revenue, better define the payment method for transportation tickets, among other aspects. The NPV calculation still lacks fine tuning and other small bug fixes. Once these issues are clarified, the breakeven point and net present value calculations can be performed in a precise manner.

4.4 Conclusion and research agenda

This final interaction for Business Cases for Scenario 1 presented the advances done in the local (micro) level economic assessment tool EASI-AV[®], which aim is to help decision makers on design a preliminary economic balance and business viability of the envisioned services.

In this final version, we showed the advances made for the on-demand fleet sizing, thus completing this tool analysis framework. Furthermore, we presented the beta version of the EASI-AV[®] web application, which allows any interested person to simulate the economic balance of services with automated shuttles in comparison with traditional human-driven services. The web

version integrates all the functionalities presented in the excel version of the tool (presented in D8.4) and goes further by integrating simulation analysis of revenue sources and NPV calculations.

However, due to constraints caused by the Covid pandemic and other time-limitations, it was not possible to fully finalize the web version of the application, therefore it is still as a beta test version, and thus, it is subject to bugs and errors.

Thus, for future studies and projects, it is suggested that the researchers continue where we left off, thus allowing the necessary corrections and adjustments to the tool, as well as the possibility of adding new features and analyses not considered in the scope of this project.

5 Expected externalities for cities

5.1 Introduction

5.1.1 Background

The AVENUE project focuses on the deployment of AM for public transportation and its economic, environmental, and social impacts. These vehicles could provide a solution to mobility gaps, strengthen the transportation network, and reduce external costs under the right circumstances (The AVENUE Consortium 2018). The externalities calculations put a monetary value on these impacts and provide insights into which deployment scenarios to adopt for the AM (Antoniali et al. 2021). Scenario planning help predict possible strategies of introducing the AM to the transportation system (González-González, Nogués et Stead 2020; Nogués, González-González et Cordera 2020). It builds on key factors such as technology advancement and urban policies (or the governance of automated mobility as a whole in a country or region) to estimate the impacts of the AM on future transportation systems. Recommendation on strategies of deployment and policy tools could be strengthened by estimating the externalities in different proposed scenarios (Shiftan, Kaplan et Hakkert 2003). Moreover, it leads to a better understanding of potentially viable deployment conditions of AM as well as the feasibility of introducing AM to the transportation network.

The following assessment addresses 6 scenarios for potential deployment in AVENUE cities and the resulting external costs. It focuses on the potential increase or decrease in externalities as an indicator for the scenarios in which mobility should evolve.

Hence, the governance of automated mobility plays an important role in the success of deployment, policies put in place can highly affect the outcomes of AV integration. In doing so, robotaxis can exacerbate the environmental and societal impacts of transportation in urban areas. Similarly, replacing all buses in the city centres of Geneva and Copenhagen would probably worsen the external costs of congestion. However, if we were to replace all cars with AM or introduce them to fill first and last mile gaps in the cities, externalities of transportation should be reduced. At the same time, deploying the AM in suburban areas would strengthen the public transport network and reduce externalities.

5.1.2 Summary of D8.4 and introduction to new content

In the previous (second) iteration of the economic deliverable (D8.4), Antoniali et al. (2021) presented an externalities model to be used with scenario planning. In this model, key parameters for potential scenarios for cities were defined, such as vehicle specifications (occupancy rate, speed), traffic situation, and mobility behaviour. The variation of these parameters helps differentiate between the different scenarios. Also, the methodology is explained in detail (categories, impacts, and marginal costs). The description of the methods used was important to understand the work of van Essen et al. (2019) in the CE Delft report, which was the backbone of the analysis and the reasoning behind the model assumptions and limitations. For instance, the marginal costs for congestion, as adopted from van Essen et al. (2019), are the results of a complicated assessment. It depends on an EU-level study to reach national marginal costs (Jochem, Doll et Fichtner 2016b). The meta-analysis requires inputs of speed-flow functions, demand curves, and value of time (VOT) and combines delay cost and deadweight loss approaches. This assessment provides relatively higher values than other marginal costs for other impacts such as air pollution and climate change. The summary of categories, impacts and methods (already presented in D8.4) using the work of van Essen et al. (2019), Jochem, Doll et

Fichtner (2016a), Hérán et Ravalet (2008), Fagnant et Kockelman (2018), and Shalkamy, Said et Radwan (2015) are to be found in Table 2.

Table 2. Recapitulation of the categories, effects and methods of externalities

Categories	Impacts	Methods
Tank to wheel (ttw) air pollution (pm2.5, pm10, nox, so2, and nmvoc)	Health effects, crop losses, building damage, and biodiversity loss	Damage cost estimation
Tank to wheel (ttw) climate change (CO ₂ , N ₂ O, and CH ₄)	Sea-level rise, biodiversity loss, water management difficulties, extreme weather conditions, and crop failures	Avoidance cost approach
Well-to-tank (wtt) aggregated emissions	Similar to TTW	Similar to TTW
Noise	Annoyances, health effects caused by road traffic noise	Willingness-to-pay, burden of disease approach
Accidents	Material damage, production losses, and administrative, medical, and human costs	Damage cost approach
Congestion	Not meeting passengers' mobility demand due to the temporary scarcity of infrastructure (traffic flow reaches its capacity)	Delay cost and deadweight loss approaches
Parking space	Urban space in km ²	Based on (Hérán et Ravalet 2008)
Production phase	Climate change emissions	Avoidance cost approach

In this iteration, the scenarios planning methodology (intuitive logic approach, key factors, and driving forces) as well as the 6 selected scenarios (replace all buses, replace all cars, expand the network, targeted expansion of the network, robotaxis, AM in MaaS) are explained. Then, the updates in the externalities categories (production phase, parking space using the fleet calculator) are introduced. First, the externalities and scenarios model is applied in detail to the case study of Geneva, where the mobility behaviour of the city, the results in terms of savings or losses per scenario and their implications are presented. Then, the results are discussed, such as the limitations of the analysis, comparison between the scenarios, potential policy recommendations, and rebound effects. Second, it is applied to the other 3 cities of AVENUE (Luxembourg, Lyon, and Copenhagen). In a final stage, a comparative analysis is conducted between the cities.

5.2 Scenarios

5.2.1 Methodology

Scenario planning is a way to imagine potential paths in the future. Derbyshire et Wright (2017) describes it as: "Scenario planning is a technique for thinking about the future that is employed widely by both business and government organisations. It is designed to broaden and challenge decision-makers' perspectives, allowing them to reconsider the standard assumption of 'business-as-usual'". The scenarios are built using the Intuitive Logic Approach (ILA). ILA defines driving forces (political, economic, technological, ecological, social, and legal) as well as key factors that

help structure the scenarios. These factors are either quantitative and predictable, such as demographics, while others are qualitative and less predictable, such as user acceptance and policies (Lindgren, Mats. et Bandhold, H. 2009; Huss et Honton 1987). The ILA strength lies in its flexibility.

For this study, the driving forces help answer how and why the AM might be deployed in each scenario; they are defined, based on Townsend (2014) AV scenarios, as follow:

- Technology advancement;
- Urban policy (political agenda for mobility and sustainability);
- Transportation offer (trends of use and modes available);
- The users (most likely to use the AM in the scenario).

As for the key factors, they were determined through a deliberative process within the AVENUE team. Indeed, the trial sites, the interdisciplinary nature of the project, as well as the work of (Viere et al. 2021; Korbee et al. 2021; Beukers 2019) were used to select the following key factors:

- whether the AM are replacing one mode of transport or multiple modes;
- whether AM supports or competes with public transport (replace buses modal share or not)

These 2 factors help estimate the modal shift within each scenario, which is crucial to estimating the future transportation performance in person-km (pkm) based on mobility censuses and the consequent externalities estimations.

The setting of key forces and key factors is combined with the system boundaries of each scenario. Figure 47 shows the classification of the scenarios based on the key factors.

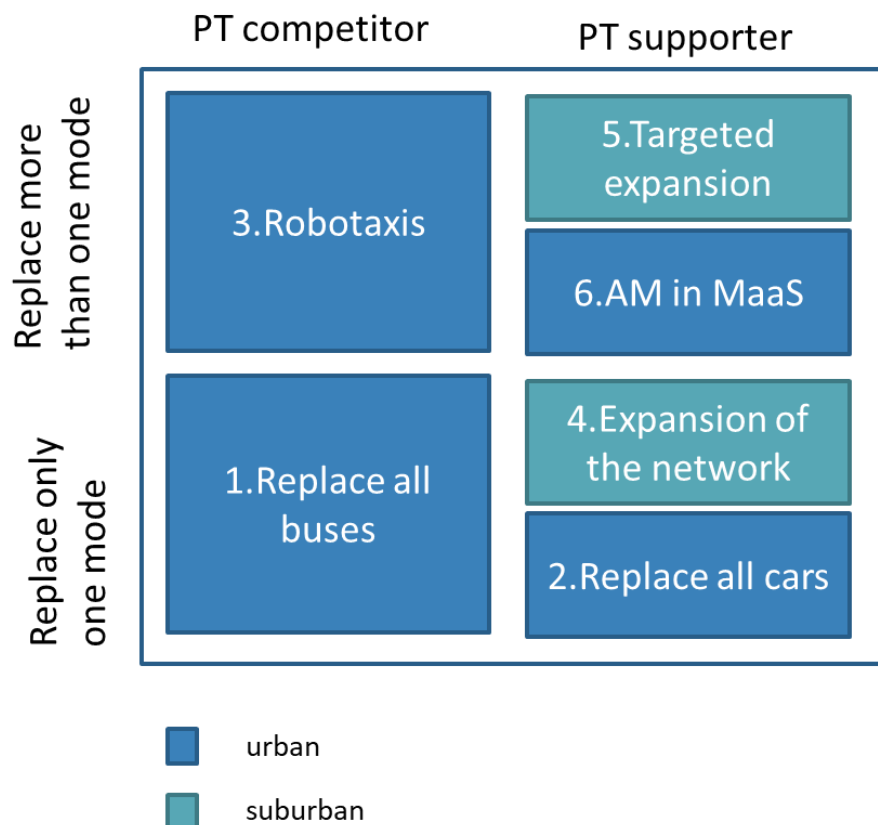


Figure 47. The classification of scenarios based on key factors

The boundaries are defined by the key parameters as described partially in the previous iteration: vehicle and circulation specifications, AM service. Thus, the analysis is continued as a qualitative assessment that studies direct and indirect consequences of the modal shift from each scenario using observations from AVENUE and previous research on AV deployment. The overall structure is presented in Figure 49, and it is the basis for the scenario description. The methodology helps limit the uncertainty of the scenarios by building plausible stories (Lindgren, Mats et Bandhold, Hans 2009; Amer, Daim et Jetter 2013), see Figure 48 below for the steps of the scenario description and Figure 49 for the methodology:

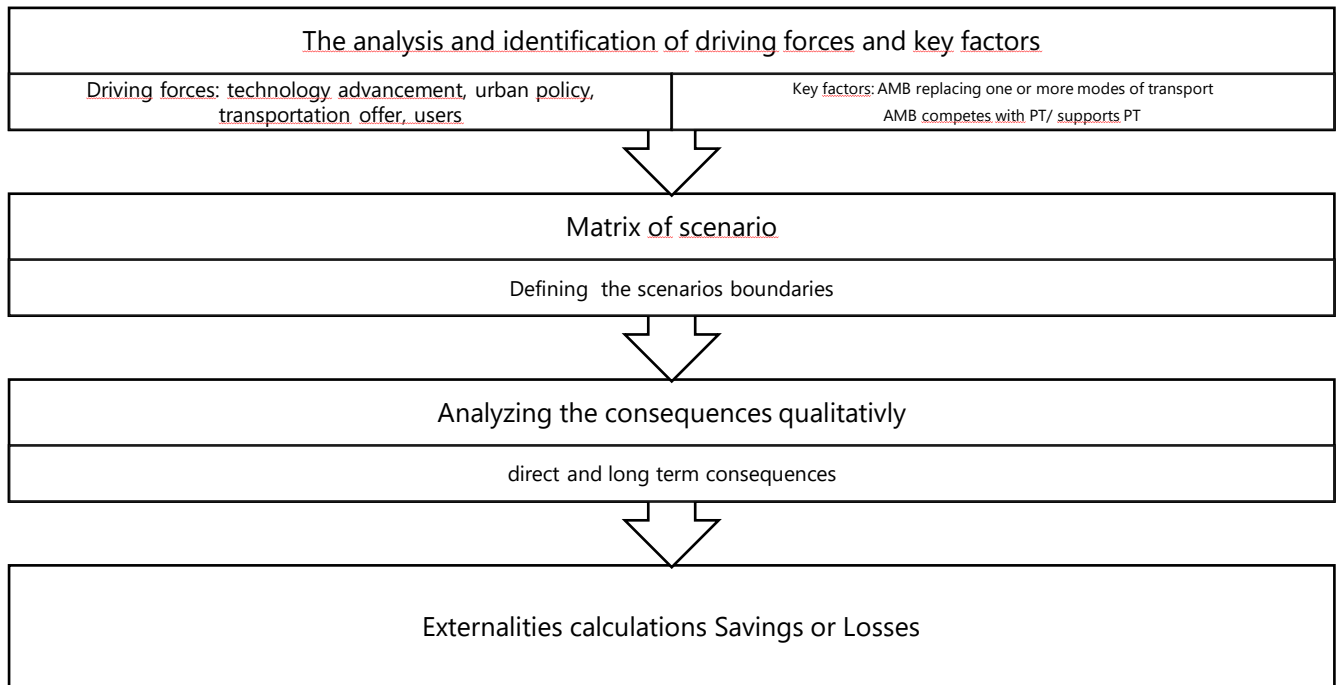


Figure 48. Steps of scenario building

Methodology framework
System Boundaries (assumptions)
Area Urban (city or city suburban) /suburban level (surrounding villages and towns)
Vehicle and circulation specification
Capacity factors
Speed limits in the area
Traffic situation: average congestion on roads
Vehicles lifetime
AM service
Intermodal and seamless, first/last mile, on demand and door-to-door
Scenario development (circumstances): Key factors (to define the scenario in the transportation system)
It supports public transport or competes with public transport

Replaces only one mode of transport or it replaces more than one modal share

Scenario development (circumstances) Driving forces (to frame the scenario):
Technology development (level of automation- SAE, Connectivity V2X)
Regulatory conditions (policies: supportive or restrictive or other)
Transportation offer (description of other modes and dominance of private or public stakeholders)
Users (profile of AM users)

Modal shift
The predicted AM modal share from absorbing other modes of transport modal share(based on the survey and literature)

The qualitative assessment: Direct consequences
Environmental and Societal impacts
Emissions,
Accidents,
Congestion
Noise
Impacts on mobility
Travel demand - Increased demand due to on-demand service,
Road capacity-levels of congestion during off/on peak hours, the value of time)
Impacts on infrastructure
Parking

The qualitative assessment: Long term consequences (rebound effects)
Impacts on mobility
On the transportation system (other secondary modal shifts mobility behaviour, induced demand-due to the convenience of service)
Impacts on infrastructure (urban development)
Roads, city plans, jobs density, demographics

Figure 49. Methodology of scenario description

5.2.2 The Scenario description

Based on the methodology described, the analysis focuses on 6 scenarios that concern the deployment of AM in cities. At this level, the scenarios occur in a standard EU city (to be applied to Geneva, Lyon, Luxembourg, and Copenhagen) and in the next decade, which is a safe estimation on when is it most likely to have AV technology on the roads (not in a pilot test) (Milakis et al. 2017).

Out of the six scenarios, five scenarios focus on different modal shifts caused by the deployment of AM, while one focuses on robotaxis. Among the overall scenarios, four are set in the city centre of a standard European city, while two are in smaller urban dwellings surrounding urban areas like villages, towns, suburban areas.

The scenarios description using the proposed methodology helps pinpoint the advantages and disadvantages of each deployment strategy. It also seeks to learn about potential obstacles and catalysers to reduce the environmental footprint of introducing AV in urban areas. The description follows the methodology of scenario planning. It presents alternative images of the future in the form of stories (Dator 2019). It is reinforced by a deliberative process with the AVENUE experts (Antoniali et al. 2021), where the most plausible scenarios are drafted based on the key factors and driving forces.

Scenario 1: Replace all buses (Sc1)

This scenario occurs in the city centre. AM are implemented on a fixed schedule, yet they operate on flexible routes within a geofenced area. The minibuses are meant to support the public transport network, mainly rail transport, by replacing outdated diesel buses. The usual bus size makes manoeuvring more difficult in already limited urban spaces, which justifies this potential path, especially in cities like Geneva, where the city centre streets date back to the 19th century (Etat de Genève 2013b). The AM are more flexible and less costly (Milakis et al. 2017).

Technological advancements such as: achieving level 4/5 automation, improved sensory capabilities, and AV platooning supports the replacement of traditional buses with the AM (Wadud, MacKenzie et Leiby 2016). Furthermore, the regulatory conditions to support this modal shift favour upscaling the public transport network, reducing external costs, and implementing smart city initiatives (Fulton, Mason et Meroux 2017). The transportation system at the time of introducing the AM does not differ significantly from the status quo. The electrification process of the bus fleet is limited; motorised individual mobility is dominant. The direct consequences of replacing the buses with AM are in general positive but also not drastic. In general, there is a reduction in emissions, yet if we account for the life cycle emissions, there is an increase in the well-to-tank emissions due to electricity production (this depends on the future of the electricity mix). Also, we estimate an increase in production and disposal emissions as more AM are manufactured to replace the current fleet of buses. As for accidents, there is a minor change since buses, in general, are not involved in a high number of accidents.

The replacement might lead to a ripple effect that reduces car use and increases train ridership in the long term. It is also wise to predict a change in the building environment, where more roads and train stations could be redesigned to assimilate the change. The city would assign more pick-up and drop off points around the stations. Eventually, modernising the public transport and integrating AM in ITS makes the city centre more attractive, thus attracting more jobs and increasing the population.

Scenario 2: Replace all cars (Sc2)

This scenario is also set in a high-density urban area such as a city centre. The AM are deployed to replace all cars trips. The service of the AM is on-demand, door-to-door, and running on flexible routes. The AM would have on average 6 people per vehicle, see Table 3. We assume no restrictions on waiting time (for a waiting time of more than 4 minutes, there is no need for an increase in fleet size to meet an increase in travel demand as well as empty runs based on (Fagnant et Kockelman 2018)).

It is also set to support public transport and only replace cars. The scenario is supported by policies that mirror the current environmental agenda of sustainable cities, such as 0-emission strategy, carbon tax, parking policies, no-go zones, and transport demand management; thus, this modal shift is plausible and even the most analysed in similar research since it presents the ultimate goal for sustainable mobility (Fournier et al. 2020; ITF 2015, 2017, 2020).

The introduction of the AM is also attributed to limited public transportation that could not cover the demand from reducing car access in the cities. Based on Alazzawi et al. (2018) replacing all standard trip cars with automated electric vehicles reduces tank-to-wheel emissions. However, similarly to the previous scenario, we can expect increased emissions in the well-to-wheel, production, and disposal phase. The replacement of cars with automated vehicles such as the AM is bound to have a significant effect on accidents rates and traffic congestion, as explained by

(Childress et al. 2015; Alazzawi et al. 2018; Auld, Sokolov et Stephens 2017; Todd Litman 2021). Less AM are needed to meet the travel demand in comparison. This leads to an increase in road capacity and thus a decrease in road traffic, especially during peak hours (Wadud, MacKenzie et Leiby 2016). Nevertheless, the AM convenience could contribute to a reduced value of time due to competitive cost fare and increased accessibility. If the time value is reduced, then people would not mind commuting more. This could affect the congestion as well as the overall mobility system in the long run. The AM would influence the mobility system.

On the one hand, the AM would be integrated better with other long-distance transportation such as trains as AM are used more by travellers. On the other hand, they might reduce the active transportation modal share (walking and biking) because the AM provides on-demand and door-to-door short-distance trips (Milakis et al. 2017). The long-term consequences on the city are a significant reduction of road space dedicated to cars. Thus, better urban planning to make the city more liveable and greener. The improved transportation system makes the city more attractive to inhabitants, thus affecting the real estate and the job market (Vleugel et Bal 2017).

Scenario 3: Robotaxis (Sc3)

Robotaxis are described as shared automated vehicles in numerous studies (Alazzawi et al. 2018; Fagnant et Kockelman 2018; Todd Litman 2021; Jones et Leibowicz 2019). Although they might be comparable to the AM in terms of services (on-demand, MaaS, door-to-door), they differ in the occupancy factors, speed, vehicle size, and integration with PT. The AM is a bigger vehicle that could carry up to 15 passengers, it rarely provides single-ride trips, and it requires longer waiting times for pick-up. On the contrary, the robotaxis (or shared AVs) are destined mostly for single ridership (even though, they could provide ridesharing services such as Uber Pool), they are operated by private stakeholders, they could drive faster, and they have reduced waiting times. They are convenient, especially if the passenger privileges their privacy (UITP 2017).

For this scenario, the robotaxis serve the city centre as well. They do offer door-to-door and on-demand trips but no ridesharing services. They are competing with public transport, replacing more than one mode of transport (cars, buses, and walking).

Higher technological development facilitates the robotaxis fleet's deployment, such as charging, centralised fuelling, platooning, and eco-driving (McKinsey & Company 2019). The regulatory conditions are described best as a "Laissez-faire" outcome. This means that there are no policies to regulate the AV market. Private stakeholders are seeking to maximise their profit which would have unpredictable consequences on sustainable mobility and people's welfare (in terms of accessibility and access, safety and security, etc.) (Niles 2019). The regulatory conditions also translate into a deteriorating public transport offer that manifests in a high dependency on individual motorised mobility. We could consider that this scenario is citizen centric and thus satisfy best individual mobility.

The trend of AV-markets driven by shareholders' interest would create a race to optimise the services: higher speeds, less waiting times, and more vehicles. This leads to a mixed effect on the emissions rates. We anticipate a reduction of greenhouse gases (GHG) during the well-to-wheel phase, an insignificant effect on air pollution, and an increase in the tank-to-wheel, production and disposal emissions. The robotaxis deployment will positively impact road safety, causing fewer accidents and consequently improving traffic flow (ITF 2015). Nevertheless, the interaction between robotaxis and non-connected vehicles would limit the full accident-reduction potential (Maurer et al. 2016)². Even more, it would limit the gains in the congestion externality if not aggravate it. Moreover, an increase in overall vehicle travelled km "VKM" is expected.

