AVENUE

Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D8.11 First Iteration Sustainability Assessment

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1 Introduction

1.1 Background

AVENUE project aims to design and implement full-scale demonstrations of autonomous minibuses in the urban transport of European cities. The fleets of autonomous minibuses will be tested in 4 demonstrator cities: Geneva, Lyon, Copenhagen; Luxembourg. Later on, it will be extended to other 3 replicator cities (AVENUE, 2018).

In the context of Work Package 8 (WP8), the sustainability assessment is part of the socio-economic and environmental evaluation. It aims to integrate and interconnect the sustainability dimensions – social, environmental, economic and governance - with the technological impacts of autonomous driving.

1.2 Research domain

Sustainable mobility is one of the greatest challenges that cities have been facing globally. This topic gains momentum in the political and planning agenda of cities when considering the rise projections in the mobility of people and goods, along with the need to reduce the impacts from this sector.

Worldwide, from 2000 to 2015, the passenger travel activity has increased 74% and the freight travel activity 68% (SLoCaT, 2018). Consequently, the negative impacts of mobility has also increased, for instance, traffic jams, air pollution and greenhouse gas (GHG) emissions, accidents and noise (Bräuninger et al., 2012).

In this perspective, the Sustainability Assessment is a tool that can support decision makers and policy makers to decide what actions to take pursuing a sustainable development for society (Devuyst, (2001).

This document applies the concepts of sustainable mobility and sustainability assessment in order to assess the potential impacts of autonomous e-minibuses in the public transport of European cities. It takes into account a transdisciplinary approach and the multi-dimensions in mobility.

1.3 Methodology

As a first step literature review provided concepts and definitions on sustainable development, sustainable mobility and sustainability assessment for this study.

In a second step, also based on literature review, the mobility context of the four AVENUE target cities is explored. It aims to contextualize the main mobility challenges in the urban areas, the current modal split and future projections, as well as the actions, goals and priorities for a better and greener mobility in those cities. This section also presents brief information and initiatives on autonomous driving in the respective countries where AVENUE have the pilot project.

As a third step, a set of indicators is proposed with the aims to measure and assess the performance of AVENUE project towards sustainable mobility. In addition, it intends to interrelate the multi-dimensions in the mobility sector.

Therefore, to build the set of indicators, literature review was applied to explore methods and indicatorframeworks for a sustainable mobility assessment. Next, 18 studies were selected for in-depth analysis considering their broad applicability, complementarity of methods, embracement of the sustainability dimensions and the application in practice in the case of some studies. For the complete list, refer to Appendix I.

Figure 1 illustrates the applied methodologies in this report.

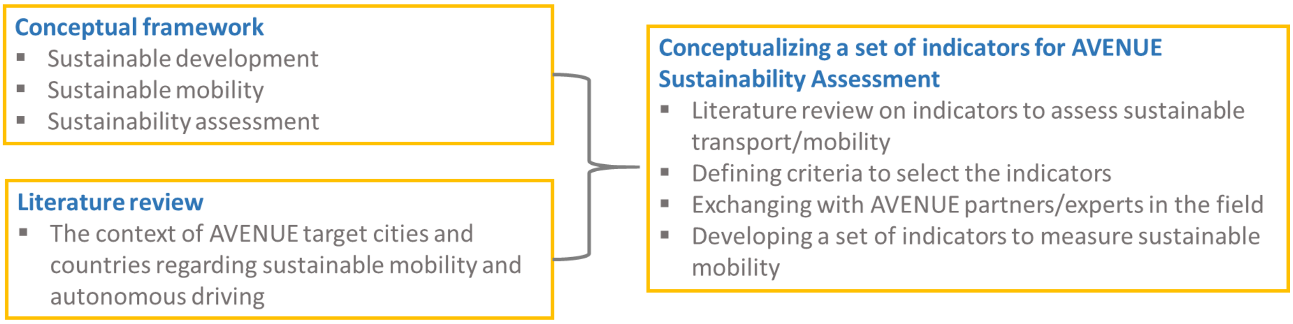

Figure 1 - Structure of the applied methodology to develop a set of indicators for AVENUE Sustainability Assessment

As further steps, the set of indicators will be applied in the AVENUE target cities, comprehending data collection, data analysis, results and exploration of the nexus among social, environmental, economic, governance and technological dimensions.

2 Concepts on sustainability

The term 'Sustainable Development' was introduced in 1980 and popularised in 1987 by the World Commission on Environment and Development report. It was endorsed in 1992 during the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, through the Agenda 21, which engaged national governments to pursue sustainable development (OECD, 1997).

