MOVE2CCAM

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Move2CCAM

MethOds and tools for comprehensive impact Assessment of the CCAM solutions for passengers and goods

HORIZON-CL5-2021-D6-01

D1.1

CCAM solutions review and gaps

WP1 – Setting the ground: CCAM scenarios, business models and KPIs

Dissemination Level		
PU	Public	x
SEN	Sensitive	

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Authors (Contributor Organisation)	Ana Quijano (CARTIF) Susana Mª Gutiérrez (CARTIF) Laura Pablos (CARTIF) Francisco Verdugo (CARTIF) Héctor Cañas (BABLE) Adriana Witkowska-Lonieczny (GZM) Paulo Anciaes (UCL) Maria Kamargianni (UCL) Konstantinos Mavovratis (MOBY) Eric Gehl (HAKISA) Matthieu Graindorge (HEL) Nikianna Kapoyianni (ELORIS)
Reviewers	Maria Kamargianni (UCL)

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Acronyms and definitions

Acronyms	Definitions
ADR	Autonomous Delivery Robot
ADV	Autonomous Driving System
ATO	Autonomous Train Operation
AV	Autonomous Vehicle
BRT	Bus Rapid Transit
CCAM	Cooperative, Connected and Automated Mobility
CORDIS	Community Research and Development Information Service
CAPEX	CApital EXpenditure
DoA	Description of Action
ERA	European Union Agency for Railways
ECU	Electronic Control Unit
EIT	European Institute of Innovation and Technology
EU	European Commission
GDP	Gross Domestic Product
GHG	Green House Gases
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
HD map	High-Definition map
ISO	International Organization for Standardization
HRT	Heavy Rail Transit
HSR	High-Speed Rail
ICT	Information and Communications Technologies
IMU	Inertial Measurement Unit
ITS	Intelligent Transportation System
IR Camera	Infrared Camera
KPI	Key Performance Indicator
LIDAR	Laser Imaging Detection and Ranging
LR Radar	Long Range Radar
LRT	Light Rail Transit
MaaS	Mobility as a Service
MR Radar	Monopulse Radar
MT	Mass Transit
NPV	Net Present Value
OPEX	OPerating EXpenditure
PM	Particulate matter

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PT	Public Transport
RADR	on-Road Autonomous Delivery Robot
ROI	Return on Investment
SD	System Dynamics
SDS	System Dynamics Model
SPS	Smart Parking Systems
S&T	Scientific and Technical
UNIDO	United Nations Industrial Development Organization

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Introduction

As this deliverable is the result of the work done within Task 1.1 (Review of CCAMs solutions and impact assessment methods), the main goal is to give information related to the review of the state-of-the-art on CCAM use cases, scenarios, business models, KPIs, impact evaluation methods, technologies, and user needs (both for organisations and citizens). All the findings have been critically assessed, and gaps have been identified. Task 1.1 (and, thus, this D1.1) represents the first step within all the tasks to be developed in the scope of WP1 (Setting the ground: CCAM scenarios, business models and KPIs), where the ground for the project is being addressed.

First of all, and in order to make all the reading of the deliverable more understandable, four terms/concepts should be defined and clarified:

- Technologies: are "methods, systems, and devices which are the result of scientific knowledge being used for practical purposes" (Collins Dictionary) (in this case, in the scope of CCAM).
- Use cases: A use case is an abstraction that describes all possible scenarios involving one functionality[1]. Use cases are used to represent a specific set of scenarios.
- Scenarios: A scenario is an instance of a use case describing a specific set of actions. Use cases are used to describe all possible cases (their focus is on completeness), while scenarios take into account specific situations.
- Business cases: , a business model describe how a specific service or product creates and captures customer value and can be represented by an interrelated set of capabilities and priorities that address the customer, value proposition, organizational architecture, and economic dimensions.

In this case, where CCAM use cases and scenarios are being studied, use cases are considered as applications of technologies, and scenarios as possible variants in those applications in terms of vehicle ownership and types of services (see section 1).

This report gives information on CCAM technologies, use cases and scenarios (both for passenger and freight transport), followed by a state-of-the-art on the most applicable business and financial models for CCAM solutions. Then, an overview of the societal and companies needs on transport and which on these can be covered by passengers and freights CCAM solutions is given. Besides, a review of Transport System Dynamic Models is addressed, supporting the developments to be done in the scope of WP4 (Move2CCAM Impact Assessment Tool). Taking into account all the aforementioned information, section 5 contains information on the long-term implications, benefits and impacts of integrating CCAM solutions into the mobility system, and existing evaluation frameworks and KPIs to quantify these potential impacts are also described. Sections 6 is closer to the final users, containing information on the needs of the prototypical areas in terms of transport, as well as a description of the barriers and challenges to overcome for the deployment of CCAM solutions. Finally (section 7), an overview of the different available methods for the co-creation and assessment of CCAM solutions is presented, followed by a section devoted to the main conclusions (concerning conclusions, it is important to notice that, as this is a very long document, multiple sections also contains information about the specific conclusions derived from the work done in each specific section).

General context

As aforementioned, this deliverable sets the ground on the development of CCAM use cases, prototype business models, scenarios and KPIs, providing material for all the activities of the

[1] Object-oriented software engineering using UML, Patterns and Java (Bruegge, Dutoit, 2010). Section 2.4.1.

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project that will follow this one. The findings of this review will be used for preparing questionnaires (T3.2 – Primary data collection tools design) and other relevant material needed to initiate the discussions with the Satellites (WP2 – Satellite network and engagement).

Deliverable objectives

The objective of this deliverable is to critically review the state-of-the-art and latest developments in the CCAM sector (both for passengers and freights) and identify gaps in KPIs, business models and methods that will guide the developments in the scientific and technical (S&T) work packages. The topics that are reviewed are related to the tasks of each S&T work package as follows:

- CCAM use cases for passengers and freight, business models and according KPIs – related to the work of WP1.
- Impact of CCAMs on citizens, industry and authorities, and according methods used to collect the data and assess the impact – work related to WP3.
- System dynamics modelling methods and data requirement – related to WP4.

The review in all sections is conducted in a consistent way to make sure that it will feed the developments in WP1, WP3 and WP4 to achieve the ultimate objective of Move2CCAM that is: "*the definition of use cases, business models and Key Performance Indicators through co-creation activities, & the development of a practical system dynamics-based impact assessment tool that will enable the evaluation of CCAM interventions' impact on mobility-, socio-economic-, public health- and environmental-related aspects considering diverse European region specifics and different actors' needs, objectives and perceptions*."

1 CCAM technologies, use cases and scenarios

1.1 Introduction

This section reviews technologies, use cases, and scenarios for CCAM solutions. Use cases are being defined as applications of technologies, and scenarios as possible variants in those applications in terms of vehicle ownership and types of services. The scope of CCAM solutions within the Move2CCAM project is focused on those that can be used for passenger or freight transport at urban, suburban or regional level. The technologies, use cases, and scenarios were identified in academic papers, reports, and policy documents.

1.2 Technologies and use cases

Table 1 lists CCAM vehicle technologies, categorised by mode (land, water, or air). It also provides examples of types of vehicles using the technology.

Table 1 Technologies and use cases

Technology	Mode	Transport sector	Vehicle types
Connected vehicles	Land	Passengers and freight	
Partly-autonomous vehicles	Land	Passengers and freight	
Autonomous vehicles	Land	Passengers	pods, cars, buses
		Freight	vans, delivery bots, platooning pods
	Water	Passengers	cruises, ferries
		Freight	barges
	Air	Passengers	unmanned aircraft, drones
		Freight	drones

In this deliverable, water transport and air passenger transport are not covered, as it is outside the scope of the project.

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Table 2 lists uses cases, i.e. how the technologies above can be offered to the public or converted into a service

Table 2 Use cases

Use	Example of use cases
Passenger transport	• Generalised use • Shuttles to other modes (to stations, parking areas) • Express services in urban areas • Tourist shuttles • 'Last mile' transport (e.g. station to home/workplace) • Transport within a site (park, airport) • Emergencies (e.g. ambulance)
Freight transport	• Generalised use • 'Last mile' deliveries from/to depots to final customer • Specific deliveries in small areas • Delivery to remote areas • Emergency deliveries (e.g. medical products) • Express delivery of high-value products • Transport within a site (factory, port, airport) • Delivery from/to ships in ports

1.3 Scenarios for passenger transport

Eleven scenarios have been defined in the scope of CCAM solutions for passenger transport, as below.

S1. Private vehicles - passengers
S2. Scheduled public transport
S3. Demand responsive transport
S4. Taxis
S5. Ride-hailing
S6. Shared cars
S7. Ride-sharing
S8. Rented cars
S9. Mobility as a Service (integration of all of the above)

Table 3 to Table 18 show, for each scenario, the user needs the scenario could fulfil, the stakeholders involved in the development of the scenario, the challenges and the potential societal impacts. The scenarios presented are for land travel. However, they also apply to air and water travel, with some differences in terms of stakeholders involved, challenges, and potential impacts.

Table 3 Scenario S1: Private vehicles - passengers

Description	Households buy their own autonomous vehicle
User needs	Flexibility, reduced effort in driving and parking, releases travel time, personal security
Technologies that can be used	Autonomous 5-seater vehicles or pods
Stakeholders involved	Vehicle developers, vehicle manufacturers, vehicle retailers, road authorities, traffic controllers, demonstration areas, cybersecurity, health experts, researchers
Challenges	Coexistence of autonomous cars with conventional cars in traffic, regulatory barriers, insufficient car parking space
Potential impacts	**Mobility/behaviour** • Increase of private transport and decrease of public transport share and possibly of walking and cycling share • Increase of overall number of car trips and km travelled **Safety** • Decrease in traffic collisions and injuries per km travelled **Public health**

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	• Less physical activity **Environment** • Decrease in emissions per km travelled **Land use** • Increase of car parking space **Network efficiency** • Increase of road congestion **Equity** • Higher accessibility for population who do not drive

Table 4 Scenario S2: Scheduled public transport

Description	Bus services running on fixed routes and schedules and using an autonomous vehicle fleet across the whole network
User needs	Access to central areas or commute to workplace, sporadic use outside area of residence, opportunity for using travel time and for socializing, less time and effort spent for parking, fast (if using dedicated road lanes)
Technologies that can be used	Autonomous 60-seat buses
Stakeholders involved	Vehicle developers, vehicle manufacturers, bus operators, road authorities, demonstration areas, cybersecurity, researchers
Challenges	Increased costs, concerns about hacking with malicious intentions, retraining staff
Potential impacts	**Mobility/behaviour** • Increase of public transport share and possibly of walking and cycling share, decrease of private transport share **Safety** • Decrease of traffic collisions and injuries **Economy** • Decrease of employment in public transport industry **Land use** • Decrease of car parking space **Network efficiency** • Decrease of road congestion and emissions

Table 5 Scenario S3: Demand-responsive public transport

Description	Services using autonomous vehicles (buses or minivans) and running when and where they are needed by users
User needs	Availability of services even when living in peripheral areas or travelling outside peak areas
Technologies that can be used	Autonomous buses or minivans
Stakeholders involved	Vehicle developers, vehicle manufacturers, bus operators, road authorities, demonstration areas, cybersecurity, researchers
Challenges	Costs
Potential impacts	**Mobility/behaviour** • Increase of public transport share and decrease of private transport share **Safety** • Decrease of traffic collisions and injuries **Environment** • Decrease of emissions **Network efficiency** • Decrease of road congestion **Land use** • Decrease of car parking space **Equity** • More accessibility for peripheral areas and people who do not travel at peak times

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Table 6 Scenario S4: Taxis

Description	Taxi services using autonomous vehicles running when and where they are needed by users
User needs	May be only option when/where this no public transport. Comfort, privacy, personal security. No intermediate stops. Fast, if allowed to use bus lanes.
Technologies that can be used	Autonomous 5-seater vehicles or pods
Stakeholders involved	Vehicle developers, vehicle manufacturers, taxi companies, road authorities, road authorities, traffic controllers, demonstration areas, cybersecurity, researchers
Challenges	Competition from other services, especially ride-hailing
Potential impacts	**Mobility/behaviour** • Decrease of public transport share **Safety** • Decrease of traffic collisions and injuries **Environment** • Possible increase of road emissions **Network efficiency** • Possible increase of road congestion

Table 7 Scenario S5: Ride-hailing

Description	App-based taxi services using an autonomous vehicle fleet
User needs	May be only option when/where this no public transport. Comfort and privacy. No intermediate stops.
Technologies that can be used	Autonomous 5-seater vehicles, pods, or minivans
Stakeholders involved	Vehicle developers, vehicle manufacturers, ride-hailing companies, road authorities, traffic controllers, car parks, demonstration areas, cybersecurity, researchers
Challenges	Costs
Potential impacts	**Mobility/behaviour** • Decrease of public transport share **Safety** • Decrease of traffic collisions and injuries **Environment** • Possible increase of emissions **Land use** • Decrease of car parking space **Network efficiency** • Possible increase of road congestion

Table 8 Scenario S6: Shared vehicles

Description	Fleet of autonomous vehicles parked at fixed or variable locations and that can be used by members of a car club
User needs	Saves cost of owning a car but keeps flexibility of using one when needed
Technologies that can be used	Autonomous 5-seater vehicles, pods, or minivans
Stakeholders involved	Vehicle developers, vehicle manufacturers, car clubs, road authorities, traffic controllers, car parks, demonstration areas, cybersecurity, researchers
Challenges	Resistance from the public
Potential impacts	**Mobility/behaviour** • Decrease of public transport share **Safety** • Decrease of traffic collisions and injuries **Land use** • Increase of car parking space

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Table 9 Scenario S7: Ride-sharing

Description	App-based services linking users with autonomous vehicle fleet owners (households or car clubs)
User needs	Saves cost of owning a car but keeps flexibility of using one when needed. Opportunity for socializing
Technologies that can be used	Autonomous 5-seater vehicles, pods, or minivans
Stakeholders involved	Vehicle developers, vehicle manufacturers, ride-sharing platforms, road authorities, traffic controllers, car parks, demonstration areas, cybersecurity, researchers
Challenges	Resistance from the public due to privacy or personal security concerns
Potential impacts	**Mobility/behaviour** • Decrease of public transport share **Safety** • Decrease of traffic collisions and injuries

Table 10 Scenario S8: Rented vehicles

Description	Use of an automated vehicle for a fixed period
User needs	Sporadic use outside area of residence, use for leisure trips, personal security
Technologies that can be used	Autonomous 5-seater vehicles, pods, or minivans
Stakeholders involved	Vehicle developers, vehicle manufacturers, car rental services, road authorities, traffic controllers, car parks, demonstration areas, cybersecurity, researchers
Challenges	Cost, lack of interest from the public if other options exist
Potential impacts	**Mobility/behaviour** • Decrease of public transport share • Increase of overall number of car trips and km travelled **Network efficiency** • Increase of road congestion **Environment** • Decrease in emissions and traffic collisions and injuries per km travelled **Land use** • Increase of car parking space

Table 11 Scenario S9: Mobility as a Service

Description	App-based trip planning offering a variety of transport modes and services
User needs	Seamless trips. Less effort for planning and wayfinding. Can be cheaper than using individual modes and services separately. Saves cost of owning car but keeps flexibility of using one.
Technologies that can be used	Autonomous vehicles (various types)
Stakeholders involved	Vehicle developers, vehicle manufacturers, transport service integrators, data providers, road authorities, demonstration areas, cybersecurity, researchers
Challenges	High car ownership, privacy concerns related to personal data, legal framework, uncooperative operators, barriers to payment integration
Potential impacts	**Mobility/behaviour** • Increase of public transport share and possibly of walking and cycling share, decrease of private transport share **Safety** • Decrease of traffic collisions and injuries **Network efficiency** • Decrease of road congestion and emissions **Economy** • Decrease of employment in public transport industry **Environment** • Decrease of emissions **Land use** • Decrease of car parking space

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1.4 Scenarios for freight transport

Seven scenarios have been defined within CCAM solutions for freight transport, as below (Table 12 to Table 18 contain their description).

S10. Single-company vehicles
S11. Last mile delivery
S12. Shared vehicles
S13. Shared vehicles (peer-to-peer)
S14. Rented vehicles
S15. Delivery drones
S16. Freight as a Service

Table 12 Scenario S10: Single-company vehicles

Description	Companies replace their fleet with autonomous vehicles
User needs	Flexibility
Technologies than can be used	Autonomous vans or trucks
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, vehicle retailers, road authorities, traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	Employment loss
Potential impacts	**Safety** • Decrease in traffic collisions and injuries per km travelled **Economy** • Higher operating costs • Decrease of employment **Environment** • Decrease in emissions

Table 13 Scenario S11: Last mile delivery

Description	Autonomous vehicles (vans or smaller vehicles) collect goods from a depot and deliver them to recipient
User needs	Need for more efficient deliveries in city centres
Technologies than can be used	Autonomous vans or minivans
Stakeholders involved	Depot operators, freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, vehicle retailers, road authorities, traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	Cost of using depot
Potential impacts	**Safety** • Decrease in traffic collisions and injuries **Economy** • Faster, more reliable and flexible delivery, leading to customer satisfaction • More efficient handling of returns • Reduced distance covered and time spent delivering, leading to cost savings • More efficient use of vehicles and warehouses • Less waste, fewer parking fees and fines **Environment** • Decrease in emissions

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Table 14 Scenario S12: Shared vehicles

Description	Autonomous freight vehicles used by more than one company
User needs	Need to reduce delivery cost and not to waste capacity of company's vehicles
Technologies than can be used	Autonomous vans or trucks
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, road authorities, traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	Lack of regulation, lack of coordination between companies
Potential impacts	**Economy** • Cost savings (not having to own a vehicle)

Table 15 Scenario S13: Shared vehicles (peer-to-peer)

Description	App-based services linking companies with other companies owning autonomous freight vehicles
User needs	Need to reduce delivery cost and not to waste capacity of company's vehicles
Technologies than can be used	Autonomous vans or trucks
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, road authorities, traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	Lack of regulation, resistance from companies due to privacy concerns
Potential impacts	**Economy** • Cost savings (not having to own a vehicle)

Table 16 Scenario S14: Rented vehicles

Description	Use of an automated vehicle for a fixed period
User needs	Need to reduce delivery cost and not to waste capacity of company's vehicles
Technologies than can be used	Autonomous vans or trucks
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, vehicle retailers, road authorities, traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	**Economy** • Cost
Potential impacts	Cost savings (not having to own a vehicle) but rental costs can also be high

Table 17 Scenario S15: Delivery drones

Description	Drones for freight delivery
User needs	Need for fast deliveries
Technologies than can be used	Drones
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, drone developers, drone manufacturers, urban planners, air traffic controllers, demonstration areas, cybersecurity, economists, researchers
Challenges	Cost, regulations, environmental impact (noise, visual intrusion), collisions with buildings and other objects, other safety risks
Potential impacts	**Economy** • Cost savings (not having to own a vehicle) but use costs can also be high

Table 18 Scenario S16: Freight as a Service

Description	App-based trip planning offering a variety of solutions for freight operators
User needs	Diversity of choices
Technologies than can be used	Autonomous vehicles (various types)
Stakeholders involved	Freight operators, companies sending deliveries, customers receiving deliveries, vehicle developers, vehicle manufacturers, transport service integrators, data

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	providers, road authorities, demonstration areas, cybersecurity, economists, researchers
Challenges	Lack of regulation, companies already own vehicles, privacy concerns related to personal data, legal framework, uncooperative operators, barriers to payment integration
Potential impacts	**Economy** • Cost savings (not having to own a vehicle)

1.5 Conclusions on CCAM technologies, use cases and scenario

The CCAM technologies found in the literature can potentially fulfil several needs of users of passenger and freight transport. However, realization of this potential, and the wider impacts of the technologies on the economy, society, and environment depend on the scenarios relative to modes of ownership and use of the technologies. In addition, each scenario has its own challenges, including financial, institutional, regulatory, and other.

2 Business and financial models for CCAM solutions

According to the “four-box” business model framework (Johnson, Christensen, & Kagermann, 2018), a business model should describe how a specific service or products creates and captures customer value and can be represented by an interrelated set of capabilities and priorities that address the customer, value proposition, organizational architecture, and economic dimensions.

The following section provide a review of the cost structure of CCAM solutions and existing or potential business and financial models to ensure their implementation. Each of them presents initially a description of the CCAM solution analysed, then a description of the business model (using the “four-box” approach), financial model applied, overview of the stakeholders involved in the implementation of the service or product, and finally, a brief description of current CCAM solutions. A comprehensive literature review was performed to collect secondary data, mostly from articles and reports in scientific journals, mobility and transport related websites, and scientific news articles.

2.1 Autonomous ridehailing services

Ride hailing services have experienced an increase in demand in recent years evidenced by the success of companies such as Uber and Lyft. This success can be attributed to the provision of a low cost, convenient, on demand, door-to-door transport alternative (Gomez, Aguilera-García, Dias, Bhat, & Vassallo, 2021). With a hailing service, users are able to search, reserve, and pay the service through one application in their mobile phones. More recently, fully autonomous electric hailing (e-hailing) services have been launched with no human driver behind the wheel and using electric vehicles.

Brief description of business model

- **Value proposition**: The service offers a unique experience to the user be riding safely on a fully autonomous vehicle. Relying purely in technology, driverless e-hailing services significantly reduces the need of human assistance, and therefore, its costs.
- **Profit formula:** ridehailing services whether autonomous or not have the same revenue model. Users book the ride online through an app or web platform and pay a price depending on the distance travelled and time spent. What differentiates autonomous services is that driver commission costs are removed.
- **Resources**: Key resources include the vehicles hardware: containing LIDAR sensors to detect objects on the road, 360° cameras with high range and thermal stability to detect and identify objects, radars to identify the proximity of the vehicle to the objects, and the computer containing CPU and GPU servers analysing the information from the

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aforementioned hardware. Regarding the software, autonomous e-hailing services have software dedicated to the contracting service and for operating autonomously.
- **Processes:** Necessary processes are; road assistance for any malfunctions with the service, customer service through the app, and maintenance of the fleet.