² The formula to calculate the accidents from van Essen et al. 2019 is used to calculate the accidents marginal cost for the automated minibus.
 $MC = r(a+b+c)(1+E) - \theta r(a+b)$, the interaction between AV and human controlled vehicles would influence "r"

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

The long-term consequences of this scenario on the mobility system are the modal shift from active modes of transport and public transportation. The proliferation of the robotaxi fleet complicates biking and movement of pedestrians. Thus, this scenario is expected to cause induced demand as a rebound effect and it could even reduce public transport ridership as it is very convenient (Niles 2019; Litman 2021; UITP 2017). Furthermore, urban planning follows car-centric strategies, where the building environment is designed to accommodate private vehicles rather than the people. The spread of AV means new roadway design features such as improved lane markings, signs designed to be read electronically, and wireless repeaters in tunnels to provide internet access (Childress et al. 2015).

Scenario 4: Expand the network (Sc4)

In this scenario, the AM are deployed to support public transportation in low-density urban areas such as small villages and suburban areas where the PT offer is limited compared to more urbanised areas. The service provided by the AM is seamless intermodal trips. The modal shift is to replace one mode of transportation, mainly cars. The technological development is similar to previous scenarios. The policies in place that enable the expansion of the transportation network with AM are drafted to increase accessibility, reduce reliance on individual vehicles, and develop surrounding areas to cities. The modal shift is partially from cars to AM. The direct repercussions of the scenario, in terms of environmental and societal impacts, are similar to the "Replace all cars" scenario. The direct effect on mobility is that the AM is more susceptible to making empty runs and carrying fewer passengers on board. The AM are meant to attract car users. Thus they should provide services that could compete with the comfort and convenience of an individual vehicle.

For the indirect consequences, we predict that the AM would increase overall PT ridership. However, it is difficult to determine the effect on walking and biking, but as it offers short trips, it could also replace some walking and biking. The improvement in the public transport network outside of densely populated areas would make them more attractive to inhabitants. Thus it would increase urban sprawl, 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 (Vleugel et al. 2017).

Scenario 5: Targeted expansion of the public transport network (Sc5)

The targeted expansion scenario is similar to scenario 4 "Expand the network". In this scenario, the AM are supporting the public transport network. It also partially replaces car modal share. The prominent feature in this scenario is that it also replaces a share of the buses. Specifically, the AM are deployed to replace night buses and low occupancy buses. The bus service is at capacity (or even over capacity) during peak hours but underutilised during the day (Pyddoke 2020).

Moreover, it runs frequently empty in areas with high car ownership (Adra, Michaux et al. 2004). Hence, substituting these buses with AM could reduce the environmental impact. This scenario's direct and indirect consequences are the same as scenario 4 but with higher gains in the environmental impacts.

Scenario 6: AM in MaaS (Sc6)

The AM are deployed within MaaS to better provide on-demand services that bridge the first and last mile and provide seamless and intermodal trips. They are deployed in highly dense areas such as city centres. Their introduction aims to support PT. They are positioned to influence more than one mode of transport (cars, walking, and biking).

The technological innovations in AV are similar to the previous scenarios. However, there are significant advancements in digital on-demand services, interoperability, ticketing, utilising mobile apps, the cloud, ride-pooling and routing algorithms (Plested 2021).

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 (production loss, material damages, administrative costs, medical costs)

θ =The share of the accident costs that is internal for each vehicle category

E = risk elasticity which reflects how much a 1% increase in traffic (measured in vkm) increases the accident risk

The regulations to support this deployment strategy rely on public and private collaboration for MaaS services, platform management, open API, and data sharing.

Other regulations (or as already mentioned above, the governance of automated mobility as a whole) in place are similar to scenario 2 "replacing all cars", where the city is seeking to implement more sustainable practices in line with the sustainable urban mobility Plan (SUMP) and smart city initiatives. They adopt fuel and parking measures and push and pull regulations (in line with transport demand management (TDM)) to prevent the use of internal combustion engine vehicle (ICEV) in the city centre and reduce the environmental and societal impact. The public transportation offer is efficient and reliable. However, there are gaps connecting travellers to mobility hubs (e.g. tram and metro stations). Thus, the AM seeks to capture first and last-mile travellers that would have driven, walked or biked to reach a train or a tram station. The modal shift to be studied in this scenario concerns the share of journeys within an intermodal trip that connect to or from a train/tram station.

The direct environmental and societal impacts are comparable to "replacing all cars" scenario. Nevertheless, we consider that for the AM to meet the travel demand and remain competitive the waiting time is less than 4 minutes. Hence, there is an increase in VKM³ due to pooling, rerouting to pick-up and drop-off passengers based on (ITF 2020; Milakis et al. 2017; Jones et Leibowicz 2019; Moreno et al. 2018).

The long-run consequences of this scenario are: an increase in Public Transport (PT) ridership, as the AM provide seamless intermodal and last-mile trips and is considered as a mobility gap filler. This improves the connectivity to other PT modes. However, the convenience of the service could replace more short-distance trips from walking and biking. As for the effects on the city, we predict urban planning oriented towards more compact cities (more walkable and developed around mobility centres) and mixed-land use (residential, commercial, and business combined in the same area). The scenario would lead to a reduction in road space. And if the city is adopting a sustainability agenda, it could repurpose this space to benefit the citizens. The city could become more attractive, thus urban density increases, and by consequence, the jobs rate increases. These effects are also attributed to an increase in access and accessibility of all inhabitants (UN 2016).

General comments

It is important to note that the speed in all scenarios is limited to 30 km/h for all road transportation (as explained in D8.4). The average occupancy factors are those of the Delft report for traditional road transportation. Also, we follow the Huber et al. (forthcoming) assessment where the AM occupancy factor is 5 passengers, it is a safe average assumption if we account for off-peak travel demand. We assume an occupancy factor of 1.2 for the robotaxis which is more comparable to a normal taxi where individual trips are significant. These factors vary in suburban scenarios to translate its deployment particularities. Table 3 presents the different occupancy factors.

Table 3. Occupancy factors based on the Delft report, (van Essen et al. 2019)

vehicle	Occupancy factors
Car	1.60
Bus	19.00
AM	6.00
Robotaxi	1.2

³ Based on (Milakis 2017) : "Shared automated vehicles could result in additional VMT because of their need to move or relocate with no one in them to serve the next traveler. Extra VMT are expected to be lower for dynamic ride-sharing systems" also Jones et al., 2019, Fagnant et al. (2016), Morenno, 2018 mention deadheading, repositioning, and empty trips to pick up the passengers in the limited waiting time as a cause of increased VKM

The description of the scenarios omitted the noise and parking impact. For parking, it is anticipated that all scenarios with a modal shift from cars to AM would lead to savings in space. The noise depends on the speed, the time of the traffic, and the congestion status. At this level, it is difficult to anticipate the effects of these deployment strategies on the noise externality. Thus, we assume the noise, in general, would be reduced. The roads where the AM are operating are near capacity (flow to the capacity ratio between 0.8 and 1.0.) in terms of congestion to reflect an average traffic situation. However, the robotaxis are assumed to circulate on congested roads to better reflect the effect of individual mobility, and by consequence the number of vehicles needed, on the traffic flow. They are also described as "other urban roads" again to reflect the majority of roads in the road network. Both labels are taken from the Delft report, and they are important to define the marginal costs (van Essen et al. 2019).

5.2.3 Modal shifts

The modal shift is essential to determine the direct and long-term consequences in the qualitative description above. Moreover, it is a key component to the externalities estimations. Thus, some assumptions were needed to determine the AM modal share in each scenario.

First, for scenario 1 and 2, the estimation is clear. For scenario 4, 5 and 6 the willingness survey questions were used as described below, to determine the modal shift from car trips to AM. Second, other studies on AV acceptance, ridesharing services, and intermodal trips helped determine the modal shift from other modes of transportation to the AM, such as scenario 3, 5, and 6. For scenario 6, we also used literature to determine the modal shift from cars to robotaxis. The modal shift explanation and resources for each scenario are in Table 4.

Table 4. Modal shift for the scenarios

Sc1	Scenario 1	Replace bus share	-
Sc2	Scenario 2	Replace car share	-
Sc3	Scenario 3	-20% from cars -6% from buses -13% walking	(Ward et al. 2019)(May et al. 2020) (Clewlow et Gouri S.Mishra 2017) (Heineke et al. 2019)
Sc4	Scenario 4	Depends on willingness question	
Sc5	Scenario 5	Depends on willingness question - 4% from buses	Mancret-Taylor et Boichon (2015), Adra, Michaux et André (2004)
Sc6	Scenario 6	Depends on willingness question Based on journey to a train station in intermodal trips - 3% from walking - 1.7% from biking	(Paydar, Fard et Khaghani 2020), (Giansoldati, Danielis et Rotaris 2020) Gebhardt et al. (2016)

5.2.4 The representative survey

The social impact assessment is based on surveys to study the potential acceptance of users and the trends related to AM use. In this assessment, we focus on the willingness questions that were part of the representative surveys. These specific questions help determine the potential modal shift in some scenarios.

- Scenario: AM in MaaS: the modal share of cars to be absorbed from cars by the AM, is determined by using the question: "how willing are you to give up your car if AM offers a

service that bridges the first and last mile?". The modal share corresponds to the percentage of respondents who were very willing, and who consider their residential area as a city centre and who use their cars daily.

- Scenario: Expand the network and targeted expansion of the network: the modal share of cars to be absorbed from cars by the AM, is determined by using the question: "how willing are you to give up your car if AM is part of a seamless, intermodal trip?". The modal share corresponds to percentage of respondents who were very willing, and who consider the area they live in to be either a big town, or a small to medium village and who use their cars daily.

5.3 The externalities methodology updates

In the previous (second) iteration (D8.4), the externalities categories of production were mentioned but not analysed. In this version, the production phase marginal costs are estimated.

Moreover, we explain the methodology used to account for saving in parking space (in D8.4, the factors in km² were introduced; in this report, we present the estimation for the fleet sizes of cars and AM).

5.3.1 Production Phase

The manufacturing of vehicles is a complex process; it accounts for steps from the extraction of raw materials until the production of the components (Chester 2008; Pero, Delogu et Pierini 2018). The assessment focuses on the climate change impact of the production phase. The emissions are CO₂, CH₄, and N₂O; it is based on climate avoidance costs. According to van Essen et al. (2019), the avoidance costs are determined by averaging values from the literature for the short-and-medium-term (up to 2030) and the long term (2040-2060). The values used in this estimation are central and short to medium run climate avoidance which is 100 €/tCO₂eq.

The marginal cost is estimated as follows:

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

The total emissions, as well as the expected lifetime mileage, were determined using the ecoinvent database for the car and electric car, while for the bus, the values were taken from Chester et Horvath (2009) analysis. Finally, (Huber et al. forthcoming) as well as Viere et al. (2021) study on the LCA of the AM were used. More details about the estimations are found in the final environmental deliverable. The marginal costs are presented in Table 5. These values are applicable at the EU level.

Table 5: Marginal cost for the production phase

Vehicle	Bus	Car	Electric car	AM
Marginal cost in €-cent/pkm	0.18	0.38	0.64	0.3

5.3.2 Parking space

In the analysis, only the savings from parking spots for private vehicles are considered. The buses are usually stored and maintained in dedicated bus garages or depots, and they do not interfere with daily traffic. Although it raises an issue for land use- and transportation planning, it presents less nuisance to cities compared with private vehicles and thus, it is not covered in this assessment, similarly for the AM (Lai et al. 2013).

In D8.4., the value for space needed to park a European car is 10m². To determine the overall parking space, the fleet size for cars and the AM is needed in each scenario. Thus, the fleet size

calculator that was also presented in the second iteration of the economic deliverable is used. It is also important to account for the fleet size for the on-demand service. Moreover, we assume a linear relation between the parking space reduced and the modal share of car trips reduced.

5.4 Assumptions and boundaries

To be able to calculate the external costs and build on work presented in Antonialli (2019) and Jaroudi et al. (2021) assessment, we assume the following:

- i) The AM deployment could affect motorised mobility, public transport and active mobility (Janasz 2018). The AM are introduced in mixed traffic (with no prior presence of automated technology on the roads).
- ii) Every additional person-kilometre travelled on the AM is travelled less on the other transportation modes. Therefore, the total transport performance remains identical compared to the reference scenario (Bubeck et al. 2014).
- iii) Active mobility's negative externalities as walking, biking are considered negligible (Keall et al. 2018).
- iv) The study does not account for the increase in transport performance due to population increase and other socio-demographic changes; we are more focused on the effect of unpredictable factors such as the integration within the transportation system and policies. The population growth is predictable and easy to estimate. That is why we chose to simplify the calculations by omitting their effects (Huss et Honton 1987).
- v) Intermodal trips consist of two or more modes of transport (car/bus/walking/biking+train) (Fraedrich, Beiker et Lenz 2015), while monomodal or unimodal trips are considered as one mode.
- vi) Walking trips accounted as a mode of transport for intermodal trips from 600 m or more (more than 5 minutes) (Gebhardt et al. 2016).
- vii) The average speed of circulation for all vehicles ranges from 25 to 30 km/h.
- viii) The shuttles operate on "other urban roads" or "other interurban roads" based on the scenario, and we estimate that the average traffic flow⁴ is near capacity.

5.5 Application of the externalities model on Geneva

The model relies on the scenarios described in part 2 as well as the marginal costs that were defined in D8.4 and updated in part 3. The model is applicable to any standard EU city as long as its mobility behaviour and transport performance are available.

In the following part, the assessment applies this model by adjusting the marginal costs (€-cent per pkm) to the context of the city and estimating the future transportation performance in person-km (PKM). It considers the 4 cities of AVENUE as a case study. First, Geneva is studied in detail to showcase the specifics of the scenarios and the externalities calculations. Second, the results are presented for Luxembourg, Lyon, and Copenhagen. The model in each scenario is applied following the steps below:

- i) Present the transportation behaviour for reference case (scenario);
- ii) Determine the marginal costs (MC_j) to be used in reference case and the scenario;
- iii) Determine the total externalities for reference case, (X);
- iv) Determine the marginal costs of the scenario in question, (Y);

⁴ Traffic flow = volume of traffic /capacity of a traffic on a link ('near capacity' is v/c between 0.8 and 1, 'congested' between 1 and 1.2, 'over capacity' is above 1.2)

- v) Use modal shift to determine new mobility behaviour of the scenario in question;
- vi) Determine the total external cost in the scenario in question;
- vii) Determine the increase or decrease in external costs, (Z).
 - Total external costs (2015), $Y = \sum_i \sum_j x_{ij}, (2015)$
 - Total external costs (scenario), $X = \sum_i \sum_j x_{ij}, (\text{scenario})$
 - Increase or decrease in external costs in future in million euros,
 $Z = X - Y = \sum_i \sum_j x_{ij}, (\text{scenario}) - \sum_i \sum_j x_{ij}, (2015)$
 - $ij = MC_j \times T_{pi}$

X_{ij} external costs

MC_j is the marginal cost per externality category

T_{Pi} is the transport performance of the vehicle

i = { bus, car, AM/robotaxi}; the vehicles

*j = { air pollution, climate change, wtt, noise, accidents, congestion, production};
the external costs categories*

The methodology is simplified in Figure 50.

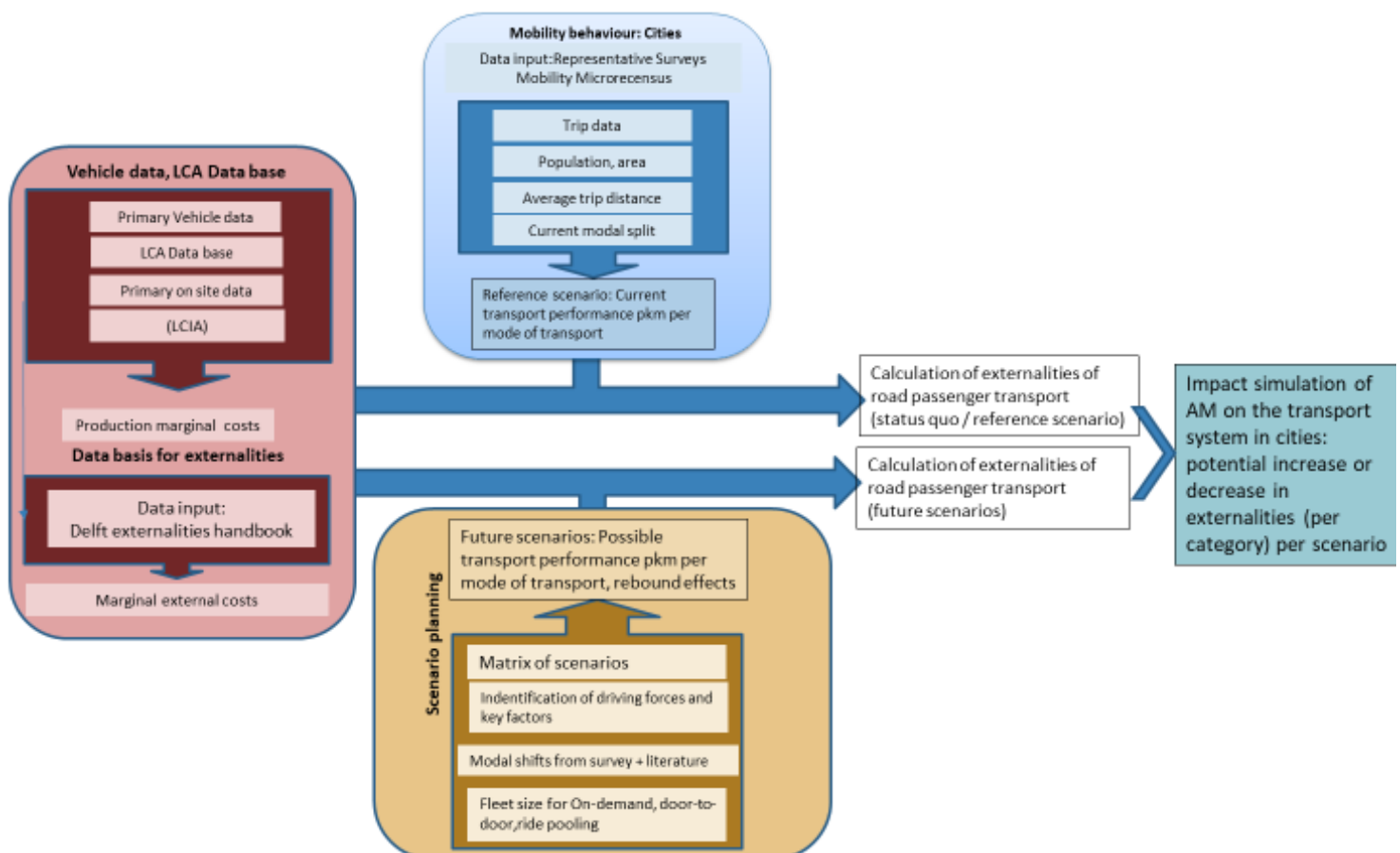


Figure 50. Externalities calculations and data methodology

5.5.1 The mobility behaviour profile in Geneva (national census data)

Geneva is the second most populated city in Switzerland, with 197 376 inhabitants. It is the capital of Geneva Canton. In order to address current and upcoming challenges in Geneva's mobility system, in 2013, the General Planning Direction launched the 'Mobilités 2030', a long-term multimodal strategy for Geneva Canton (Etat de Genève 2013a).

According to 'Mobilités 2030', we can distinguish three main challenges regarding mobility in the Canton of Geneva:

- 1- The first challenge results from the development of a mono-centric agglomeration. Currently, 75% of the jobs from the conurbation area are concentrated in Canton Geneva. As a result, public transport is underdeveloped in low-density areas.
- 2- Secondly, the city centre streets date back to the 19th century, which means they are narrow and do not absorb the current transport flow.
- 3- Thirdly, the absence of tangential routes aggravated the mobility flow. One can state that the multimodal strategy prioritises different modes of transport according to the different urban zones. This justifies the AM in MaaS scenario choice. In the centre of the conurbation and compact urban areas, the soft modes and public transport are favoured. The 2030 objectives target a shift in central areas, from private vehicles and public transport to active modes of transport. This aligns with our scenarios to replace all cars and to replace all buses.

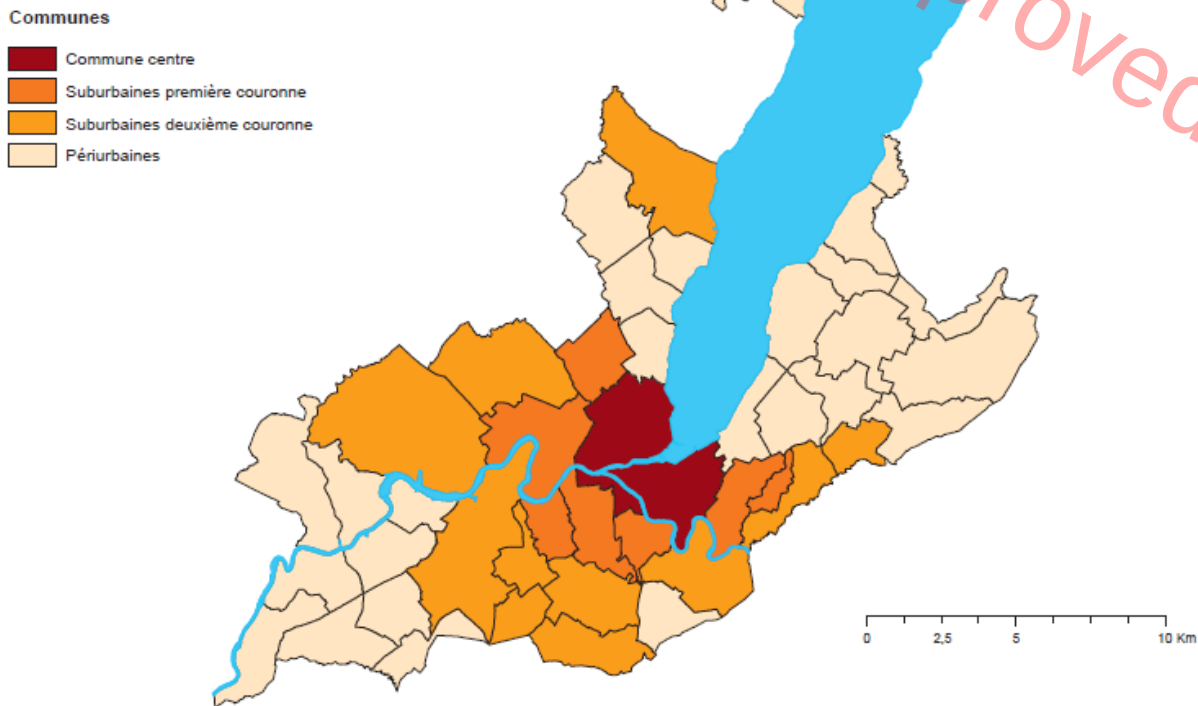
The Climate Plan 2018-2022 for Geneva Canton comprehends the promotion of low-carbon mobility as one of its axes. Hence, the targeted integration of new mobility models within the transport ecosystem falls in line with this strategy.