According to the Brutland Report 'Our Common Future' (1987) "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future."

'Sustainable transportation' and 'sustainable mobility' are synonyms, and it expresses the concepts of sustainable development within the transport sector (OECD, 1997).

Main definitions on sustainable mobility comprehends:

OECD (1997) definition of 'environmentally sustainable transport' (EST) as a "transportation that does not endanger public health or ecosystems and meets mobility needs consistent with (a) use of renewable resources at below their rates of regeneration and (b) use of non-renewable resources at below the rates of development of renewable substitutes."

The Centre for Sustainable Transportation (2005) defines 'sustainable transportation system' as the one that:

- "allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
- limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise."

The World Business Council for Sustainable Development (2015) defines Sustainable mobility as "the ability to meet society's need to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future."

With regard to the concept of 'Sustainability Assessment', it has its roots from environmental impact assessment (EIA), and strategic environmental assessment (SEA), as a tool or a process "by which the implications of an initiative on sustainability are evaluated" (Pope, Annandale, & Morrison-Saunders, 2004).

Ness et al (2007) presented three main category tools for sustainability assessment:

i. indicators/indices to measure the three-pillars – social, environmental and economic;
ii. product related assessment, evaluates the energy and material flows of goods and services, e.g.: Life cycle assessment, Product energy analysis, Product material flow analysis.
iii. integrated assessment tools, as supporting decision tools applied in complex situations, e.g.: Multi-Criteria Analysis, Vulnerability Analysis, Risk Analysis, Cost Benefit Analysis.

3 Contextualizing the sustainable andautonomous mobility agenda of AVENUE target cities and countries

This section explores the AVENUE cities' mobility context by addressing the main factors that have impacted their mobility systems, for instance, the demographic factors, urbanisation processes. It depicts the cities' modal split, integration of the central areas with suburban areas, the traffic infrastructure and the main challenges and external costs to be tackled on mobility (e.g. congestion, parking space, air pollution) (European Commission, 2007).

This chapter presents the cities' mobility plans in order to contextualize their priorities and strategies to enlarge and to improve the mobility services while reducing GHG emissions and the negative impacts from mobility. Pursuing the objective to achieve the country and the EU climate targets.

It presents the cities' innovativeness in mobility, by integrating in their mobility agenda and planning new trends such as electro mobility, shared mobility and autonomous driving.

In addition, it describes briefly the autonomous driving context of the respective countries of AVENUE target cities.

3.1 Geneva

Geneva is the second most populated city in Switzerland, with 203.113 inhabitants, it is the capital of Geneva Canton, composed of 45 municipalities (OCSTAT, 2018b; Ville de Genève, 2011).

The Geneva Canton has 500.148 inhabitants (OCSTAT, 2018a), located in a transnational area, in the border with France, and in the heart of a conurbation area, characterized by its economic attractiveness, job opportunities and good quality of life. Over the past years the population density has increased continuously, with residential areas expanding on the periphery, while jobs are concentrated in the central area of the Canton (Etat de Genève, 2013).

The demographic projections for 2030 point an increase of 100.000 inhabitants and 70.000 jobs (Etat de Genève, 2013). Such demographic and economic dynamic have impacted mobility with congestion problems and routes saturation, reaching the roads limits.

Hence, in order to address current and upcoming challenges in Genevas mobility system, as well as in the conurbation area, in 2013, the General Planning Direction launched the 'Mobilités 2030', a long-term multi modal strategy for Geneva Canton.

According to 'Mobilités 2030', we can distinguish three main challenges regarding mobility in the Canton of Geneva. 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. Secondly, the city centre streets date back to the 19th century and do not absorb the current transport flow. Thirdly, the absence of tangential routes aggravated the mobility flow.

Table 1 presents the transport modal split in 2009, the projections for 2030 and objectives by 2030 considering the heart of the conurbation and connected areas.

According to the figure, one can state that the multimodal strategy prioritizes different modes of transport according to the different urban zones. In the centre of the conurbation and in compact urban areas the soft modes and public transport are favoured. The objectives by 2030 target a shift in central areas notably from private vehicle and public transport to bicycles. In the areas connected to the centre, the shift is characterized from private vehicles to public transport.

Table 1: Transport modal split in the centre and connected areas in Geneva Canton.