Description of the financial model

- Financing sources
    - As ridehailing services operate with electric vehicles, service provider can opt to receive government subsidies, for example, in Germany, a subsidy of €7.500 can be obtained for the purchase of an electric vehicle (Federal Ministry for Economic Affairs and Energy , 2022).
    - Ridehailing services companies can also seek to raise private capital. As an example, the US-based company Lyft raised €605 million during their first years of foundation (Reuters, 2017).
- Cost Structure:

The cost structure of an autonomous ridehailing service is composed by three costs; namely, fixed costs, variable costs depending on the number of trips, and variable costs depending on the distance travelled (Negro, et al., 2021). Table 19 describes the underlying costs in each cost structure:

Table 19 Costs for an e-ridehailing autonomous service

Fixed Costs	Variable Costs (per trip)	Variable Costs (per km)
Vehicle Acquisition Hardware and software for enhancing autonomous ride Software for hailing service Service supporting staff Office and facilities Parking space fees Connectivity fee	Vehicle interior cleaning	Vehicle exterior cleaning Maintenance and wear Energy

According to (Negro, et al., 2021), the acquisition of an electric vehicle that can be adapted to a Level 5 of autonomous driving is approximately €41.000. Furthermore, the hardware and software for the autonomous driving technology is expected to range between €10.000 – €40.000, this price, however, tends towards the higher range. Regarding the costs to build the hailing service app, (Imaginovation Insider, 2022) assigns a range of €67.000 to €150.000 for one or two user apps (for iOS and Android), respectively. The costs for parking spaces and parking garages have been estimated by (APCOA Parking, 2022) to be €78.74 per vehicle per month, based on the average of various inner-city parking locations. Consequently, the fleet operator of 80 vehicles is calculated to have a monthly salary of €4,670 (Negro, et al., 2021).

- Revenue streams:
    - Revenue is primarily generated by selling door-to-door rides services to users. In some cases, the revenue can also be produced when the service provider has a promotional partnerships that runs through the app that pay for advertisements.

Actors involved in the business model

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Table 20 shows the stakeholders involved in an autonomous e-Hailing service.

Table 20. Stakeholder description for an autonomous e-Hailing service

Type of actor	Goals	Responsibilities
Service provider	Maximise profitability from value creation Increase userbase and number of rides	Guarantee a safe and timely transport
City Council / Transport regulator	Increase liveability of their community Reduce the dependency of the private vehicle Reduce accidents and fatality rate from mobility	Make available the infrastructure to allow the operation of the service
Users/customers	Best cost-benefit transportation	Payment of service Sharing of personal data to enhance and facilitate the operation of service

Current status of the business model

Business model already applied:

- Name of service: Google´s Waymo One
- Use Case Variant: Autonomous e-hailing
- Location: Phoenix, Arizona and San Francisco, California
- Brief Description: Waymo One™ is an on-demand ride-hailing service offering Level 4 autonomous rides in the East Valley area of Phoenix, Arizona and in San Francisco, California. Users can access a ride at any time through the Waymo One app and requesting a vehicle. Furthermore, users can also express their interest in travelling in the Phoenix metropolitan area as part of the Waymo Trusted Verifier programme in the app. or the time being, trips in the Phoenix metro area will have an autonomous vehicle specialist in the front seat.

2.2 On-demand autonomous shuttle bus service

Fixed on-demand autonomous shuttle bus services have been launched in different parts of the world (Germany, Singapore, France, Florida, The Netherlands, and Turin) as support for traditional public transport. Autonomous shuttle buses are capable of moving in normal urban traffic, detecting any type of obstacles (i.e., cars, bicycles, or pedestrians) and are efficient, reliable in real-time (Sustainable Bus, 2022), and can be accessible to people with disabilities. Autonomous Shuttle bus combines several benefits and can carry up to 15 people. Operators can increase productivity on private sites and reduce certain traffic congestion in metropolitan areas since the shuttles only run when there is demand. Additionally, travellers can maximize their travel time, avoiding unnecessary waiting time at bus stops.

Brief description of business model

- **Value proposition**: Autonomous Shuttle has been designed to satisfy the requirements of a self-driving vehicle while also enhancing navigation and safety features. The on-demand autonomous shuttle bus optimises navigation as it uses effective guidance and a combination of several technologies for the detection of objects, people, obstacles, weather conditions, etc. “It enables new, economically viable mobility concepts such as improving connections between rural and suburban areas and city centres Tapping into this potential would revolutionize public transport with timetable-free and demand-

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responsive routes, supporting equal transport opportunities for urban and rural areas" (Gollewski, 2021).

- **Profit formula:** on-demand autonomous shuttle service is now being tested in several cities and rural areas, so there is little experience with its pricing model. The service functions with an app where the passenger can book a bus and indicate the location to be picked up from.
- **Resources**: the principal technologies are the vehicle, sensor systems (LIDAR, IR Camera, GNSS, LR Radar, IMU, MR Radar, Camera, Ultrasound) route specifications, where the Electronic Control Unit (ECU) creates a virtual model of the Autonomous Vehicles (AVs) moving environment, reproducing the conditions, geographical area, climate, and operational safety measures (Iclodean, Cordos, & Varga, 2020). Finally, in case the vehicle has any issues, there could be a "safety driver" which is trained to support and take control of the vehicle.
- **Processes**: According to NAVYA, there are 5 steps for on-demand autonomous shuttle bus services: Feasibility study, approval for open roads, mapping (LIDAR and HD maps of the location are created to identify traffic lanes, road components, and the trajectory to follow), training, service launch and operations. (NAVYA, 2022)

Description of the financial model

- Financing sources
  - Funding is given specifically to deploy pilot demonstrators in cities. As an example, the autonomous shuttle bus company NAVYA was initially funded as a European Commission project. Public funding helped them launch in 2018 thirteen shuttle buses in six European cities (NAVYA, 2022). Now, operating as a private company, they are transitioning from experimentation to the deployment of the shuttles on a larger scale.
- More detailed Cost Structure explanation
  - CAPEX Capital Expenditure
    - Assets
      - Vehicle $500,000+ (Driveline, sensory system, high-voltage battery, Steering, braking, charging system, LIDAR, radar, camera, GPS, Inertial measurement unit (IMU), autonomous driving systems (ADV) (Quarles, Kockelman, & Mohamed, 2020)
  - OPEX Operational Expenditure
    - Maintenance and training $67,500+ (Quarles, Kockelman, & Mohamed, 2020)
- Revenue streams
  - "Improving accessibility and increasing the public transport network helps to bring more visitors to the area, as well as easing the daily commutes of the local residents, ensuring they are not dependent on private transport modes" (14)

Actors involved in the business model

The main actors involved in this business model are described in Table 21.

Table 21 Main actors involved in an on-demand autonomous shuttle bus service

Type of actor	Goals	Responsibilities
Manufacturers of AVs	Provide the autonomous shuttle in the best conditions	Provide a high-quality bus structure and system.
City/regulator	Allow the free and effective mobility of the autonomous shuttle bus service	Define the standards and regulations

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Citizens	Maximizing and normalizing the effective use of the autonomous shuttle bus services	Taking care of the facilities and make a better use of the vehicles
Industry player	Provide quality training about the usage of the vehicle and prevention of accidents	Keeping track of possible challenges that the vehicle might face while providing the necessary training for the qualified personnel

Current status of the business model

Business model already applied:

Use case: Business Park, Groupama Stadium, Lyon, France

Groupama Stadium created a self-driving shuttle service connecting the Décines Grand Large tram stop on the T3 line to the Olympique Lyonnais stadium as part of Lyon's public transportation system in France. In a congested metropolitan road environment frequented by thousands of automobiles, pedestrians, and bicycles each day, 2 Autonomous shuttles completed a 1.4 km round trip. The route included significant technical difficulties, such as the crossing of four intersections with traffic lights, a roundabout, and eight pedestrian crossings. The project was funded by H2020 initiative for the development of autonomous cars in European cities includes this partnership with SYTRAL and Keolis. (NAVYA, 2022)

Use case: City-centres, Lake Nona, Florida, USA

To offer a more convenient mode of transportation that puts people closer to neighbourhood shops and amenities inside a planned community for Lake Nona residents, employees, and visitors. Since September 2019, Beep has been operating 2 Autonomous Shuttles on a 1.9-kilometre route across an urban area with vehicular traffic. These shuttles enhance Lake Nona guests' quality of life while bolstering the regional transportation system (NAVYA, 2022).

2.3 Autonomous freight trucks

In 2021, the average distance travelled per tonne in road freight transport in the EU was 140.7 kilometres (eurostat, 2022). Compared to the distance travelled by a passenger car of 14.000 km per year, freight transport covers much higher mileage. Level 2 or Partial Automation has already been reached due to the high maturity of vehicle components such as adaptive cruise control, emergency braking and lane keeping assistant, however, Level 3 automation (conditional automation) and above, has still room for maturity growth (Fritschy & Spinler, 2019). It is estimated by (Berger, 2016) that a level 4 (high automation) will be probably reached by 2030. In the freight transport industry, autonomous driving technologies present themselves as a solution to improve safety and driver wellness, reduce road dangers due to drivers' distractions, and increase the hours of service.

Brief description of business model

- **Value proposition**: Autonomous trucks have two main benefits; namely, increasing drivers' comfort and safety through fully automated vehicle operation, and secondly, improving aerodynamics and fuel consumption through reduced inter-vehicle sharing while driving (Berger, 2016). By increasing the drivers' comfort freight companies can assure optimized driver rest periods, fuel efficiency gains from predictive driving, eliminate human error, and eventually, have a driverless vehicle. Furthermore, by reducing inter-vehicles spacing, trucks can have additional fuel efficiency gains by reducing air drag.
- **Profit formula:** The profit formula must be analysed from both the truck manufacturer's perspective and the road freight company operating with autonomous trucks. With respect to truck manufacturers, such as MAN, Volvo Trucks, and Continental, financial benefit is

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achieved by maintaining a high gross margin in the truck selling price, and by securing a high volume of sales. On the other hand, for companies in the road freight sector, financial benefits are achieved when they are able to have a higher distance transported per tonne and by reducing their variable costs per kilometre. It has been identified by (Berger, 2016) that fully autonomous trucks (level 5) can reduce up to 40% of the cost items for road freight operators, when compared to trucks with level 2 of autonomy.

- **Resources**: Autonomous trucks are enabled by an interaction of technology areas including hardware, software, and integrated controls. Key technology requirements in automated trucks are shown in Figure 1.

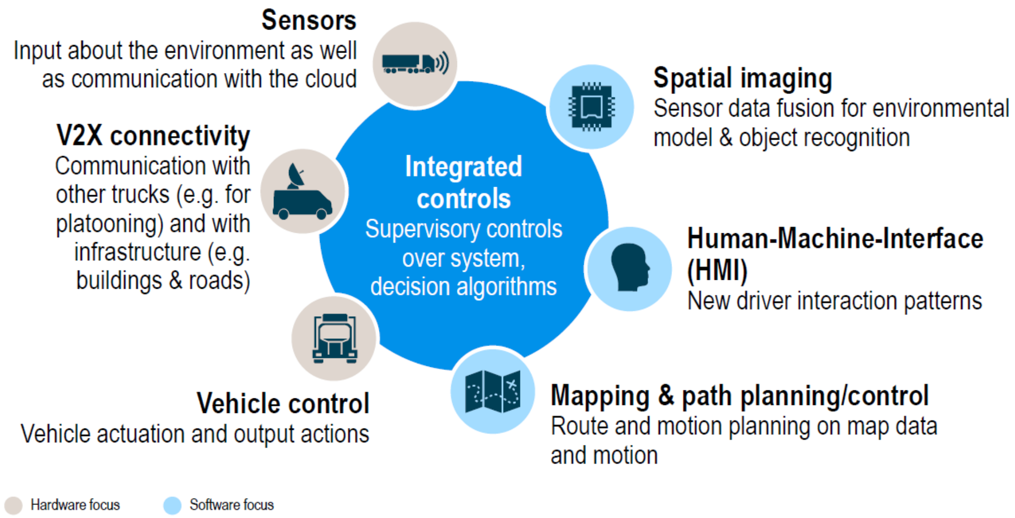

Figure 1. Key technology requirements in autonomous trucks. Extracted from (21)

- **Processes**: In order to guarantee safety to customers operating within a cloud base system, Volvo trucks offers high level of cybers security to ensure the identification and prevention of potential hacking attempts to the trucks in service (Volvo, 2022).

Description of the financial model

- Financing sources

Companies manufacturing autonomous trucks finance the R&D for increase their autonomous level primarily with their own budget. As an example, just in 2021, Daimler Trucks had a total of €1.57 billion in research and development expenditure (Statista, 2022). However, manufacturers are also members of consortiums and associations that channel public funding to invest in topics that are of collective interest, for example the ENSEMBLE H2020 project brings together 6 truck manufacturers to evaluate methods for platooning among trucks to increase aerodynamics while on the road (ENSEMBLE).

- Cost Structure
    - CAPEX

Capital expenditure would focus on the inclusion of hardware and software to increase the autonomous level of trucks. t’s estimated that this technology will cost somewhere between €30,000 and €100,000 per truck depending of the level of autonomy to be reached (United World Transportation, 2022).

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- OPEX

Operational expenditure is appointed to be between 10 and 20% of the total capital expenditure (Andersson & Ivehammar, 2019)

- Revenue streams: The revenue streams for autonomous trucks are summarised in Table 22.

Table 22. Revenue streams for both autonomous truck manufacturers and road freight operators with autonomous trucks

Truck manufacturers	Road Freight & Haulage Operators
Sales from trucks Leasing of trucks to transport & logistics operators Maintenance and repairs Selling of parts	Transport of cargo • Earnings depend on the type of container, distance, time, and volume of the cargo

Actors involved in the business model

The stakeholders involved for the successful implementation and operation of this CCAM solution are described in Table 23. The description includes the type of stakeholders, goals they are pursuing by taking part or interest in the solution, and the responsibilities they have regarding the operation.

Table 23 Stakeholder description for autonomous freight trucks

Type of actor	Goals	Responsibilities
Freight operators	Maximizing distance and cargo travelled Innovative image Minimizing vehicle stopping time Safe transportation	Guarantee delivery time and cargo safety
Truck manufacturers	High sales Brand value recognition Differentiate from competitors Customer satisfaction	Ensure road safety for passengers and other road users Provide best quality and price
Local and Regional transport authority	Ensure safety to all road users Develop and enhance sustainable networks, systems and solutions for roads, traffic, and transportation Enhance policies, processes, and transport governance	Establish standards and norms to regulate technology development Provide the necessary road infrastructure for the operation of autonomous trucks

Current status of the business model

Business models already applied:

- Name of project/product: Autonomous transport solution to Brønnøy Kalk AS by Volvo (Volvo Trucks, 2018)
- Use Case Variant: Dry Bulk Cargo Transport
- Location: Velfjord, Norway

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- Brief Description: The solution for Brønnøy Kalk AS consists of limestone being transported by six autonomous Volvo FH trucks on a five-kilometre route through tunnels along the mine. The pilot was launched in 2018 and became fully operational in 2019. One of the greatest impacts achieved was increasing efficiency and productivity, as the plant is operational day and night. Volvo has adopted a new business model with the mining company, as Volvo trucks sell the transport service taking full responsibility for the delivery of the limestone throughout the route.

2.4 Carsharing services with AVs

Carsharing provides an alternative solution to private car ownership by allowing temporarily car use in an on-demand basis. It is a business model of car rental where people rent cars for short periods, often by the hour. Carsharing enables an occasional use of a vehicle or access to different brands of vehicles. The cars on the carsharing fleet become available to the users through a variety of means, ranging from the simplicity of using an app to unlocking the car in real time (Wu T. a., 2022). The growth of vehicle-sharing systems is driven by urbanisation, increased smartphone usage, growth in the presence of IoT, climate change, regulations, and growing awareness about the environment and personal health. With the development of automated vehicles, it is anticipated that carsharing services will integrate AVs into their fleet.

Brief description of the business model

- **Value proposition**: Free-floating carsharing service with a large-scale fleet is considered an innovative and environmentally friendly transportation service as current AV vehicles use electric power (Nemoto, 2021). The service brings flexibility, convenience, usability, and accessibility to vehicles for the customer. A key element of the carsharing services is operating on a large scale in cities, covering the most important central areas with a high number of vehicles in their fleet. Its value proposition is based on delivering an innovative and environmentally friendly transportation service, offering flexible urban mobility.
- **Profit formula:** The usually fixed cost structure for such services is: vehicle fleet acquisition, maintenance, fuelling and cleaning vehicles, personnel costs and customer services, insurance contracts, and municipality taxes (Zafar, 2022). The revenues: all-inclusive rental fees (per minute, hour, or daily rate) and extra fees per kilometre (above the included mileage per trip). Advertisements can be placed in the stations and booking apps (Zafar, 2022).
- **Resources**: Vehicle fleet, service team, integrated system with a website and/or application.

Description of the financial model

- Financing sources

Subscription fees (charged upon the registration of new customers) and rental fees (including rental, fuel consumption, mileage, insurance, parking in authorized areas, and maintenance) are the two main revenue streams for the carsharing business model. As initial investment costs for developing a carsharing service are considerably high such models get finance in the form of loans (Stocker, 2017).

- Cost Structure explanation

The cost structure of car-sharing companies is characterized by a high portion of fixed costs, related to fleet acquisition and the development of complex information systems to operate the business. Station-based operators incur higher infrastructure costs for the installation of the stations, although free-floating operators also must install proprietary parking spots in locations with lower availability of public parking spots. Other common costs among the companies are

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related to maintenance, cleaning and refuelling/recharging the vehicles, fleet management (including vehicle repositioning), municipal taxes included in the agreements for the service authorization and use of public facilities, and personnel costs (Stocker, 2017).

- CAPEX
- Vehicle fleet (approximately 25k – 35k per car)
- Integrated system (website/app)
- Parking stations
-
- OPEX
- Maintenance, fuelling, and cleaning of vehicles
- Personnel costs and customer services
- Insurance contracts
- Municipality taxes
- Expenses related to improper use of the service

- Revenue streams

The revenue streams consist of subscription fees (charged upon the registration of new customers) and rental fees (including rental, fuel consumption, mileage, insurance, parking in authorized areas, and maintenance) are the two main revenue streams for the carsharing business model.

Actors involved in the business model

Table 24 shows a summary of the actors involved within the business model that is being described.

Table 24 Carsharing services with Avs - actors involved

Type of actor	Goals	Responsibilities
City/Regulator	Decrease Urban Traffic and pollution	Defines standards and regulations
Insurance companies	Insure customers with low probabilities of damages	Provide insurance packets for the vehicle fleet
Customer	Have a comfortable, fast, and readily available mode of transport	Data sharing Payment of service
Service provider	Supply transport, make revenue, promote sustainable mobility	Vehicle maintenance, fleet management, customer service, marketing

Current status of the business model

Name of product: Tesla Ride Sharing

- Use Case Variant: Autonomous carsharing
- Location: United States
- Brief Description: Tesla Model 3 and Y are the current models that have an autonomous level 3. According to Ridester, Tesla is planning to allow Tesla owners to share or rent out their vehicles through the Tesla Network app (Ridester, 2022). This would eventually turn the app as a carsharing service. Nevertheless, this functionality is not yet developed but has already been presented as a future project by Elon Musk.

2.5 Bus fleets replacement with AVs

Autonomous buses are being introduced as pilot projects that are usually part of larger smart mobility programmes in multiple cities across Europe and Asia. Autonomous bus fleets could be used to replace conventional public transport by adding to a more efficient bus system which could

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increase the modal share of public transport and reduce car travel. Autonomous buses may have demand-driven schedules and could potentially dynamically adjust their capacity, trajectory, and stopping according to passenger demand (Quarles N. a., 2018). Autonomous buses may have lower operational costs than regular buses and may offer potential environmental benefits.

Brief description of business model

- **Value proposition**: Integrating AVs in the bus fleet have the potential to provide many benefits such as: increases safety by reducing the collision rate, increase lane capacity due to the high level of communication between AVs, improve accessibility for people with limited transportation such as old people and disabled.
- **Profit formula:** Assets: Mobility Platform, Digital Ecosystem, AV Software, AV Hardware, AV Bus fleet. Revenue streams will be similar to the current public transportation stream (usage fares), but one of the most significant operating costs for public transport which are crew costs will be cut in fully automated models (Quarles N. a., 2018). The arrival of Autonomous Vehicles for Collective Transport (AVCT) can help balance this scale not only by reducing operating costs for PTOs but also by being able to offer flexible on-demand transport with significant potential for lower density, first- and last-mile trips, offering a more efficient service with better levels of user experience (Quarles N. a., 2018).
- **Resources**: Mobility Platform, Digital Ecosystem, Users, AV Software, AV Bus Fleet, AV Hardware, Infrastructure system.

Description of the financial model

- Financing sources
- Figure 2 shows a financing scheme for bus fleet procurement and operation. As seen, asset owners can access financing from trust funds that are funded by government subsidies and user fares. Furthermore, individual investors can finance asset owners in exchange for equity or debt of the bus fleet company. More detailed Cost Structure explanation
    - CAPEX
        - AV Bus Fleet
        - Digital Ecosystem
        - AV Software
        - AV Hardware
        - Charging infrastructure
    - OPEX
        - Bus Maintenance and cleaning
        - Personnel costs and customer service
        - Municipal taxes
    - Revenue streams
        - User fares

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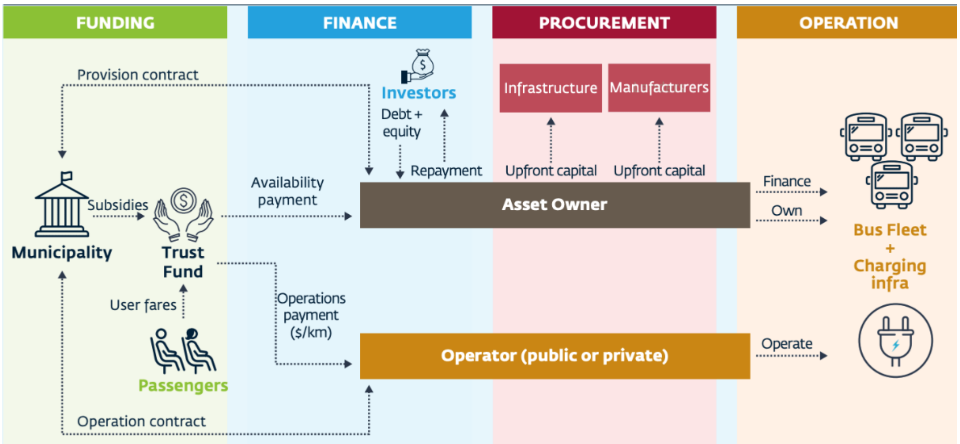

Figure 2 Bus fleets replacement with AVs - Financial model

Actors involved in the business model

Table 25 Bus fleets replacement with AVs - Actors involved

Type of actor	Goals	Responsibilities
City/Regulator	Improve accessibility, transport efficiency and safety	Define standards and regulations
Operator	Maximizing usage of buses, minimizing costs in the long run, remain able to operate in all areas	Supplies the mobility solution
Customer		Uses infrastructure
Infrastructure Provider	Provide infrastructure for traffic and AV bus fleets.	Supplies the infrastructure and data
Integrator	Integrate bus systems in their data; customer and data monetization	Supplies data.