AM could change mobility patterns: replace motorised individual mobility, support the existing offer of public transport, and promote active modes of transport. Even more, it could make the transportation system more robust against crises such as the Covid-19 pandemic (Jenelius et Cebecauer 2020). The legal framework for automated driving has to be developed. In this regard, the Federal Office of Roads (FEDRO) has worked to adapt the traffic rules and conditions for autonomous vehicles to be integrated on the roads.

Furthermore, the 'Digital Switzerland' (OFCOM 2018) is a strategy action plan adopted by the Federal Council in 2018 to work on the digital key factors for autonomous driving implementation. It will address data policy, the creation of data infrastructure for multimodal and interconnected traffic management, security and protection from cyber-risks.

5.5.2 Mobility behaviour – the reference scenarios

To calculate the externalities, we refer to the current status with no AV on the roads. Based on the data available, we used the mobility census for Geneva in 2015. To distinguish between our urban and suburban scenarios, we present 2 reference scenarios; each is characterised by the modal split, average daily travelled distance per the mode of transportation, area in km², population, and transportation performance (pkm). The first one is for the city of Geneva (described as commune central in (Figure 51), while the second is for the second suburban ring (suburbaines 2eme couronne), also where the Belle Idée pilot is operated, see Figure 51.



Source : OCSTAT / Fond de carte : DIT

Figure 51. Topographic division of Geneva Canton (source OCSTAT)

The analysis relies on mobility behaviour data from a census (microrecensements mobilité et transports (MRMT)) realised between 2000 and 2015 by the statistical office of the Canton of Geneva (Montfort, De Faveri et Bisso 2019) as well as Geneva Public Transport-TPG (2016). The MRMT has also been introduced in D8.4, where the model was applied to a preliminary scenario of replacing 18% of cars in the city of Geneva. The MRMT is an extension of a Suisse national census comprising the participation of 4,500 residents. The census accounts for the evolution of mobility trends for 15 years (Montfort, De Faveri et Bisso (2019)). The analysis provides trip distribution and the average daily distance per mode of transport in 2015. These values help estimate the total pkm per mode of transport.

5.5.2.1 Reference scenario (Sc01) – City of Geneva

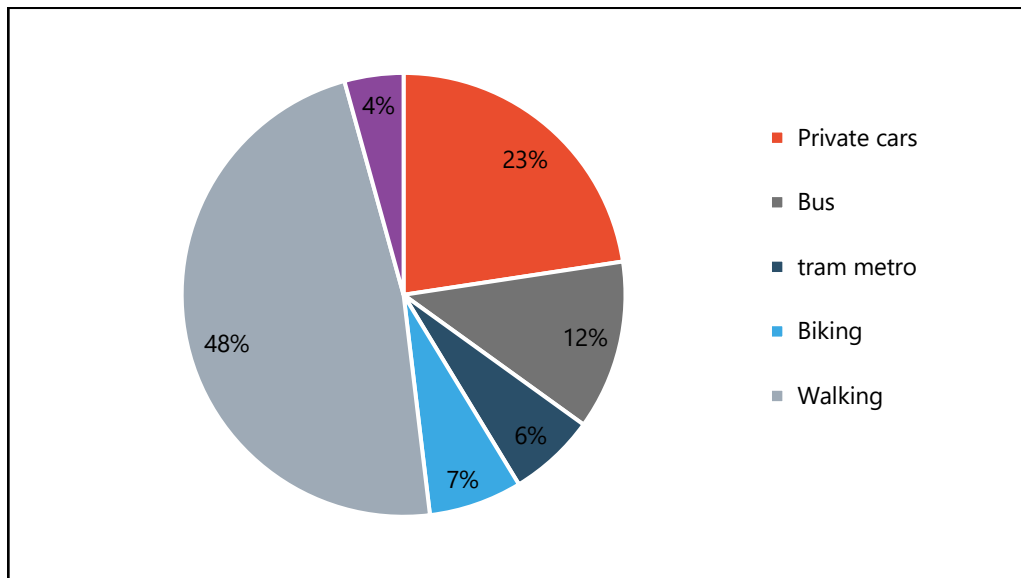
This scenario is the comparison point for the scenarios "replace all cars", "replace all buses", "Robotaxis", and "AM in MaaS".

The trip distribution and the average daily distance per mode of transport in 2015 are computed in **Table 6**. The population is 197,376 for the city of Geneva (Rietschin 2015). The area in the city of Geneva is 15.93 km² (Service de la mensuration officielle 2005). The overall daily trips amount to 711,000 trips (Montfort, De Faveri et Bisso 2019). The modal split is estimated using Montfort, De Faveri et Bisso (2019) and PG (2016) analysis for the mobility in Geneva (Figure 52).

These values are also used to estimate the new transport performance for the scenarios. The estimated transport performance is in Table 6, and the modal split for the city level are in Figure 52.

Table 6: Mobility behaviour and transport performance in the city of Geneva 2015

Mode of transport		Total transport performance in million pkm = Transport performance * population	Transport performance (pkm)	Average daily distance (km)	Modal share (trips)
Private mode	Private cars	972.57	4,927.50	13.50	22.60%
Public mode	Bus	389.03	1,971.00	5.40	12.30%
	Tram metro	-	-	0	6.40%
Active mobility	Biking	72.04	365.00	1	6.80%
	Walking	187.31	949.00	2.6	47.60%
Other		72.04	365.00	1	4.30%

**Figure 52: Modal share in city of Geneva 2015**

Using annual transport performance from Table 6, and the marginal costs for buses and cars for Switzerland from Table 7, we estimate the total external costs for road passenger transport for Geneva in 2015.

Table 7: Marginal costs in €-cent per pkm in city of Geneva

Externality category	Car	Bus
air pollution	0.63	0.76
climate change	1.31	0.44
wt	0.42	0.19
noise	1.92	0.84
accidents	1.35	1.62
congestion	39.30	6.50
production	0.38	0.18

The total external costs in 2015 (

Table 8) are important because they represent the reference point that is used to compare the impacts of the AM introduction and calculate the potential increase or decrease in external costs (before and after the deployment of the AM)

Table 8. Total externalities for passenger road transport in the city of Geneva 2015

Externality type	Mode of transportation	
	Car	Bus
Air pollution	6.09	2.94
Climate change	12.72	1.70
Wtt	4.09	0.74
Noise	18.67	3.27
Accidents	13.13	6.30
Congestion	382.22	25.29
Production	3.68	0.71
Total externalities per mode of transport	440.61	40.95
Total externalities – reference scenario	481.56	

5.5.2.2 Reference scenario (Sc02): Second couronne

This area has an overall population of 26,102 inhabitants and an area of 162km² (Federal Statistical Office 2013; Service de la mensuration officielle 2005). Based on Montfort, De Faveri et Bisso (2019), we estimate around 94,000 daily trips for all the inhabitants in the 2nd couronne consisting of 11 municipalities. The modal split is in Figure 54.

The mobility behaviour and the transportation performance in

Table 9 present the values used to estimate the new pkm per mode of transportation used in the scenarios.

Table 9. The mobility behaviour and transport performance for the 2nd suburban ring in Geneva, 2015

Area		Suburban – 2 nd ring, 2015			
Mode of transport		Total transport performance in million pkm	Transport performance (pkm)	Average daily distance in km	Modal share
Private mode	Private cars	240.1	9198.00	25.2	43.9%
Public mode	Bus	39.1	1496.50	4.1	9.504%
	Tram metro	19.1	730.00	2	4.896%
Active mobility	Biking	7.6	292.00	0.8	4.5%
	Walking	21.0	803.00	2.2	31.5%
	Other	20.0	766.50	2.1	5.7%

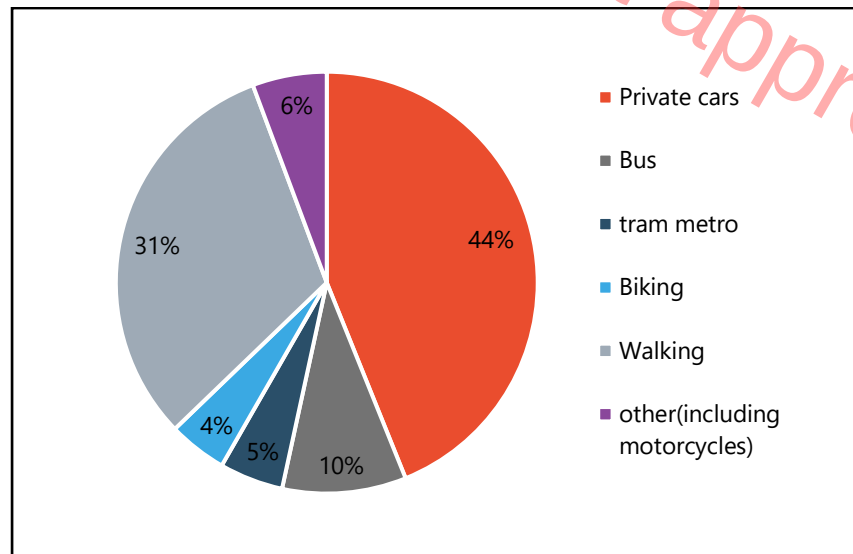


Figure 53. Modal split in the second suburban ring in Geneva, 2015

In this scenario, to better reflect the reduced public transportation offer, we adjust the occupancy factors. The bus has an average 10 passengers on board. The estimation is based on the higher dependency on cars and a lower modal share of public transport, in general, in suburban areas compared to city centres (high density population areas): The car modal share is 44% compared to 22.3% in the city centre. And the buses modal share is 10% while it is 15% in the city of Geneva. We assume that the AM are circulating on interurban other roads. The marginal costs are adjusted accordingly and included in

Table 10.

Table 10. Marginal costs in €-cent per pkkm in 2nd suburban ring in Geneva

Externality category	Car	bus
air pollution	0.63	1.43
climate change	1.31	0.83
wtt	0.42	0.36
noise	1.92	1.60
accidents	1.35	3.08
congestion	25.50	7.98

In conclusion, using total external costs (Total external costs (2015), $Y = \sum_i \sum_j x_{ij}, (2015)$), the total externalities in the reference scenario in suburban areas is included in Table 11. These values are used to estimate the increase or decrease in external costs in scenarios: "Expand the network" and "Targeted expansion of the network."

Table 11. Total external costs for road passenger transport in 2nd suburban ring of Geneva

Externality type	private vehicles	buses
Mode of transportation		
air pollution	1.50	0.56
climate change	3.14	0.33
wtt	1.01	0.14
noise	4.61	0.62
accidents	3.24	1.20

congestion	61.22	3.12
Production	0.91	0.14
Total externalities per mode of transport	75.64	6.11
Total externalities	81.74	

In the following part, the scenarios in the city centre are analysed. Afterwards, those in suburban parts are presented. The assessment relies on data from the marginal costs from Table 5, Table 7, and

Table 10, 0 scenario description, and 0 the reference scenarios (see Figure 50) by applying the steps from 0 application of the externalities model.

5.5.3 Scenarios in city centre

5.5.3.1 Replace all buses (Sc1)

In the following, the scenario “replace all buses” is tested in the city of Geneva. First, the marginal costs for the vehicles are presented in Table 12 based on Table 7 and the marginal costs for the AM (estimated in D8.4). Second, the AM are deployed to replace the 12.3% bus trips share. Thus, the estimated new modal share is as shown in Figure 54.

Table 12. Marginal costs (Car, Bus, and AM) in €-cent per pkm in Geneva city

Externality category	Car	Bus	AM
air pollution	0.63	0.76	0.05
climate change	1.31	0.44	-
wt	0.42	0.19	0.54
noise	1.92	0.84	0.30
accidents	1.35	1.62	-
congestion	39.30	6.50	13.10

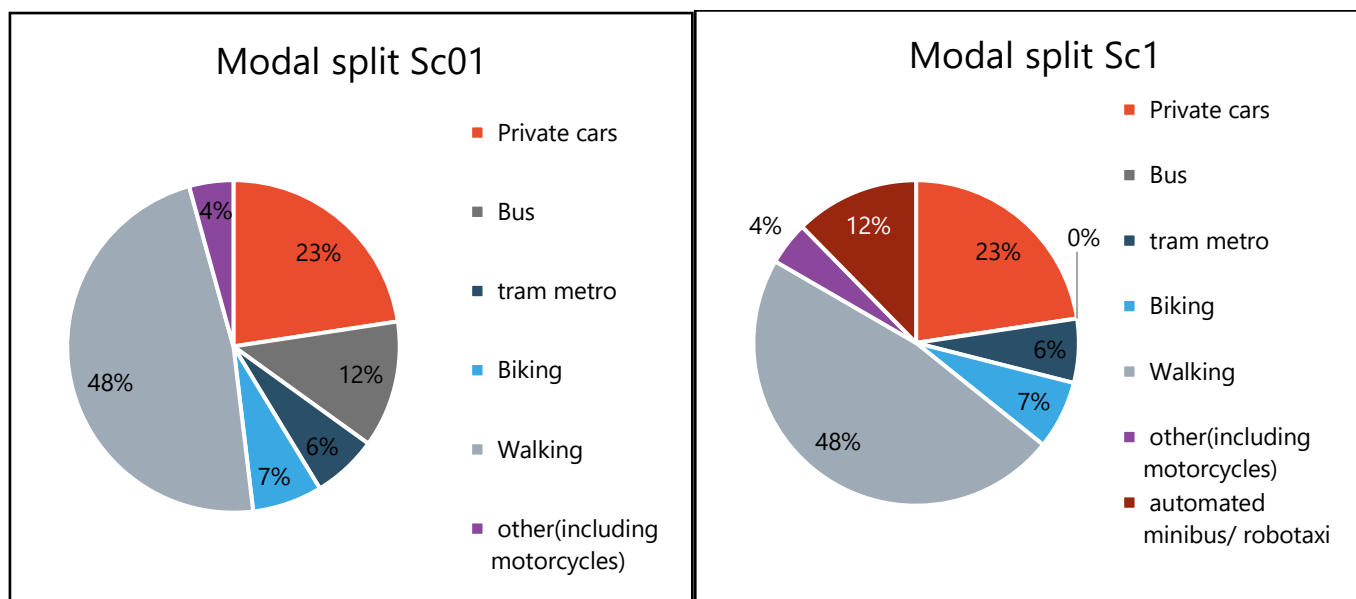


Figure 54. Modal shift for the scenario: Replacing all buses in Geneva

Similarly, we assume that the AM will conduct the trips of the buses with the same average distance of the bus trips from the reference scenario. This led to a prediction of the transport performance and consequently the total externalities (see Annex 1).

Scenario (Sc1) leads to an increase in external costs compared to (Sc01), mostly due to congestion. The increase in externalities equals around +12 million euros see Figure 55. If the congestion is omitted, the scenario shows a decrease in externalities of -11 million euros. The wt costs more in terms of external costs, but all the other environmental impacts are considered positive if the buses are replaced with AM (see Figure 55). However, this is still offset by almost +23 million lost due to congestion. The congestion is also explained by the occupancy of an AM being lower than that of a bus, as well as the difference in the sizes of the vehicles (both factors interfere in the estimation of the marginal cost of congestion).

In this scenario, there is no estimation for parking space since it focuses on bus replacement.

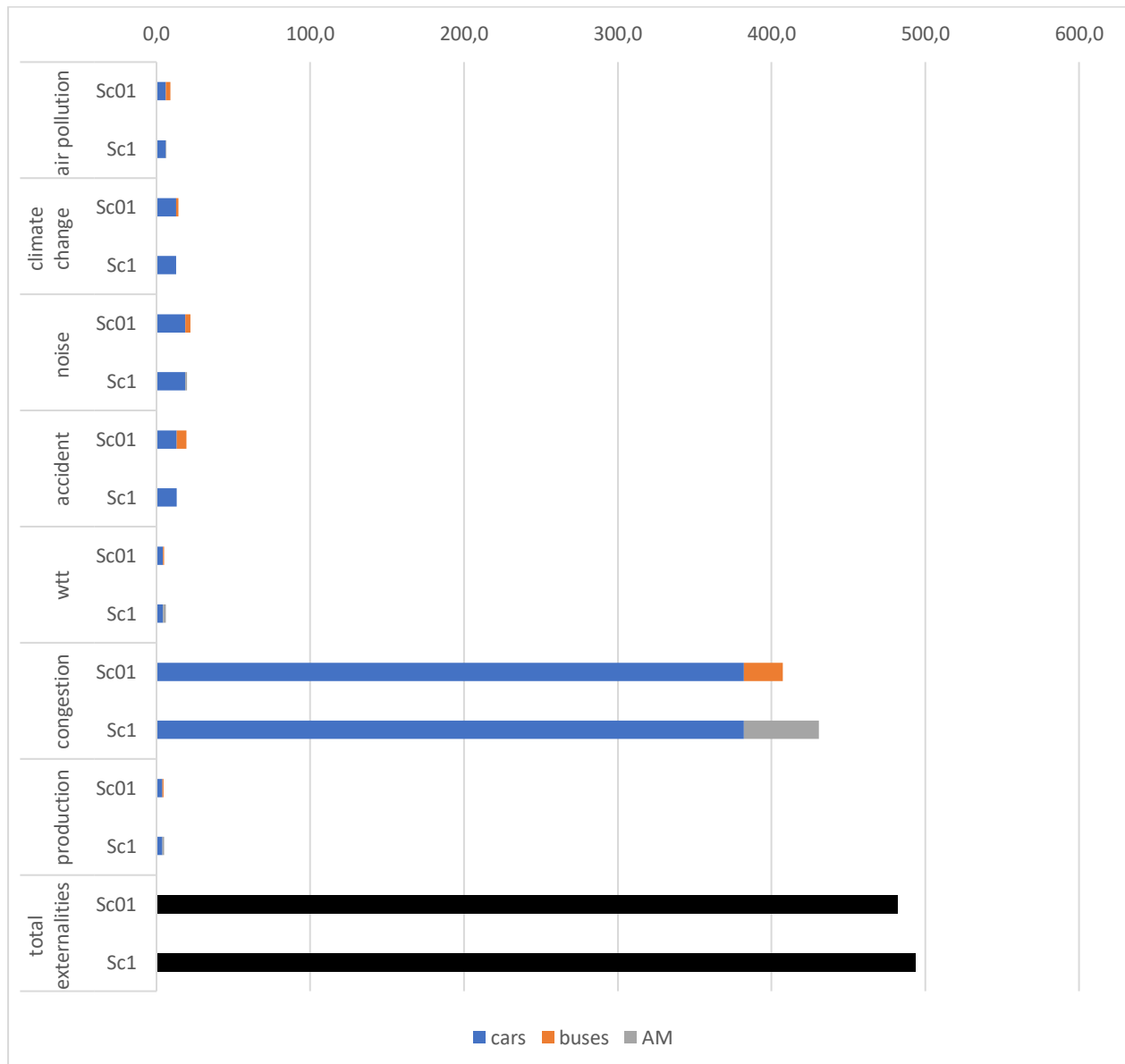


Figure 55. The increases or decreases in externalities with congestion in million euros in Sc1

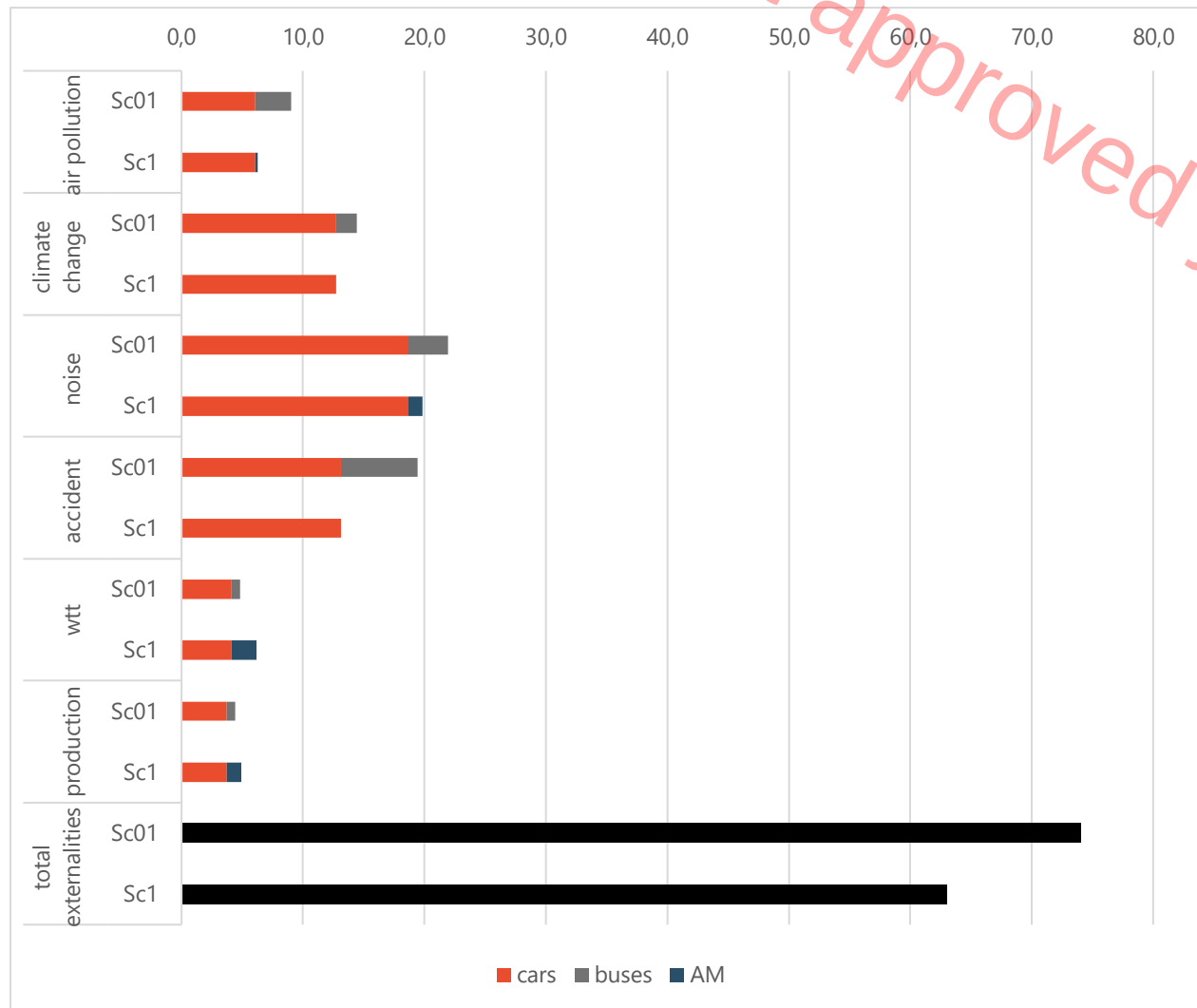


Figure 56. The increases or decreases in externalities without congestion in million euros in Sc1

5.5.3.2 Replace all cars (Sc2)

The marginal costs are those in Table 12 (from Sc1). We replace the car modal share in the city of Geneva (i.e. 22.6%) with the traffic circumstances of 2015 (Figure 57). The transport performance and the total externalities for this scenario are in the

Annex **2**.