		Walking	Private vehicle	Public transport	Nonmotorized two wheelers
Centre of the conurbation	**2009**	47%	30%	16%	7%
	Trend 2030	45%	27%	21%	7%
	Objective 2030	47%	25%	13%	15%
Areas connected to the centre	**2009**	21%	60%	17%	2%
	Trend 2030	18%	53%	27%	2%
	Objective 2030	19%	44%	34%	3%

Source: (Etat de Genève, 2013)

In 2012, GHG emissions from mobility were responsible for 19% of the total GHG emissions of the Canton of Geneva (Conseil d'Etat (CE), Service Cantonal du Développement Durable, 2017). To tackle this issue and reduce the emissions, the Climate Plan 2018-2022 for Geneva Canton comprehends as one of its axes the promotion of a low-carbon mobility.

Moreover, the Electro-mobility strategy from Geneva Canton aims to reach 10% of electric vehicles in the Geneva car fleet by 2030. The plan targets to reduce 16% of the CO2 emissions from transport compared to 2012 emission levels in Geneva Canton (Etat de Genève, 2013).

Regarding the autonomous vehicles in Switzerland, the Coordination Office for Sustainable Mobility (COMO) has launched a pilot project addressing mobility combined with autonomous vehicles. As main objectives, it targets to develop models to integrate autonomous mobility to promote environmental benefits, shared mobility and to analyse the customer acceptance towards this new technology (SuisseEnergie, 2019).

As pioneer initiatives in Switzerland, in 2016 the 'SmartShuttle' project started to test two autonomous buses in the city centre of Sion. In 2017, the city of Zug also has started the tests of two autonomous shuttles.

The legal framework for autonomous 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 that will work on the digital key factors for autonomous driving implementation. It will address data policy, the creation data infrastructure for multimodal and interconnected traffic management, security and protection from cyber-risks and so on.

3.2 Lyon

Lyon is the third most populated city in France, with approximately 513.275 inhabitants (Insee, 2015). Its metropolitan area has presented a significant demographic growth since the late 1990s, accounting 9% more inhabitants between the period of 1999 and 2011 (Sytral, 2017). And nowadays it is characterized by the peri-urban development.

Regarding the city mobility system, according to the Sustainable Cities Mobility Index 2017 conducted by (Arcadis Batten, John J. & Ghrels), Lyon ranks in 15th among the 100 cities rated around the world. The assessment applied 23 indicators to measure the quality and sustainability of the mobility systems in cities.

From 2014, the metropolis of Lyon launched the strategy 'Grand Lyon Métropole Intelligente', composed by four pillars: new mobility; digital services; energy and the conditions for innovation.

Hence, the 'new mobility' pillar prioritizes multimodal modes of transport, shared mobility solutions and develop tools for traffic prediction, flow management and urban logistics optimization (La Métropole de Lyon, 2019).

In addition, in the context of new mobility strategies, Navly, an autonomous electric shuttle, has been tested since 2016 in *La Confluence*, a living lab area for smart city experimentation in Lyon. In this regard, in 2018, on national scale, the French strategy for autonomous vehicles development was launched. The strategy considers autonomous vehicles as an alternative to freight transport, public and individual transport, aiming the deployment of highly automated vehicles by 2020.

When it comes to the soft modes of transport, in 2017 Lyon accounted 349 stations for bike sharing (Vélo'v), more than 600 km network of cycle routes and an application 'Géovélo' to guide bicycle journeys (Sytral, 2017).

Alongside to the advances on facilities to cycle, data from the recent years point positive changes in behaviour mobility towards cycling in Lyon. The bicycle traffic had an average increase of 15% between 2010 and 2015 and jumped by 26% in 2016 in the metropolitan area. Therefore, in some central areas bicycles represent a third of total vehicle traffic (Mairie de Lyon, 2017). This numbers places Lyon as one of the main most cycling-friendly cities in France.

Table **2** presents the evolution in the transport modal share of the inhabitants of Lyon conurbation in 1995 and 2015. The percentages indicate that although the number of journeys has increased in the metropolitan area, the individual mobility has decreased, giving place to the increase in the use of public transport, walking, bicycle and motorized two wheelers.

Table 2: Transport modal split in Lyon conurbations in 1995 and 2015.

	Walking	Two-wheelers (bicycle + motorized two wheelers)	Private vehicle	Public Transport
Situation 1995	31,5%	1,3%	53,1%	14,1%
Situation 2015	34,1%	2,2%	43,9%	19,8%

Source: Sytral, EMD, PDU 2017/2030.

For the upcoming years, the Urban Transport Plan of 2017 (Plan de déplacements urbains - PDU) for Lyon metropolitan area presents new ambitions regarding the future transport modal share, aiming to reach: 35% of the transport by cars and motorized two wheelers; 35% walking; 22% public transport; and 8% bicycle.

Other objectives include the reduction of emissions of pollutants (NO_x, PM_{10}) from road transport, reduction of GHG, halve the number of accidents and deaths caused by road transport, an inclusive transport for people with reduced mobility and vulnerable populations and so on.