Current status of the business model

Business model already applied: Such concepts are still in the very early stages of trialling around the world.

- Name of project/product: Mcity Driverless Shuttle (Norton, 2020)
- Use Case Variant: Automated Shuttle
- Location: Michigan, US
- Brief Description: In June 2018, Mcity, a public-private partnership at the University of Michigan (U-M), launched the first driverless shuttle project in the United States to focus on user behaviour research and extensive data collection. With two shuttles transporting students, faculty, and staff on the U-M campus, the project is designed to support data collection to understand vehicle performance, roadway interactions, and passenger attitudes. The ultimate goal is long-term deployment of driverless shuttles in the real world.

2.6 MaaS Integrated Multimodal/Intermodal services

Mobility as a Service (MaaS) offers a potential integrated solution to these complex user needs. MaaS applications offer users access to various travel options via a single platform, such as trams, bikes, trains, buses, shared cars, and scooters. It also combines these to present users with a single, seamless journey that incorporates real-time information, reliable planning and considers different payment possibilities (Eckhardt, Aapaoja, Nykänen, & Sochor, 2017).

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Brief description of business model

- **Value proposition**: The aim of MaaS is to be the best value proposition for its users, providing an alternative to the private use of the car that may be as convenient, more sustainable, and even cheaper (Eckhardt, Aapaoja, Nykänen, & Sochor, 2017). MaaS aims to become the best value proposition for both private and business users, by helping them meet their mobility needs and solve the inconvenient parts of individual journeys, as well as to improve the efficiency of the entire transport system (Eckhardt, Aapaoja, Nykänen, & Sochor, 2017). The aim of MaaS is to offer more choices, more freedom and more certainty to the end users. The MaaS concept serves as an integrated planning and payment platform which integrates end-users with and mobility service providers.
- **Profit formula:** Cost structure: Platform management and development including customer support, brand creation and marketing, platform design and development, ICT operations and application, contract negotiations, customer liability and personnel (Kamargianni & Matyas, 2017).The Revenue streams consist of sell on commission, service advertisement, fixed contracts with service providers, fixed contracts with end-users.
- **Resources**: Brand, Service design: Technology, Quality Assurance, user – orientation, coverage and ITS competence

Description of the financial model

Financing sources

Private:

1. Technology providers (investors): companies offering digital mobility platforms
2. Financial – services firms (loans): banks, investment funds, private equity

Public:

1. Government programmes: grants, matching funds and seed programmes
2. Academic institutions: Universities partnering together to fund pilot MaaS pilot programmes.

    - CAPEX

- Platform design and development
- Brand creation
- Contract negotiations with transport operators
- Maas Software and Hardware

    - OPEX

- Platform maintenance
- Personnel costs and customer service
- Municipal taxes

Revenue streams: The revenue stream is generated by a combination of factors that consist of: sell on commission, service advertisement, fixed contracts with service providers, fixed contracts with end-users and transportation service outsourcing (Kamargianni & Matyas, 2017).

Actors involved in the business model

Table below contains the list of actors involved within MaaS integrated multimodal/intermodal services.

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Table 26 MaaS Integrated Multimodal/Intermodal services - Actors involved

Type of actor	Goals	Responsibilities
MaaS Provider	Offer MaaS Services	Coordinate and manage stakeholders
Transport operators	Opportunity to access a wider market and increase their market share. Grow their revenue from previously ‘unreachable’ customer markets and increase the level of satisfaction of their customer.	Transport operators sell their capacity to MaaS operators and provide access to their data via secure APIs
Regulatory organisations	Avoid different open standards across different regions that will hinder interoperability. Scaling up.	Provide and regulate for open standards and interoperable data formats. Provide policy frameworks and recommendations for the sustainable development of the market, fair competition, financing, passenger rights, privacy and security, service quality standards, social inclusion, and safety.
Technology and platform providers	Provide technological solutions and support to the MaaS provider in order to develop its own intelligence and platform	Provide a reliable and user-friendly platform

Current status of the business model

Business model already applied:

- Name of project/product: Whim app operated by Maas Global
- Location: Helsinki
- Brief Description: Through its subscription-based integrated mobility app, Whim, MaaS Global offers users access to a variety of transportation options, from taxis to rental cars, public transport, and bikeshare. The app learns users’ preferences and syncs with their calendars to intelligently suggest ways to get to an event.

2.7 Delivery Robots

It is no surprise to know that e-commerce and package deliveries are growing now at a fast pace, even after the pandemic. In 2020, Amazon alone increased their deliveries by approximate of 2.3 billion packages from 2019 (CNN, 2021). This sudden increase in delivery capacity has presented the opportunity for several start-ups to launch new solutions in last-mile delivery utilizing Autonomous Delivery Robots (ADRs) (Figgliozzi & Jennings, 2020). ADRs are electric powered motorized vehicles that deliver packages without the intervention of a delivery person. Figliozzi et al. (Figgliozzi & Jennings, 2020) categorizes ADRs into two types; Sidewalk autonomous delivery robots (SADRs) and On-road autonomous delivery robots (RADRs). The difference falls in the fact that ADRs move in sidewalks or pathways and RADRs travel on roadways shared with conventional motorized vehicles.

Brief description of business mode

- **Value proposition**: ADRs added value include lower costs of delivery for businesses (ADRs can optimize and do joint delivery scheduling with delivery trucks (Heimfarth, Ostermeier, & Hübner, 2022)), faster service to customers by optimizing routes, energy saving and sustainability, avoiding the use of delivery personnel, and higher accuracy when delivering the package.

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- **Profit formula:** Companies developing ADRs operate through two business models; the first, providing the delivery service themselves. This entails setting up a marketplace web platform or mobile application in which users can buy and order a product. These products are then delivered by an ADR. Financial benefit is achieved through a commission fee charged to the seller of the product and by charging a delivery fee to the end-customer. The second business model centralises only in selling the ADRs to delivery companies, including the white label marketplace for managing the orders.
- **Resources**: For hardware and software; the ADR and marketplace web platform or mobile application. Other resources include delivery trucks (if joint delivery is used), storage warehouse to receive the packages from stores, and staff supporting any delivery issue and online troubleshooting.
- **Processes**: Partnerships with companies that have a high demand of deliveries. Also, ADRs must be equipped with anti-theft functionalities to guarantee the safety of the packages they are transporting.

Description of the financial model

- Financing sources

Financing is most likely to be secured through equity investment. As an example, company Starship Technologies raised a total of $17 million in their first round of investment. In 2022, though, the company also receive an investment of the European Investment Bank of €50 million. Meaning financing can also be achieved through a multilateral financial institution (Crunchbase, 2022).

More detailed cost structure:

Table 27 summarizes the cost structure of an ADR service considering a joint delivery method, meaning, the ADRs are transported by a truck together with the packages to a part of the city, then the ADRs are unloaded and set to transport all packages inside.

Table 27. Costs of a joint delivery method (truck with ADRs)

Type of Cost	Description
Truck-related	Purchase of truck Salary for truck driver (which is incurred at an hourly rate) Fuel consumption Tolls (if any) during the route Truck amortization
Robot-related	Hourly cost of the ADR service, covering amortization, maintenance, electrical energy, rent for the depot space in warehouse and charging stations. - The hourly cost of the ADR service is 2 EUR/hour (Heimfarth, Ostermeier, & Hübner, 2022)
Service related	Service-related costs account for any delayed deliveries. This means that a late delivery will incur hourly penalty costs if a consumer does not receive the parcel within the agreed time window.

Revenue stream

Revenue is generated by the provision of the delivery service of packages. ADR companies charge the full delivery cost to the logistics company (if the package was not bought in their marketplace) or a commission fee to the company manufacturing the product (if the product was sold in their ecommerce marketplace). If the latter occurs, the ADR company will also charge a delivery fee to the end-consumer.

Actors involved in the business model

Table 28 contains the list of actors involved within the business model devoted to delivery robots.

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Table 28 Delivery robots - actors involved

Type of actor	Goals	Responsibilities
ADR provider	Hours of ADR sold Create awareness of autonomous last-mile delivery High satisfaction along the delivery value chain	Ensure safe delivery conditions to all road and sidewalk users Successfully deliver the package (time and integrity)
End-consumer	Certainty of delivery (time, date, and correct package) Fast, affordable, and safe (integrity of the package) delivery Great customer service	Pay delivery fee Provide correct delivery data
Logistics company	Reduce delivery fixed and variable costs High brand awareness and reputation Maximise packages delivery rate	Successfully deliver the package (time and integrity) Pay ADR service costs
e-commerce platform provider	High end-customer (buyer) satisfaction Reduce delivery time (item sold to handed to customer) Increase delivery fee margin	Pay delivery fee Provide correct delivery data Provide package to logistics company
City council/transport authority	Maintain safe conditions to road and sidewalk users Reduce environmental impact in the transport sector	Enforce transport rules and norms

Current status of the business model

Business model already applied:

- Name of product: Starship Self-Driving Delivery Robot (Starship Technologies, 2022)
- Use Case Variant: Autonomous Delivery Robot – Sidewalk ADR
- Location: In 15 countries around the world
- Brief Description: US based Estonian company Starship Technologies has developed an ADR and online marketplace app in which users can buy and order food and groceries. Starship has also partner up with food e-commerce companies DoorDash and JustEat in order to deliver their orders. The ADRs of Starship include anti-theft and vandalism functionalities that help to navigate securely through the city.

2.8 Automatic Train Operation

Automatic Train Operation (ATO) systems have gained high popularity in the latest decade due to the rapid development of rail transportation systems, as they ensure safe, punctual, energy-saving and comfortable train operation (Wu, Wang, & Feng, 2015). There is a grade of automation (GoA) that ATO systems provide, which consists of 4 grades (Fortune Business Insights, 2021). According to the GoA level, the train is automatically controlled without supervision. A GoA level 4 has been already commercially achieved, examples are the Paris Metro Line 4, Barcelona Metro Line 9, and Sydney Metro (Wikipedia, 2022).

Brief description of business model

- **Value proposition**: Installing ATO systems guarantee greater safety in trains as speed and braking is controlled and limited, and they also increase the capacity of transportation as there is a reduction of the minimum distance or time between trains, among others.
- **Profit formula:** ATO systems allow the increase of transportation capacity, this results in a higher number of passengers transported, thus increasing the comfort and availability of trains. This increase of capacity encourages citizens to prefer train transportation over other methods, reflecting in a higher ticketing.

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- **Resources**: ATO systems are partitioned into two interrelate systems: one collects necessary data and distributes them to the trains (called trackside), and another one that drives and controls the trains using the received data (called onboard) (Lieskovsky, Myslivec, & Zemlicka, 2020). Trackside systems depend on the available infrastructure along the tracks, all these are called Traffic Management Systems. On the other hand, onboard systems are both hardware and software allowing to control the positioning, computing the dynamic speed, and activating the braking control of the train.
- **Processes**: Ways of working together to address recurrent tasks in a consistent way: training, development, manufacturing, budgeting, planning, etc.

Description of the financial model

- Financing sources

Advances in ATO systems have been primarily fostered by the standardization efforts of the regional railway authorities. In Europe, the European Union Agency for Railways (ERA) sets the requirements for the interoperability, safety targets, common safety methods and common safety indicators of trains. These usually are established after high R&D efforts to make operating systems available that can make the amendments feasible. Therefore, ATO systems are most commonly funded through public funding programmes such as Shift2Rail (Shift2Rail, 2021).

- Cost Structure

The following analysis of the cost structure focuses on the onboard systems. Capital expenditure is done for the ATO Unit which controls

ATO onboard systems

- Revenue streams

The installation of ATO units, both onboard and trackside, and paired up with complementary train control systems have been found to increase up to 30% more throughput on shared tracks, save up to 37% of energy, and lowering operating costs. Therefore, revenue is generated indirectly.

Actors involved in the business model

Table 29 contains a list of the main actors involved within the business model devoted to automatic train operation.

Table 29 Automatic Train Operation - Actors involved

Type of actor	Goals	Responsibilities
Train manufacturers	High sales Brand value recognition Differentiate from competitors Customer satisfaction	Ensure road safety for passengers and other road users Provide best quality and price Comply with current standards and norms
Transport Authorities	Ensure safe, fast, and reliable transportation to citizens	Provide the necessary infrastructure for the correct integration of ATO systems
Academia; Research Institutes and Universities	Support the efforts of the private sector in R&D and innovation	Train students and professionals to meet the knowledge requirements of the sector
Technology providers	Establish partnerships with train manufacturers Create loyalty of their products (have manufacturers use only their products)	Meet the demand of hardware and software of train manufacturers

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Citizens	Arrive to destination in the shortest time possible Select the most cost-beneficial mode of transport	Share their data to enhance the service

Current status of the business model

Business model already applied:

- Name of project: Paris Metro Line 4
- Use Case Variant: ATO with GoA level 4 in urban trains
- Location: Paris
- Brief Description: Line 4 of the Paris metro is the third fully automated line of the Paris region metro network. The metro line is operated by the Parisian transport administration RATP and is currently the second busiest metro line of the Paris region (Rail Tech, 2022).
- The GoA level 4 makes it possible that the intervals between the metro trains are reduced from 105 to 85 seconds. With this, the transport capacity has been increased significantly. Other advantages include real-time adaptation of the service, increased safety and regularity, and more staff on the ground at the service of passengers.
- The automation was requested by transport authority Île-de-France Mobilités, with the goal of complete automation of line 4 by the end of 2023. The cost of its automation represents an investment of around 470 million euros, financed fully by the transport authority (International Railway Journal, 2020).

2.9 Privately Owned AV

Autonomous vehicles (AV) replace some or all of the human labour of driving with electronic or mechanical devices (Shladover). These functions that AVs aim to replace include information acquisition, localization, perception, planning, control, and management (Asif Faisal, 2019). Autonomous vehicles will likely be deployed for both private and commercial use, but the focus here is private use, which contains many perceived benefits. There is potential for autonomous private cars to be available for use for anyone in the family, regardless of age or ability. The quality and productivity of the time spent in cars should be also be improved by AVs. In addition, the safety and efficiency of roads and traffic should be increased (Wilko Schwarting, 2018). There are multiple potential business models for autonomous cars. This section will focus on the traditional model, in which the business model is built on the production and sale of the product which then belongs to the private buyer.

Brief description of business model

Privately-owned autonomous vehicles offer increased flexibility in who can use the utility of the vehicle, providing increased mobility to the elderly and disabled. There is also great potential for improved traffic safety and efficiency through the removal of human error. Third, the comfort and productivity of driving should be improved (Asif Faisal, 2019).

The most important assets to provide privately owned AVs would be the means to develop and produce AVs and, of course, the vehicles themselves. The industry leaders are still expected to spend additional billions before the technology becomes commonplace (Metz, 2021). The Google Car, in 2012, was confirmed to have $150,000 in technology attached to a modified Toyota Prius, including a sophisticated LIDAR system (Poczter, 2013).

The resources required to deliver this value proposition are extremely significant. The market currently consists mainly of Google's parent company, Alphabet and auto giants, along with a few start-ups. Lyft and Uber both sold their autonomous vehicle units in the past years (Metz, 2021).

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Only those with the deepest pockets are able to stay in the race towards developing this technology.

As the technology has yet to be made commercially viable, it will be essential that any company offering the product guarantees safety to its passengers. This will require some element of 'proving it,' but can also be given in processes such as warranties and safety guarantees. Maintenance and upgrades to software can also be included in warranties, as there will inevitably be improvements with time, and first buyers can't be made to feel left out.

Description of the financial model

- Financing sources

Financing sources include venture capital and some government grants (Funding guidelines for autonomous and connected driving in public traffic: first call for applications published, 2022).

- More detailed Cost Structure explanation
  - CAPEX
  - Very significant and include the car itself, LIDAR sensors, cameras and artificial intelligence software.
  - OPEX
  - In this model, the customer operates the service.
- Revenue streams
- Profits from sales

Actors involved in the business model

Table 30 Privately Owned AV - Actors involved

Type of actor	Goals	Responsibilities
Product provider	Sell as many units as possible, have a superior product than competitors	Thoroughly test their products
Customer	Improved mobility experience	Assumes all expenses related to the product once purchased
Regulators	Improved traffic efficiency, no injuries caused by faulty technology	Protect citizens, while also enabling better mobility

Current status of the business model

Business model already applied:

- Name of project/product: Tesla's Full Self-Driving Capability Subscriptions
- Use Case Variant: Subscription Add-on
- Location: USA
- Brief Description: Tesla owners can purchase an upgraded computer system that allows access to a suite of more advanced driver assistance features. It still requires active supervision, but assists with steering, accelerating and braking. The subscription is an enhancement of "Basic Autopilot" and costs $199 each month. Tesla promises to make the features more capable over time but they do not make the vehicle autonomous. There are also hardware upgrades required in order to access the service (Full Self-Driving Capability Subscriptions, n.d.).

2.10 Integrated multi-modal services

This solution refers to offering a combination of autonomous vehicle services via a single app where riders can access all services seamlessly. Owning a car is no longer the status symbol it

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once was and new mobility services offer exciting alternative possibilities. These are enabled by mobility technologies such as autonomous vehicles, smartphones and the internet of things. Autonomous vehicles can be accessed on demand through a service platform, instead of mobility depending on private vehicle ownership. According to Wong et al. mobility as a service (MaaS) is a one-stop travel management platform and, under appropriate regulatory mechanisms, can enable network efficiency (Wong, David, & Mulley).

Brief description of business model

- **Value proposition**: A product that helps customers to do a job more effectively, conveniently, and affordably they have been trying to do.

  The value proposition of a MaaS app that connects passengers with a variety of autonomous modes of transportation is enabling more effective mobility. By having many choices and types of transport presented in one place with information given such as travel time and price, it gives customers a new level of mobility options and convenience.

- **Profit formula:** Most important assets and fixed cost structure, and the margin and velocity required to cover them.

  Who acts as the broker will determine how the profit formula is shaped in the case of multi-modal services, which by definition includes such a large number of players. Figure 3 (Wong, David, & Mulley) illustrates the three service delivery models. Both of the scenarios where a company acts as a broker would have a profit formula based on subscription fees. There is also potential for a fee-based profit model where the MaaS app provider receives a percentage of the fees from the suppliers of the mobility service.

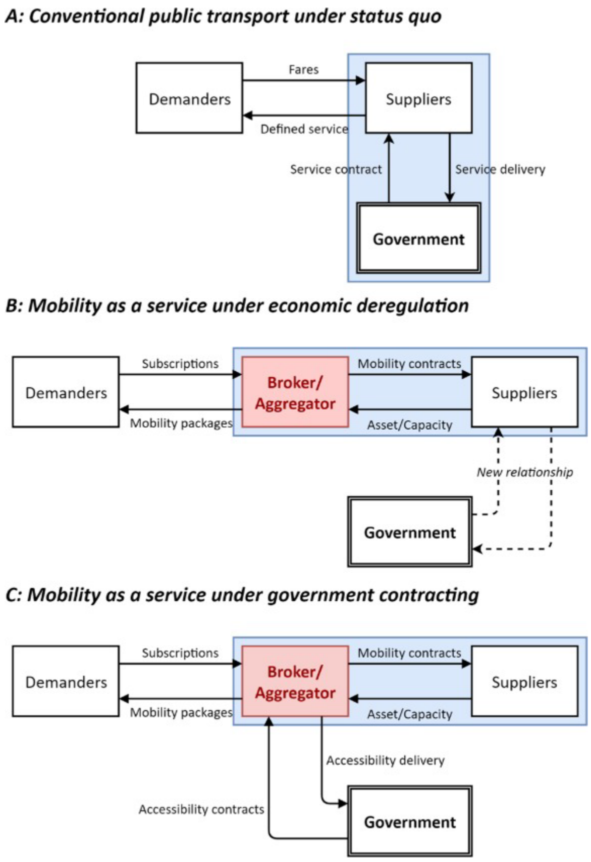

Figure 3 Integrated muti-modal services – Service delivery models

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- **Resources**: People, technology, products, facilities, equipment, brands and the cash that are required to deliver this value proposition to the targeted customer.

  Integrated multi-modal services will require bringing together an number of specialised businesses. These include incumbent providers of passenger transport services (e.g public transport operators, taxi operators carshare operators, bikeshare operators), vehicle manufacturers, technology providers, insurance companies and financial enterprises (Wong, David, & Mulley).

- **Processes**: Ways of working together to address recurrent tasks in a consistent way: training, development, manufacturing, budgeting, planning, etc.

Combining such a large number of specialised businesses together will require putting large amounts of resources into coordination and legal agreements with all the suppliers.

Description of the financial model

- Financing sources
- Major investments will be required from both private equity and government sources, depending on the model.
- More detailed Cost Structure explanation
  - CAPEX
  - From the perspective of the app provider, the capital costs are primarily app maintenance. However, there is enormous CAPEX from the perspective of the transport modal operators and infrastructure operators that that are being integrated into a MaaS application.
  - OPEX
  - Operating expenses include app development, insurance, legal costs, etc.
- Revenue streams

There are different models (see table above) but the app provider would likely receive revenues through subscriptions from the users of the mobility services.

Actors involved in the business model

Table 31 contains a list of the main actors involved within the use case devoted to integrated multi-modal services.