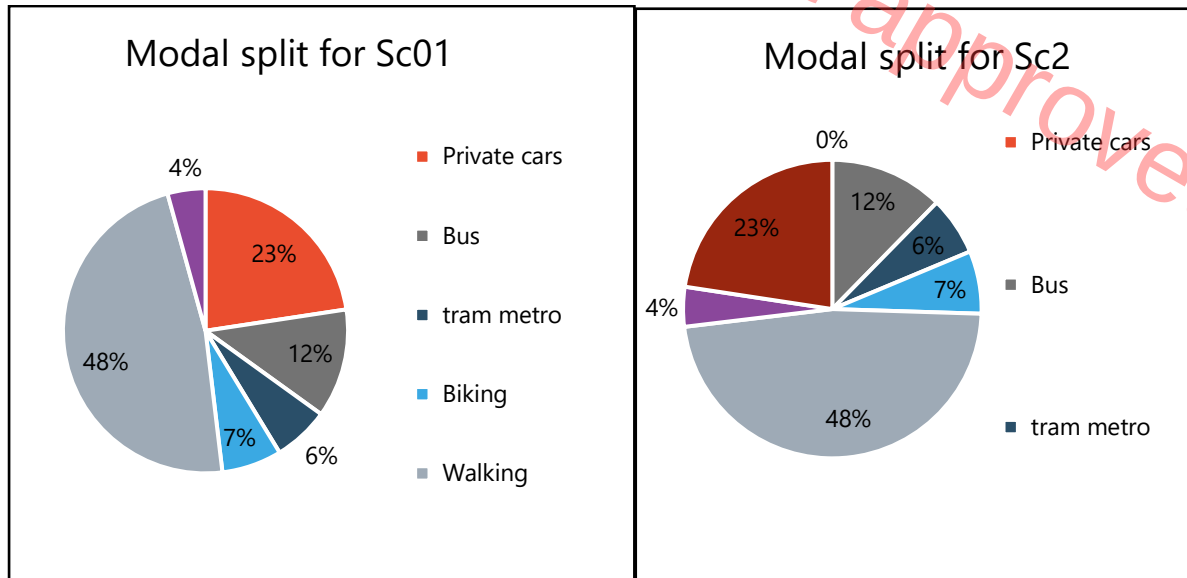


Figure 57. Modal shift for scenario Sc2: Replacing all cars in Geneva

Replacing all cars leads to a reduction in all external cost categories except the wtt costs, where there is an increase of +3.4 million euros. In general, this scenario could save up to 308 million euros, with the majority coming from the congestion savings (-210 million euros), see Figure 58 and Figure 59.

The environmental impact of replacing all cars with the AM is reflected in gains of around 40 million euros. The findings are aligned with most studies that support a shift from individual motorised mobility towards electric and shared transportation. Using the fleet calculator, the estimated fleet size needed to replace all car trips in the city of Geneva with AM, is around 1,380 minibuses for a waiting time superior to 4 minutes. Finally, the savings in parking space is 0.65 km², the equivalent of 64,824 parking spots.

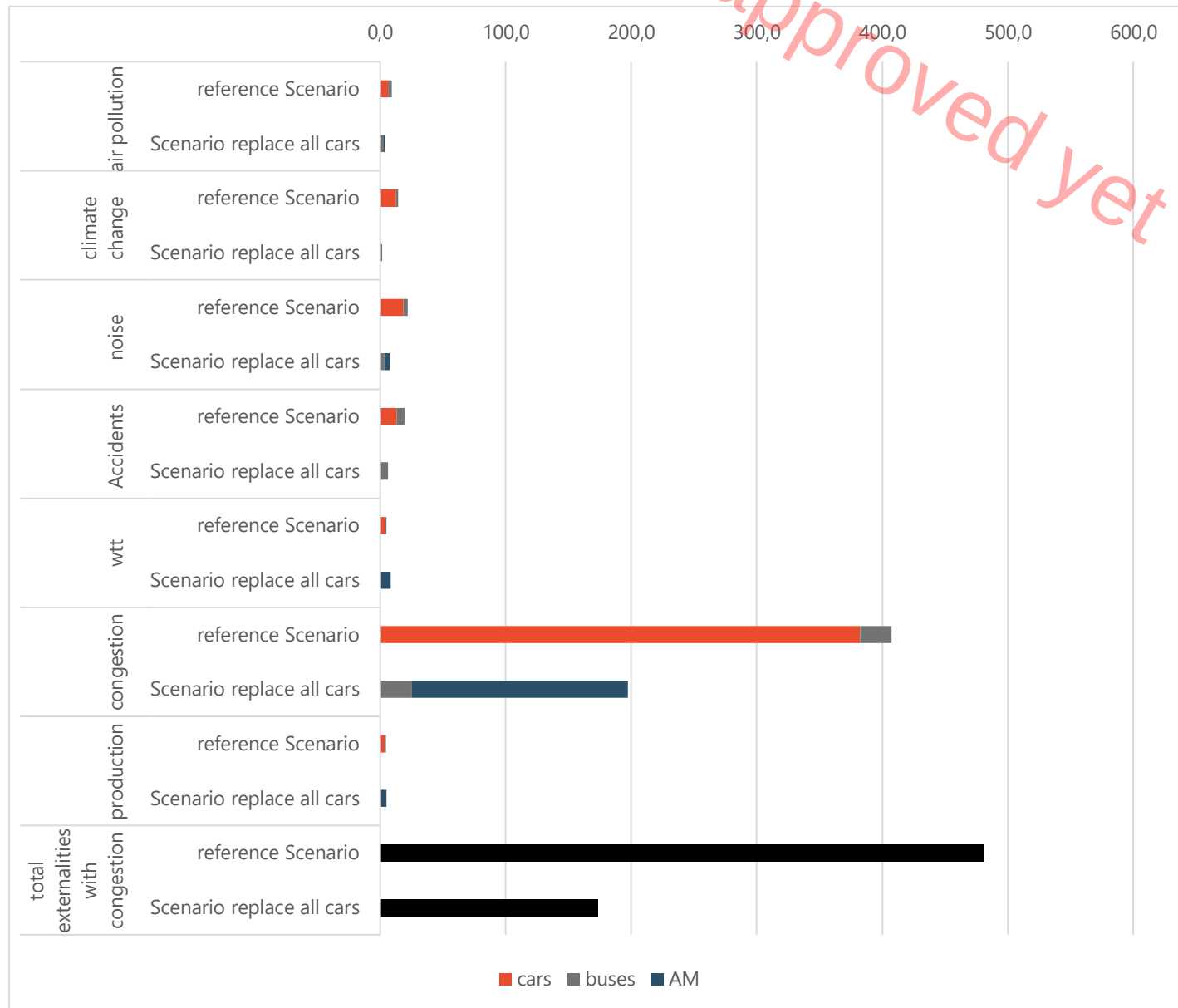


Figure 58. The increases or decreases in externalities with congestion in million euros in Sc2

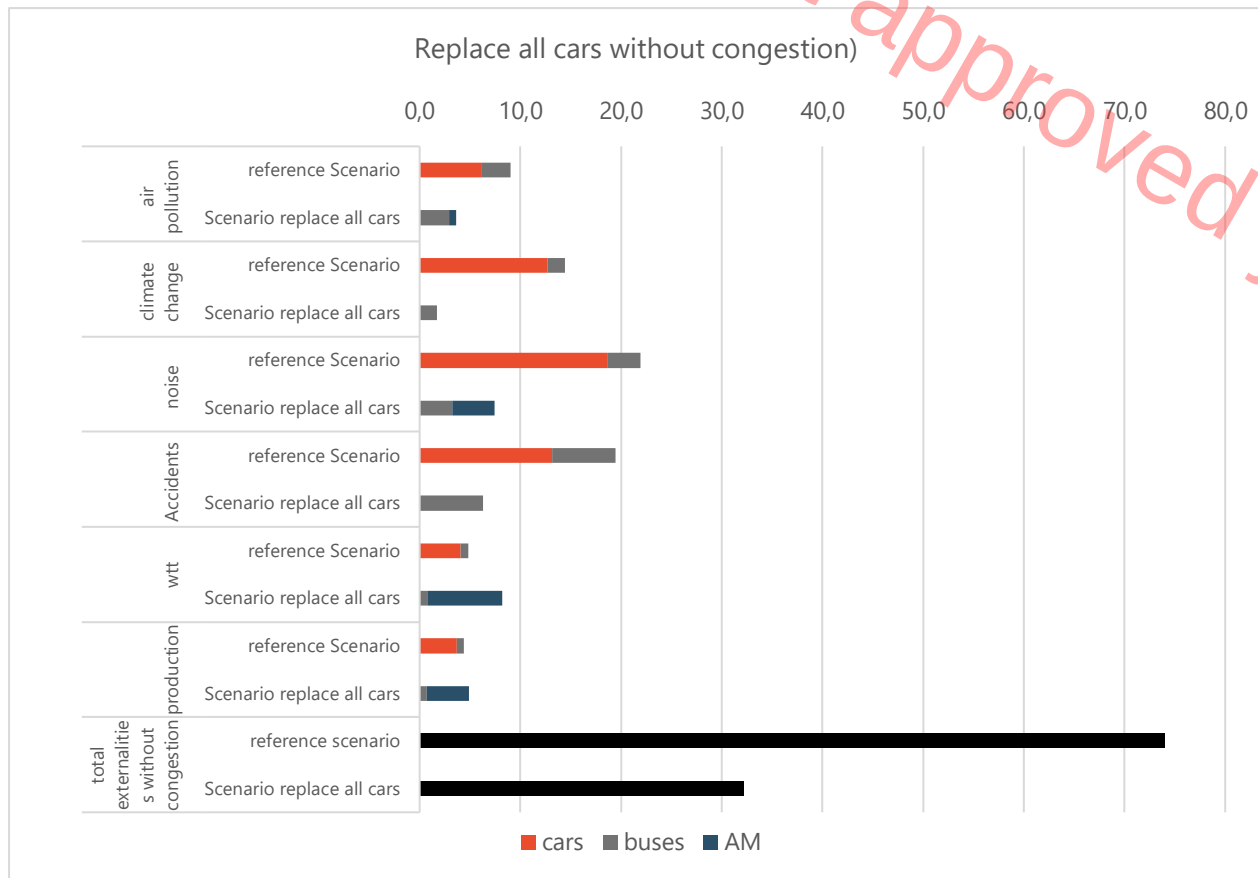


Figure 59. The increases or decreases in externalities without congestion in million euros in Sc2

5.5.3.3 Scenario 3: Robotaxis (Sc3)

As described in part 2, this scenario focuses on AV's integration in the transportation network in the form of robotaxis. The marginal costs for the robotaxis depend on van Essen et al. (2019) estimations for electric vehicles (EV). In this scenario, we estimate an occupancy factor for the roboaxi of 1.2. The marginal costs in the Delft assessment for the electric vehicle use an estimation of an occupancy factor of 1.6 (as well as for an ICEV, Table 3). Thus, the marginal costs for the different external costs categories are adjusted for an occupancy factor of 1.2 (new marginal cost for robotaxi = marginal cost for EV x 1.6/1.2).

The robotaxis marginal costs are presented in Table 13. Furthermore, to better translate the effect of the low occupancy factors, we assume that the robotaxis are operating on congested roads.

Table 13. Marginal costs for scenario robotaxis in €-cent per pkm

Externality category	Car	Bus	Robotaxis
air pollution	0.63	0.76	0.07
climate change	1.31	0.44	-
wtt	0.42	0.19	1.11
noise	1.92	0.84	1.92
accidents	1.35	1.62	-
congestion	48.50	8.00	64.67

The robotaxis modal share is explained in the table below and in Figure 60, the new modal split of the scenario in Figure 61. 20% of cars modal share (~22%) means the AM will absorb around 5% of car trips, similarly, a 6% reduction in bus share means around 1% of trips replaced by AM.

Finally, for the walking trips, we assume the new modal share of walking is 37% (~48%-13%=37%).

The transport performance and the total external costs for Sc3 are in

Annex **3**.

Table 14. Robotaxis modal share composition

Robotaxi share 18.2%	4.5	% (reduced from cars)	Ward et al., 2019; Zhong et al., 2020
	13.0	% (reduced from walking)	May, 2017, Fournier 2020
	1.0	% (reduced from buses)	Clewlow & Mishra, 2015

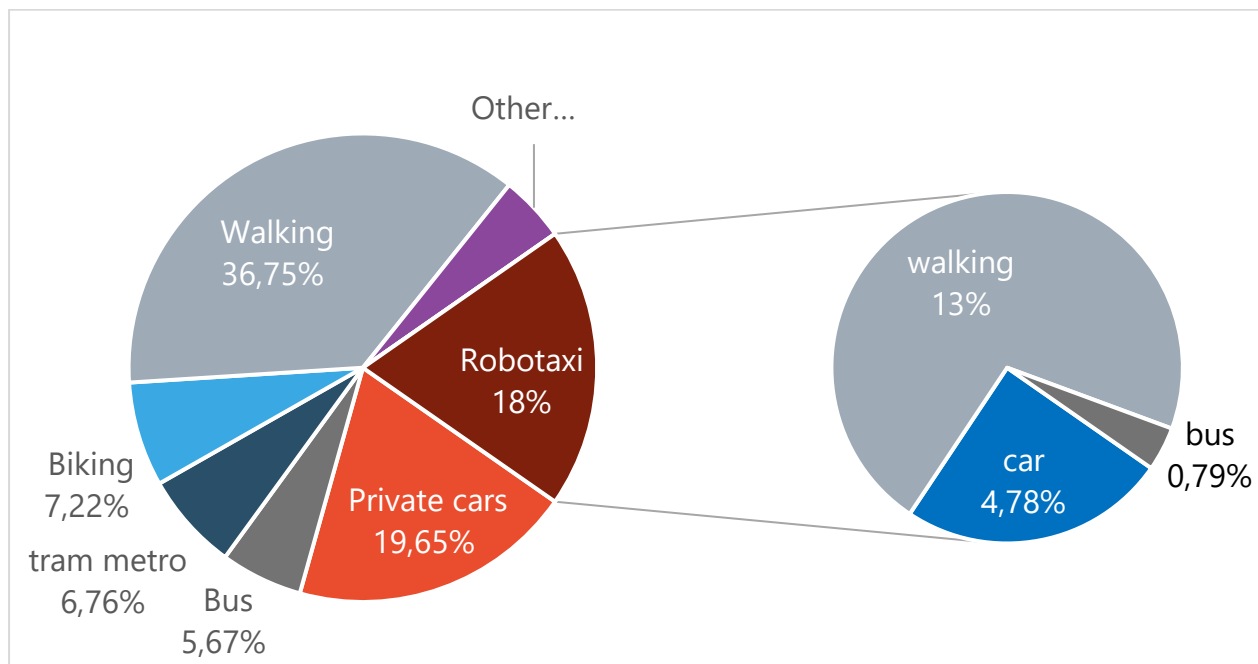


Figure 60. Modal share of robotaxis

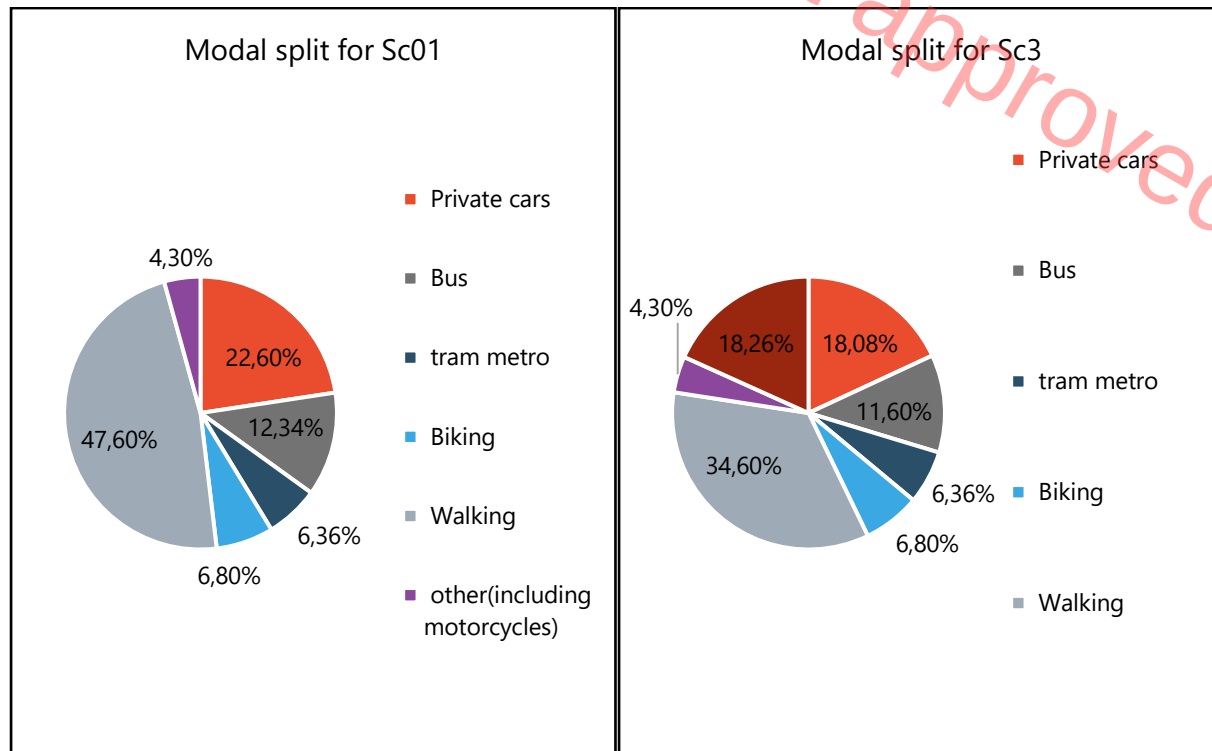


Figure 61. Modal shift for scenario Sc3: Robotaxis in Geneva

The deployment of robotaxis in the city centre with a laissez-faire outcome causes a significant increase in external costs compared to Sc01. In fact, it is estimated to cost around +162 million euros in terms of environmental and societal impacts (see Figure 62). Figure 63 is used to gauge the environmental impacts. The scenario also leads to decreases gains in the environmental and accidents categories except for the noise and wtt categories. The overall difference in external costs compared to Sc01 without the congestion are around 1 million euros.