Regarding the air quality, a report from 'Low Emission Zone Project' (Métropole de Lyon, 2018) points that in the last 17 years, the annual emissions of nitrogen dioxide (NO2), fine particulate matter (PM10) and (PM2.5) have dropped more than 50%. Nonetheless, even considering this reduction, in 2016 the inhabitants of the metropolitan area were exposed to nitrogen dioxide levels above European limits.

3.3 Copenhagen

Copenhagen is the capital and biggest city from Denmark, accounting more than 600.000 inhabitants (Municipality of Copenhagen, 2018). Compared to European standards, the average population density in Copenhagen is relatively low and the urban population growth follows the global cities trends, characterized by a stronger growth and concentration in the inner city. For instance, between 1993 and 2013, the municipalities of Copenhagen and Frederiksberg presented an increase of 20% population in the inner city (LSE Cities, London School of Economics and Political, 2014).

Concerning mobility, the city is ranked on 12th among 100 cities according to (Arcadis Batten, John J. & Ghrels) Sustainable Cities Mobility Index 2017, assuming a leading position and a reference on green mobility.

In 2012 Copenhagen launched the 'CPH 2025 Climate Plan' (The city of Copenhagen, 2012), based on four pillars - energy consumption; energy production; green mobility; city administration initiatives – according to this strategic plan, Copenhagen aims to be the first carbon neutral capital in the world by 2025.

Therefore, the City of Copenhagen has prioritized cycling, walking and the use of public transport, with the goal that by 2025, 75% of all journeys in Copenhagen will be on foot, by bicycle or by public transport. In order to achieve the goal of a carbon neutral city and as a response to the air pollution, notably the high levels of NOx, light and heavy vehicles are encouraged to use new fuels, such as electricity, hydrogen, biogas or bioethanol.

With regards to the goals by 2025, a (Deloitte) study (2018) showed that the modal split for Copenhagen Metropolitan Area is about to achieve its goal, composed by 26% of private car, 27% of public transport, 41% of bicycle and 6% of walking. Such modal split places Copenhagen among the most bicycle-friendly cities in the world and among the least congested Nordic cities. Nonetheless, as main challenges, the air contains high levels of nitrogen oxides (NOx) and the bicycle paths have reached their capacity at peak times (Deloitte, 2018).

In addition, from 2012 to 2015, the Local agenda 21 Plan for Copenhagen, named 'A greener and better everyday life' (City of Copenhagen, 2013), was structured according to five themes: home; resources;

urban spaces; transport and interdisciplinary theme. The theme transport pursued alternative to private cars, as e-mobility and car schemes and promoted green mobility by improving cycling attractiveness.

In 2014 Copenhagen was elected the ‘European Green Capital’, standing out due to its eco-innovation initiatives, urban planning and design, environmental management, goals for a carbon-neutral capital, for being one of the world’s best city for cyclists and for the establishment of the low-emission zones. Underway to achieve its ambitions as carbon neutral city, between 2005 and 2012, Copenhagen cut 24% of carbon emissions (European Union, 2013).

In addition, the ‘ITS Action Plan 2015-2016’ is one action in the scope of ‘CPH 2025 Climate Plan’, in which through Intelligent Transport systems (ITS) the collection and processing of traffic data and Smart City concepts are applied to improve the Traffic Management Plan and contribute to reduce CO_2 emissions. Among other, it has as main objectives to “improve mobility and traffic flow for all types of road users; use of ITS solutions to improve traffic safety; collection and processing of real-time data about traffic, overview and strategic traffic management” (Centre of Traffic and Urban Live, City of Copenhagen, 2014).

Other good indicators point that in 2017, Copenhagen Metropolitan Area accounted 85% of municipal vehicles as electric, hydrogen or hybrid-power and by 2020 it is expected to have 500 electric charging points (Deloitte, 2018).

The city of Copenhagen has started to test autonomous vehicles in 2018. Nonetheless, the legislations are in progress to allow tests on autonomous vehicles in Denmark according to the road safety requirements. So far, the autonomous vehicle tests are limited to specific road sections and to specific vehicle types.

3.4 Luxembourg

The country of Luxembourg accounts 602.000 inhabitants and Luxembourg capital 116.323 inhabitants, being the most populated city in Luxembourg (Statec, 2018).

Statistical data for Luxembourg point that citizens travel on average 1.27 hours a day, and the mobility represents on average 16% of a household's annual expenses (Ministère du Développement durable et des Infrastructures, 2018).