Table 31 Integrated muti-modal services – Actors involved

Type of actor	Goals	Responsibilities
Mobility providers	Provide a mode of mobility to as many people as possible	Provide good services
Vehicle manufacturers	Sell vehicles	Enable the vehicle software to be integrated into the third party app
Technology providers	Integrate multiple modes of mobility	Make the app as comprehensive and convenient as possible
Governmental organisations	Enable efficient transportation	Allow public transport to be included in the app services
Regulators	Protect citizens	Prevent monopolies, prevent increased congestion in cities
Passengers	Have more and better mobility choices	N/A

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Current status of the business model

Business model already applied:

- Name of project/product: MVGO
- Use Case Variant: Public transport authority as the broker
- Location: Munich, Germany
- Brief Description: The MVGO app was launched by Munich's public transport authority MVG, using the white label application from Trafi. It enables access to all of Munich's mobility services in one app for users to plan, fins and book their trips. Payments can be made on the app and the vehicles can be observed in real time on the app (Trafi, 2021). The app does not include autonomous modes of transportation but they could be added to such a platform.

2.11 Scheduled airport shuttles

Scheduled airport shuttles refer to using air mobility to move passengers to, from, or between airports along fixed routes (Rohit Goyal, 2021). The service offers an additional option for mobility to users. There is potential to save passengers time, depending on the route, by flying with electric vertical takeoff and landing aircraft (EVTOL). By having these routes scheduled connecting people in cities to airports, the congestion and traffic on the way to the airport can be avoided. Factors including weather, infrastructure, safety, noise and acceptance still need to be considered when planning for this solution (Rohit Goyal, 2021).

Brief description of business model

- **Value proposition**: A product that helps customers to do a job more effectively, conveniently, and affordably they have been trying to do.

  The value proposition is safe, cheap, clean mobility that is significantly faster than a car and doesn't require a runway (Nagesh, 2021). For example, a ride that may take hours by taxi could be made in mere minutes and potentially for the same cost as a high-end rideshare service. Airports are often built outside of urban centres and are locations with high traffic congestion, where people frequently need to go. Thus, using EVTOL technology for a scheduled shuttle route to the airport can maximize the use and effectiveness of such technologies.

- **Profit formula:** Most important assets and fixed cost structure, and the margin and velocity required to cover them.
- The costs are outlined in detail below but a study from Goyal et al. estimates costs of $4-20 per passenger mile. The passenger fees would then clearly need to be higher than this to cover costs and make profit. The study estimates that air taxi and airport shuttles markets could reach a 0.5% mode share, representing an annual market valuation of 2.5 billion USD (Rohit Goyal, 2021).
- **Resources**: People, technology, products, facilities, equipment, brands and the cash that are required to deliver this value proposition to the targeted customer.
- This business model would require a fleet of EVTOL vehicles with set routes. Each pickup and drop-off station would require a vertical aerospace port. At a minimum, there would need to be one at the airport and one at a strategically located space in the city. The number and type of EVTOL helicopters is flexible. There will have to be enough cash on hand to build a customer base as public acceptance may be low at first.
- **Processes**: Ways of working together to address recurrent tasks in a consistent way: training, development, manufacturing, budgeting, planning, etc.
- It will be essential that these routes are punctual, comfortable and reliable. Due to their purpose of bringing people to the airport for long-distance flights, this has increased

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importance than a normal taxi service. Customers should be able to book tickets well in advance and backup vehicles should be available in case of technical malfunctions.

Description of the financial model

- Financing sources
    - Financing can come from investors or from government grant programmes. There is potential for policy alignment alongside other electric mobility programmes and funding from a government's perspective.
- More detailed Cost Structure explanation
    - Figure 4 and Figure 5 (Goyal et al.) illustrate in detail the associated costs involved in a business model of this nature. Costs per passenger mile vary based on what kind of vehicle is being used and how many seats are available and range from about $4-20 per passenger mile. The costs considered are associated with capital and insurance, energy and battery, crew, other infrastructure, and maintenance.

Cost Component	Key Steps	Key Assumptions		
		Parameter	Min	Max
Capital and insurance cost	• Capital cost is the sum of the depreciation cost and the finance cost. Certification costs were included in the aircraft price. • Residual value of the aircraft was assumed to be negligible. • Aircraft insurance is the sum of liability and hull insurance, calculated as a % of aircraft price.	Vehicle life (flight hours) Depreciation rate (%) Finance rate (%)	12 k 5% 5%	15 k 10% 10%
Energy and battery cost	• Energy required was calculated as the sum of energy required in each phase of the flight. • Battery pack sizing was done based on the longest mission and battery recycling was assumed to be negligible.	Battery specific energy in Wh/kg Battery capacity specific cost (USD/kWh) Energy conversion efficiency (%)	300 200 90%	400 250 98%
Crew cost	• Assumed one full time equivalent pilot per aircraft and one full time equivalent ground crew member in the initial years of service. • Each crew member undergoes annual training.	Pilot salary per year (USD) Ground crew salary per year (USD)	50 k 20 k	90 k 30 k
Infrastructure cost	• Calculated infrastructure cost by extrapolating car parking garage style architecture and construction to fit an aircraft. • Same infrastructure was also used to park the aircraft overnight. A nightly parking fee was added.	Cost of one supercharger (USD) Cost of one regular charger (USD)	200 k 10 k	300 k 20 k
Maintenance cost	• Calculated based on per-mission basis by multiplying the ratio of maintenance man hours to flight hours and the mechanic wrap rate.	Mechanic wrap rate (USD per hour) Maintenance manhours per flight hour	60 0.25	100 1

Figure 4 Scheduled airport shuttles - Cost-component assumptions

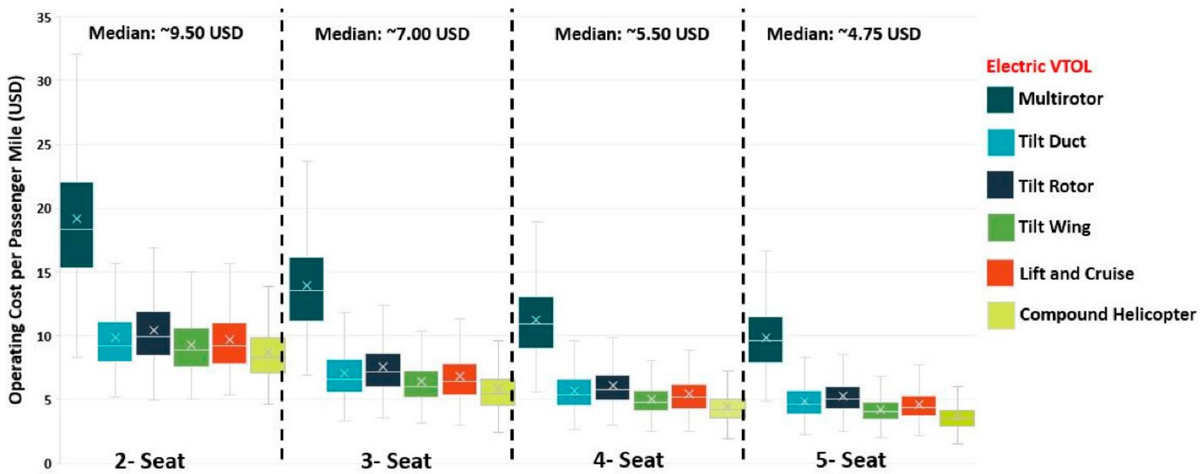

Figure 5 Scheduled airport shuttles - Study of the costs involved in the business model

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- Revenue streams
  - Revenue streams would come from sale of tickets to passengers, with flexibility for other pricing models for frequent flyers, for example.

Actors involved in the business model

The main actors involved in the business case related to scheduled airport shuttles are listed in Table 32.

Table 32 Scheduled airport shuttles - Actors involved

Type of actor	Goals	Responsibilities
Service provider	Provide high quality rides	Having a reliable service
City	Enable clean mobility	Provide space/permits for the port
Airport	Increase accessibility for its users	Provide space/ permits for the port
Regulator	Passenger safety	Create and enforce regulations for the technology
Passengers	Reach airport	Shape public acceptance levels

Current status of the business model

Business model already applied:

- Name of project/product: Voloport
- Use Case Variant: Air taxi takeoff and landing infrastructure
- Location: Prototype in Singapore
- Brief Description: In 2019, the German air taxi company Volocopter unveiled a full-scale 'vertiport' at the Intelligent Transport Systems World Congress in Singapore. The design of the vertiport is modular, with the intention of adaptability to rooftops, railway stations, parking lots and other metropolitan locations. The goal is to have them at key traffic junctions within a city such as airports (Volocopter, n.d.).

2.12 Drone Delivery

Drones, today, deliver goods ranging from food to medical supplies to electronics. A drone is an unmanned aerial vehicle. There are over 100 companies competing in the industry currently, as drones are much less capital intensive than commercial aviation (Carter, 2022). The advantage of drone delivery is that the technology enables covering large distances in short time frames at a cheaper cost than driving vehicles do. There is also potential for large scale delivery of items that would not be possible with on-the-ground delivery.

Brief description of business model

The value proposition of drone delivery for customers is the potential for increased same-day delivery and time-window delivery. This is especially true for customers in rural areas, where people live long distances from fulfilment centres (Joerss, 2016). Customers increasingly value quicker delivery times for online purchases and the quality of delivery is a major decision-making criterion for online customers (Joerss, 2016).

About a quarter of consumers would pay a premium for same-day delivery. Drones may be the only solution to offering same-day delivery in rural areas (Joerss, 2016). In addition, quick and high-quality delivery directly affects e-commerce players' success in the marketplace.

As mentioned above, drones the capital intensity of drones is much less than that of commercial aviation, allowing for a competitive landscape in the industry. The cost of drones will continue to decrease, but so will other innovative delivery options. The amount of regulation will also play a large role in the resources required. For example, how many drones operators will be allowed to control simultaneously will play a big role in the number of employees required (Carter, 2022).

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- **Processes**: Ways of working together to address recurrent tasks in a consistent way: training, development, manufacturing, budgeting, planning, etc.

Description of the financial model

- Financing sources

Drone-delivery companies have received more than $1 billion in disclosed funding in the last decade (Carter, 2022).

- More detailed Cost Structure explanation

The main capital expenses are building the drones, and then operating the drones will depend on regulation and technology specifics.

- Revenue streams

The revenue streams will come from shipping fees or from being hired by an e-commerce company. From the e-commerce perspective, the revenue streams come with achieving a greater market share.

Actors involved in the business model

Information about the actors involved within the business model linked with drone delivery are shown in Table 33.

Table 33 Drone Delivery - Actors involved

Type of actor	Goals	Responsibilities
Regulators	Ensure public safety	Dictate the type of drone operations allowed and safety requirements
The public	Receive deliveries in an acceptable way	Public acceptance will be needed for this business model to be a success
Drone companies	Earn revenue through drone deliveries	Provide and operate drones in compliance with regulations
Online retail	Deliver goods as quickly and cheaply as possible	Comply with regulations

Current status of the business model

Business model already applied:

- Name of project/product: Amazon Prime Air
- Use Case Variant: Drones without visual observers
- Location: Lockeford, California, USA
- Brief Description: Amazon is testing its drone delivery programme in a California town. The goal is for them to get items to their customers at scale in a time-efficient, cost-effective way. The city of Lockeford will receive free drone delivery in exchange for feedback about their pilot project, Prime Air (Amazon Staff, 2022).

2.13 Smart Parking

Smart Parking Systems (SPS) have great potential to become essential elements of the transportation system in cities, it is estimated that in the EU alone, there are approximately 300 million public parking spaces. Current SPS systems deal with digital data related to the parking domain, such as parking infrastructure, parking demand and offer, and transactions data (Lubrich, 2021). In highly compact and densely populated urban areas, lack of parking space is a major challenge. It is estimated that around 30% of the vehicles on the roads of major cities are manually

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searching for vacant parking lots and it takes around 7.8 min to find a suitable parking space (Geng & Cassandras, 2012). It is, therefore, getting harder for vehicle users to find an available parking lot.

Brief description of business model

- **Value proposition:** SPS presents a solution to save driving time and fuel energy and reduce traffic when looking for a parking space. It facilitates the driver to do this task more effectively, conveniently as the vehicle can locate a desired parking space in a certain area of the city via real time data coming from sensors (Lin, 2017).

  In parallel to assisting drivers while parking, Smart Parking Solutions generates high amounts of data, which combined with other databases (city instruments, delivery companies etc.), processes, and systems, can aid city planners understand driver patterns and behaviour leading to measures optimizing the flow of traffic and reducing congestion (Kher, 2020).

- **Profit formula:** The cost structure consists of the hardware, software, marketing, and wages costs. Only the hardware costs are included in the capital expenses because it consists of the sensors that are purchased at the initial phase. The assumption is that the physical infrastructure (the parking lots) is already in place. The other three costs are operating costs (Mangiaracina, 2017). Depending on the revenue model the margin and velocity may vary between different SPS implementation. However, due to the SPS numerous benefits and revenue streams (mobile payment, municipal fines, data analytics, advertisement) the margin and velocity required to cover the costs is relatively small.
- **Resources**
  - People: Private and/or Public Stakeholders, Contractors, Marketing Team, Software Developers, Landowners, Parking Operators, Mobile Operator (relevant for Cities), Head of Parking Services, Executives at service provider
  - Technology: Ground Sensor Technology, Counter Technology, Overhead Sensor, Cameras, Software Clouds, Smart Phone App, Internet of Things, Interactive Maps, Smart Signage, GPS, User Location, Processing Unity, Data Analytics, Data Analysation
  - Products: Smart Parking Sensor, Hardware Infrastructure, Smart Phone App, Software Infrastructure, Database, Sensor Networks, and modems

Description of the financial model

The financing sources of the SPS depend on the site and purpose of implementation. In the case of public SPS implementation the funding may commence from a combination of city funding, regional/national tenders, and grants. In the case, of private SPS implementation the funding may commence from private investments and/or bank loans.

Table below provides a more detailed Cost Structure explanation consisting of the CAPEX and OPEX.

Table 34 Cost structure of Smart Parking Business models

General description of the cost item	Capex	Opex
Sensors	Cost of sensor	Regularly testing Replacement
Network communications	Purchase of network hubs (e.g. Wi-Fi)	Fees to network providers, mobile or fixed operators
Database(s)	Purchase and installation of database equipment	Service charge of network cloud – database as a service
Data processing		Data analysis as a service

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Application	Cost of developing app	
Data access	Data services	Connectivity costs – network service changes
Managing data	Security software	Policy data access

The most common smart parking revenue streams are presented below:

- Parking Apps

With the help of seamless parking apps, drivers can directly receive the parking information on their phone. Since they will be paying a certain amount to access the information, this will generate a revenue stream for parking lot operators. The smart parking technology also combines various data sources into a single set of data for accurate parking guidance. Data providers can charge for this information, hence smoothening the parking process and generating more revenue. Apps may include advertisement and/or offer additional promotional packages combining services (Mangiaracina, 2017).

- Data Analytics

There are various smart parking softwares that offer data analytics to help operators with policy and pricing. With the help of such IoT-informed technologies, operators will have to face fewer revenue leakages and accurate accounting for usage. Such tools can be put to use by city administrations and operators for efficient and hassle-free parking across the city (Mangiaracina, 2017).

- Payment through Mobile

This aspect is beneficial for parking operators who can generate revenue by charging users a small commission on mobile payments. In addition to that, operators can also adjust the reservation fee according to the demand for the parking lot at the moment.

- IoT and Mobility Players

smart parking heavily relies on sensors, cameras, RFID technology, license plate readers, and mobile payment options to make parking a smooth experience for users. Parking operators nowadays use Mobile IoT to cover a wide area and transmit information from sensors to a centralized database. This provides an opportunity for IoT and mobility players to up their game and generate a lot of revenue.

- Parking Operators

Not losing money is also an aspect of generating revenue. For operators, implementing smart parking strategies in their parking means improved operational and management efficiency. Since the traditional method of manual operation often results in leakages and inefficiencies, smart parking reduces the inadequacies (Mangiaracina, 2017). Operators can also leverage customer data to employ dynamic pricing, and henceforth, generate more revenue.

- Municipal corporations

Smart parking systems help governments enforce and identify violators easily. This automatically increases the collection of fines, which is another way of generating revenue. Not only that but the dynamic pricing and accurate billing done through IoT sensors is also beneficial for cities, especially those who have on-street parking where parking time is hard to measure. Through IoT technology, authorities can get real-time information on the parked vehicles and send the bill directly to charge the drivers. Fluctuating prices (as opposed to fixed) can also be implemented to support policy goals.

Actors involved in the business model

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Table 35shows the stakeholders involved in a smart parking system project.

Table 35. Stakeholder description table in a Smart Parking System

Type of actor	Goals	Responsibilities
City/Regulator	Preservation of orderly public space; prevention of accidents; decrease urban traffic; Increase liveability of their community	Defines standards and regulations
Operator	Maximise profitability from value creation	Supplies the smart parking solution
Customer	Convenience of parking and paying	
Integrator	Data and monetization	Supplies the data gathered by the IT/Service Provider to the customer
IT/Service Provider	Generates and sends data	Supplies the Integrator

Current status of the business model

Business model already applied:

- Name of service: Smart Parking in Ettelbruck
- Use Case Variant: Smart Parking
- Location: Ettelbruck, Germany

Brief Description

The city deployed 32 UPCITI sensors enabling real-time monitoring of 954 of its 1700 parking spaces. The collected data is transmitted to RMS.lu, an enterprise based in Ettelbruck that processes the data.The information is then transmitted to the users via 34 panels installed across various point in the city, which display the number of parking places available in each of the 8 parking lots, and in real-time via the website of the Ville d'Ettelbruck.

2.14 Conclusions about business models

Although the business models that can be more promising or beneficial within the project will be discussed during the co-creation activities, some conclusions around the aforementioned business models are presented in this subsection, such us the identification of gaps in the literature research done and a few words about the most promising applications which seems to have the potential to create positive impact and business models.

Gaps found in the research activity carried out

Although the technology included in CCAM Solutions has advanced and evolved fast during the past years, its implementation – especially at scale – is still in its infancy. All the reviewed solutions in this chapter are being tested in real-life settings in small pilots all over the world. However, this also implies that the business models connected to these solutions are quite immature, since they have not been tested in a commercial way or at scale. To conduct the analysis in this chapter, and whenever there was no or limited bibliography on CCAM Solutions' business models, traditional business models have been considered. For instance, for hailing solutions, there is very little experience and literature with autonomous vehicles, thus it has been considered traditional hailing services as a proxy to reflect on its business models although taking notes of the remaining gaps.

These are additional gaps found on the literature:

- Hailing services: business models are proven for traditional services, but **little experience and thus literature exists** on proven autonomous hailing services. In addition, more

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information on the revenue streams is needed, especially when compared with services that have staff costs (drivers).
- On-demand autonomous shuttle bus service: this is a solution that has started to be tested in the past 2 -5 years. It has proven most of its potential on roads and journeys where there were little to no transport services (especially in rural areas). The literature and the experience are very limited so the business models are mainly relying on the information about the technologies with little information on the revenue streams. Bus fleets replacement by AVs is very similar to this case, where cost savings potential increases with the reduction of personnel which is only attainable by fully automated models. More analysis and experience is needed to better understand the changes in **business models with several degrees of automation**.
- Autonomous freight trucks: lower levels of automation have been tested and have shown the benefits this technology can have. Revenue streams are clear to manufacturers as well as truck users. The challenge will lie in **the financial streams and the road infrastructure** which are an underlying condition for this solution, especially in advanced levels of automation.
- Car sharing services with AV: car sharing is already a well proven technology, however, there is a lack of information on the business models for services including AVs. Its **economic viability and business model are still yet to be developed** and proven.

The implementation of CCAM solutions depend on the availability of digital infrastructure (e.g. 5G, sensors, etc.) that connect to the passing vehicles, sending and collecting information is an important barrier to wide scale application of the most advanced solutions. Furthermore, appropriate road conditions need to be met for certain vehicles to be able to travel. For instance, privately owned AV (level 4 or above) can drive only in specific highways in Germany, where the aforementioned conditions are met. These aspects lower the pace at which pilots are tested and thus, commercial applications and their business model developed.

Regulations is another aspect that affects and will continue to affect CCAM Solutions' business models and where a knowledge gap already exists. Certain regulations can make business models unviable or affect the ROI of a specific application. This is expected in solutions that utilise combustion engines which are progressively banned from city centres or must pay additional taxes for old engines. Due to climate change, air pollution, and other challenges faced all across the world, regulations will be changed and updated in the upcoming years, and thus there is a need to develop business models that consider diverse regulatory scenarios and which can support better decision making.

- Apart from individual business models, it is important to count with comparative data to assess whether CCAM solutions vs others are more advantageous (economically, socially and environmentally).

Beneficial business models

From the CCAM solutions studied and their business models, the following seem the most promising applications which have the potential to create positive impact and business models.

- Automated freight trucks: when done at scale, it has a large potential to reduce transport and logistics costs, as well as to increase the drivers' safety and wellbeing.
- Autonomous Shuttle Bus in rural areas: usually where transport services don't exist due to a lack of availability of works or too expensive staff costs, which would be addressed by automated, on-demand solutions
- MaaS: it is one of most effective business models studied and is well established (though not necessarily with automated vehicles)

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- Robot delivery: it has been tested with small vehicles and reached positive outcomes since it can increase the efficiency of the delivery, they are safe riding at a low speed on the sidewalk and using voice command to communicate with people.
- Drone delivery: this has shown huge potential in disaster-affected areas though it is still to be studied other applications and its economic viability.

3 CCAM perceptions and needs

This section reviews evidence on the perceptions of citizens and organizations regarding CCAM solutions. A systematic review procedure has been followed to find relevant studies, since the volume of the literature on this topic is large. As it is the largest database of academic research, Scopus was selected to be used for this review. The search combined three terms, covering CCAM technology, use of that technology, and perceptions/needs (Table 36). The search was applied in the title, abstract, and keywords of the articles. We imposed three additional conditions: 1) documents published since 2013, 2) in English, and 3) categorised under Social Science.