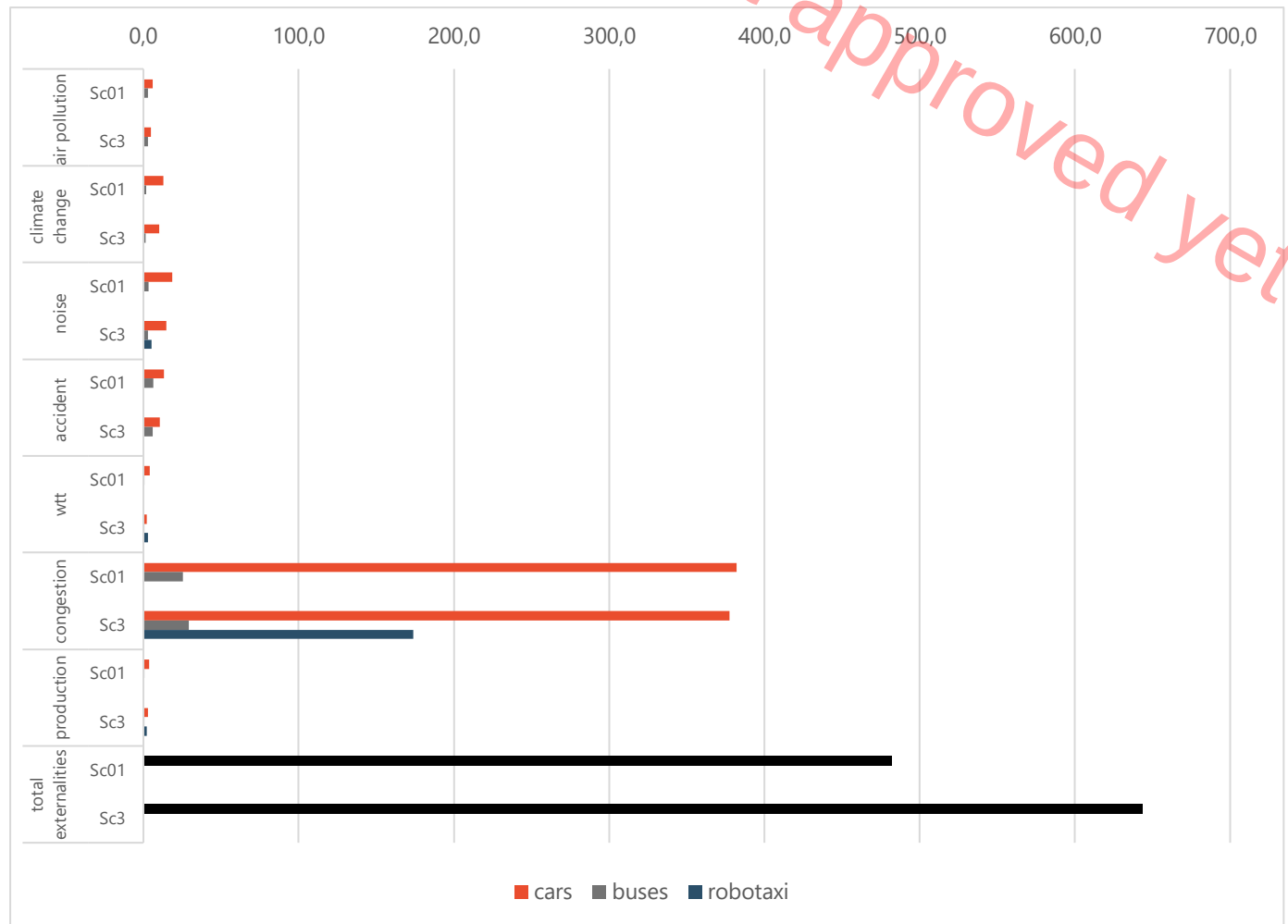


Figure 62. The increases or decreases in externalities with congestion in million euros in Sc3

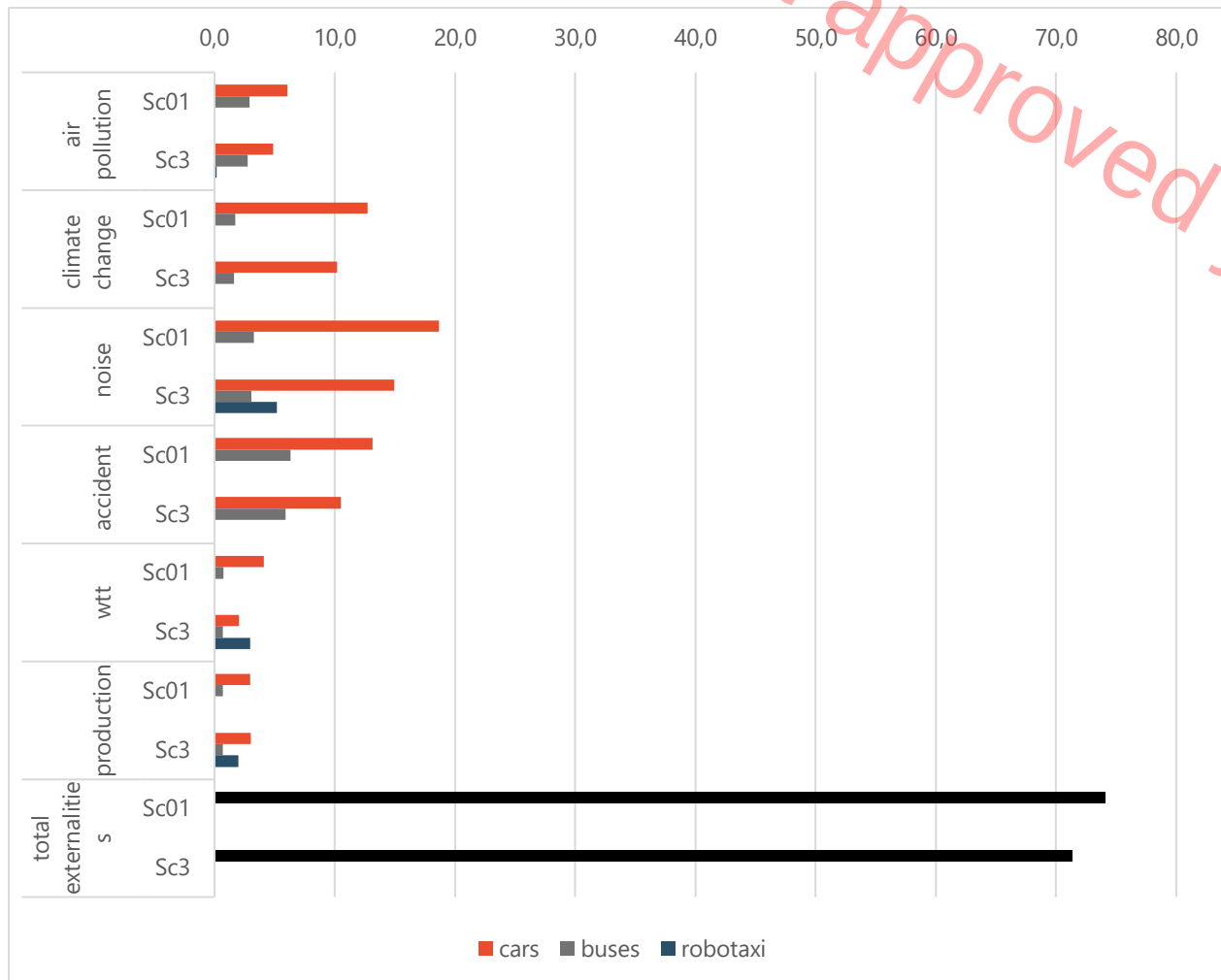


Figure 63. The increases or decreases in externalities without congestion in million euros in Sc3

Accounting for the increased travel demand, the fleet calculator by Fournier et al. (2020) shows a fleet of 1,058 robotaxis for an on-demand service with a waiting time of 1 minute. The 1,058 robotaxis could cover 18.2% of all daily trips within a geofenced area of 15.93km². We follow the simulation results from (Bischoff et Maciejewski 2016) since the simulation has similar conditions to Sc3; thus, one robotaxi replaces 10 cars. Hence the new car fleet is 54,624 cars compared to the original 64,824 cars (Bischoff et Maciejewski 2016). The 10,200 parking spots saved result in an additional 0.1 km² available space. We do not account for parking space for robotaxis based on numerous studies that assume the robotaxis are to be stored off roads in special facilities (AV parks) to be maintained and charged or would be circulating all day (Nourinejad, Bahrami et Roorda 2018; Hayes 2011; ITF 2015; Zhang et Guhathakurta 2017). Moreover, these garages are not part of the public domain since they belong to the private stakeholders (the robotaxis are operated by private stakeholders, see 0, scenario 3 robotaxis); hence, they would not affect public infrastructure.

Finally, we test the results for when the robotaxis are a part of a pooling service. Based on Alazzawi et al. (2018), we account of an occupancy factor of 2.4 instead of 1.2. The subscenario with ridesharing registers an increase in externalities that accounts for around 76 million euros. Alternatively, if we consider Mosquet et al. (2015) estimation for an average 4 people per vehicles, the increase is around 41 million euros. See table below

Table 15. Scenario 3 robotaxis applied with and without ridesharing service in Geneva, increase in externalities

service	individual	ridesharing	
Occupancy factor (average person per vehicle)	1.2	2.4	4
Increase in externalities in million euros	163.2	75.8	41.8

This shows a correlation between the occupancy factors and the externalities. Hence, ridesharing could contribute to a better environmental and societal impact when deploying robotaxis.

5.5.3.4 Scenario 6: AM in MaaS (Sc6)

Table 12 includes the marginal costs used to calculate the externalities of integrating the AM in MaaS in the city centre of Geneva. The transport performance and the total external costs are in Annex 4.

The modal split of Sc6 is explained in Table 4. The willingness to give up the cars for daily car users in the city centre of Geneva is used to estimate the modal share of cars that is absorbed by the AM. It is important to note that the sample for daily car users in the city of Geneva was limited, with only 34 respondents.

However, based on the social assessment, the trends of willingness to use the AM in Geneva, in general, were comparable to Lyon. Hence, the sample used is the people using their cars daily and live in the city centre from Lyon and Geneva combined, 81 people.

From this sample, 23 respondents said they were very willing to give up their cars if the AM bridges first and last miles. Eventually, we consider 28% of car trips could be replaced by the AM in MaaS, the equivalent of 6.42% of all trips. The AM is also replacing 3% from walking and 1.7% from biking trips, based on Table 4.

The table and figure below show the composition of the modal share of the AM in this scenario.

Table 16. AM in MaaS modal share composition

The AM modal share = 11.12%	6.42	% of cars
	3.00	% of walking
	1.70	% of biking

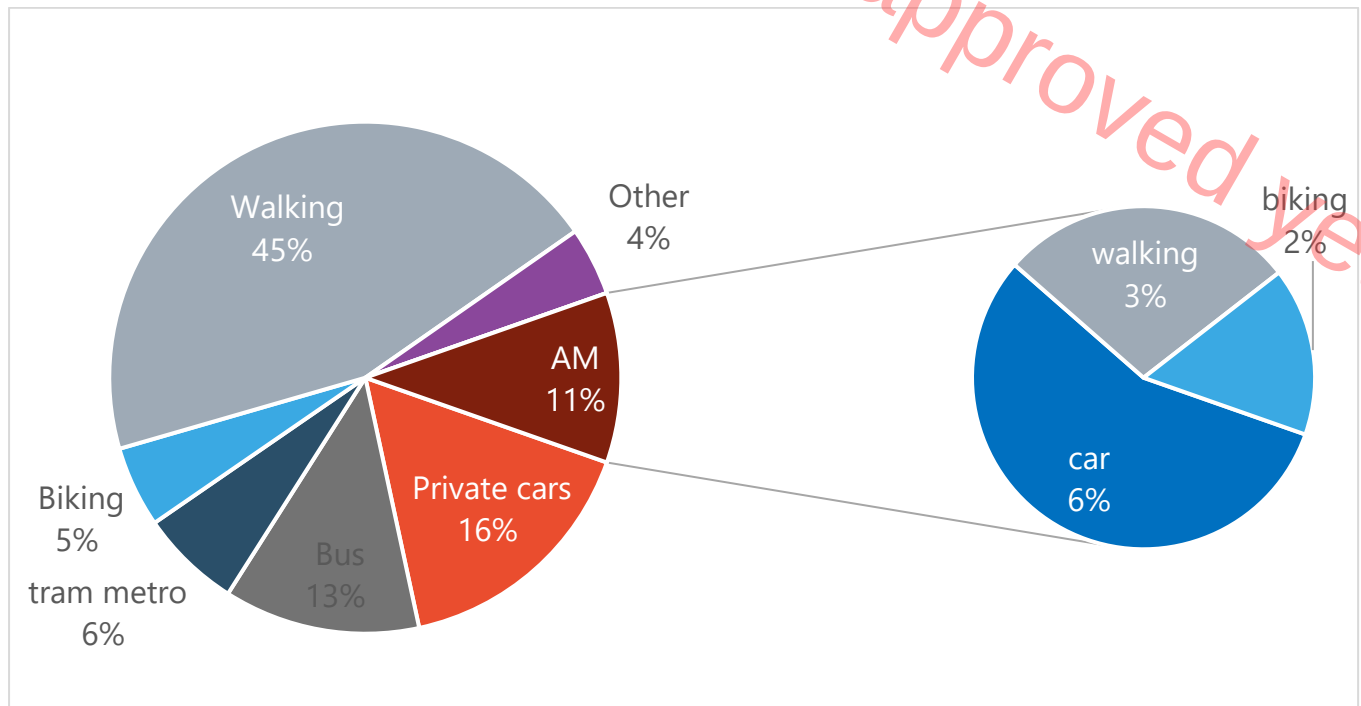


Figure 64. Modal share of AM in MaaS

The new modal split compared to the modal split from Sc01 is shown in Figure 65.

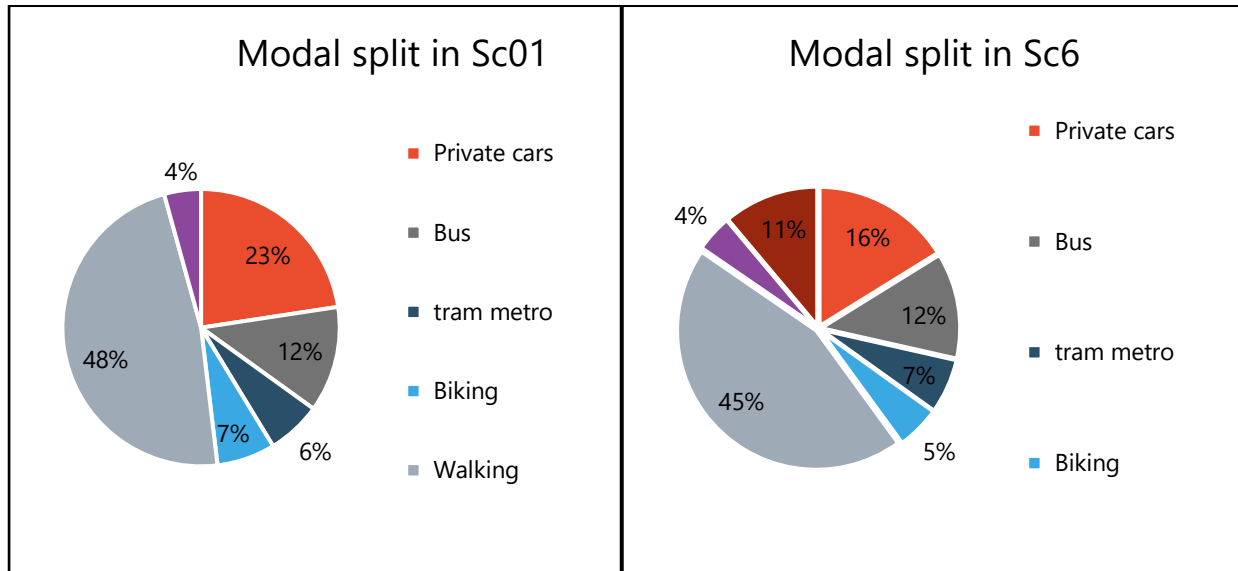


Figure 65. Modal shift for scenario Sc6: AM in MaaS in Geneva

Following the same methodology to estimate the externalities, the scenario is predicted to lead to reductions in external costs that amount to -83.3 million euros compared to Sc01 (AM in MaaS will reduce the external costs from the reference scenario by 83.3 million euros). The reductions without congestion are around -13 million euros. Similarly to previous scenarios, the wtt impact, when introducing the AM in densely populated areas, is negative (leading to an increase in the wtt external costs). This is explained mostly by the effect of electricity production on air pollution. Congestion presents the bulk of the reductions, around -70 million euros. We estimate around -4

million euros in savings for the categories of climate change, accidents, and noise. See Figure 66 for the results with congestion and Figure 67 for results without congestion.

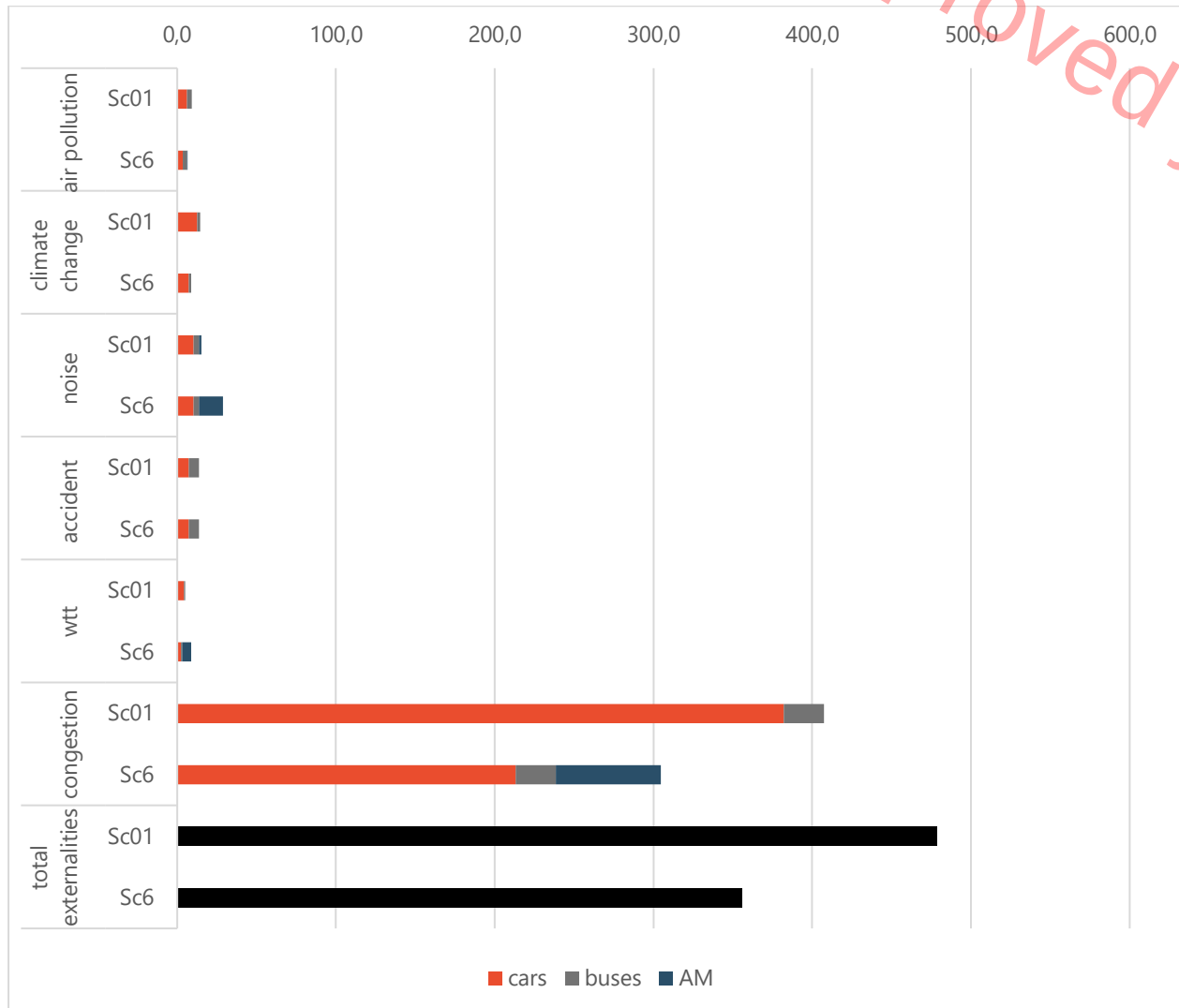


Figure 66. The increases or decreases in externalities with congestion in million euros in Sc6

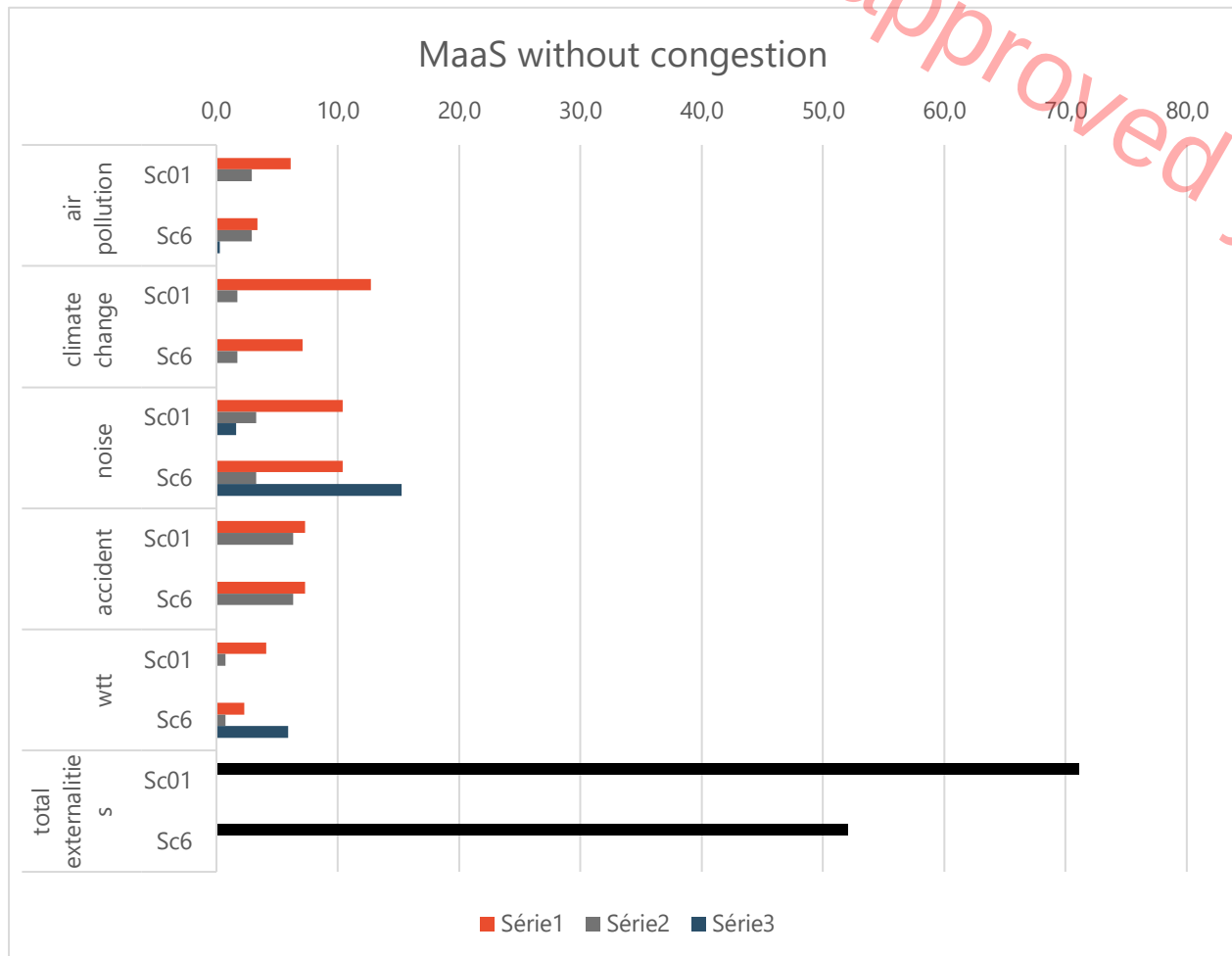


Figure 67. The increases or decreases in externalities without congestion in million euros in Sc6

This contributes to savings in parking space of 0.04 km² or around 4,160 parking spots.

Finally, we consider the results if the AM in MaaS is deployed in suburban areas. This could be interesting to see the difference of applying the same scenario in different settings (urban and suburban) and it highlights the importance of targeted and context-based deployment strategy. The analysis for suburban scenarios from 0 and 0 is applied in this case.

Based on the social survey, we can anticipate a replacement rate of cars by AM of 12.3%. The AM will also absorb 3% of walking and 1.7% of biking similarly to the analysis of the urban version of the scenario described previously. The decrease of externalities is estimated to be around 12 million euros. Without accounting for the congestion, we have a decrease of 2 million euros, see comparative table below

Table 17. Scenario 6 AM in MaaS applied in urban and suburban Geneva

Decrease in externalities in million euros	Setting for AM in MaaS	
	urban	suburban
With congestion	83.38	11.95
Without congestion	12.92	1,85

5.5.4 Suburban scenarios

For our two suburban scenarios, we use the mobility behaviour of the 2nd suburban ring in Geneva (Sc02).