To tackle such issues, in 2012 Luxembourg launched ‘Modu’, a national strategy for sustainable mobility, which was updated in 2018, resulting in Modu 2.0 (Ministère du Développement durable et des Infrastructures, 2018).

Modu 2.0 aims to trigger a mobility shift from private vehicles to public transport, multi modal transport and active modes as walking and cycling. The strategy presents four main objectives: to increase the car occupancy rate; to improve the attractiveness of public transport; to change the modal split from home to work; and from home to school.

In addition, the mobility strategy has included measures targeting 4 specific spheres and groups - State, Municipality, Employer and Citizen – in order to engage actors and provide measures for them to contribute for a better mobility.

The current modal split on 2017 and the objectives for 2025 in the agglomeration of the city of Luxembourg are detailed in Table 3. Considering the objectives for 2025, both journeys, from home to work and from home to school, they target the shift from private cars to public transport, walking and cycling. However, the mobility behaviour shift is more significant from home to school.

Table 3 - Modal split in 2017 and objectives for 2025 in the agglomeration of the city of Luxembourg

	Private vehicle	Public transport	Walking	Cycling
Modal split 2017	69%	17%	12%	2%
Objective by 2025 from home to work	65%	22%	9%	4%
Objective by 2025 from home to school	20%	45%	25%	10%

Source: Modu 2.0, Stratégie pour une mobilité durable, (Ministère du Développement durable et des Infrastructures, 2018).

Other initiatives on sustainable mobility have been deployed on a national scale, for instance:

- The use of smartphones to promote multimodal mobility;
- Investments in public infrastructure to achieve by 2020 1.600 points for cars' electric recharge supplied by renewable energies;
- From 2018 all new vehicles acquired by the State must be electric or hybrid;
- In 2018, the creation of a carpool portal 'CoPilote' for the Grand Duchy and the neighbouring region to encourage shared rides particularly between home and work;
- The expansion of cycle paths, among others (Ministère du Développement durable et des Infrastructures, 2018).

Concerning autonomous vehicles, in 2017, Luxembourg, France and Germany signed an agreement to test autonomous vehicles in real conditions and long distances. Such initiative is aligned with of the strategic study for the Third Industrial Revolution (Ministère de l'Économie, la Chambre de Commerce, IMS Luxembourg, 2017) applied on the mobility field.

Moreover, in September 2018 Sales-Lentz inaugurated 3 lines with autonomous e-minibuses available for the population. This innovation in mobility might present valuable findings concerning the introduction of a new technology and the interaction in society, human behaviour as well as to foresee future scenarios for mobility. Regarding the legislative framework, as in other countries, it has to be adapted for the introduction of autonomous vehicles in the traffic.

4 THE AVENUE set of indicators for Sustainability Assessment

4.1 The conceptualization and aims

The choice of indicator as a tool to measure and assess sustainable mobility considered that urban sustainability indicators are fundamental to support on target setting, performance reviews and to enable the communication among the policy makers, experts and general public (Shen, Jorge Ochoa, Shah, & Zhang, 2011; Verbruggen, H., Kuik O., 1991).

Moreover, Castillo and Pitfield's (2010) study on sustainable transport assessment tools point the attractiveness and convenience of indicators due to their 'ability to capture the multidimensionality of sustainable transport'.

Hence, the set of indicators for AVENUE Sustainability Assessment aims to evaluate the project performance according to the multi-dimensions of sustainable mobility: social, environmental, economic and governance (Shen et al., 2011), coupled with the technological dimension of autonomous driving.

Its conceptualization is in line with the AVENUE principles towards public transport: environmentally friendly, accessible and inclusive, personalised, affordable and innovative.

4.2 Defining criteria for selection of indicators

SMART indicators were considered as general criteria to select the indicators (ECA, 2019; EU, 2017):

- Specific: the indicator is clear and directly relates to the outcome;
- Measurable: the indicator can be counted and analysed to track the project's progress and goals achievement;
- Achievable: the indicator and project targets are achievable;
- Realistic/Relevant: the indicator is a valid measure of the outcomes;
- Time-limited: the indicators are attached to an achievable time frame considering the project's time.

In addition, further criteria were considered regarding the project's context and specificities:

- Data availability within AVENUE project context: indicators have to be accessible, frequent and easy to collect;
- Data quality: data accuracy and suitable for comparison,
- Indicator relevance according to the Avenue project goal and objectives, and relevant to the European mobility context;

- Indicators reflect the balance among the sustainability dimensions.