Table 36 Search terms

	Technology			Use			Perception/need
	CCAM			mobility			perceptions
OR	automat*		OR	vehicle		OR	attitudes
OR	autonomous		OR	car		OR	concerns
OR	driverless		OR	automobile			
OR	connected	AND	OR	freight	AND		
OR	drone		OR	passenger			
OR	self-driv*		OR	transport			
OR	self-pilot*						
OR	unmanned						

The search returned 2,255 results 1,944 were excluded after reading the abstract, and a further 237 after reading the full article. Some of these studies were excluded because they did not report the results of engagement with potential users of CCAM solutions (e.g., they were thought pieces, reviews, or studies reporting engagement with experts or stakeholders other than the end user of the CCAM solution). Other studies were not inside the scope of the review, such as studies on:

- Connected but not autonomous vehicles
- Advanced driver assistance systems
- Perceptions of other road users (pedestrians, cyclists)
- Intention to use CCAM solutions
- Willingness to pay to use them
- Preferences and choices among CCAM solutions and between CCAM and other mobility solutions
- Effect on travel behaviour
- Views regarding how to solve ethical dilemmas in case of risk situations
- Rail-based autonomous vehicles
- Perceptions of drones in general (not linked to passenger or freight transport use)

74 studies remained after this selection. Four studies that cite or are cited by those 74 and not in the initial list of results were added.

Standardized information was then collected from each study to allow the comparison of findings. This included: year, country where evidence was collected, type of area (urban or rural),

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technology, use (passenger or freight), specific user group studied, ownership scenario, outcome studied, method, sample size, main results, and differences by group.

Finally, the results were split into the following uses:

- Passenger transport by land (42 studies, reviewed in Section 4.2, plus studies focusing on specific groups, reviewed in Section 4.3, including older people (6 studies), people with disabilities (10 studies) and children (2 studies)
- Freight transport by land (3 studies, Section 4.6)

Some of the studies selected analyse general perceptions about CCAM solutions. Others analyse perceptions after using a specific solution (in most cases, shuttle minibuses trialled in an urban environment), or a simulator.

The following sub-sections review the results of the selected studies, synthesizing and assessing the information on user perceptions. The methods used in the literature are not reviewed (but inform the considerations made in Section 8 of this deliverable on co-creation methods to use in this project).

The reviews in Sections 3.1 and 3.2 (perceptions of passenger land transport in general and among specific groups) are organised by topic (perceived benefits and concerns), referring to studies that provide evidence on each topic. The other sections (on passenger air and water transport and on freight transport) report in more detail the results of individual studies, given the small number of studies found.

3.1 Solutions for passenger land transport: general perceptions

3.1.1 Perceived benefits

Autonomous vehicles tend to be perceived by the public as a convenient mode of transport that can bring flexibility to travel planning (König and Neumayr 2017, Chng et al 2021a, Nordhoff et al 2019, Paddeu et al 2020, Strömberg et al 2021). Not having to drive (which is stressful or tedious for many drivers) is also seen as a benefit for some users (Nordhoff et al 2019, Wu et al 2020, Islam et al 2022). Automated driving are also useful for non-drivers (Wu et al 2020) and for drivers who have impairments, both in the long-term (Cunningham et al 2019) and temporarily (König and Neumayr 2017). Not having to drive also releases time that can be used for other activities when travelling (Kyriakidis et al 2015, König and Neumayr 2017, Nordhoff et al 2019, Chng et al 2021a, Islam et al 2022). Automated driving also reduces the chance of becoming lost, as wayfinding will be incorporated into the system (Thomas et al 2020).

Automation can also be linked with pleasure derived from the trip, especially mitigating situations in which drivers usually feel frustrated, providing assistance for parking and queuing in congested roads (Bjørner 2019, Cunningham et al 2019). A simulator study has also found that drivers reported more driving comfort in an automated drive than a manual drive. Older drivers also reported more enjoyment (but younger drivers reported less enjoyment) (Hartwich et al 2018).

There is also some evidence on perceived social status derived from owning an automated vehicle. In a study among students in the USA, 54% agreed that they would be proud to show the vehicle to others and 43% agreed that would make them have a high profile among others (Islam et al 2022). In another study, the proportion agreeing they would be proud to show the vehicle was around one third (Panagiotopoulos and Dimitrakopoulos 2018).

There is also a belief that automated vehicles are safer than conventional ones and will lead to a reduction in collisions (Woldeamanuel and Nguyen 2018, Panagiotopoulos and Dimitrakopoulos 2018, Nordhoff et al 2019, Thomas et al 2020, Strömberg et al 2021, Olaru et al 2021, Molina et al 2021, Islam et al 2022). In a survey in the USA (Ahmed et al 2020), more than two thirds of

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participants stated that it was likely that autonomous vehicles will lead to fewer collisions overall and to fewer severe collisions.

Evaluation of trials of autonomous shuttles also tends to show positive results. Most users report the system as safe (Salonen 2018, Rehrl and Zankl 2018, Zoellick et al 2019, Papadima 2020, Nordoff et al 2020, Rosell and Allen 2020, Bernhard et al 2020, Hilgarter and Granig 2020, Mouratidis and Cobeña Serrano 2021, Launonen et al 2021). In some studies, the trip was also assessed as comfortable and smooth (Portouli et al 2017, Rombaut et al 2020, Nordoff et al 2020).

3.1.2 Concerns

Despite the widespread conviction that automated vehicles will decrease collisions, the safety of these vehicles is a major concern for many potential users, as reported in several studies (Kyriakidis et al 2015, Paddeu et al 2020, Strömberg et al 2021, Chng et al 2021b, Olaru et al 2021, Dichabeng et al 2021). Individuals are concerned with the general risks of failure or system errors (Piao et al 2016; König and Neumayr 2017; Chng et al 2021a, 2021b; Liljamo et al 2018; Tennant et al 2019, Thomas et al 2020; Soltani et al 2021; Etminani-Ghasrodashti et al 2021; Cugurullo et al 2021; Sharma and Mishra 2022; Islam et al 2022). Others are concerned about failure in special conditions such as poor weather or low visibility (Woldeamanuel and Nguyen 2018, Wu et al 2020, Ahmed et al 2020, Islam et al 2022).

In some cases, study participants reported that they do not trust in automation (Bjørner 2019, König and Neumayr 2017). In a larger number of studies, the problem was not automation per se, but complete automation, i.e., the situation where automation handles all driving situations without intervention by a human driver (Liljamo et al 2018, Woldeamanuel and Nguyen 2018, Thomas et al 2020, Rezaei and Caulfield 2020, Strömberg et al 2021, Dichabeng et al 2021, Etminani-Ghasrodashti et al 2021, Islam et al 2022). There is also concern that automated vehicles might be dangerous to others road users, especially cyclists and pedestrians (Cugurullo et al 2021, Islam et al 2022).

Some users are also uncomfortable with the idea of the vehicle making ethical decisions in the case of collisions (Nordhoff et al 2019, Liljamo et al 2018, Chng et al 2021b, Gill 2021). There is also a concern about liability when a collision is caused by an automated vehicle (Kyriakidis et al 2015, Piao et al 2016, Lu et al 2017, König and Neumayr 2017, Chng et al 2021a, Cunningham et al 2019, Thomas et al 2020, Strömberg et al 2021, Olaru et al 2021, Islam et al 2022).

Security is another general concern. This includes cybersecurity and the threat of malicious uses of the system for crime and terrorism (Piao et al 2016; Lu et al 2017, Ahmed et al 2020, Olaru et al 2021, Chng et al 2021b, Dichabeng et al 2021, Cugurullo et al 2021, Islam et al 2022). In the case of public transport or shared solutions, security from crime and harassment can also be a problem, due to fear of travelling alone with other passengers and no staff on-board (Dichabeng et al 2021, Launonen et al 2021). This was confirmed in some real-world trials, as some passengers shared concerns about personal security, especially in the case of women (Salonen 2018) and older people (Launonen et al 2021).

A third concern is privacy. This is related to the possibility of surveillance due to the transmission of data from the vehicle to surrounding vehicles, vehicle developers, insurance companies, and roadway organizations (Piao et al 2016, König and Neumayr 2017, Rezaei and Caulfield 2020, Hilgarter and Granig 2020, Islam et al 2022). Another aspect is the possibility of misuse of personal data in the case of hacking (Kyriakidis et al 2015, König and Neumayr 2017, Cunningham et al 2019, Ahmed et al 2020, Soltani et al 2021, Sharma and Mishra 2022). Personal data that might be at risk include travel behaviour (e.g., trip origins and destinations, trip frequency, travel hours).

The cost of owning or using an automated vehicle is also a concern (Piao et al 2016, Thomas et al 2020, Hilgarter and Granig 2020, Strömberg et al 2021, Chng et al 2021b, Islam et al 2022,

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Sharma and Mishra 2022). This is linked to a belief by some that automation will only benefit the wealthy (Strömberg et al 2021).

Automation can also remove the sense of freedom and control that drivers derive from driving (König and Neumayr 2017, Bjørner 2019), or simply the pleasure of driving (Tennant et al 2019, Islam et al 2022).

Some individuals have also noted as a disadvantage having to learn how to use automated vehicles (Woldeamanuel and Nguyen 2018). In addition, there is also a belief among some that a connected automated vehicle might not operate in internet connectivity is poor (Sharma and Mishra 2022) and that the software (e.g. road maps) not be up-to-date (Piao et al 2016).

There is also anxiety regarding possible job losses due to automation, which means that professional drivers may no longer be needed. This anxiety was expressed both among professional drivers (Dubljević et al 2022) and the general public (König and Neumayr 2017, Nordhoff et al 2019, Chng et al 2021a, Hilgarter and Granig 2020).

In some real-world trials, some users complained about the low speed of the vehicles (Nordhoff et al 2018, 2019; Bernhard et al 2020; Mouratidis and Cobeña Serrano 2021) and others about strong and abrupt braking (Nordhoff et al 2019, Mouratidis and Cobeña Serrano 2021), and incapability to overtake obstacles (Nordhoff et al 2019).

3.2 Solutions for passenger land transport: perceptions among specific groups

Some studies have focused on the perception of specific user groups that tend to have more travel constraints, including older people, people with disabilities, and children.

3.2.1 Older people

Surveys found that older people tend to perceive autonomous vehicles as enhancing their opportunities for mobility (Faber and Lierop 2020, Zandieh and Acheampong 2021, Hassan et al 2021, Booth et al 2022). It is also viewed as a way to promote social interaction (with other passengers and people at trip destinations) (Faber and Lierop 2020, Zandieh and Acheampong 2021) and physical activity (by allowing more visits to parks) (Zandieh and Acheampong 2021). Furthermore, it allows for more flexibility (Faber and Lierop 2020) and a less stressful travel experience, with less driving and parking demands (Zandieh and Acheampong 2021). These benefits are perceived to be higher in the case of public transport and shared services using autonomous vehicles (Zandieh and Acheampong 2021).

However, there are concerns about safety (Faber and Lierop 2020, Hassan et al 2021, Zandieh and Acheampong 2021). This is linked with distrust in technology. For example, in the study of Hassan et al (2019), 81% of participants agreed that they would prefer to be in control of the vehicle because technologies can fail. In addition, 48% agreed that they would feel comfortable using an autonomous vehicle only if they could intervene when needed.

Again, cost is a concern. In the study of Rahman et al (2020) in the US, the majority of participants mentioned that owning an autonomous vehicle was not affordable for them. Other barriers include problems in physical accessibility (to get in/off the vehicle) (Booth et al 2022), having to learn to use the autonomous vehicles technology (Zandieh and Acheampong 2021), and concern about liability in case a technology failure causes a collision (Hassan et al 2021). The lack of a human driver also reduces the opportunities for support during the trip (besides social interaction) (Booth et al 2022, Zandieh and Acheampong 2021). In the study of Zandieh and Acheampong (2021), participants also mentioned the risk of autonomous vehicles disrespecting “road etiquette”, such as not yielding to other vehicles is situations that a human driver probably would.

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3.2.2 People with disabilities

Focus groups and surveys with people with disabilities showed that autonomous vehicles are generally perceived as a solution that can increase their independent mobility and accessibility (Brinkley et al 2017; Bennett et al 2020; Hwang et al 2020, 2021; Patel et al 2021, Miller et al. 2022). The technology could also have specific benefits during trips, for example, removing the need for parking (Hwang et al 2021).

Nevertheless, there is also evidence that some people with disabilities perceive autonomous vehicles negatively (Kassens-Noor et al 2021) and have more negative attitudes towards autonomous vehicles than those with no disabilities (Bennett et al 2019). This can be explained by a concern about safety (Kassens-Noor et al 2020, 2021; Hwang et al 2021; Bennett et al 2019, 2020). It can also be explained by the belief that their needs are not being fully considered in the development of autonomous vehicles (Brinkley et al 2017, Bennett et al 2020). For example, in the case of public transport systems, the benefits of autonomous vehicles depend on the geographic coverage of the service (which may not cover, for example, healthcare facilities), the presence of an onboard safety assistant, physical accessibility to the vehicle (e.g. wheelchair access).

People with visual impairments have several additional concerns. Those considering using private autonomous vehicles concern about not being aware of how the vehicle is interacting with other vehicles and the infrastructure at each moment of the trip, and not knowing how to provide guidance to the vehicle on where to park or how to find the vehicle in the parking lot (Brinkley et al 2017). Those considering using public transport concern about the suitability of booking systems (Patel et al 2021). Despite these concerns, a trial evaluation of a small autonomous vehicle in the UK found that people with visual impairments expressed happiness as the predominant emotion during the trip, assessed with facial expression analysis (Kempapidis et al 2020).

Negative perceptions have been recorded for people with other types of disability. For example, in the study of Kassens-Noor et al (2021), 67% of participants with hearing impairment and 63% of those with mobility impairments had negative views. For the former, the negative views could be related with concerns about the user interface (Miller et al 2022). For the latter, it could be related with physical accessibility of vehicles (Hwang et al 2020).

3.2.3 Children

Two studies have looked at the perceptions of adults regarding children using autonomous vehicles. Lee and Mirman (2018) found that these vehicles could enhance mobility and wellbeing of children and/or parents. In the scenario that parents are also using the autonomous vehicle, many parents felt that they could spend quality time with the child and engage in several activities with them. In the scenario where children are using the vehicle independently, parents pointed to extra time for them (because no longer having to drive the children to school). A simulator study found that both parents and children felt comfortable in an autonomous driving situation (Tremoulet et al 2020).

Parents also have concerns, especially in the case of children travelling independently. These include the lack of trust in the safety of the vehicle and personal security issues related to the child travelling without an adult and having no one to escort them to/from the place the vehicle stops until the final destination (Lee and Mirman 2018). These concerns are especially relevant in the case of mothers and parents with young children (Lee and Mirman 2018). In the simulation study of Tremoulet et al (2020), parents also indicated several features that autonomous vehicles need to have in order to be safe and secure for children travelling independently, including safety, communication and parent control features (e.g. only allowing parents to set destinations, notifying parents when the child has arrived).

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3.3 Solutions for freight land transport

Schomakers et al (2022) studied perceptions of ‘Ducktrain’, a platoon of automated small vehicles following a leading person. This solution can be used for urban last-mile delivery. It was generally perceived by the public as better than conventional delivery vans in almost all aspects except reliability. However, the perception may be related to features other than automation (e.g. the fact that the vehicle is electric and conventional delivery vans are not). Concerns identified by the study's participants include doubts about the general need for this kind of vehicles, safety concerns, and liabilities in the case of collisions

There is little evidence on perceptions of organisations about autonomous freight transport. A survey to trucking companies in the USA (Simpson et al 2022) found moderate levels of agreement with potential benefits or costs of connected autonomous trucks. In a scale from 1-7, the average agreement that this solution would be better and more cost-effective was 4.1 and 3.8, respectively, The study of Sindi and Woodman (2021) in the UK used interviews to individuals with professional experience in the logistics industry. Participants thought the solution may bring flexibility and cost but there would be a negative effect on employment. The replacement of drivers also means that other solutions are needed to alert the autonomous driving system to problems related to the security of the load. In addition, connectivity with road and other vehicles might imply sharing data with other companies, with possible data security problems. There were different views among participants regarding safety and liability in case of collision.

3.4 Solutions for freight air transport

National-level surveys have reached similar conclusions about solutions for freight air transport. There is a concern with the potential for drones to be used with malicious intent for terrorism or crime. In the UK Department for Transport Technology Public Attitudes Tracker, this was identified as a concern by 72% of respondents (higher among older people) while privacy issues were identified by 70% of respondents (UK DfT 2021).

In a survey by the US Postal Service (USPS 2016), the majority of participants agreed that deliveries by drone would be fast and environmentally friendly, but only 39% agreed deliveries would cost less and only 32% agreed they would be safe. Overall, 78% were concerned about malfunctions (that would damage the package or property, or injure people). 52% were concerned about intentional misuses (drones can be used to transport illicit goods, used in a way that violates privacy, or intentionally used to injure people or damage property). In rural areas, and among women and older people, levels of agreement with benefits were consistently smaller and concerns were higher.

The study of Kellermann and Fischer (2020) looked at perceptions about using drones for parcel delivery in German cities. The focus group participants agreed that drones should be used for emergency deliveries, but there was less enthusiasm in the case of standard parcel deliveries. The perceived benefits were faster and more flexible deliveries, adapted to customer needs (i.e. at the exact time and place). However, as in the case of passenger transport, there was concern about safety and security. There was a belief that drones could only transport a limited amount of (small) things. This was associated with a belief that the solution would be less environmentally friendly than land transport because drones would have to deliver every parcel separately while vans could transport many parcels. There was also a conviction that delivery by drone would imply higher delivery prices.

In the qualitative study of Boucher (2016) in the UK, the use of drones for deliveries was perceived by some participants as offering little advantage to society, besides creating congestion in air space and having privacy issues.

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Overall, the evidence points to perceived benefits such as delivery speed but also to concerns about safety, security, privacy, and environmental effects. However, the literature is still scarce. There is also little evidence on the perceptions of organisations (e.g. companies sending or receiving freight, freight operators). This is a gap in the literature.

3.5 Conclusion on perceptions

The literature suggests that people perceive CCAM technologies as useful, releasing travel time and some of the stress associated with driving. However, they also have a number of concerns. In the case of passenger land transport, the main concern is safety, especially in the case of fully automated vehicles with no human operators. This is despite the facts that in general people think that automated vehicles can be safer than conventional ones, and hat users of automated vehicles in trial schemes tend to report feeling safe. Other main concerns are security (from hackers and from other passengers), and privacy. Specific groups, such as the elderly and people with disabilities, see CCAM technologies as a potential enhancer of their mobility and accessibility, but have additional concerns, such as the physical accessibility of the vehicles. Parents with children also concern about personal security. The evidence for other uses of CCAM technologies is less extensive. Solutions for freight air transport have been identified by some as costly and with potential for creating congestion in air space.

4 Review of Transport System Dynamic Models

4.1 SDM in general

As today's world evolves rapidly and complexity becomes the norm, holistic approaches are needed in order to better understand challenges of complex, interconnected and impactful systems we implement. Missing the holistic approach interdependencies and consequent issues arising from the structures of the systems could be missed. A System Dynamics approach provides tools and methods to understand this complexity in interoperating systems.

A common definition of System Dynamics (SD) is an approach aimed at better understanding nonlinear or dynamic behaviours of complex systems over time using stocks, flows, feedback loops, table functions and time delays.

System dynamics is very similar to systems thinking and constructs the same causal loop diagrams of systems with feedback. However, system dynamics typically goes further and utilises simulation to study the behaviour of the different systems implemented. This simulation method is based on finding stocks, flows and feedbacks that are relevant to the problem of interest. Computer software is today used to simulate a system dynamics model of the situation being studied.

The SDM Systems Dynamics Models will be based on software-based simulation models using digital relations and interconnections across activities and processes. Those models are aimed at better understanding the complexity and potential impact of industrial economic systems and implied environmental and population challenges of our modern world. Like all simulation models, all results are contingent upon the assumed inputs.

After mapping the system structures involved in the targeted fields of activities, computers are used to develop a model of the interconnected systems via quantifying the relations between the different system components. The model is simulated on computer software to observe the output of the system. Simulations to test certain policies on such a model can greatly aid in understanding how the system changes over time.

The main components and principles of the SDM can be described as follow:

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- The variables, accumulation, and time delays:
  Feedback loops are basically chains of cause-and-effect relations that forms a loop where its output routes back to the chain as an input. Hence, these systems feed back into itself. All systems contain feedback loops since all dynamics of systems arise from interactions of feedback loops. Therefore, identifying the feedback loops is crucial in system dynamics methodology.
- Feedback loops:
  Feedback loops are basically chains of cause-and-effect relations that forms a loop where its output routes back to the chain as an input. Hence, these systems feed back into itself. All systems contain feedback loops since all dynamics of systems arise from interactions of feedback loops. Therefore, identifying the feedback loops is crucial in system dynamics methodology.
- System structure:
  Components of the system build feedback loops and the relations between these feedback loops create structures which form the behaviour and events of in a system. Every system has an underlying structure which determines the behaviour of the system. Hence, to understand the system, it is necessary to discover the underlying structure through mapping it.
- Modelling and simulation:
  After mapping the system structure, software-based applications will simulated and quantifying the relations between the different system components which will enable observation of the output of the system.
- Policy design and strategy development:
  Observing the behaviour of the system with computer simulation allows us to analyse the system and the underlying structure helping understanding of the complex systems and designing policies to solve eventual issues or adapt strategies.

System dynamics should be used to understand and explore the nature of the problems and gives the modeller also the opportunity to investigate general dynamic tendencies.

It is quite essential to consider and recognise that the structure of any system, the many circular, interlocking, sometimes time-delayed relationships among its components, is often just as important in determining its behaviour as the individual components themselves.

Our work in Move2CCAM using the system dynamics approach and model shall contribute to the international dynamics of inclusive and sustainable mobility for our modern societies with real impact on business and policy.

System Dynamics was initially developed by Forrester from MIT in the 1950-60s, (Forester, 1958) and it is a powerful methodology developed from system theory, information science, organisational theory, control theory, tactical decision-making, cybernetics and military games.”

4.2 SDM and transport

The use of System Dynamic Models in the transportation sector is a concept that has been brought up into various studies time and again, for the purpose of evaluating its applicability for being used as a tool for assessing transport policies in a more holistic standpoint. The main notion behind SD models is that particular focus is given on key causal ecosystem relationships (hypotheses) which eventually yield the intermediate and final states of a complex system. SD techniques explain system behaviour by providing a causal theory, and then use that theory as the basis for designing policy interventions into the system structure which change the resulting behaviour and improve performance (Lane, 2008).