Table 10 is used to calculate the total externalities in the scenarios. The AM marginal costs are also adjusted to take into account that the AM will compensate for the shortage of public transportation in these areas. The occupancy factor is 8, and the marginal costs estimated in D8.4 are adjusted accordingly in the table below.

Table 18. Marginal costs (Car, Bus, and AM) in €-cent per pkm in 2nd suburban ring of Geneva

Externality category	Car	Bus	AM
air pollution	0.63	1.43	0.04
climate change	1.31	0.83	-
wt	0.42	0.36	0.41
noise	1.92	1.60	0.23
accidents	1.35	3.08	-
congestion	25.50	7.98	6.38

5.5.4.1 Scenario 4: Expand the network (Sc4)

To expand the network in suburban areas, the AM are deployed to replace a percentage of cars' modal share. Thus, we rely on the explanation from Table 4 as well as why we used the sample of Lyon and Geneva from scenario 6, from 0.

Finally, the modal share of the AM equals 11.2%, absorbed from the cars modal share as presented in Figure 68. The transport performance and the total externalities are in Annex 5.

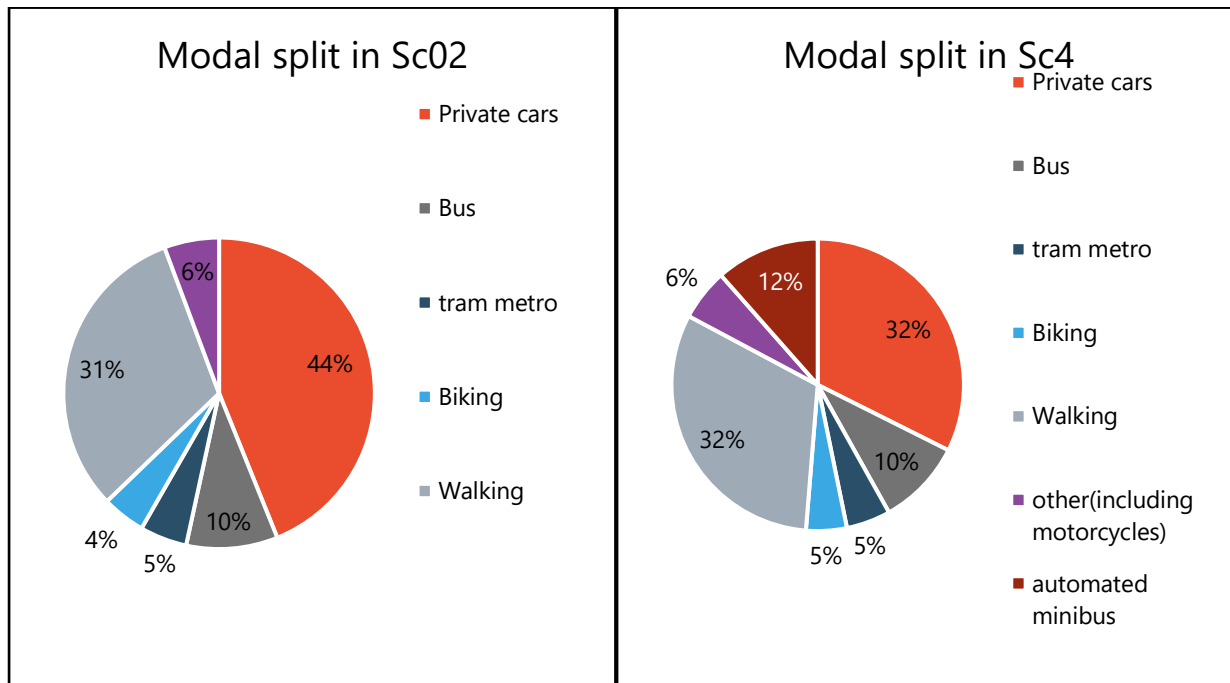


Figure 68. Modal shift of Sc4: Expand the network compared to Sc02

This modal shift leads to a decrease in externalities. We account for around -13 million euros. Consistent with the previous scenarios, congestion account for the highest impact, around -12.3

million euros, see Figure 69. We register a slight reduction in the WTT category in this scenario. In general, there are reductions in all externalities categories. Without congestion, the reductions are around -3 million euros, see Figure 70.

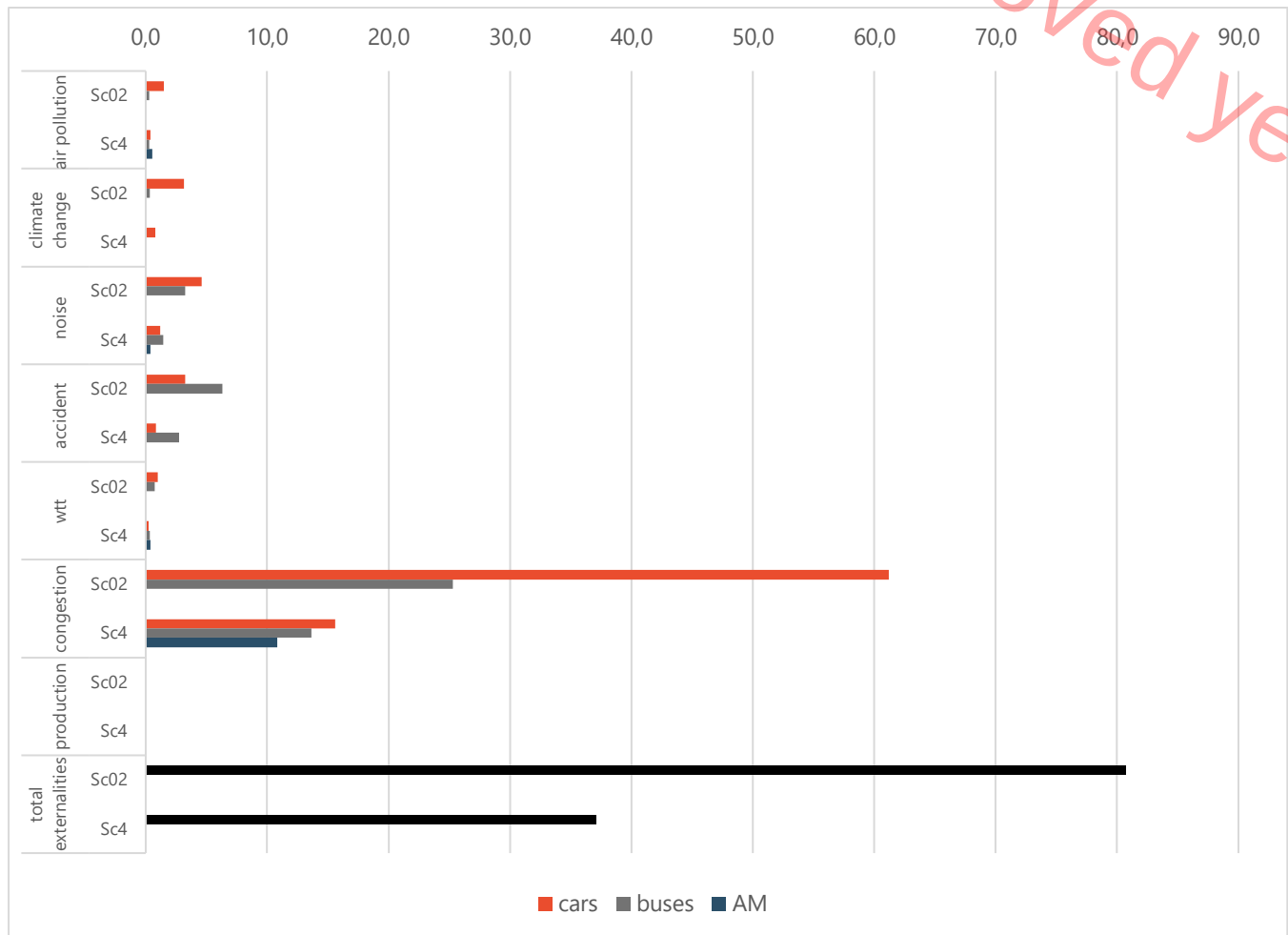


Figure 69. The increases or decreases in externalities with congestion in million euros in Sc4

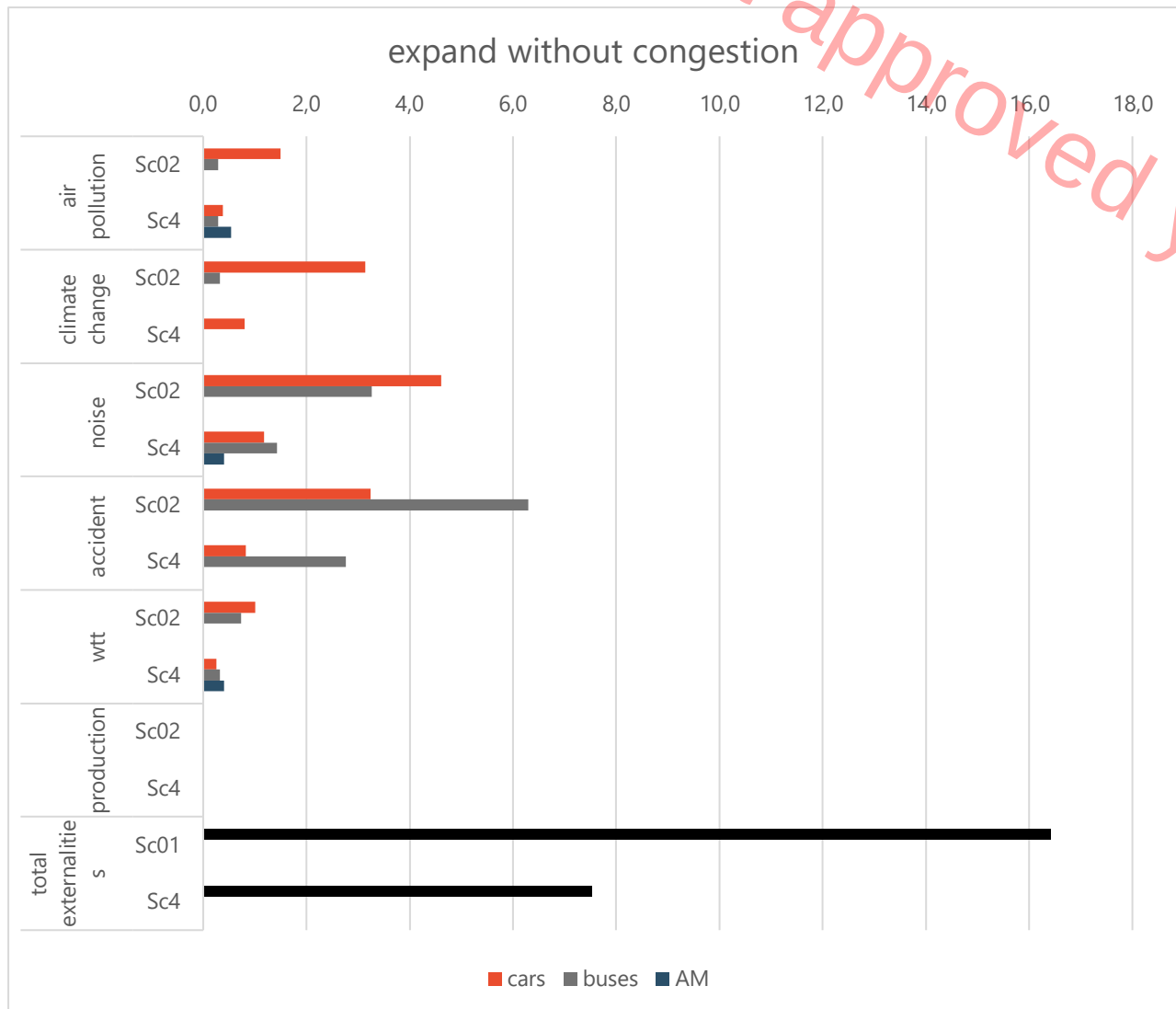


Figure 70. The increases or decreases in externalities without congestion in million euros in Sc4

The scenario presents reductions in external costs of -18 million euros for the city. If the congestion is not accounted for, the targeted expansion still leads to reductions of around -5 million euros. The fleet size for AM is estimated as 220, with a waiting time of 6 minutes and exit and entry time of 3 minutes (Fournier et al. 2020).

In conclusion, the savings in parking space equals 0.01 km², around 1 367 parking spots.

5.5.4.2 Scenario 5: Targeted expansion (SC5)

The targeted expansion scenario builds on the previous scenario. The same modal shift from cars to AM remains around 11.2%. However, in this case, we consider that the AM are targeted to also replace low occupancy buses and night buses. The demand for public transport fluctuates during the day and during its route. The notion of welfare optimisation justifies maximising the capacity of the bus (the bigger bus, the better the ability to meet the peak time travel demands). Thus, public transport operators would justify running big buses (fitting up to 60 passengers). First, it is difficult to predict exactly when a bus is running empty (even during off-peak time, there might be exceptional demand). Second, operating another fleet of smaller vehicles would require more

drivers and thus more costs than just keeping the big buses. However, as drivers are no longer necessary in an automated vehicle, these costs are eliminated. Furthermore, the on-demand feature makes the service customizable according to the demand (Pyddoke 2020).

Determining the specific ratio of buses with low ridership is a complex process since the number varies unpredictably. That is why we consider Adra, Michaux et André (2004) study. In their analysis, empty running km⁵ for buses are around 11% based on data from Paris public transport system (RATP). Moreover, Mancret-Taylor et Boichon (2015) report stipulates around 4% of bus trips are taken between midnight and 5 a.m. Hence, we assume that more than 12% of all bus trips in suburban areas are replaced by AM trips. Finally, the modal share of AM in this scenario is 13.4%. Sc5 also registers reductions in external costs of around -15 million euros and -4 million euros without counting the external costs from congestions; see figures below. The used transport performance and the resulting total external costs for Sc5 are in Annex 6. The parking savings are similar to the previous scenario, "Expand the network", we estimate savings of 0.1 km².

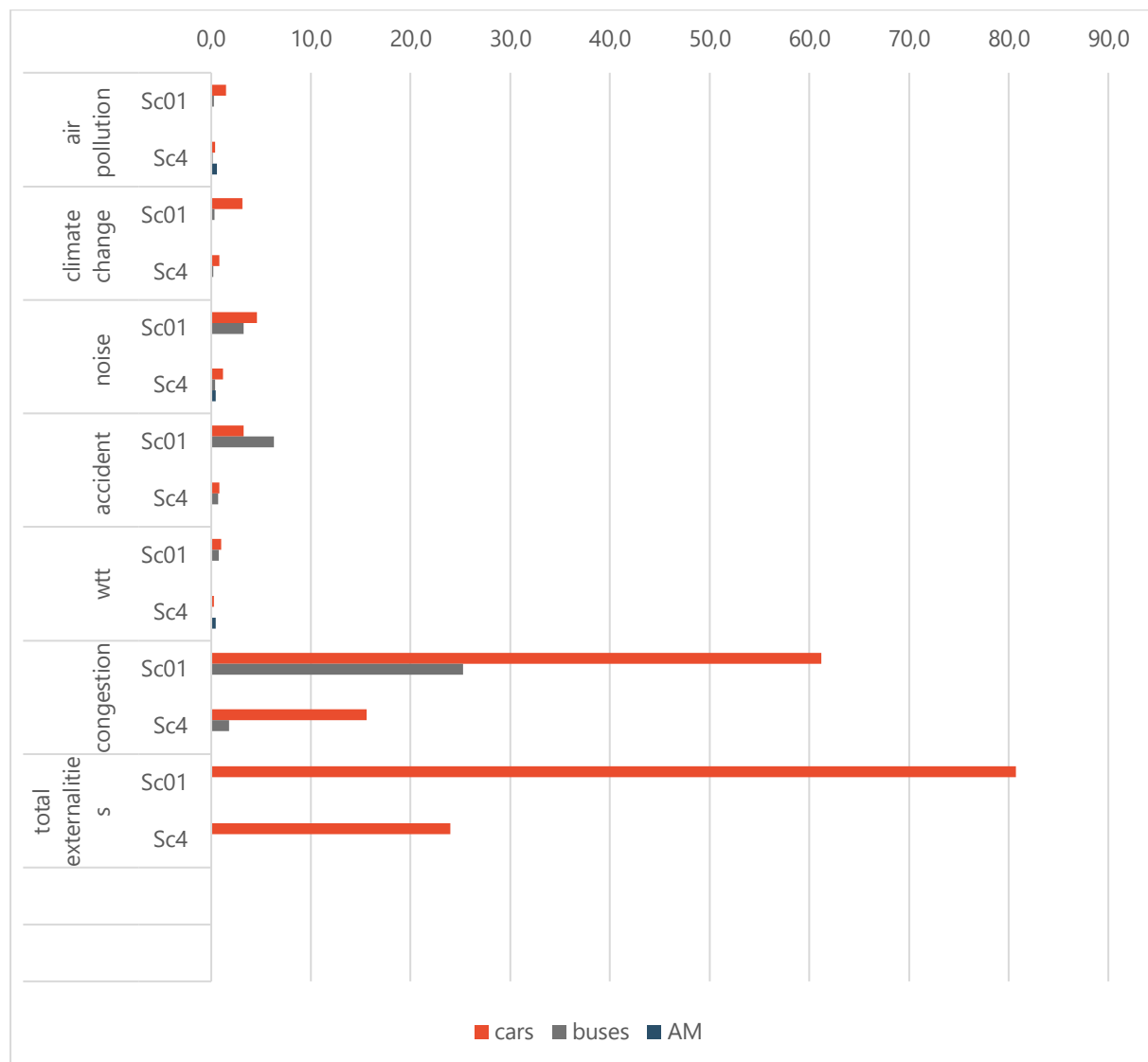


Figure 71. The increases or decreases in externalities with congestion in million euros in Sc5

⁵ The rate of empty running vehicles is the rate of vehicle-kilometres without goods or passengers (Adra, Michaux et André 2004).

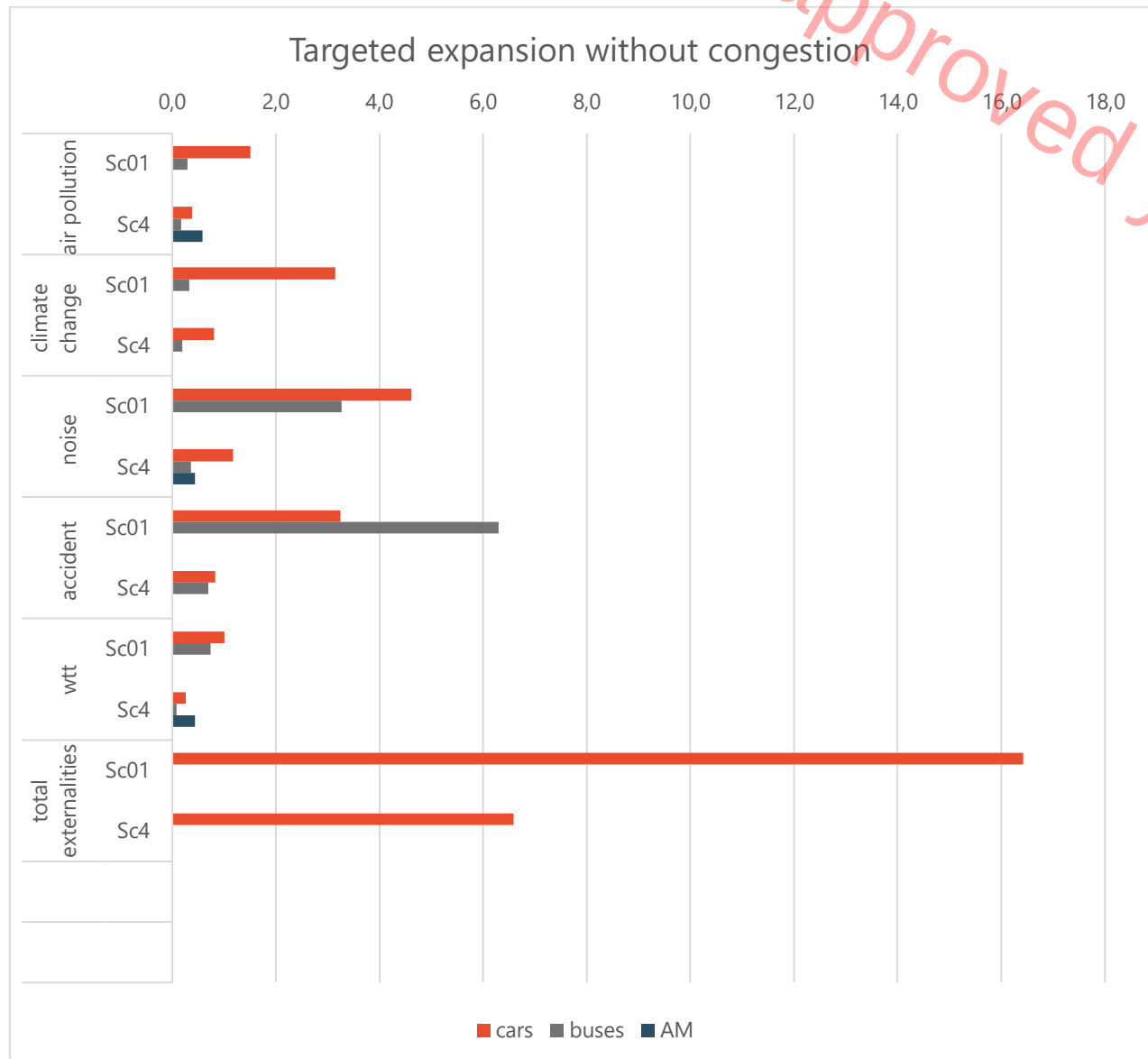


Figure 72. The increases or decreases in externalities without congestion in million euros in Sc5

5.6 Discussion

To better demonstrate the scenarios and compare the results, the table below includes increases or decreases in external costs per scenario for each of the 6 scenarios analysed.