4.3 The AVENUE set of indicator for sustainable mobility

The AVENUE set of indicators for Sustainability Assessment (Figure 2) is composed of 19 indicators, which address one or more of the five following dimensions:

- the social dimension addresses key points for social acceptance, users' perceptions and satisfaction during the ride in the autonomous e-minibus, accessibility for PRM's (people with reduced mobility), safety and security issues;
- the environmental dimension evaluates the environmental-friendliness of the autonomous e-minibus regarding energy efficiency, climate change emissions, noise, air pollution and further relevant impact categories;
- the economic dimension approaches the affordability of the new mode of transport for users, transport operators and municipalities, impacts on the mobility external costs, and economic incentives towards autonomous vehicles;
- the governance dimension addresses the institutional development in terms of policies and regulations towards autonomous driving;
- the system performance dimension assesses the technology performance of the autonomous e-minibus as a mean of transport.

These five dimensions and indicators can be more directly or indirectly interrelated, hence this is a factor that will be explored in the next steps of the Sustainability Assessment. In order to illustrate this interrelation, as an example: the autonomous e-minibus system performance will affect the user's acceptance; consequently, a lower or higher number of users influences the environmental performance. Considering that in terms of energy efficiency, the goal is to have a low energy consumption for passenger per km.

It is also relevant to point that during the data collection process, the units of measure can be adapted or modified according to data availability, data from different cities, etc. In this case, it will be explained and justified. In addition, some of the indicators and unit of measures will be based on the inputs and results from the social, environmental and economic studies developed in WP8. For instance, the user's surveys applied on the social impact (WP8.3) will provide inputs for the social and system performance indicators, Life Cycle Assessment (LCA) studies on WP8.1 and economic studies on WP8.2 will contribute as well with inputs for the assessed multi-dimensions.

The multi-dimensions are depicted in the right side with different colours, and the different colours represent each dimension.

AVENUE set of indicators for sustainable mobility

Indicators	Unit of measurement	Multidimensions: Social	Environ.	Economic	Govern.	System perform.
Accessibility	Autonomous e-minibus (AEMB) coverage area of service: Percentage of the city population that has convenient access (within 0.5 km) to the AEMB transport; (%)					
	AEMB accessible digitally					
Accessibility for people with reduced mobility	External environment facilities Stops adaption for impaired/disabled people? Tactile surfaces information Internal environment facilities Audible warning equipment for visually impaired people Access by physically disabled people (e.g. Wheelchair access)					
	Users with reduced mobility rating concerning AEMB experience					
Safety	Number of traffic incidents envolving Autonomous e-minibus (AEMB);					
	Number of traffic accidents and fatalities envolving AEMB; nr/year					
Security	Number of criminal occurrences; nr/year					
	Number of cybersecurity threats or attacks; nr/year					
Passenger's affordability	The price of the ride on AEMB (considering fixed itinerary or on demand) compared to other public transport; (Euro)					
User acceptance	User's perception about the readiness of the technology User's willingness to pay Safety feeling Security feeling					
User satisfaction	User rating concerning AEMB experience (comfort, speed, ponctuality, information, frequency, connection to other means of transport)					
Energy Efficiency	Energy consumed for passenger per km (kWh/pkm)					
Renewable energy	Use phase: Energy source and percentage of renewable energy sources (%)					
Air Pollution	AEMB emissions of air pollutants: PM 10 levels (ug/m3); PM2.5 levels; NOx, Sox, CO, O3, emissions					
Climate change	AEMB GHG emissions: CO2, N2O, CH4					
Noise Pollution	AEMB traffic noise (dB)					
Investiments on mobility	Public and Private annual average investment on transport concerning autonomous vehicles (Euro/year) e.g. infrastructure, operational expenditures (cost of personnel, software system, etc), investments on the vehicle R&D.					
Economic incentives to autonomous and sustainable mobility	Incentives and subsidies for autonomous and sustainable mobility (e.g. shared, eletric, autonomous, zero-emission, vehicles) (Euro)					
Economic profitability	TCO (Total Cost of Onwership) TCM (Total Cost of Mobility) Cost / km /passenger					
External costs related to AEMB	AEMB impacts on congestion avoidance, accidents reduction, noise reduction, air pollution (PM, Nox) reduction, QALY (quality adjusted life years) reduction, land/parking reduction, vehicle savings					
Institutional development and innovation	Local policies and regulations concerning autonomous vehicles Existence of open data or APIS for transport					
Performance and Reliability	AEMB's . trip length, speed, frequency of departure/average waiting time, ponctuality/delays, number of journeys per day, bus stops per km2, average total passenger per km travelled per day, % operational service . performance on different seasons/weather (number of riding days according to the different seasons) . on demand availability . vehicle occupancy (mean number of people per vehicle) . effective system capacity (maximum of passengers per vehicle) . average life time of the vehicle .Number of disengagements . Number of km driven autonomously . Number of situation handeled autonomously . Level of service (PTO's)					
System efficiency	AEMB integration with other means of transport					

Figure 2 - The AVENUE set of indicator for sustainable mobility

To conceptualize the set of indicators, this study considered some definitions based on the Report 'Safety first for automated driving' (2019)[1]:

- Accident

"An accident is an undesirable, unplanned event that leads to an unrecoverable loss of service due to unfavourable external conditions, typically involving material damage, financial loss and (lethally) injured humans."