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In one of the first ever studies that bring together SDM and transportation, Abbas and Bell (1994) point out that SDM “can contribute to understanding better the relationships between elements of the transport system and between transport and its environment”. They claim that the modelling approach used in system dynamics brings along an array of advantages when compared to traditional transport modelling. The major advantages of using SDM include:

- It allows for the representation of complex systems in a clear and simple way
- It helps to identify the key drivers and factors that influence the behaviour of the system over time
- It allows for the simulation of the system's behaviour under different scenarios and conditions
- It helps to identify feedback loops and other dynamic relationships within the system
- It can be used to develop and test policies and interventions for improving the performance of the transport system

For these reasons they specifically recommend that the use of SDM for decision making should be used as decision support tool for policy analysis. The complexity of transportation systems is in big part captured by the involvement of multiple stakeholders with often contradicting goals, leading to feedbacks with different time-delayed responses between different types of users.

In 2014, Shepherd published a meta-analysis of 54 papers on the topic of SDM on transportation that have emerged since Abbas’ paper in 1994. These studies were grouped into six different application areas, as follows:

- Strategic policy at Urban, Regional and National levels
- Modelling the uptake of Alternate Fuel Vehicles
- Airlines and airports
- Emerging areas
- Supply Chain Management with Transportation
- Highway Maintenance/Construction

Examining the above topics via the use of SDM offers the benefit of examining the impacts within each case both in themselves as well as in relation to their related systems. For instance, when modelling the uptake of alternative fuel vehicles, it is possible to predict and evaluate a multitude of factors, ranging from manufacturing volume & cost, consumer preferences, depreciation of existing fleet, material availability, fuel consumption, environmental impacts, to policy, subsidies, incentives and regulation. The important aspect in the approach, despite the apparent capability of including multiple facets of a system, is the possibility to examine the time dimension correctly, by coding the time lag between interactions of the different entities of an SDM.

There is therefore an ample amount of work in the past couple of decades regarding using System Dynamics techniques to model transport-related topics. There is however little to no research ongoing regarding the introduction of CCAM, perhaps with the sole exception of the U.S. Department of Transportation that in 2020 published a report titled “System Dynamics Perspective for Automated Vehicle Impact Assessment”. Within this report, a first attempt is made to model the impacts of adopting automated vehicles and identifies causal factors that would influence the penetration of AVs.

The model uses causal loop diagrams to represent the relationship between entities, signifying reinforcing or negative loops. Through workshops and co-creation activities, participants identified impact linkages between the entities of the diagram and the various institutions that partake in the

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ecosystem of AVs. The result of the workshop is presented in a high-level schematic in Figure 6 below.

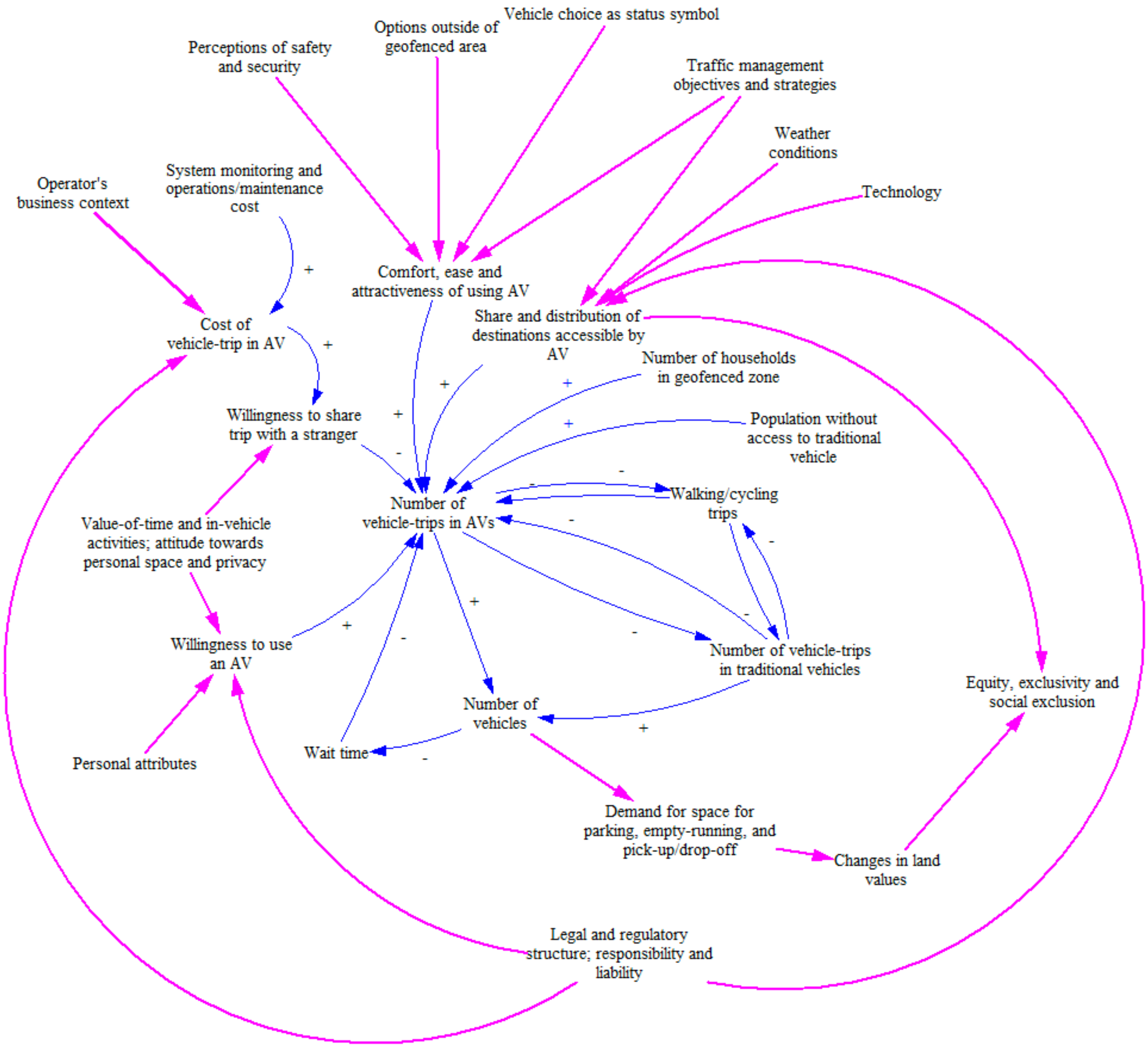

Figure 6 High-level schematic of the causal loop structure (DOT, 2020)

As the penetration of AVs in the market increases, and new initiatives are taken in this direction, the relations that constitute the SDM of AVs is changing. Similarly, quantifying the relationships between entities is also drastically impacted by the changes in the real world, and by events that affect travel behaviour, decision making and the economies of both individuals and infrastructure owners. The emergence of connected vehicles and the rapid improvements of related technologies will have to be documented and monitored, in an ever-changing environment and an economic climate that is challenging and dynamic. Move2CCAM will have to make use of the existing foundation, and incrementally improve the modelling framework to accurately describe the topology of all affecting entities that partakes in the acceptance and promotion of Autonomous and Connected Vehicles.

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4.3 Conclusions for the use of System Dynamic Modelling for Transport

A review of the relevant literature provided insight into the key variables and factors that may influence the adoption and impact of connected and autonomous mobility. These variables vary depending on the existing maturity of each application area, which may be captured within technological, economic, social, and environmental factors. Co-creation activities such as workshops and brainstorming sessions with the participation of public authorities, local stakeholders and citizens will help formulate a conceptual map of the interconnected variables that characterise the current state of associations between variables (as seen in Figure 6 above).

In the same time, it is important to collect information on the current state of CCAM technology status and required infrastructure, as well as indicators that capture the potential impacts of CAVs, such as car manufacturers, policy makers, and consumers. This information can either be appended with the outcome of the mapping or used as a basis and a starting point for the stakeholder engagement activities. The information of the above processes will be further used to guide the development of System Dynamic Models within the Impact Assessment Tool which can then be supplemented by relevant datasets. By incorporating data on these factors, system dynamic models can provide insights into the likely adoption of CCAM in different countries/regions, as well as the potential impacts on various stakeholders such as car manufacturers, policy makers, and consumers. Additionally, these models can be used to test the effectiveness of different policy interventions or strategies for promoting the adoption of CCAM in Europe.

5 CCAM solutions: Impacts to reach and KPIs to measure

5.1 Introduction

The evaluation of impacts due to the deployment of a technology and the acceptance assessment on a new product or service are often a challenge because are costly processes and time-consuming. However, both are of great importance in the planning making process since allow to know the effects of their implementation as well as the non-technical factors that could hinder its deployment.

Impacts attributed to a technology can be measured taking into account the whole life cycle (i.e. manufacture, operation and disposal) and environmental, economic and social aspects or considering only one of these stages and specific aspects. For the case of assessment acceptation, the focus of the analysis can be social acceptance (i.e. response given by persons affected by the new technology such as users) or market acceptance (i.e. market adoption of the innovation from consumers and investors).

In the case of MOVE2CCAM, a system dynamic model will be designed in order to gain insight on potential effects of CCAM solutions during their use on the environment, the society and the economy in basis to a causal loope structure related to non-technical factors. Specifically, this causal loope will be designed from perceptions from citizens and stakeholders on CCAM solutions which will be collected in activities carried out with the actors which take part of satellite group. Additionally, a social and environmental lifecycle analysis will allow to detect the effects of the CCAM solutions from their whole life.

Thus, in order to design the system dynamic model tool and built its causal loop structure as well as to focus the lifecycle evaluation to deploy in the project, it is required to analyse the existing evaluation frameworks about impacts quantification of mobility solutions and their acceptance assessment. This analysis will allow to detect which dimensions and indicators are used in evaluation procedures already established.

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An evaluation framework is a tailored tool that sets out the plan on how to measure an outcome. To this end, it defines relevant concepts and key terms and identifies components, dimensions and indicators to be applied in the evaluation process. Also the evaluation frameworks are useful to substantiate or reject a proposed hypotheses. Thus, based on the selection of the KPIs and the configured relationship, the evaluation framework is constructed on different levels or components.

Indicators are by definition quantitative, qualitative or descriptive measures (ISO, 37120) that enable information on a complex phenomenon, such as the dynamic urban environment, to be simplified into a form that is relatively easy to use and understand. There are diverse types of indicators. Table 37 shows the types of indicators according to the stage in the evaluation process (adapted definition from CITYkeys, 2017).

Table 37 Types of indicators

Type of indicator	What is measured?	Type of assessment	When to use?
Input	Resources needed for interventions	Planning	Planning of needed resources to achieve some goal (e.g. materials, financial resources)
Process	Implementation of activities	Quality assessment on means of implementation	Evaluation of implementation (e.g. number of training courses carried out)
Output	Effectiveness of implementation	Short-term monitoring	Reporting on immediate progress of implementation (e.g. number of new electric busses in the city)
Outcome	To which extent did the activities reach their objectives?	Mid-term evaluation	Reporting on intermediate results (e.g. adoption in “quantity” (“how many”) and quality (“how well”)
Impact	What was achieved by the intervention?	Long-term evaluation	Reporting on real impacts or overall performance (e.g. measurable change in quality of life, reduced energy use)

Additionally, there are qualitative and quantitative indicators. Qualitative indicators can be defined as people’s judgements and perceptions about a subject whereas quantitative indicators refer to a measure of quantity.

5.2 Evaluation frameworks and indicators for CCAM solutions

During the preparation of this deliverable, a systematic review procedure has been followed to find relevant studies, since the volume of the literature on evaluation frameworks and indicators is large.

The review of the literature has focused on frameworks already defined by key initiatives, projects and plans working in mobility and CCAM solutions but also in smart and sustainable cities since CCAM solutions can be considered as a smart and sustainable solution. Additionally, these requirements have been considered in the selection of the documents to be used as reference: frameworks developed in the last eight years and defined through groups of selected experts in the field and/or considering a systematic review of recent existing studies.

The documents selected to identify the types of impacts, acceptance factors and indicators can be grouped as follows:

- Documents on urban developments towards smart and sustainable cities developed by key initiatives such as International Organization for Standardization (ISO), United for Smart Sustainable Cities (U4SSC), United Nations Industrial Development Organization (UNIDO) and EUROSTAT, the EU statistical office as well as key projects such as Lighthouse initiative funded by the European Union.

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- Documents related to (sustainable) transport/mobility developed by key initiatives promoted by the EU such as CIVITAS and EIT (European Institute of Innovation and Technology), key projects funded by EC such as SUMI, SPROUT and MORE and key plans from EU and United States.
- Documents related to CCAM solutions developed by relevant groups such as "Trilateral EU-US-JP Automation in Road Transportation WG", key iniatives funded by EC such as CATRE Coordination and Support Action and EC projects such as HARMONY, AVENUE, LEVITATE, PAsCAL, SUaaVE and Trustonomy, some of them recommended by the topic which funds Move2CCAM.
- Papers that deal with synthesize impacts and indicators from multiple studies with a holistic perspective.
- Documents on theretical frameworks for measure factors that influence the adoption of new mobility technology and services. These correspond with developments of projects that measure the acceptance of new innovative technology in the energy and mobility sector such as MAtchUP, mySMARTLife, SunHorizon, PAsCAL, SUaaVE, Trustonomy and HARMONY.
- Documents that deals with social and environental life cycle impacts.

A description of the initiatives, projects and papers taken in consideration in the literature review as well as the outputs developed can be found in Annex I.

5.3 Impacts to reach and perceptions due to CCAM solutions considered in the literature

The project aims as part of the T1.1, in which this deliverable is part, a review of the literature with the intention to explore the potential impacts and perceptions of CCAM solutions and how they are evaluated through dimensions and indicators.

The review has been carried out as follow:

- How extent the areas of evaluation identified in the DoA (Description of Action) are considered in key initiatives, projects and papers as well as linked indicators.
- Others areas of evaluation and linked indicators considered by the reference documents from the literature.

The result of this review is provided in this section as follow:

- Focus of the evaluation of initial dimensions in the reference documents and remarks on the findings.
- Focus of the evaluation contemplated by reference documents and remarks on the findings.
- Tentative areas of evaluation and linked indicators, which have to be validated in next steps of the project.

Additionally, the result of the analysis related to life cycle analysis is included in the Annex II to short the size of the core document. The reason to move this outcome of the research is the fact that these indicators will not be calculated in the tool to be designed in the project. The social and environment analysis evaluation is a separate task that will complement the estimations performed by this tool.

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5.3.1 Initial dimensions in the literature

During the preparation of the project, a set of impacts, perceptions, needs and attitudes on CCAM solutions were thought and included in the Description of Action (DoA), following the categories described in the topic of the call which funds the project and which appears in the Community Research and Development Information Service (CORDIS) from the European Commission.

These initial categories to evaluate already defined consist of:

- Equity
- Mobility behaviour
- Safety
- Health
- Economy
- Environment
- Land-use
- Network efficiency

Table 39 details how the literature reviewed deals with the focus areas included in the DoA.

Table 38 Focus areas from DoA considered in the literature

Evaluation framework name	Focus areas							
	Equity	Mobility behaviour	Safety	Health	Economy	Environment	Land use	Network efficiency
ISO: 37120			X	X	X	X		
ISO: 37122			X	X	X	X		
CITYKEYS			X	X	X	X		
SCIS					X	X		
MAtchUP	X	X	X	X	X	X		
mySMARTLife		X			X	X		
REMOURBAN		X			X	X	X	
United 4 Smart Sustainable Cities			X	X	X	X		
United Nations Industrial Development Organization (UNIDO)	X					X		
Sustainable development in the EU (EUROSTAT)	X			X	X			
Civitas Capital		X	X			X		
Sprout project			X		X	X		
Urban agenda for EU		X	X		X			
Federal Transit Administration from United States		X	X	X	X			X
EU-US-JP road transportation working group		X	X	X	X	X	X	X
AVENUE project		X	X		X	X		
CATRE project		X	X	X	X	X	X	X
PAsCAL project			X	X	X			X
Report “System-level impacts of self-driving vehicles: terminology, impact		X	X	X	X	X	X	X

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frameworks and existing literature syntheses (KTH, 2018)"								
Paper "Key performance indicators as element of assessment and towards the development of sustainable mobility (Tundys B. 2015)"			X		X	X		
Paper "Measuring System-Level Impacts of Corporate Mobility as a Service (CMaaS) Based on Empirical Evidence (Vaddadi, 2020)"		X			X	X	X	

From this analysis, it can conclude that:

- Not all the reference documents classify impacts and indicators under categories but list a set of indicators without considering these under any dimension.
- Reference documents define the dimensions to evaluate according to the evaluation goal established. The documents considered as key in the literature review have a holistic approach but this does not mean than deals with all the dimensions identified during the project preparation. Thus, the areas under evaluation of the reviewed documents include in most of the cases economy, environment, health and safety as core categories. However, only some of them deal with all the categories defined in the initial stage of the project. On other hand, the reviewed documents can have additional categories.
- Some of the documents analysed deals with the same categories and this is because have been designed taking into account a same reference document. This happens in LH projects documents that use ISO: 37120 as document of reference. Also, some initiatives and projects related to CCAM solutions have the same approach and this is because have the work developed by the Trilateral ART WG as referent.

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5.3.2 Indicators linked with initial dimensions

This subsection is about the indicators considered by the reviewed documents in each one of the areas of evaluation proposed in the initial plans of the project. Also the projects, initiatives or papers where they appear are mentioned.

Note: To describe the focus of the evaluation of each dimension, it has added some indicators in those dimensions that rarely were considered as key category (i.e. equity and land case) but however the evaluation framework analysed included indicators that represent these concepts.

Table 39 Indicators from Equity dimension

Equity dimension
Inclusion of vulnerable groups (MATchUP)
Vulnerable groups accessibility (Sprout)
Targeted people reached (MATchUP)
Mediam income (MAtchUP)
GINI (MAtchUP)
Energy poverty (MAtchUP)
Fuel poverty (CITYKEYS)
Material deprivation (MAtchUP)
Housing cost overburden rate (MAtchUP)
Housing overcrowding rate (MAtchUP)
Social equity (AVENUE project)
Community livability (AVENUE project)
Livability: walkability (AVENUE project)
Equity: fairness horizontal equity (AVENUE project)
Equity: income vertical equity (AVENUE project)
Affordability of public transport for the poorest group (SUMI)
Accesibility of public transport for mobility-impaired groups (SUMI)

Focus of the evaluation: How vulnerable groups have been considered or reached, how extent the poverty exists and how vulnerable groups cover their basic needs.

Table 40 Indicators from Mobility behaviour dimension

Mobility behaviour dimension
Number of trips (CATRE)
Number and type of trips per week (in total and per inhabitant) (Trilateral Impact Assessment Sub-Group for ART)
Transport trips by mode (Tundys)
Daily trips on foot and by bicycle (Tundys)
Daily trips by private motorized modes (Tundys)
Daily trips by public transport (Tundys)
Total number of trips made (Vaddadi)
Total travel time (CATRE)
Vehicle-km travelled (by road) (EIT)
Average travel time for commuting trips (EIT)
Total duration of trips per week (in total and per inhabitant) (Trilateral Impact Assessment Sub-Group for ART)
Timing of travel (Trilateral Impact Assessment Sub-Group for ART)
Total kilometres travelled (CATRE)
Total kilometres or miles travelled per week in a region (Trilateral Impact Assessment Sub-Group for ART)
Vehicle kilometres/miles travelled per person and per vehicle (Trilateral Impact Assessment Sub-Group for ART)
Share of each transport mode (car) (CATRE)
Share of each transport mode (public transport) (CATRE)
Share of each transport mode (bicycle) (CATRE)
Share of transport modes (modal split) per week (based on number of trips) (Trilateral Impact Assessment Sub-Group for ART)
Modal share of walking and cycling trips (EIT)
Number of multimodal trips (Vaddadi)
Share of used road types per week (based on km or miles travelled) (Trilateral Impact Assessment Sub-Group for ART)
Network-level journey time per week (Trilateral Impact Assessment Sub-Group for ART)

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Average vehicle occupancy rates (persons/veh.) (Trilateral Impact Assessment Sub-Group for ART)
Relation of travel times and costs from public Transport, PT-AV-Shuttles and private cars (Trilateral Impact Assessment Sub-Group for ART)
Average speed of trip (Tundys)
Travelling at peak hours (timing) (CATRE)
Travelling reliability (CATRE)
Variability in travel time for commuting trips (EIT)
% of travellers satisfied with trip quality (EIT)
Travelling comfort (CATRE)
Accessibility of lower density areas (CATRE)
Annual volume of container traffic (Tundys)
Travel cost per trip (EIT)
Collisions/injuries/fatality rates (EIT)

Focus of the evaluation: Amount of travels (trips, distances and in peak hours), travels mode, travel time, traveling features (speed, comfort, occupancy), accessibility, collisions and costs.