Table 19. The increases (+) and decreases (-) in external costs in the 6 scenarios of AM deployment in the Canton de Geneve

	Scenario	Setting	The modal share of AV	The scenario modal shift	Sources used for modal shift	Decrease (-) or increase (+) in external costs in million euros	Savings in Parking space in km ²	Equivalent number of parking spaces
1	Replacing all buses	urban	12 %	-Replace all bus trips in city center => 12% of all trips		+ 12.11	-	-
2	Replace all cars	urban	23 %	-Replace all car trips in city center => 23% of all trips		- 307.95	0.65	64,824
3	Robotaxis	urban	18 %	-Replace 7% of bus trips=>1% of all trips -Replace 20% of car trips => 4.5% of all trips -Replace 13% of all trips (from walking modal share)	(Ward et al. 2019)(May et al. 2020) (Clewlow et Gouri S.Mishra 2017) (Heineke et al. 2019)	+ 161.8	0.16	15,800
4	Expand network	suburban	12 %	-Replace the car trips from daily car users who would give up their car - 26% of car trips => 11.5% of all trips	- representative survey	-12.94	0.01	1,367
5	Targeted expansion	suburban	13 %	-Same for car trips from Sc4 => 11.5% from all trips -Replace all trips on night buses and empty-running buses-12% from all bus trips => 1.2% from all trips	- representative survey Mancret-Taylor et Boichon (2015), Adra, Michaux et André (2004)	-14.86	0.01	1,367
6	AM in MaaS	urban	11 %	-same for car trips from Sc4 - Replace car last/first mile trips to connect to a rail station => 6.5% of all trips -Replace walking last/first mile trips to	- representative survey (Paydar, Fard et Khaghani 2020), (Giansoldati, Danielis et Rotaris 2020)	-83.38	0.04	4,160

				connect to a rail station => 3% of all trips -Replace biking last/first mile trips to connect to a rail station => 1.7% of all trips	Gebhardt et al. (2016)			
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The two scenarios that incurred increases in external costs were: "robotaxis" and "Replacing all buses". The first is set to compete with public transport, while the second is set to update the bus service. However, both demonstrate that replacing traditional public transportation without a planned strategy (or with a laissez-faire outcome) would worsen the impact of deploying AV in cities and diminish their potential benefits on the environment and society.

Replacing the buses scenario results matches the simulation of replacing buses with shared AV in Helsinki (ITF 2017). Thus, it is not recommended to replace all the buses with AM, rather target the off-peak hours' bus trips like in scenario 5 "targeted expansion," where the bus service is mixed with AM on-demand. The path to update the bus service would be better by replacing the fleet with electric buses.

The robotaxis further aggravate the shortcomings of the transportation system. It reinforces a model of individual mobility that has proven over time to be harmful to the city and the environment. Numerous studies would recommend deploying the robotaxis with a ridesharing service which would decrease their external costs and even support the public transport network.

Alternatively, replacing all cars presents the most savings. This corroborates with most urban strategies to reduce the use of cars. Indeed, this fits with Geneva urban strategy to promote sustainable mobility (soft modes and public transport). Replacing all cars clearly leads to savings, yet it is easier to apply in city centres and not suburban areas, this limit its gains as well as AM potential (Duarte et Ratti 2018; McCallum 2020; ITF 2015, 2017). Moreover, it is more challenging to realise as it depends strongly on people acceptance of the technology and their willingness to get rid of their cars.

On a larger scale, MaaS could reduce environmental deterioration and increase the efficiency of the shuttles even if it absorbs some active mobility means. It is the most realistic and could provide better results accompanied by TDM measures to promote active mobility. It could be part of an on-demand and door-to-door service across the canton of Geneva to reduce the long-distance trips conducted with cars and improve connectivity to mobility hubs.

Moreover, the suburban scenarios show optimistic results, which justifies the need to strengthen the transportation network where there are shortcomings of public transport. The gains might be limited compared to other scenarios gains (AM in MaaS, or Replacing all cars). Nevertheless, these deployment strategies would strengthen the overall transportation offer across the canton and encourage passengers to use trains more. This would lead to further gains in suburban and urban areas alike. Concurrently, high-density population areas usually contain more short-distance trips in smaller areas, as opposed to suburban and interurban areas. In this case study, the city of Geneva (one commune with a population density of 12,500 inhabitant/km²) accounts for 711,000 daily trips while the 2nd suburban couronne (11 communes with a population density of 161 inhabitant/km²) accounts for 94,000 daily trips. Hence, this makes the comparison between the 2 sets of scenarios biased. In order to maximise the savings, the AM could cover longer distances and connects communes (rather than operate exclusively within the commune).

If we focus on the externalities categories, we notice that the congestion presents the factor that leads to the biggest reduction in external costs (Sc 2, 4, 5, and 6) or biggest increases (Sc 1 & Sc 3). It reflects the transport pricing and value of time. Replacing buses that usually operate within specific lanes with AM would potentially slow down the traffic flow, whereas deploying more individual vehicles like robotaxis would affect the traffic congestion.

This is incremental for policymakers as it showcases the perils of traffic jams as it worsens the traffic flow, which affects daily life and air pollution and GHG emissions. Reducing congestion is a leading cause of externalities gains in our scenarios. Dominating congestion externalities are aligned with Jochem, Doll et Fichtner (2016a) and van Essen et al. (2019) results for road traffic congestion.

The categories of accidents, air pollution, production, and climate change show savings across the 6 scenarios. Hence, any introduction of AV, whether AM or robotaxis, will have positive impacts on accidents rates and air pollution GHG emissions. The air pollution and GHG emissions externalities during the wtt phase, on the other hand, shows negative results for all urban scenarios. This is explained by the fact that the production of electricity for battery charging is strongly energy-intensive, and it involves air emissions, thus causing a not negligible environmental burden, as proved by Pero, Delogu et Pierini (2018). Furthermore, the Robotaxis scenario is the only case where it causes a negative noise externality which is understandable since the marginal cost is the same as that of an ICEV. The decision not to distinguish between an EV and ICEV is due to the similarity in speed and the occupancy factors for both vehicles (Jochem, Doll et Fichtner 2016b).

Also, the introduction of AV in the city will, in general, lead to savings in parking space. The more cars are replaced, the more urban area is free. Free urban space means reshaping the built environment to be more green and livable, which again aligns with the urban strategy of Geneva (Etat de Genève 2013b).

The direct costs of the deployment on a microscale for the pilots were analysed previously in Antonialli et al. (2021). Building on this analysis, we note that it is important to account for the effects of letting go of the drivers. The AM are operating with safety drivers on board in the AVENUE pilots. However, in the future, they would operate without human interference on board. This used a major advantage for replacing traditional public transport with AM as it will significantly cut the costs for the public transport operators, which would make it easier for them to adopt the technology and make their public transport more attractive and competitive. However, the layoffs mean an increase in the unemployment rate. For instance, Transport Public de Geneve (TPG), the public transport operator in Geneva, hires almost 1,300 bus drivers. In Sc1, eliminating all buses might seem disadvantageous for the city in terms of environmental and societal impacts. It could reduce around 50 million euros of labour costs for TPG. However, this would have a more negative impact on the society by decreasing 1,300 jobs, even if we account for the creation of new jobs: off-site safety operator positions are limited and would not compensate around 1,000 posts, which would create labour market disruption and have a significant effect on the economy as well (Nikitas, Vitel et Cotet 2021; Sousa et al. 2018).

To conclude, the externalities calculations supported most of the initial assumption for the consequences of the deployment in the scenarios (presented in part 2). It also helps clarify the ambiguity of the direct environmental effects of the AM. The analysis provides insights that would help policymakers decide on how to deploy the AM (or roboaxis) to support the prosperity of their cities.

5.7 The model applied to other cities

In this part, we apply selected scenarios to the AVENUE cities. First, we use the representative survey to filter which scenarios are interesting to be studied based on the sample of respondents that are using their cars daily in the geographic areas of the city centre, large town, and small to medium village.

For Luxembourg, the sample of respondents that are daily car users and living in the city was too small. Thus, we select the scenarios in the suburban and preurban parts.

For Lyon, we follow the same analysis as for Geneva; we combine the samples for Lyon and Geneva.

Finally, for Copenhagen, we focus on the urban scenarios (replacing all cars, replacing all buses, robotaxis, and AM in MaaS) since the sample of respondents is significantly larger than those from small to medium villages.

5.7.1 Copenhagen

Copenhagen municipality is one of the 4 municipalities of the city of Copenhagen. The city is at the centre of the metropolitan area of Copenhagen; see Figure 73. The municipality of Copenhagen is the most populated city in Denmark. It has a goal of becoming the first CO₂-neutral capital by 2025 (The city of Copenhagen 2013). Copenhagen has a strong sustainability agenda. It is committed to achieving the Sustainable Development Goals (SDG), by drafting policies and setting targets for each of the 17 SDGs (The city of Copenhagen 2014). Thus, it has set targets to strengthen its public transportation network and further promote biking and walking. Indeed, it ranks first in the current sustainable mobility ranking (Kodukula et al. 2018). However, it ranks low in public transportation modal share. The reduced public transport modal share is explained by high urban density as well as efficient biking infrastructure (Kodukula et al. 2018).

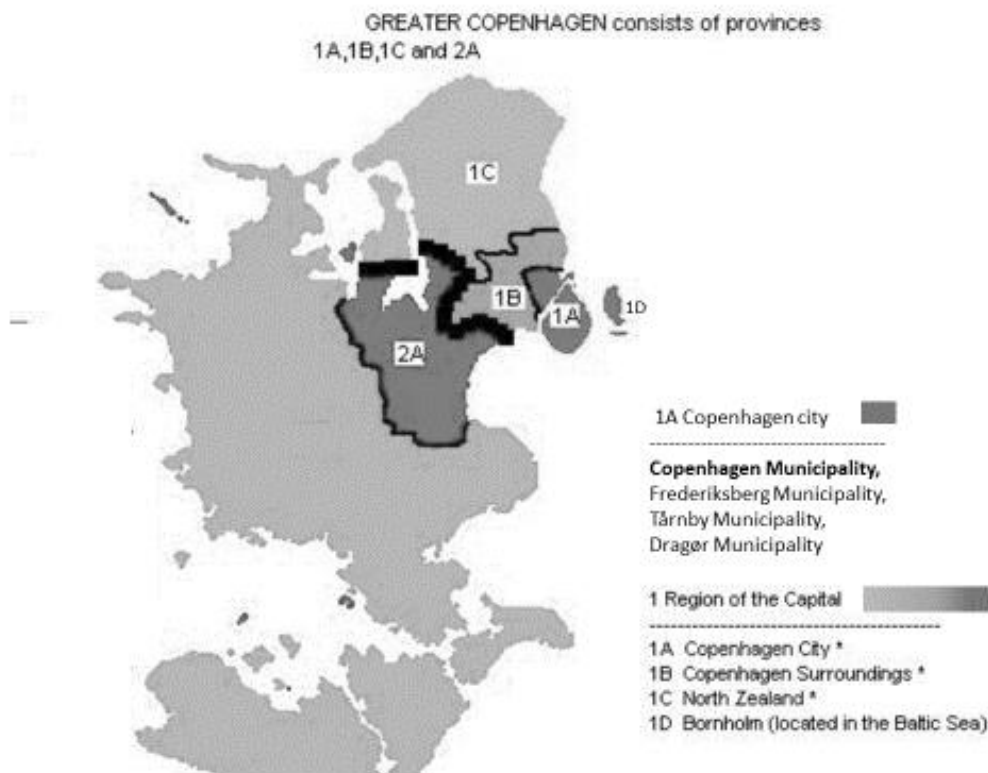


Figure 73. Topographic area of Copenhagen

For this study, we focus on the municipality of Copenhagen for the four urban scenarios. The data used is based on the Danish national census for 2019 (Christiansen et Baescu 2021). The modal share for the urban scenarios is from 2015 based on Kayser (2017). This represents the most recent data we could find that represents the mobility behaviour for the municipality of Copenhagen. The modal share is presented in Figure 74. This is combined with the average distances per the mode of transport from the greater area of Copenhagen based on Christiansen et Baescu (2021).

Copenhagen municipality has around 623 000 residents and an area of 86.4 km² (Statistics Denmark 2021). The average daily trips per person are around 2.8. We account for a fleet of 252 600 cars and around 1,000 buses (Movia 2019).

The scenarios applied in this case are: “Replacing all cars”, “Replacing all buses”, “Robotaxis”, and “AM in MaaS”. By using the same analysis and methods described for Geneva, we obtain the potential increase or decrease in external costs as presented in the table below.

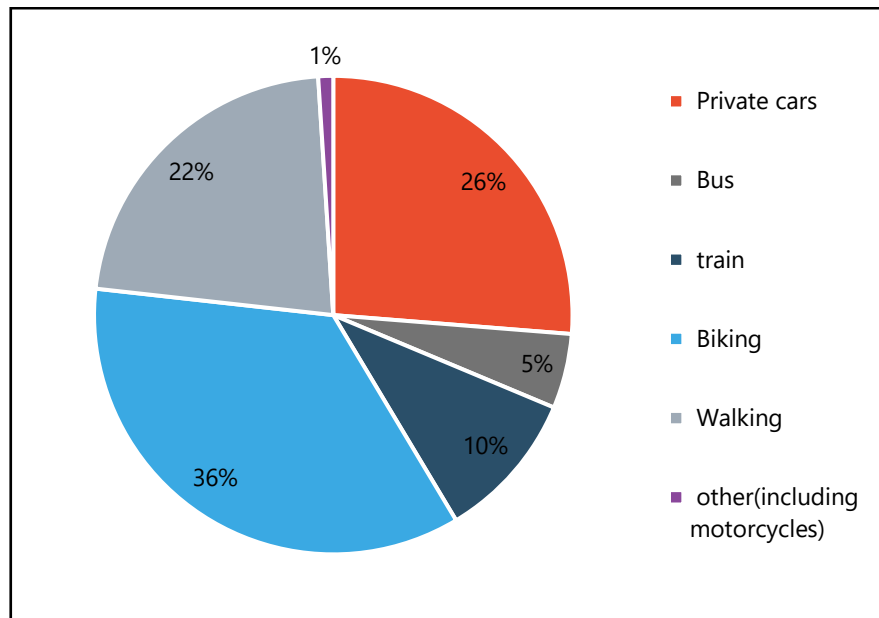


Figure 74. Modal share for Copenhagen

Table 20. The potential increases or decreases in external costs in Copenhagen for Sc1, Sc2, Sc3, and Sc6

Scenario	The modal share of AV (AM or robotaxi)	The difference in externalities (million euros)	The decrease in external costs without congestion
Replacing all buses	5%	+ (8.28)	- 1.33
Replace all cars	26%	- 964.96	-94.27
Robotaxis	18 %	+ (452.07)	-3.28
AM in MaaS	7 %	- 86.54	-8.37

The robotaxis scenario remains the one with the highest potential increase in external costs compared to the status quo, while “Replacing all cars” is the one with the highest reductions in external costs. The values are significant due to the mobility patterns in Copenhagen as well as the large population (623 404 inhabitants).

In general, the shift from combustion engine vehicles to AM leads to reductions in externalities, and that is why we register decreases in environmental and accidents categories (decrease without congestion in Table 20).

Although, due to the impact of electricity production as estimated by van Essen et al. (2019), the external costs from wtt emissions increase for all tested scenarios.

Congestion remains the most significant impact in terms of increasing externalities.

“Replacing all buses” is still considered disadvantageous to the city. In general, bus ridership in the Copenhagen area has constantly been decreasing since 2010 (the modal share of bus trips in 2010 is 6%, in 2015 it is 5%, and in 2019 it is 3.1%). Supporting public transport is a recommended strategy. On the one hand, replacing the buses with new technology might increase their attractiveness. On the other hand, it might aggravate congestion. Thus, a targeted strategy such as the AM in MaaS would have better societal and environmental impacts, as it will fill the mobility gap and promote public transport use.

Copenhagen is a biking city, and its urban sustainable development strategy is succeeding in limiting access of cars while increasing active mobility. Hence, it is recommended that they adopt scenarios that support public transportation without compromising their achievements in cycling modal share. Reinforcing their existing policies to reduce cars circulation is the best policy recommendation. If the city seeks to deploy AV, it should be in the form of AM to better encourage inhabitants to stop using individual motorized transportation, which eventually leads to replacing all car trips. Alternatively, integrating AM in MaaS could offer mobility solutions to PRM, the elderly, and children, mostly people who find commuting with a bike challenging.

5.7.2 Luxembourg

Luxembourg is recognised as the country with the highest motorization in the EU, with around 681 cars per 1,000 residents (Eurostat 2021). The canton of Luxembourg has 11 communes, one of them is the city of Luxembourg, the capital of the Grand Duchy of Luxembourg, as well as Contern, where the AVENUE pilot is operating. The scenario that we consider for Luxembourg is the communes of the Luxembourg canton without the city of Luxembourg. The area is 187 km², and the population is 58 079 inhabitants (Ville de Luxembourg 2021). The mobility behaviour data was limited. Therefore, we used averages for modal share from Luxembourg and average distances on EU-level. There is a new mobility survey that will be published soon, and it will improve the results. For now, we suffice with the EU averages.

The externalities results following the estimations in marginal costs for Luxembourg, the transport performance, and the predicted modal shift are presented in the table below.

Table 21. The decrease in external costs in Luxembourg for Sc4 and Sc5

Scenario	Setting	AM modal share	Decrease in external costs in million euros
Expand network	suburban	10 %	-23.89
Targeted expansion	suburban	12 %	-27.11

The results show that Luxembourg canton would reduce its external costs if it deploys the AM in the suburban parts. In general, we note decreases in all the external costs categories with the highest effect contributed to the congestion estimations for both scenarios. The scenario for the targeted expansion shows an extra reduction of around 3 million euros. The replacement of night buses and empty buses would benefit the city as well as the public transport operators. However, the estimation for the modal share of these bus trips remains limited. Better specific data is needed to optimise the analysis. Moreover, for Luxembourg, the AM would be better deployed a seamless intermodal mode of transport (similar to the suburban scenarios) due to the high rate of cross-border commuters, which creates traffic congestion across the canton. Luxembourg is already developing park-and-ride schemes at rail stations (Brunsden 2019). The AM could further replace the use of cars to connect to the trains.

5.7.3 Lyon

We focus on the area of the Greater Lyon (Metropole de Lyon) composed of the areas of Lyon-Villeurbanne (the center Lyon) as the city center, and The ring of the Lyon Metropole (Couronne de la Metropole de Lyon), see Figure 75. Thus, the reference scenarios are applied to these areas: Sc01 is the scenario of Lyon-Villeurbanne, and Sc02 is the scenario of The ring of the Lyon Metropole, both in 2015.



Figure 75. Topography of Lyon (Sytral 2016)

The transport performance and the mobility behaviour data are computed using a mobility survey for 2015, conducted by Lyon (Sytral 2016).

The City of Lyon is one of the most populated cities in France, with a population of around 500 000 inhabitants and a surface of 47.9 km². As for the mobility behaviour, using the average number

of 3.3 daily trips for each inhabitant, we could estimate a sum of 1.65 million overall trips a day. In the city, the motorisation rate is 414 cars per 1,000 residents. Thus, we count 207 000 cars. The modal split is introduced in Figure 76.

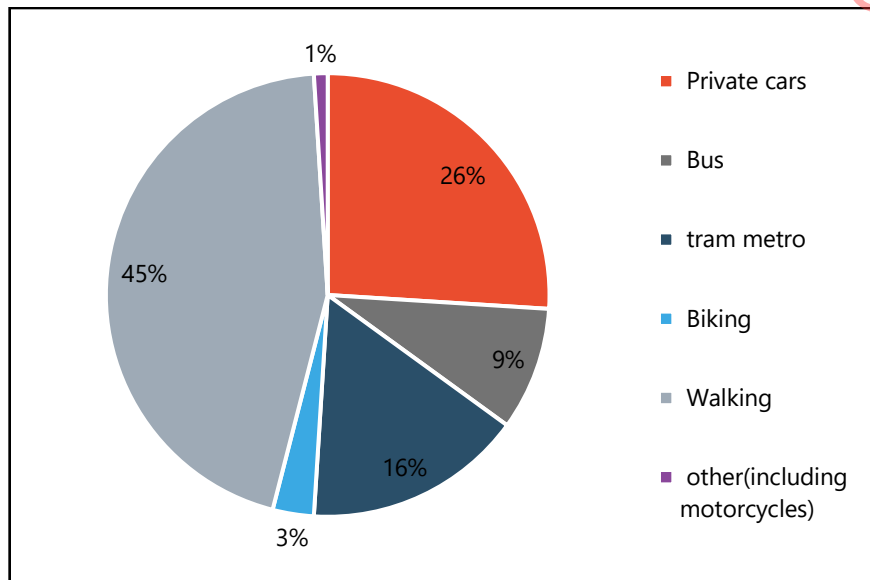


Figure 76. Modal split for the city of Lyon, 2015

For the suburban ring, the population is around 885,927 inhabitants, and the surface is 486 km². The average number of daily trips is 3.43 for an average distance of 20 km compared to the 13 km average for the city of Lyon. In this area, there are around 30 million daily trips. The car fleet accounts for 575,853 cars. The modal split is presented below in Figure 32.

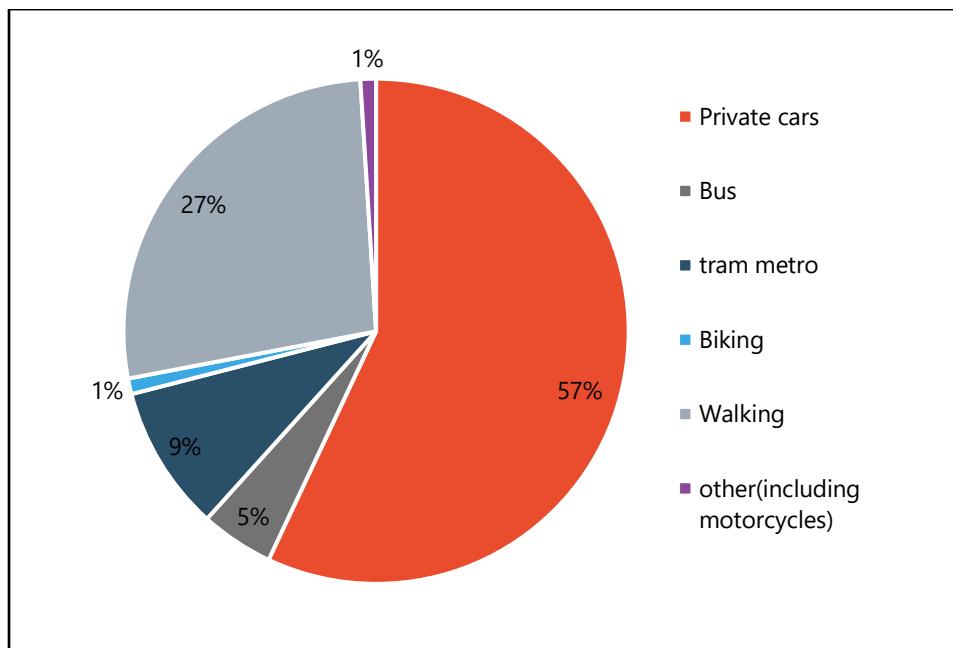


Figure 77. Modal split for the ring of Lyon, 2015

We apply the scenarios and the externalities model as it was applied for Geneva. The results are presented in Table 22 below.