- Incident

"An incident is an undesirable, unplanned event that leads to a recoverable loss of service due to favourable external conditions, typically sparing any material damage, financial loss and (lethally) injured humans."

- Reliability

"This refers to the ability of a system to continuously provide correct service."

- Safety

"This refers to the absence of unreasonable risk due to hazards."

"it focuses on the proper functioning of a system"

- Security

"Security is the protection against intentional subversion or forced failure."

"it focuses on the system's ability to resist some form of intentionally malicious action"

- Disengagement (according to California Department of Motor Vehicles, 2018)

"deactivation of the autonomous mode when a failure of the autonomous technology is detected or when the safe operation of the vehicle requires that the autonomous vehicle test driver disengages the autonomous mode and takes immediate manual control of the vehicle."

In this regard, the rate of disengagements points the capacity of the vehicle to recognize the environment and handle a variety of driving situations.

Lastly, it is also relevant to mention the potential limitations of the pilot projects that influence the impact assessment studies in general. Considering that the autonomous e-minibuses are operating in limited conditions, such as, fixed itineraries, low passenger capacity, low total mileage, speed limit of 25km/h, requirement of supervisors on board the vehicle, limited interaction with other vehicles, the different cities' requirements and regulatory frameworks, among others.

4.4 Data collection, analysis and results

The set of indicators will be applied in the four AVENUE target cities.

It is estimated two series of data collection:

[1] by Aptiv Services US, LLC; AUDI AG; Bayrische Motoren Werke AG; Beijing Baidu Netcom Science Technology Co., Ltd; Continental Teves AG & Co oHG; Daimler AG; FCA US LLC; HERE Global B.V.; Infineon Technologies AG; Intel; Volkswagen AG.

- First: Spring/2020
- Second: summer/2021

Nonetheless, data will be gathered along these two periods considering that different indicators have different units of measurement and frequency of data.

Following the data collection, the data analysis comprehends the definition of a parameter for each indicator and respective score, and the results will be presented and compared based on a spider chart. For these steps, guidelines, such as ‘Methodology and indicator calculation method for sustainable urban mobility’ from World Business Council for Sustainable Development (2015), will provide basis for data analysis and results.

5 Conclusion and research agenda

The first iteration on sustainability assessment presented introductory concepts and definitions on sustainability and sustainable mobility as well as the state of the art on the sustainable mobility agenda and goals in the AVENUE target cities.

These introductory concepts along with the AVENUE project background and targets provided the basis to conceptualize a set of indicators to assess the social, environmental, economic, governance and technical impacts of the implementation of autonomous e-minibuses in the transport system of European cities.

The AVENUE sustainability assessment, besides assessing the performance and goals achievements of the AVENUE project, shall contribute to future research and to fulfil knowledge gaps on this field with a focus on the European context.

The initial elaboration of the mobility´s agenda of the four target cities reveal important disparities among them. For instance, Copenhagen is a reference on green mobility, with ambitious goals to be a carbon neutral capital, and it presents a modal split for private cars of 26% (2018), while in Luxembourg private cars represents 69% (2017), in Lyon 44% (2015) and in Geneva 30% in the centre and 60% in connected areas. Therefore, further comparative research will be conducted.

The sustainability assessment will apply the set of indicators in the target cities, present analysis, results and performance comparisons. Hence, it will provide building blocks to explore leverage points to enhance sustainability by deploying autonomous vehicles in the public transport as well as potential rebound effects and mitigation actions.

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Appendix I:

List of methods and references considered for in depth analysis in the Literature Review on sustainable mobility/transport assessment. Organized by decreasing order according to the publication year.