Table 41 Indicators from Safety dimension

Safety dimension
Reduction of traffic accidents (CITYKEYS)
Number of traffic incidents envolving Autonomous e-minibus (AVENUE project)
Number of traffic accidents and fatalities envolving Autonomous e-minibus (AVENUE project)
Traffic accidents (CITYKEYS)
Traffic fatalities (injuries and death) (AVENUE project)
Number of fatalities and injuries in each mode of transport (AVENUE project)
Road fatalities (AVENUE project), (Tundys)
Injury rate (Federal Transit Administration from United States)
Fatality or serious injury per 100,000 trips (Federal Transit Administration from United States)
People killed and seriously injured in traffic collisions (CIVITAS CAPITAL)
Number of injuries (Urban Agenda for the EU)
Number of fatalities (Urban Agenda for the EU)
Crime rates on public transport (Tundys)
Share of urban mobility accidents involving micromobility means (SPROUT)
Share of urban mobility accidents involving on-demand bike/scooter deliveries (SPROUT)
Number of crashes (distinguishing property damage, and crashes with injuries and fatalities), in total and per 100 million km or miles (Trilateral Impact Assessment Sub-Group for ART)
Number of conflicts encountered where time-to-collision (TTC) is less than a pre-determined threshold / 100 million km or miles (Trilateral Impact Assessment Sub-Group for ART)
Working condition: accident, precarious employment conditions (AVENUE project)
Safety perception (Federal Transit Administration from United States)
Perception of safety by pedestrians, bicyclists, and others sharing the road with AVs. (Trilateral Impact Assessment Sub-Group for ART)
Privacy preference (Federal Transit Administration from United States)
Sense of safety from injury caused by motorised transport or cycling(Urban Agenda for the EU)
Active level crossings (AVENUE project)
Provision of safe crossings (Urban Agenda for the EU)
Transit safety (AVENUE project)
Proportion of time when time-to-collision (TTC) is less than a pre-determined threshold (Trilateral Impact Assessment Sub-Group for ART)
Distribution of TTC at brake onsets (Trilateral Impact Assessment Sub-Group for ART)
Number of instances with hard braking (high deceleration) / 1000 km or miles (Trilateral Impact Assessment Sub-Group for ART)
Number of selected traffic violations / 1000 km or miles of driving (Trilateral Impact Assessment Sub-Group for ART)
Number of instances where the driver must take manual control / 1000 km or miles (Trilateral Impact Assessment Sub-Group for ART)
Number of false positives / 1000 km or miles, i.e. instances where the vehicle takes unnecessary collision avoidance action (Trilateral Impact Assessment Sub-Group for ART)
Number of instances rated by a human as being of increased risk or not correctly handled by the automated vehicle / 1000 km or miles (Trilateral Impact Assessment Sub-Group for ART)
Time to take over vehicle control when system cannot provide support / handle the driving situation (Trilateral Impact Assessment Sub-Group for ART)

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Quality/Type of drivers reaction to a take-over request by the system (Trilateral Impact Assessment Sub-Group for ART)
Number of instances when not reacting to a pedestrian appropriately (% of all pedestrians encountered) (Trilateral Impact Assessment Sub-Group for ART)
Number of instances when not reacting to a cyclist appropriately (% of all cyclists encountered) (Trilateral Impact Assessment Sub-Group for ART)
Cibersecurity (CITYKEYS)
Data privacy (CITYKEYS)
Improved cybersecurity (CITYKEYS)
Improved data privacy (CITYKEYS)
Percentage of the city area covered by digital surveillance cameras (ISO 37122)

Focus of the evaluation: Traffic fatalities (injuries and death), safety perception, cybersecurity and privacy.

Table 42 Indicators from Health dimension

Health
Encouraging a healthy lifestyle (CITYKEYS)
Waiting time (CITYKEYS)
Average life expectancy (MAtchUP), (ISO 37120-2014), (U4SCC)
Quality-adjusted life years (Trilateral Impact Assessment Sub-Group for ART)
Traffic accidents (MAtchUP)
Number of fatalities and injuries per year per million inhabitants (Trilateral Impact Assessment Sub-Group for ART)
Congestion (MAtchUP)
Population exposure to air pollution (Trilateral Impact Assessment Sub-Group for ART)
Walking or biking sufficiently for health (AVENUE project)
Modal share (%) and total mileage travelled (kms) by active modes of transportation (walking and bicycle) (Trilateral Impact Assessment Sub-Group for ART)
Proportion of people with improved access to health services (Trilateral Impact Assessment Sub-Group for ART)
Proportion of people with improved access to recreation and other services (Trilateral Impact Assessment Sub-Group for ART)

Focus of the evaluation: Healthy lifestyle, average life, traffic accidents, congestion, modal share, access to health services and other services and exposition to air pollution.

Table 43 Indicators from Health and Safety dimension

Health and safety
Number of injuries (CARTRE)
Number of fatalities (CARTRE)
Total mileage travelled by active modes of transportation (walking and bicycle) (CARTRE)
Proportion of people with improved access to health services (CARTRE)
Improved access to recreation and other services (CARTRE)
Social isolation (CARTRE)

Focus of the evaluation: Traffic accidents, modal share, access to health services and social isolation.

Table 44 Indicators from Economy dimension

Economy dimension
Net Present Value (NPV) (CITYKEYS), (mySMARTLife), (MAtchUP)
Internal rate of return (IRR) (CITYKEYS), (mySMARTLife), (MAtchUP)
Payback Period (CITYKEYS), (MAtchUP), (SCIS), (mySMARTLife)
Revenues variation (MAtchUP)
Return on Investment (ROI) (SCIS), (mySMARTLife)
Cost recovery (proportion of costs recovered) (AVENUE project)
Total investment (SCIS), (mySMARTLife), (MAtchUP)
Capital cost per CAD vehicle (CARTRE)

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Cost of purchased automated vehicle (CARTRE) Total anual costs (SCIS) Operating cost for deployed system (CARTRE) Investment cost for digital infrastructure and connectivity network (CARTRE) Operation and maintenance cost for digital infrastructure and connectivity network (CARTRE) Investment cost for physical infrastructure (CARTRE) Operation and maintenance cost for physical infrastructure (CARTRE) Operation and Maintenance costs variation (MAtchUP) Annual expenditures for investments and operates (total and per resident) (AVENUE project) Investment on mobility. (AVENUE project) Expenditure on mobility per capita (AVENUE project) Transport investments by mode (AVENUE project) Total per capita transport expenditures (vehicles, parking, roads and transit services) (AVENUE project) Annual costs chargeable to residents of the conurbation (AVENUE project) Annual operating cost related to infrastructure expenditure (AVENUE project) Capital cost per vehicle for the deployed system (infrastructure, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Cost of purchased automated vehicle (market price, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Average annual maintenance costs of automated vehicles (currency/veh./year) (Trilateral Impact Assessment Sub-Group for ART) Operating cost for the deployed system (per vehicle-hour or per vehicle-km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Investment cost for physical infrastructure (per road km or mile, monetary value) Operation and maintenance cost for physical infrastructure (per road km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Investment cost for digital infrastructure (per road km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Operation and maintenance cost for digital infrastructure (per road km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Investment cost for connectivity network (per road km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Operation and maintenance cost for connectivity network (per road km or mile, monetary value) (Trilateral Impact Assessment Sub-Group for ART) External costs related to the transport system (congestion and crash costs) (AVENUE project) External costs related to environment (AVENUE project) Cost of education per driver (monetary value) (Trilateral Impact Assessment Sub-Group for ART) Cost for retro-fit kits (Trilateral Impact Assessment Sub-Group for ART) Total cost per mile (purchase, maintenance, operation) (Trilateral Impact Assessment Sub-Group for ART) Cost per trip for user (CARTRE) Cost per trip (for user, monetary value) (Trilateral Impact Assessment Sub-Group for ART) Price of fuel to price of electricity ratio (AVENUE project) Transport budget (AVENUE project) Finance for ecomobility (AVENUE project) Net public finance: Public finance & Economic subsidies (AVENUE project) Grants (SCIS) Funding sources (mySMARTLife), (MAtchUP) Total cost vs. Subsidies (CITYKEYS) Income (mySMARTLife) Public revenues from taxes and traffic system charging (AVENUE project) Cost efficiency (AVENUE project) Transport pricing efficiency and reforms (AVENUE project) Financial incentives for zero-emission vehicles (AVENUE project) Minimum taxation on fuel (AVENUE project) Relative taxation of vehicles and vehicle use (AVENUE project) Structure of road fuel prices and taxation (AVENUE project) Electric vehicles incentives (AVENUE project) R&D Expenditure (REMOURBAN), (mySMARTLife), (U4SCC) Socio-economic benefit-cost ratio (Trilateral Impact Assessment Sub-Group for ART) Financial benefit for the end user (CITYKEYS), (MAtchUP) Energy consumption reduction cost (mySMARTLife), (MAtchUP) CO2 reduction costs efficiency (mySMARTLife), (MAtchUP) Benefit from air pollution reduction (MAtchUP) Benefit from avoided CO2 emissions (MAtchUP)

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Work time lost from illnesses related to air pollution [hours per year, overall and per capita; monetary value] (Trilateral Impact Assessment Sub-Group for ART) Work time gained due to ability to multitask while traveling (hours per year, overall and per capita; monetary value) (Trilateral Impact Assessment Sub-Group for ART) Work time lost from traffic crashes (hours per year, overall and per capita; monetary value) (Trilateral Impact Assessment Sub-Group for ART) Cost of vehicle congestion (Tundys) Value of travel time savings (MAtchUP) Expenditure in local economy (mySMARTLife) Number of jobs created (mySMARTLife), (MAtchUP) Type of new contracts (mySMARTLife), (MAtchUP) Employment rate (REMOURBAN) City's unemployment rate (ISO 37120-2014), (mySMARTLife), (U4SCC) Percentage of persons in full-time employment (ISO 37120-2014) Youth unemployment rate (ISO 37120-2014), (mySMARTLife), (U4SCC) Number of jobs accessible (Federal Transit Administration from United States) Number of vanished/disappeared jobs (Trilateral Impact Assessment Sub-Group for ART) Off-peak access to jobs by public transportation (Federal Transit Administration from United States) Median number of jobs that can be accessed in 45 minutes (Federal Transit Administration from United States) Percentage of the labour force employed in occupations in the ICT sector (ISO 37122), (REMOURBAN), (mySMARTLife) ICT Industry Employment (U4SCC) Employment accessibility (AVENUE project) Percentage of the labour force employed in occupations in the education and research and development sectors (ISO 37122) Median gross earnings of newly contracted employees Number of SMEs introducing innovation to the market (mySMARTLife) Number of large companies introducing innovation to the market (mySMARTLife) Impact in business unit (mySMARTLife) New business registered (MAtchUP), (CITYKEYS) New established businesses (CARTRE) Number of businesses per 100 000 population (ISO 37120-2014), (REMOURBAN), (mySMARTLife) Survival rate of new business per 100000 population (ISO 37122) New established businesses / job creation (Trilateral Impact Assessment Sub-Group for ART) Small and Medium-Sized Enterprises (U4SCC) New start-up (mySMARTLife) Economic opportunity (AVENUE project) Growth of automotive industry (manufacturing) (CARTRE) Growth of transport services sector (CARTRE) Portion of mobility expenditures of house-hold income (Trilateral Impact Assessment Sub-Group for ART) Change in full poverty (mySMARTLife) Percentage of city population living in poverty (ISO 37120-2014), (REMOURBAN), (mySMARTLife) Fuel poverty (mySMARTLife) Median disposable income (CITYKEYS), (REMOURBAN), (mySMARTLife) Gender income equity (REMOURBAN) Increased safety (MAtchUP) Increased use of local workforce (MATchUP) Market orientation (MAtchUP) Market demand (MAtchUP) Number of new patents per 100 000 population per year (ISO 37120-2014), (REMOURBAN) Patents (U4SCC), (MAtchUP) Gross Domestic Product (CITYKEYS), (REMOURBAN), (mySMARTLife) Annual percentage of growth in GDP that can be attributable to mobility integration and improved mobility to access opportunities (Federal Transit Administration from United States) Gross value added (AVENUE project) Gross Domestic Product (hours per year, overall and per capita; monetary value) (Trilateral Impact Assessment Sub-Group for ART) Labour productivity (REMOURBAN) Total factor productivity / multi-factor productivity estimates (Trilateral Impact Assessment Sub-Group for ART) Labour force participation rate – overall and for non-drivers (Trilateral Impact Assessment Sub-Group for ART) Total factor productivity/multi-factor productivity estimates (CARTRE) Computing platforms (REMOURBAN) Number of Providers of AV-fleets in a local market (Trilateral Impact Assessment Sub-Group for ART) Market share of trips in shared fleet and privately owned cars (Trilateral Impact Assessment Sub-Group for ART)

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Number of public services within 10-min walk and job opportunities within 30-min commute of residents (AVENUE project) Mode split for personal travel (AVENUE project) Average commute travel time and reliability (AVENUE project) Integration and shared mobility (AVENUE project) Average time per trip (AVENUE project) Passenger km travelled per unit GDP (AVENUE project) Public Transport Network (U4SCC) Public Transport Network Access (U4SCC) Bicycle Network (U4SCC) Transportation Mode Share (U4SCC) Travel Time Index (U4SCC) Shared Bicycles (U4SCC) Shared Vehicles (U4SCC) Low-Carbon Emission (U4SCC) Passenger Vehicles (U4SCC) Pedestrian infrastructure (U4SCC) Public Wi-Fi (U4SSC) Traffic monitoring (U4SCC) Intersection control (U4SCC) Urban Development and Spatial Planning (U4SCC) Planning quality (AVENUE project) Land use planning (AVENUE project)

Focus of the evaluation: Profitability of solutions & cost recovery; mobility solution costs (investment, operation and maintenance), income, cost savings and financial scheme; external cost of mobility solution (air pollution, accidents, congestion, value of travel time); expenditure in local economy in the deployment of mobility solutions; impacts due to mobility solutions, business, services, employment and in energy poverty; city characteristics (GDP, vehicles, infrastructure, travel mode, duration of travelling and access to job) and planning.

Table 45 Indicators from Environment dimension

Environment dimension
Carbon dioxide emission reduction (CITYKEYS), (SCIS), (mySMARTLife) Reduction in lifecycle CO2 emissions (CITYKEYS) Local freight transport fuel mix (CITYKEYS) Climate resilience measures (CITYKEYS) Decreased emissions of Nitrogen oxides (NOx) (CITYKEYS) Decreased emissions of Particulate matter (PM2,5) (CITYKEYS) Reduced exposure to noise pollution (CITYKEYS) Air quality index (CITYKEYS), (mySMARTLife) Air pollution (U4SCC) Days exceeding critical levels of emissions (EIT) Annual polluting emission due to passenger transport per inhabitant (Tundys) Per capita air pollution emissions (various types), disaggregated by mode (AVENUE project) Population exposed to air pollution from transport (AVENUE project) Transport emissions of air pollutants (AVENUE project) Exceedances of air quality objectives due to traffic (AVENUE project) CO2 emissions (CITYKEYS), (ISO 37120-2014), (REMOURBAN), (mySMARTLife), (U4SCC) Transports greenhouse gas emissions per capita (mySMARTLife) CO2 emissions from personal transport per capita (CIVITAS CAPITAL) Global GHG emissions from the transport sector (GT CO2e) (AVENUE project) Greenhouse gas emission from passenger travel (Tundys) CO2-emissions from road traffic (Ton) (AVENUE project) CO2-emissons from road per capita (kg/cap) (AVENUE project) Annual traffic CO2 emissions (tonnes/year) on a route or in a region (Trilateral Impact Assessment Sub-Group for ART) Tailpipe carbon dioxide (CO2) emissions in total per year and per vehicle-km or mile (Trilateral Impact Assessment Sub-Group for ART) Amount change CO2-emissions (mobile sources), 1991–2009 Ton (AVENUE project) % change CO2-emissions (mobile sources) 1991–2009 (AVENUE project) Overall CO2 emission reduction target (mySMARTLife)

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Levels of CO, NOx, hydrocarbons and particles (in g/m2, total and per resident) (AVENUE project) Tailpipe criteria pollutant emissions (NOX, CO, PM10, PM2.5, VOC) in total per year and per vehicle-km or mile (Trilateral Impact Assessment Sub-Group for ART) NOx from road traffic (Kg) (AVENUE project) NOx per capita (kg/cap) (AVENUE project) Nitrogen oxide emissions (NOx) (CITYKEYS), (ISO 37120-2014), (REMOURBAN), (mySMARTLife) Fine particulate matter emissions (PM2.5) (CITYKEYS), (ISO 37120-2014), (REMOURBAN), (mySMARTLife) Particulate matter (PM10) concentration (ISO 37120-2014), (REMOURBAN) PM10 (particulate matter) from road traffic (Kg) (AVENUE project) PM (particulate matter) per capita (kg/cap) (AVENUE project) SO_2 (sulphur dioxide) concentration (ISO 37120-2014) O_3 (Ozone) concentration (ISO 37120-2014) Annual premature deaths due to air pollution and physical inactivity from transport-related sources (AVENUE project) Life time extension (CITYKEYS) Noise pollution (CITYKEYS), (ISO 37120-2014), (REMOURBAN), (mySMARTLife) Noise exposure of residents (EIT) Percentage of urban dwellers exposed to Lden/ (AVENUE project) Lnight noise levels from transport above 55 dB/40 dB (percent of total inhabitants) (AVENUE project) Noise exposure (U4SCC) Population exposed to transport noise greater than 65 dB (AVENUE project) Traffic noise: people exposed to traffic noise above 55 LAeq,T (AVENUE project) Annual average of the proportion of time when noise level above threshold (Trilateral Impact Assessment Sub-Group for ART) Reduction in annual final energy consumption (CITYKEYS), (SCIS), (mySMARTLife) Energy savings due to reduced air resistance (CATRE) Energy use for incar IT technology (CATRE) Reduction in primary energy consumption (SCIS), (mySMARTLife) Reduction in lifecycle energy use (CITYKEYS) Reduction of embodied energy of products and services used in the project (CITYKEYS) Energy use/emissions per second (Trilateral Impact Assessment Sub-Group for ART) Energy consumption of a vehicle (kWh/year) (Trilateral Impact Assessment Sub-Group for ART) Energy consumption of a vehicle (litres/100km or miles per gallon or electric equivalent) (Trilateral Impact Assessment Sub-Group for ART) Structure of road energy consumption by type of fuel (AVENUE project) Annual energy consumption for passenger transport per inhabitant (Tundys) Annual energy consumption of transport (Tundys) Transport final energy consumption by mode (AVENUE project) Fossil fuel consumption for transport per resident (EIT) Personal energy consumption (annual average kWh/person-km and kWh/person) (Trilateral Impact Assessment Sub-Group for ART) Energy efficiency and specific CO2 emissions (AVENUE project) Annual final energy consumption (CITYKEYS), (REMOURBAN) Primary energy consumption (REMOURBAN) Increase in local renewable energy production (CITYKEYS), (mySMARTLife) Increase of degree of energy self-supply by RES (mySMARTLife) Percentage of renewable energy use in public transport (mySMARTLife) Total fossil (gasoline, diesel, compressed and liquefied natural gas) energy consumption from highway transportation (tonnes/year) (Trilateral Impact Assessment Sub-Group for ART)Energy consumption in transport (AVENUE project) Biofuel and fossil fuel used per VKT or per capita (Tundys) Local freight transport fuel mix (CITYKEYS) Renewable energy generated within the city (CITYKEYS), (REMOURBAN) Renewable energy consumption (U4SCC) Energy poverty (REMOURBAN) BTUs per completed trip -- with trips broken out by length and type of trip. (Trilateral Impact Assessment Sub-Group for ART) BTUs per value of trip (e.g. by trip purpose) (Trilateral Impact Assessment Sub-Group for ART) Portion of electric vehicles (Trilateral Impact Assessment Sub-Group for ART) Increase in compactness (CITYKEYS)

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Focus of the evaluation: energy consumption, air quality of territory (GHG, NO_x, SO_x, PM, Ozone, VOC), Climate change emissions (CO_2), RES sources, energy poverty, e-vehicles, compactness and deaths due to air pollution.

Table 46 Indicators from Land use dimension

Land use dimension
Population density (CITYKEYS), (mySMARTLife)
Land consumption (mySMARTLife)
Urban compactness (REMOURBAN)
Density of housing (Trilateral Impact Assessment Sub-Group for ART)
Fragmentation of land (AVENUE project)
Space taken up by transport infrastructures (AVENUE project)
Transport infrastructure/ urban dense area (%) (AVENUE project)
Per capita land devoted to transport facilities (AVENUE project)
Land area consumed by public transport facilities (AVENUE project)
Daily individual consumption of public space (AVENUE project)
Involved in travelling and parking (in m2.h) (AVENUE project)
Underground parking space in city centre areas (CARTRE)
Street parking space in city centre areas (CARTRE)
Road network design (Trilateral Impact Assessment Sub-Group for ART)
Bike route (REMOURBAN)
Green areas (REMOURBAN)
Density of employment and shopping (Trilateral Impact Assessment Sub-Group for ART)
Public space WIFI coverage (REMOURBAN)
Distance in time to employment (Trilateral Impact Assessment Sub-Group for ART)
Location of employment (distance from city centre) (CARTRE)
Location of employment (Trilateral Impact Assessment Sub-Group for ART)
Number of lanes (CARTRE)
Number of parking slots (Trilateral Impact Assessment Sub-Group for ART)
Location of recreation (Trilateral Impact Assessment Sub-Group for ART)
Location of parking (Trilateral Impact Assessment Sub-Group for ART)
Creation of new real estate developments or new towns with transportation infrastructure designed specifically for AV access (Trilateral Impact Assessment Sub-Group for ART)
Space needed for road (Trilateral Impact Assessment Sub-Group for ART)
Space needed for transport and parking (Trilateral Impact Assessment Sub-Group for ART)

Focus of the evaluation: population density, compactness and fragmentation of territory, land area used for mobility infrastructure and space needed for transport infrastructure.

Table 47 Indicators from Network efficiency dimension

Network efficiency dimension
Road capacity (CARTRE)
Road capacity at design speed (for a given road section) (Trilateral Impact Assessment Sub-Group for ART)
Maximum road capacity (for a given road section) (Trilateral Impact Assessment Sub-Group for ART)
Intersection capacity (CARTRE)
Effective capacity (Trilateral Impact Assessment Sub-Group for ART)
Throughput i.e. number of vehicles per hour through a particular road section or intersection approach, normalised to number of lanes and proportion of green time (where relevant) (Trilateral Impact Assessment Sub-Group for ART)
Total or average travel time per road-km (CARTRE)
Average travel time (minutes) per road-km or mile (Trilateral Impact Assessment Sub-Group for ART)
Peak period travel time along a route (Trilateral Impact Assessment Sub-Group for ART)
95th percentile travel time (minutes) per road-km or mile (Trilateral Impact Assessment Sub-Group for ART)
Total travel time and distance travelled per road section or route (Trilateral Impact Assessment Sub-Group for ART)
Travel time variability (5th and 95th percentile travel time, to determine certainty in travel time) (Trilateral Impact Assessment Sub-Group for ART)
Full distributions of travel times and speeds for highway section or network (Trilateral Impact Assessment Sub-Group for ART)
Ratios of peak to average travel times and speeds (Trilateral Impact Assessment Sub-Group for ART)
Average headway (Trilateral Impact Assessment Sub-Group for ART)

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Free flow speed (on a given road section) (Trilateral Impact Assessment Sub-Group for ART) Median speed (on a given road section) (Trilateral Impact Assessment Sub-Group for ART) Lowest and highest 5th percentile speed (on a given road section) - addresses "worst case" reliability (Trilateral Impact Assessment Sub-Group for ART)

Focus of the evaluation: road capacity, travel time, peak period travel time and speed in routes.