Table 22. The potential increase or decrease in external costs in million euros Lyon for all 6 scenarios

Scenario	Setting	The modal share of AV	Increase + or decrease – in externalities	Increase + or decrease – in externalities – without congestion
Sc1-Replacing all buses	urban	9%	-6.41	2.7
Sc2-Replace all cars	urban	26%	-319.65	41.86
Sc3-Robotaxis	urban	19%	+133.75	4.98
Sc4-Expand network	suburban	15%	-170.74	30.32
Sc5-Targeted expansion	suburban	16%	-174.21	32.82
Sc6- AM in MaaS	urban	12%	-88.89	11.6

The results here differ slightly from previous findings. Deploying robotaxis remains the scenario that causes the biggest increase in external costs (around 133 million euros more than Sc01), and replacing all car trips with AM is still the scenario that causes the most decrease in externalities (around 310 million euros less compared to Sc01). However, replacing all buses in the city centre leads to decreases in externalities (around 7 million euros). In this case, updating the city's bus fleet by replacing the vehicles with AM would lead to decreases in the external costs.

The suburban scenarios are profitable in terms of reductions in external costs for Grand Lyon. The bus trips substitution in Sc5 compared to Sc4 reduces the external costs further by around 4 million euros.

This is attributed to a high motorisation rate: almost half a million cars make 60% of all trips on these territories compared to 207,000 cars and a modal share of 26% in the city of Lyon.

The suggested modal shift from cars to AM leads to significant reductions. However, the comparison between urban and suburban areas remains limited, as in the case of Geneva due to the different modal split and population density (1,823 inhabitants per km² in the ring compared to 10438 inhabitants per km² in the city).

Thus, Grand Lyon should draft more policies to strengthen the public transport network on two levels. On the one hand, the development of intermodal and seamless transport in its suburban areas would improve the connections to the city centre. The deployment of the AM could convince passengers to let go of their cars and use more public transport. On the other hand, Grand Lyon would benefit from restricting car trips in its city; the AM would significantly reduce the environmental and societal externalities.

5.8 Conclusion

Table 23. Summary of the results for AVENUE Cities, increase (+) or decrease (-) in external costs for each scenario in million euros

		Geneva		Lyon		Copenhagen		Luxembourg	
Scenario	Setting	Modal share AV	Increase or decrease million euros	Modal share AV	Increase or decrease in million euros	Modal share AV	Increase or decrease in million euros	Modal share AV	Increase or decrease in million euros
Replacing all buses	urban	12 %	+ 12.11	9%	+6.41	5%	+ (8.28)	⁻⁶	-
Replace all cars	urban	23 %	- 251.94	26%	-319.65	26 %	- 964.96 ⁷	-	-
Robotaxis	urban	18 %	+ 161.8	19%	+133.75	18 %	+ (452.07)	-	-
Expand network	suburban	12 %	-15.42	15%	-170.74	-	-	10 %	-23.89
Targeted expansion	suburban	13 %	-17.63	16%	-174.21 ⁸	-	-	12 %	-27.11
AM in MaaS	urban	11%	-83.38	12%	-88.89	7%	-86.54	-	-

Table 24. Summary of the results for AVENUE without congestion

		Geneva		Lyon		Copenhagen		Luxembourg	
Scenario	Setting	Modal share AV	decrease million euros	Modal share AV	decrease million euros	Modal share AV	decrease million euros	Modal share AV	decrease million euros
Replacing all buses	urban	12 %	11.02	9%	2.7	5%	1.33	-	-
Replace all cars	urban	23 %	46.77	26%	41.86	26 %	94.27	-	-
Robotaxis	urban	18 %	2.57	19%	4.98	18 %	3.28	-	-
Expand network	suburban	12 %	3.24	15%	30.32	-	-	10 %	3.29
Targeted expansion	suburban	13 %	4.75	16%	32.82	-	-	12 %	5.5
AM in MaaS	urban	11%	12.92	12%	11.66	7%	8.37	-	-

⁶ As explained in 5.7 "For Luxembourg, the sample of respondents that are daily car users and living in the city was too small. Thus, we select the scenarios in the suburban and preurban parts."

⁷ As explained in 5.7.1, "The values are significant due to the mobility patterns in Copenhagen as well as the large population (623 404 inhabitants)."

⁸ As explained in 5.7.4 and later in the conclusion, This is attributed to a higher urban density, higher population and bigger area, affect the number of trip and pkm

In general, the robotaxis scenario will always lead to increases in external costs when deployed in competition with public transport. A deployment with ridesharing could improve the balance as explained in 0 in For the results without accounting for the congestion (the congestion is the highest source of external costs as explained in 0). The environmental and accident categories record a slight decrease in externalities, but the decrease in external costs (without congestion) remains the lowest out of all the urban scenarios (sc1, sc2, sc3, and sc6).

The AM in MaaS, replacing all cars and the suburban scenarios consistently show decreases in external costs. Replacing all cars leads to the highest reduction in externalities (for all the external costs categories). While AM in MaaS is a user-centric approach pull strategy, replacing all cars is a typical (not popular) push strategy which forbids car in the city.

For Copenhagen, the most appealing scenario seems to be to replace all car trips by the AM. This is evident in Table 24, where it shows the highest decrease in the urban scenarios, almost 95 million euros. The number of the city's residents (~600 000 inhabitants) and the high average daily distance for car trips would justify this potential reduction.

Lyon shows that the emphasis should be on strengthening its public transport in suburban parts deploying the AM serving seamless and intermodal services and also in the city, where the AM could be deployed within MaaS to bridge first and last-mile gaps and enhance connections to the rail stations.

Geneva would benefit from the AM deployment in the urban areas mostly as seen in scenario 2 and 6 since it has the highest reduction in externalities. It could reduce car access to the city centre and introduce the AM to support public transport and replace all car trips in these areas. The results from the social surveys (see 0) could be used to understand the willingness of the users to give up their cars and adopt new forms of mobility. Thus, relying on the users acceptance, the most realistic approach is to introduce the AM gradually, first as part of a MaaS service. Where AM are filling existing mobility gaps rather than completely replacing individual mobility. As the users' acceptance increases, passengers would switch more and more to the AM instead of relying on their cars. If this introduction is accompanied by urban policies such as road pricing and no-car zones, it will further deter citizens from using their cars in the city centre, which would increase the modal shift to the AM, active mobility, and public transport. Finally, deploying the AM in suburban areas in Luxembourg also shows a reduction in externalities. This strategy fits with the canton plans to reduce car use and improve connections to train stations to better serve cross-border travellers.

The scenarios with the externalities calculations provide indicators on the recommended deployment strategy that would fit with a European city sustainable development. However, the model has some limitations that are described in the following part.

5.8.1 Limitations of the model

It is important to present the limitations of the model and where it falls short. It is a given that the accuracy of the results is dependant on the accuracy of the input data. For instance, Luxembourg and Copenhagen case studies would benefit greatly from updating the mobility behaviour data to better reflect the areas in question (city centre or suburban ring).

This study provides important results on AM as a new force capable of transforming the transportation sector. It foresees scenarios of embedding AM in societal and political contexts and their impacts.

It has the potential to be more robust if the following limitations are addressed:

- i- The external noise costs depend on the population density, traffic status, and time of day. However, the data on a country level for these specific contexts is limited. This requires more finetuning to reflect the contextual impact.
- ii- Similarly, monetising congestion is complicated as it depends on an EU-level study to reach national marginal costs (Jochem, Doll et Fichtner 2016b). The meta-analysis requires inputs of speed-flow functions, demand curves, and Value-of-Time (VOT) at a large scale and poses a challenge to downscale to smaller cities, see 0.
- iii- The use of national-level marginal costs for city-level assessment is a limitation. For instance, air pollution national external costs might underestimate those on an

- urban level (PM emissions differ between rural and urban areas). This could be addressed using the European values for urban and rural parts in a sensitivity analysis.
- iv- We should also consider whether the use of AM will increase the use of traditional public transport and estimate this increase in modal share. Notably, the study of the induced demand requires more analysis since it is difficult to predict the exact numbers for this rebound effect.
 - v- An optimised assessment should also account for the potential demographic changes and their effect on VKM (in Geneva between 2000 and 2015, there was an increase in travel demand by 10% attributed to the increase in the population, for example).
 - vi- The reliance only on one source to estimate the marginal costs (The delft hadbook of external costs by van Essen et al. (2019)), gives one version of the analysis, a sensitivity analysis using different marginal costs would make the model more robust.
 - vii- A further limitation is accidents marginal costs estimation when AV are interacting with human driving, the methodology of calculation is still evolving with growing knowledge.

5.8.2 Rebound effects

As mentioned in the limitations, the deployment of the scenarios should account for potential rebound effects. Since this analysis tries to imagine potential future scenarios based on current data and observations, it is limited to what could be extrapolated quantitatively. The study of rebound effects thus is better addressed qualitatively.

Hymel, Small et van Dender (2010) describe the rebound effect as an increase in vehicle usage due to an unintended effect of raising fuel efficiency and decreasing the cost of car usage through policies and technological advancements. They also mention induced demand as a rebound effect to road transportation where an increase in infrastructure capacity attract new traffic and causes it to reach its capacity, which was not the intended goal (Hymel, Small et van Dender 2010). The AM would provide a convenient, affordable and safe option to passengers. Thus, it could lead to more trips, as it provides more trips to people who were not commuting with vehicles in the first place, such as children and the elderly. In addition, it might cause a secondary modal shift after its implementation. It could reduce active mobility and public transportation shares even further than first predicted (Childress et al. 2015; Fagnant et Kockelman 2018; Zmud et Sener 2017). This might lead to a vicious circle of deploying more vehicles to meet the new demand. Then, as an unintended effect, more people shift to use the AM. Thus, the operators will need to deploy even more vehicles to meet the increasing demand. Thus, the AM would aggravate the traffic congestion and increase the environmental footprint. Hence, the rebound effect undermines the gains from reducing the use of individual mobility by causing new external costs because of reducing walking, biking, and public transport trips. Ergo, it is crucial that the deployment is accompanied by a regulatory framework to monitor the introduction of the AV in the transportation system and reduce potential rebound effects.

5.8.3 Policy recommendations

Here we describe briefly potential policies that could optimise the externalities gains and minimise rebound effects. This will be further developed in the final sustainability deliverable. The policies support the deployment of AM in MaaS as the most plausible scenario but also looks into the potential solutions and conditions to make "replace all cars" a possible reality. Furthermore, the robotaxis scenario could be a solution to tackle car usage if proposed with ridesharing as shown in 0.

These results of the externalities and scenarios model help orient policymakers to which strategies to adopt. Indeed, we refer to Sustainable Urban Mobility Plans SUMP as a strong guide to accompany the deployment of this technology.

For instance, CoEXist, also an H2020 project, has recognised 8 SUMP principles of road vehicle automation. It addresses governance structure changes, long-term implementation plans, future performance assessment, stakeholder's collaboration, citizen involvement, monitoring structures, and quality insurance. It also focuses on the axes of policy, infrastructure, planning, and traffic management (Backhaus, Rupprecht et Franco 2015). The results from our study support the SUMP approach, targeting the reduction of the use of private cars and the integration of all modes of transport.

Moreover, another robust strategy to accompany the deployment of the AM is transport demand management TDM. Based on the results of our methodology, we suggest replacing cars in city centres and applying localised on-demand MaaS service across the Canton of Geneva. TDM pull and push measures are perfect for implementing the previously-mentioned strategy. Indeed, those measures constitute the framework of most internalisation policies of external costs (TUMI 2018).

Moreover, other internalisation measures could help counterbalance the external costs. Policy Packaging is a way to set taxes to balance external costs like fuel taxes and road pricing and is widely used in Europe. Another measure is the use of revenues (e.g. from policy packaging taxes) to make users accountable for the externalities they produce. The revenues will be directed towards new infrastructure or improving public transport services as long as the pricing reform is conducted to increase efficiency and equity and is accepted by the public (van Essen H.P. et al. 2008). Also, trading emissions limits greenhouse gas emissions, such as the Cap & Trade scheme, where a limit is set for emissions with tradable emission rights.

More detailed analysis is needed to better assign the proper TDM measures to deployment scenarios based on the indicator of externalities savings or costs. Also, thorough research on land-use policies could better

6. General Conclusion

The deliverable D8.6 presents the final advances of the work of WP8, T8.3. It completes the economic assessment analysis of the AVENUE project and gives guidelines for future projects and research ventures. Following the overall pattern of the task T8.3, this deliverable presents the economic assessment into two levels: macro and micro.

At the macro level, further details are given on the proposed business scenario Customer/Citizen centered intermodal MaaS ecosystem. For the practical application of the elaborated results on all 4 Design Steps for Strategic Business Planning for the Business Scenarios BS2, BS3, BS4 – it is recommended for a future AVENUE entrepreneur to identify and analyze the concrete focus use case adapting these Design Steps as a systematic guide and identify, analyze and select the business scenarios, business opportunities, business strategies and business models suggested stepwise iteratively for relevance. On each Design Step level further iterative adaption, discussion and refinement processes have to be conducted and decisions have to be made before a final strategic business planning concept for the concrete use case can be compiled and implemented.

Another important outcome in the macro level comes from the externalities assessment, the presented with the externalities calculations provide indicators on the recommended deployment strategy that would fit with a European city sustainable development. Indeed, the deployment of AM in MaaS is shown as the most plausible scenario but also looks into the potential solutions and conditions to make "replace all cars" a possible reality. The robotaxis scenario could also be a solution to tackle car usage if proposed with ridesharing. Furthermore, another robust strategy to accompany the deployment of the AM is transport demand management. These results of the externalities and scenarios model help orient policymakers to which strategies to adopt. Indeed, we refer to Sustainable Urban Mobility Plans SUMP as a strong guide to accompany the deployment of this technology.

At last, in the micro level, this deliverable presented the advances in the economic assessment tool EASI-AV[®], such as the implementation of the on-demand fleet size calculation option and the beta version of the tool's web application, that enables the calculation of not only the service costs (CAPEX and OPEX), but also the simulation of revenue sources, and the net present value of the service. Thus, it can be a useful tool for any stakeholder interested in accessing the economic impact of services with automated vehicles for public transport.

Finally, we conclude that the efforts and work done were significant for the advancement of the state of the art on the subject in its scientific scope, besides drawing the attention of the public and private spheres to the importance of considering the aspects of economic viability of this type of project, in order to work on the areas that make this business model still very limited in scope and scale compared to traditional services.

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Annex 1

scenario		Replace all buses				
mode of transport		Total transport performance in million pkm	transport performance (pkm)	average daily distance	Modal share	potential fleet size
Private mode	cars	972.57	4,927.50	13.50	22.60%	64,824
Public mode	Bus	-	-	-	-	-
	tram metro	-	-	-	6.36%	-
Active mobility	Biking	72.04	365.00	1.00	6.80%	-
	Walking	187.31	949.00	2.60	47.60%	-
other		72.04	365.00	1.00	4.30%	-
AM		389.03	1,971.00	5.40	12.34%	-

externalities in million euros					
City		Ville de Geneva			
Scenario		Replacing all buses			
Externality	type	private vehicles	buses	automated minibus	total per category
Mode of transportation					
modal share		22.60	-	12.34	
air pollution		6.09	-	0.19	6.28
climate change		12.72	-	-	12.72
wtt		4.09	-	2.10	6.20
noise		18.67	-	1.17	19.84
accidents		13.13	-	-	13.13
congestion		382.22	-	50.96	433.18
reduced congestion due to av penetration				48.41	430.63
production		3.68	-	1.19	4.87
total externalities per mode of transport		440.61	-	53.06	493.67
Total externalities		493.67			

Annex 2

scenario		Replace all cars				
mode of transport		Total transport performance in million pkm	transport performance (pkm)	average daily distance	Modal share	potential fleet size
Private mode	cars	-	-	-	-	1296
Public mode	Bus	389.03	1,971.00	5.40	12.34	452.00
	tram metro	-	-	-	6.36	-
Active mobility	Biking	72.04	365.00	1.00	6.80	
	Walking	187.31	949.00	2.60	47.60	

other	72.04	365.00	1.00	4.30	-
AM	972.57	4,927.50	13.50	22.60	1380

externalities in million euros					
City	Ville de Geneva				
Scenario	Replacing all cars				
Externality Mode of transportation	type	private vehicles	buses	automated minibus	total per category
modal share		-	12.34	22.60	
air pollution		-	2.94	0.49	3.42
climate change		-	1.70	-	1.70
wtt		-	0.74	5.25	5.99
noise		-	3.27	2.92	6.19
accidents		-	6.30	-	6.30
congestion		-	25.29	127.41	152.69
reduced congestion due to av penetration				121.04	146.32
production		-	0.71	2.96	3.68
total externalities per mode of transport		-	40.95	132.66	
Total externalities		229.62			

Annex 3

scenario		robotaxis				
mode of transport		Total transport performance million pkm	transport performanc e (pkm)	average daily distance	Modal share	potenti al fleet size
Private mode	cars	778.06	-	10.80	18.08	49 024
Public mode	Bus	365.69	1,971.00	5.08	11.60	
	tram metro	-	-	-	6.36	
Active mobility	Biking	72.04	365.00	1.00	6.80	
	Walking	136.15	949.00	1.89	34.60	
other		72.04	72.04	1.00	4.30	
Robotaxi		269.01	269.01	3.73	18.26	1580

externalities in million euros					
City	Ville de Geneva				
Scenario	robotaxis				
Externality Mode of transportation	type	private vehicles	buses	Robotax i	total category
modal share		18.08	11.60	18.26	
air pollution		4.87	2.76	0.18	7.81
climate change		10.18	1.60	-	11.78
wtt		3.28	0.69	2.98	6.95

noise	14.94	3.07	5.17	23.18
accidents	10.50	5.92	-	16.43
congestion	377.36	29.25	173.96	580.57
reduced congestion due to av penetration			165.26	571.88
production	2.95	0.67	1.73	5.34
total externalities per mode of transport	424.07	43.98	175.31	643.3
Total externalities	643.36			
Without congestion	46.7			

Annex 4

scenario		AM in MaaS				
mode of transport		Total transport performance in million pkm	transport performance (pkm)	average daily distance	Modal share	potential fleet size
Private mode	cars	696.41	3,528.33	9.67	16.18	9724
Public mode	Bus	389.03	1,971.00	5.40	12.34	
	tram metro	-	-	-	6.36	
Active mobility	Biking	54.03	273.75	0.75	5.10	
	Walking	175.50	889.19	2.44	44.60	
other		72.04	365	1	4.3	
AM		305.98	1,550.23	11.12	11.12	580

externalities in million euros					
City	Ville de Geneva				
Scenario	AM in MaaS				
Externality Mode of transportation	type	private vehicles	buses	AM	total per category
modal share		16.18	12.34	11.12	
air pollution		4.36	2.94	0.15	7.45
climate change		9.11	1.70	-	10.81
wtt		2.93	0.74	1.65	5.32
noise		13.37	3.27	0.92	17.56
accidents		9.40	6.30	-	15.70
congestion		273.69	25.29	40.08	339.06
reduced congestion due to av penetration				38.08	337.05
production		2.64	0.71	0.93	4.28
total externalities per mode of transport		315.50	40.95	41.73	398.18
Total externalities		398.18			
Without congestion		61.1			

Annex 5

scenario		expand the network				
mode of transport		total transport performance in million pkm	Transport performance (pkm)	average daily distance (km/person)	percentages of annual trips (residents)	fleet size
Private mode	Private cars	177.1	6786.3	18.59	32.39	1781
Public mode	Bus	39.1	1496.5	4.1	9.5	
	tram metro	19.1	730.0	2.0	4.9	
Active mobility	Biking	7.6	292.0	0.8	4.5	
	Walking	21.0	803.0	2.2	31.5	
	other(including motorcycles)	20.0	766.5	2.1	5.7	
	automated minibus	62.9	2411.7	6.6	11.51	630.00
Sums		346.8	13286.0	36.40	100.0	

Scenario	Expand the network			
Externality type Mode of transportation	private vehicles	buses	AM	TOTAL PER CATEGORY
MODAL SHARE	32.39	9.50	11.51	
air pollution	1.11	0.56	0.02	1.69
climate change	2.32	0.33	-	2.64
wtt	0.75	0.14	0.25	1.14
noise	3.40	0.62	0.14	4.17
accidents	2.39	1.20	-	3.59
congestion	45.17	3.12	4.01	52.30
Reduced congestion due to AV penetration			3.81	52.10
Production	0.67	0.14	0.12	0.93
Total externalities per mode of transport	55.80	6.11	4.35	
Total externalities per scenario	66.26			
Total externalities per scenario without congestion	14.16			

Annex 6

scenario	Targeted expansion				
Area					
mode of transport	total transport performance	Transport performance	average daily distance	percentages of annual	fleet size

		e in million pkm			trips (residents)	
Private mode	Private cars	177.1	6786.3	18.6	32.4	1781
Public mode	Bus	34.4	1316.9	3.6	8.4	
	tram metro	19.1	730.0	2.0	4.9	
Active mobility	Biking	5.7	218.0	0.6	3.4	
	Walking	21.0	803.0	2.2	31.5	
	other(including motorcycles)	20.0	766.5	2.1	5.7	
	automated minibus	67.6	2591.3	7.1	12.7	630.00
Sums		344.9	13212.0	36.2	100.0	

Reference	targeted expansion				
Externality Mode of transportation	type	private vehicles	buses	AM	TOTAL PER CATEGORY
MODAL SHARE		32.39	4.90	12.65	
air pollution		1.11	0.26	0.03	1.39
climate change		2.32	0.15	-	2.47
wtt		0.75	0.07	0.27	1.08
noise		3.40	0.29	0.15	3.84
accidents		2.39	0.56	-	2.95
congestion		45.17	2.23	4.31	51.72
Reduced congestion due to AV penetration				4.10	51.50
Production		0.67	0.12	0.13	0.92
Total externalities per mode of transport		55.80	3.67	4.68	
Total externalities per scenario		64.16			
Total externalities per scenario without congestion		12.66			