Method	Reference
Deloitte Mobility City Index (Deloitte, 2019)	Deloitte (2019). *The 2019 Deloitte City Mobility Index: Gauging global readiness for the future of mobility*. Retrieved from https://www2.deloitte.com/content/dam/insights/us/articles/4331_Deloitte-City-Mobility-Index/4740_DCMI_Overview.pdf
Indicators for Sustainable and Livable Transport Planning (Litman, 2018)	Litman, T. (2018). Well Measured Developing Indicators for Sustainable and Livable Transport Planning.
The Urban Mobility Index (CEBR, 2017)	CEBR (2017). *Urban Mobility Index*. Retrieved from Qualcomm. Retrieved from: https://www.qualcomm.com/media/documents/files/urban-mobility-index-report.pdf
Sustainable Cities Mobility Index (Arcadis Batten, John J. & Ghrels, 2017)	Arcadis Batten, John J., & Ghrels, C. (2017). *Sustainable Cities Mobility Index 2017 Bold Moves.*
Sustainability Measures of Urban Public Transport in Cities (Gruyter, Currie, & Rose, 2017)	Gruyter, C. de, Currie, G., & Rose, G. (2017). Sustainability Measures of Urban Public Transport in Cities: A World Review and Focus on the Asia/Middle East Region. *Sustainability*, *9*(1), 43. https://doi.org/10.3390/su9010043
Elementary Global Tracking Framework for Transport (Sustainable Mobility for All, 2017)	Sustainable Mobility for All (2017). GLOBAL MOBILITY REPORT 2017: Tracking Sector Performance.
Eco-mobility SHIFT (ICLEI – Local Governments for Sustainability, 2017)	ICLEI – Local Governments for Sustainability (2017). *EcoMobility Alliance Report Phase 2016-2017*. Bonn.
TERM 2016: Transport indicators tracking progress towards environmental targets in Europe (EEA, 2016)	EEA (2016). *Transitions towards a more sustainable mobility system: TERM 2016: Transport indicators tracking progress towards environmental targets in Europe*. Luxembourg.
The Sustainable Urban Mobility Indicators (World Business Council for Sustainable Development, 2015)	World Business Council for Sustainable Development (2015). *Methodology and Indicators for Sustainable Urban Mobility*. Sustainable Mobility Project 2.0 (SMP2.0).
The Sustrans Index (Dobranskyte-Niskota, Perujo,	Dobranskyte-Niskota, A., Perujo, A., & Pregl, M. (2007). *Indicators to assess sustainability of transport activities part 1: Part 1: Review of the Existing Transport Sustainability*

& Pregl, 2007)	*Indicators Initiatives and Development of an Indicator Set to Assess Transport Sustainability Performance* (EUR. Scientific and technical research series). Luxembourg.
Transportation Index for Sustainable Places (TISP) (Zheng, Garrick, Atkinson-Palombo, McCahill, & Marshall, 2013)	Zheng, J., Garrick, N. W., Atkinson-Palombo, C., McCahill, C., & Marshall, W. (2013). Guidelines on developing performance metrics for evaluating transportation sustainability. *Research in Transportation Business & Management*, *7*, 4–13. https://doi.org/10.1016/j.rtbm.2013.02.001
Indicators for sustainable urban mobility (Institute of Transport Economics [TØI], 2012)	Institute of Transport Economics (2012). Indicators for sustainable urban mobility – Norwegian relationships and comparisons.
Transport for sustainable development in the ECE region (UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, 2011)	UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE. (2011). *TRANSPORT FOR SUSTAINABLE DEVELOPMENT IN THE ECE REGION.* https://doi.org/10.18356/29f213fa-en
Sustainable Transportation Indicators (Sustainable Transportation Indicators Subcommittee of the Transportation Research Board (ADD40 [1]], 2008)	Sustainable Transportation Indicators Subcommittee of the Transportation Research Board (ADD40 (2008). *Sustainable Transportation Indicators A Recommended Research Program For Developing Sustainable Transportation Indicators and Data.*
Indicators for Comprehensive and Sustainable Transport Planning (Litman, 2007)	Litman, T. (2007). Developing Indicators for Comprehensive and Sustainable Transport Planning. *Transportation Research Record: Journal of the Transportation Research Board*, *2017*(1), 10–15. https://doi.org/10.3141/2017-02
Defining Sustainable Transportation (The Centre for Sustainable Transportation, 2005)	The Centre for Sustainable Transportation (2005). *Defining Sustainable Transportation.*
Towards Sustainable Mobility Indicators: Application to the Lyons Conurbation (Jean-Pierre Nicolas, Pascal Pochet, Hélène Poimboeuf, 2003)	Jean-Pierre Nicolas, Pascal Pochet, Hélène Poimboeuf (2003). Towards Sustainable Mobility Indicators: Application to the Lyons Conurbation.
Indicators for the integration of environmental concerns into transport policies (OECD, 1999)	OECD (1999). *Indicators for the integration of environmental concerns into transport policies*. Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=ENV/EPOC/SE(98)1/FINAL