Some conclusions from the review related to the indicators linked with initial dimensions are described below:

- The dimensions of the project can be evaluated with a wide number of different indicators since a same indicator can be used to evaluate different categories (i.e. accidents as safety or health). There is not any rules to classify indicators in dimensions since this is established during the own design of the structure of the evaluation frameworks in which is decided which objective of evaluation is measured with each dimension defined.
- A same indicator can be appointed with different names or can be calculated with different formulas.
- Impacts calculation with these indicators needs in many cases the values of the baseline (i.e. the initial value of the indicator before the technology was implemented).
- Not all these indicators could be useful / relevant for the system dynamics model to be created in the project and it is required to deploy a selection process.
- Literature remarks that the existing evaluation frameworks could not include indicators or dimensions that are needed for the evaluation of a new technology/service or plan. In this case, the own process to design the new evaluation framework could define new dimensions and indicators.

5.3.3 Impacts dimensions in the literature

In this section, the finding from the literature related to dimensions to use in the evaluation of the effects of a new mobility technology/service in a territory and the potentials impacts that they can generate are described.

Table 49 identifies the dimensions found and the documents where they are compiled.

Table 48 Dimensions considered in documents reviewed

Dimension	Evaluation framework *(Project, Initiative, Paper)*
Social	FTA Report, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018), EIT, mySMARTLife
Safety	U4SCC, CITYKEYS project, AVENUE project, CIVITAS, FTA Report, URBAN AGENDA FOR THE EU, ISO 37120, ISO 37122, SPROUT, Paper (Tundys, 2015), CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Security	AVENUE project, FTA Report, URBAN AGENDA FOR THE EU
Environment	U4SCC, CIVITAS, ISO 37120, ISO 37122, SCIS, CARTRE, LEVITATE, EIT, HARMONY, mySMARTLife, MAtchUP
Air pollution	U4SCC, CITYKEYS project, AVENUE project, MAtchUP, mySMARTLife, Paper (Vaddadi, 2020), SPROUT, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)

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Climate change and GHG emissions	AVENUE project, SPROUT
Noise	AVENUE project, SPROUT
Energy	U4SCC, CITYKEYS project, AVENUE project, MAtchUP, mySMARTLife, ISO 37120, ISO 37122, Paper (Vaddadi, 2020), CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Land use	CITYKEYS project, AVENUE project, REMOURBAN, Paper (Vaddadi, 2020), CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Health	U4SCC, CITYKEYS project, AVENUE project, MAtchUP, ISO 37120, ISO 37122, CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Equity	CITYKEYS project, AVENUE project, MAtchUP
Social inclusion	U4SCC
Diversity and Social inclusion	CITYKEYS project
Affordability	AVENUE project, URBAN AGENDA FOR THE EU, Paper (Tundys, 2015)
Accessibility	U4SCC, AVENUE project, CIVITAS, MAtchUP D1.1, FTA Report, URBAN AGENDA FOR THE EU, Paper (Vaddadi, 2020), SPROUT, Paper (Tundys, 2015), LEVITATE
Liveability	CIVITAS
Employment	U4SCC, CITYKEYS project, Paper (Vaddadi, 2020), SPROUT, LEVITATE
Economy	FTA Report, URBAN AGENDA FOR THE EU, ISO 37120, ISO 37122, SCIS, SPROUT, CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018), HARMONY, mySMARTLife, MAtchUP
Economy performance	CITYKEYS project, AVENUE project
Green economy	CITYKEYS project
Business	Paper (Vaddadi, 2020)
Budget	FTA Report
Expenditure	AVENUE project
Cost/Travel cost	AVENUE project, FTA Report, Paper (Vaddadi, 2020), Paper (Tundys, 2015), LEVITATE
Incentive	AVENUE project, URBAN AGENDA FOR THE EU
Finances	URBAN AGENDA FOR THE EU, ISO 37120, ISO 37122, LEVITATE
Efficiency	AVENUE project, FTA Report
Effectiveness	FTA Report
Reliability	FTA Report
Availability	FTA Report
Utilization	FTA Report, CARTRE
Network efficiency	CARTRE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Travel/mobility behaviour	CIVITAS, MAtchUP, REMOURBAN, FTA Report, URBAN AGENDA FOR THE EU, Paper (Vaddadi, 2020), Paper (Tundys, 2015), CARTRE, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018), EIT
Time	FTA Report,LEVITATE
Transport	U4SCC, REMOURBAN, ISO 37120, ISO 37122
Walking	CIVITAS
Cycling	CIVITAS
Public transport	CIVITAS
Cars and parkings	CIVITAS
Vehicle operations	URBAN AGENDA FOR THE EU, LEVITATE, Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)
Operational efficiency	Paper (Tundys, 2015)
Clean alternativas	MAtchUP D1.1
Infrastructures	U4SCC, URBAN AGENDA FOR THE EU, Paper (Tundys, 2015), mySMARTLife
Road capacity	CARTRE
Mobility system performance	HARMONY
Communication infrastructure	MAtchUP
Telecomunications	ISO 37120, ISO 37122

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ICT extent	U4SCC, MAtchUP, mySMARTLife
Smart buildings	CIVITAS
Smart management systems	MAtchUP
Urban platform	MAtchUP, mySMARTLife
Productivity	U4SCC
Innovation	U4SCC, CITYKEYS project, ISO 37120, ISO 37122, MAtchUP
Attractiveness and competitiveness	CITYKEYS project
Education	U4SCC, CITYKEYS project
Cultural and social values	AVENUE project
Quality of housing and built environment	CITYKEYS project, MAtchUP
Resource efficiency	AVENUE project
Resources (Materials, Water)	CITYKEYS project, AVENUE project, ISO 37120, ISO 37122
Waste	ISO 37120, ISO 37122
Ecosystem	CITYKEYS project
Environment conservation	Paper (Tundys, 2015)
Habitat and ecological impact	AVENUE project
Quality of life	Paper (Vaddadi, 2020), Paper (Tundys, 2015), HARMONY
Organization	CITYKEYS project
Community involvement	CITYKEYS project, MAtchUP
Governance	URBAN AGENDA FOR THE EU, ISO 37120, ISO 37122, MAtchUP
Multiple governance	CITYKEYS project
Participation	AVENUE project
Urban planning	U4SCC, MAtchUP, mySMARTLIFE, ISO 37120, ISO 37122
Strategic vision & planning	AVENUE project
Climate resilience	CITYKEYS project
Transparency	AVENUE project
Replicability & scalability	CITYKEYS project
Future	FTA Report
Factors of success	CITYKEYS project, MAtchUP, mySMARTLife
Income and material living conditions	MAtchUP
Plurality	MAtchUP
Experience	URBAN AGENDA FOR THE EU
Fire and emergency response	ISO 37120, ISO 37122
Recreation	ISO 37120, ISO 37122

Additionally, the frequency of topics to be considered in the evaluation of self-driving vehicles found in Cavolid et al. 2017 is shown in figure Figure 7. This figure can help in the identification of dimensions to include in the evaluation framework to design in the project.

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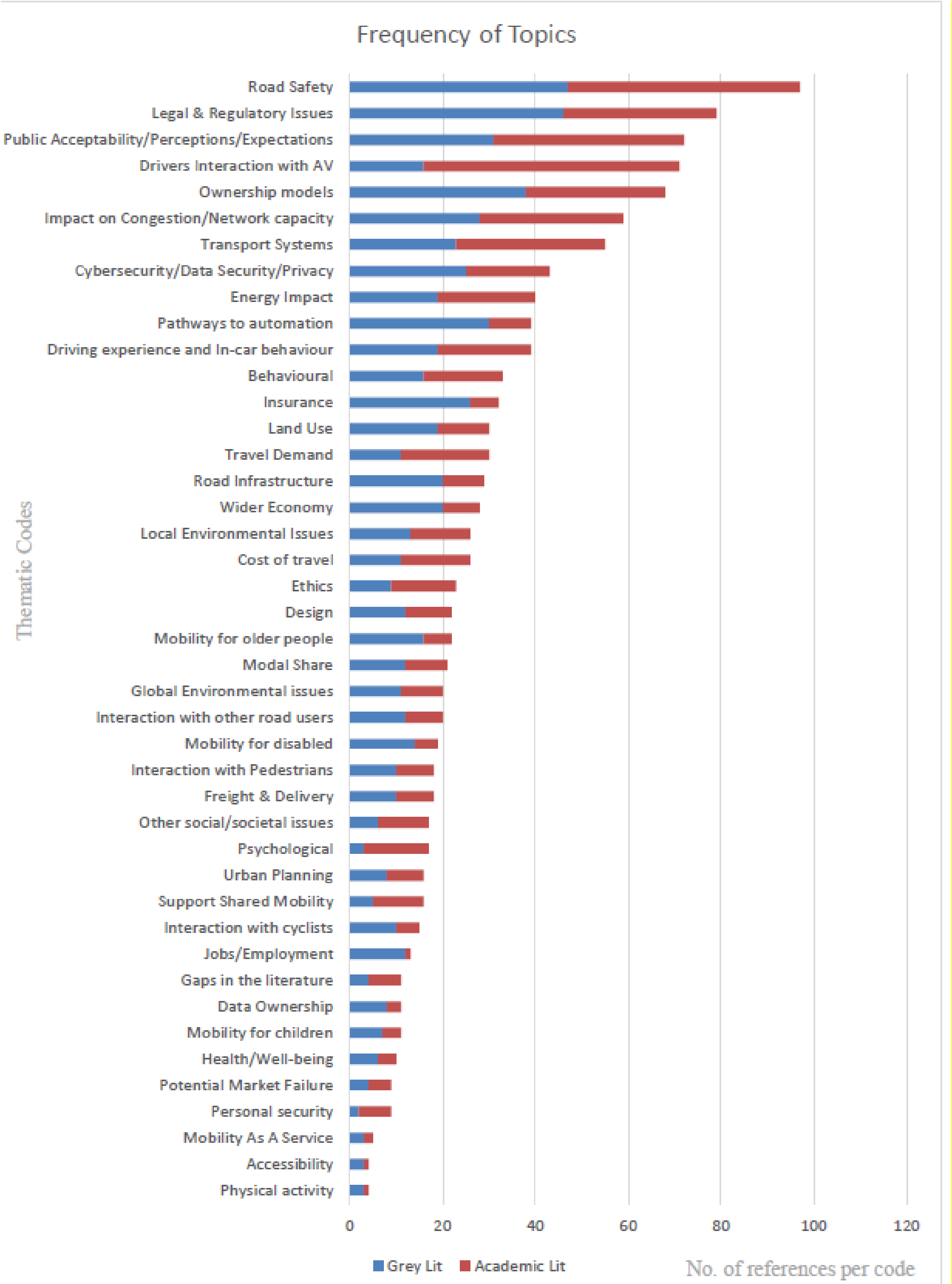

Figure 7 Frequency of topics for the evaluation of self-driving vehicles

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From this analysis, it can conclude that:

- There are dimensions that are more frequent than others which reveals the relevance of these dimension for the quantification of impacts.
- There are some dimensions that are not relevant for the evaluation of CCAM solutions. They have been included by the reference documents because these deal with a wider approach of the evaluation.
- There are some dimensions that can be grouped under a same category.

5.3.4 Technology acceptance dimensions in the literature

In this section, it is included the dimensions related to technology acceptance considered in the literature that deals with the conceptualization of market and social acceptance evaluation on new technologies.

The technology acceptance model was introduced by Davis, F. (Davis, 1989) and has been continuously studied and adapted. According to this initial framework, the use of a new technology is directly predicted by intentions, and intentions are directly predicted by attitudes and these how the technology is perceived and other external variables.

This model concept is described in figure below.

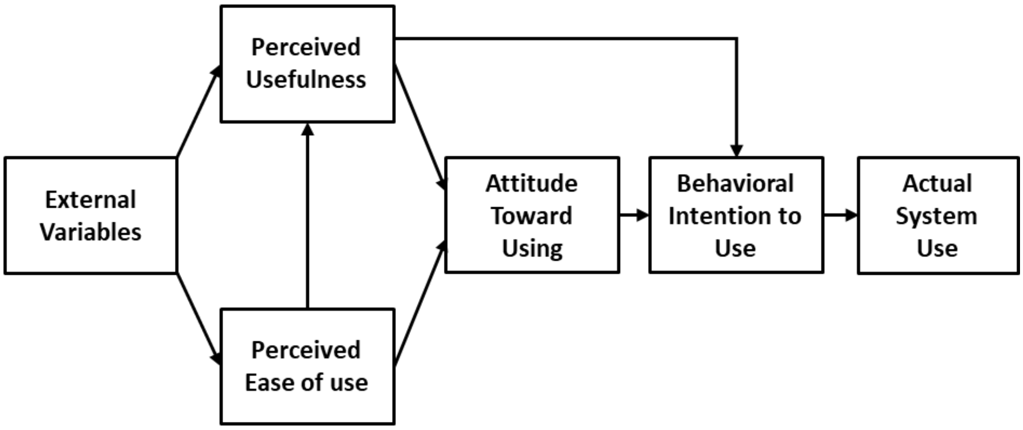

Figure 8 Technology Acceptance Model (Davis 1991)

An adapted version of this concept is done by Venkatesh & Bala, 2008 which stated that the acceptance of a technology follows the following approach: the intention to use the technology is directly predicted by cognitive beliefs regarding i) perceived usefulness of technology and ii) perceived ease to use the technology. Also, both issues are to be determined by four factors:

- individual factors such as personality characteristics, gender and age.
- system and design features of the technology.
- social influence that is defined as the implicit influence of others in our decision-making.
- facilitating conditions such as legal and policy support around the new technology.

This model concept is described in figure below.

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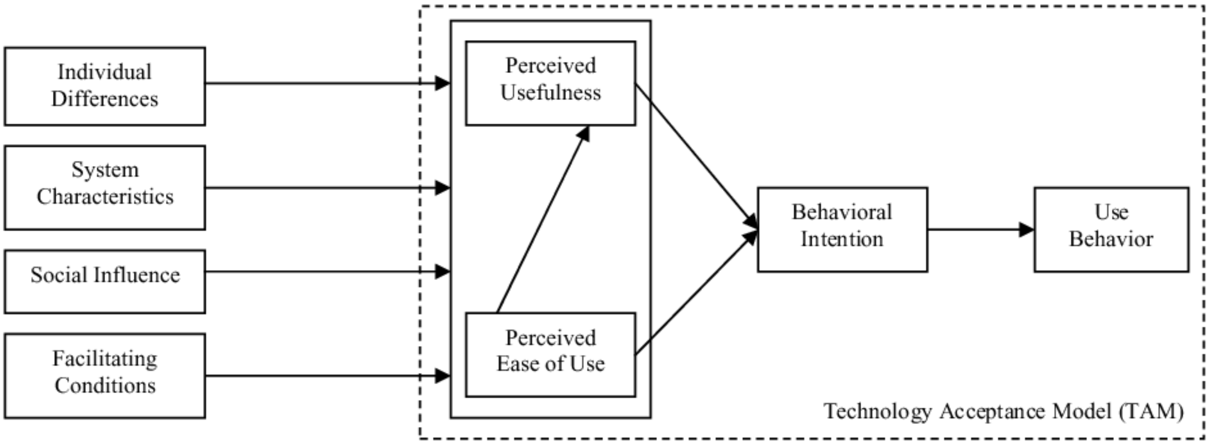

Figure 9 Technology Acceptance Model (*Venkatesh & Bala, 2008)*

On other hand, several projects have defined the factors that influence in the user acceptance of a new technology. Table 50 collects the factors that condition the user acceptance of CCAM solutions and the documents reviewed.

Table 49 Factors user acceptance (CCAM solutions)

Evaluation framework	Factors user acceptance
HARMONY project & Paper Yuerong Zhang & Maria Kamargianni (2022)	**Exogenous factors:** Socio-demographic (*gender, age, education, income, household with children*), mobility and travel related patterns (*travel distance, driving frequency, uni-mode preference, car ownership*), geography (*geographical regions*), built environment (*residence types, proximity to services, bike friendly infrastructure/topography*), weather & environment (*temperature, weather, air quality, noise, pollution, wildlife*), personal traits (*technology interest*), attitude (*passionate for driving, environment concern, public transport, pro-AV sentiment, safety, security, locus of control, mobility on savviness, multiple transport mode*), technologies acceptance theories related factors (*perceived usefulness, perceived ease to use, social influence, perceived trust, perceived safety, attitude towards the technology, facilitating conditions*) **Endogenous factors:** technology and service related attributes (*e.g. automation levels, noise degree, convenience, price and subscription business models*)
SUAAVE project	**Individual differences** (*gender, age, type of road user, vulnerabilities, driving style, experience with innovation, motives, personality factors, personal values)* **Social influence** **Perceived characteristic of technology** (*control, safety, trust, convenience, pleasure*)
PaSCAL project	**Individual perceptions** (*Perceived risks, Perceived ease of use, Perceived quality of travel, Perceived usefulness*) **Behavioural intentions and attitudes** (*Willingness to pay,to adopt,to have others to use, changed mobility patterns*) **Perceived safety and security** (*Perceived Safety, Perceptions of security and privacy, Perceived risks and impacts on attitudes and behaviour*) **Functional design and reliability** (*Perception on the functional design, Perceptions on reliability, Perceived ease of use and impact on attitudes and behaviour*) **Comfort and ergonomics** (*Comfort, Ergonomics, Perceived quality of travel and impact on attitudes and behaviour)* **Convenience in usage and self-actualisation** (*Convenience, Self-actualization, Perceived usefulness and impact on attitudes and behaviour*) **Psychological skills and states and CAV** (*Psychological skills, Technical skills*)
Paper Zmud, J. P., & Sener, I. N. (2017)	Car Technology Acceptance Variables: effort expectancy, performance expectancy, social influence, perceived safety, anxiety, attitudes about the technology, desire for control, technology use, technology acceptance

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Table 51 deals with projects working with energy and mobility solutions in which the factors that condition the acceptance have been also defined.

Table 50 Factors user acceptance (energy and mobility solutions)

Evaluation framework	Factors user acceptance
MAtchUP project	**Social factors**: material living conditions, health, education, living environment Social acceptance: (values, motivation, behaviours, perceived barriers, perceived benefits, social influence)
mySMARTLife project	Social acceptance measured as: • **Technical aspects:** perceived benefit, perceived usefulness, perceived ease of use • **Economic aspects**: perceived costs, riks and benefit.
SunHorizon project	**Social acceptance:** Financial aspects, Technology aspects, Social aspects, Comfort aspects, Space requirements, Aesthetics of technology, Environment aspects **Market acceptance:** Economic aspects, Technology aspects, Organizational/Business, Availability of information, Trust and Legal.

From this analysis, it can conclude that:

- Factors found in projects and papers analysed that influence in the technology acceptance are linked with the acceptance models defined for the conceptualization of technology acceptance.
- Most of the factors found have been identified in all the reference documents although they have been classified under different categories.
- Factors related to technology acceptance identified in the literature correspond with perceptions, needs and attitudes on CCAM solutions, which are exactly the non-technical factors to be measured in the project.

5.3.5 Indicators in the literature linked to project dimensions

This subsection is about the list of indicators found during the literature review, although their names have been shorten to simplify the long list of indicators found. This is because a same concept can be measured with indicators named different because the boundary to evaluate, calculation procedure or unit is different. For example, the indicator named as travel distance can be defined in terms of travel distance per person, for all territory population, per day, per month or per year. In the case of the indicator named as number of trips can be defined per type of mode, per person/all territory population, per day/month/year.

Also, the indicators found in the literature have been classified in this section under potential areas of evaluation. Note that some indicators from this list could not be relevant and a deep analysis on this will be done in the next steps of the project.

Table 52 reflects the classification of indicators under proposed dimensions.

Table 51 Potential areas of evaluation and indicators (impacts)

Dimension	Indicators
Territory features (5 indicators)	Inhabitants Surface Population density Type of territory Degree of hilliness
Mobility behaviour (17 indicators)	**Amount of vehicles by type** Vehicle fleet Total number of transport vehicles for passengers Average number of vehicles entering the city on a daily basis Car ownership per capita of residents

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	Distances and trips Travel distance Number of trips Total number of daily trips by walking and public transport Trip lengths by different modes Vehicle kilometres travelled per person and per vehicle Average number of daily urban freight trips Average distance work-home Main mode work home Passenger kilometres Freight movement **Transport mode** Share of each transport mode / modal split Number of multimodal trips Mode split for personal travel
Safety (6 indicators)	**Accidents** Traffic accidents Traffic safety active modes Number of injuries Number of fatalities Road deaths Number of fatalities and injuries in each mode of transport
Security (4 indicators)	**Security** Percentage of the city area covered by digital surveillance cameras Cybersecurity Data privacy Security
Health (7 indicators)	**Healthy life** Population exposure to air pollution Population exposed to air pollution from transport Modal share and total mileage travelled by active modes of transportation (walking and bicycle) Proportion of people with improved access to health services Average life expectancy Healthy lifestyle reached Social isolation
Economy (40 indicators)	**Costs and revenue structure** Investment Operational and maintenance costs Proportion cost for operation / investment cost External costs (congestion, air pollution, accidents, value of travel time) Income **Funding sources** Funding sources Expenditure on mobility per capita Percentage of municipal budget spent on smart city innovations and initiatives per year **Efficiency** Net Present Value (NPV) Return on Investment (ROI) Internal rate of return Payback Period Revenues variation Revenues of local business Cost recovery Financial benefit for the end user CO_2 reduction cost efficiency Energy consumption reduction cost **Economy performance** Gross Domestic Product (GDP) Annual percentage of growth in GDP that can be attributable to mobility integration and improved mobility to access opportunities Tourist as % of GDP Industry as % of GDP

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	Use of local workforce **Business and Innovation** Research intensity of the city R&D Expenditure Number of businesses per 100 000 population Annual number of new start-ups per 100 000 population New business registered Survival rate of new businesses Number of SMEs introducing innovation to the market Number of large companies introducing innovation to the market Number of new patents Percentage of labour force employed in the Information and Communications Technology (ICT) sector ICT Industry Employment Percentage of the labour force employed in the Education and Research & Development sectors Number of Science, Technology, Engineering, and Mathematics (STEM) higher education degrees per 100 000 population Number of datasets offered on the municipal open data portal per 100 000 population Percentage of municipal datasets available to the public Open data Accessibility of open data
Citizens/Social (23 indicators)	**Income, material living conditions and vulnerable groups** Median disposable income GINI index Energy poverty Population living in poverty People at risk of poverty or social exclusion Housing cost overburden rate Housing overcrowding rate Portion of mobility expenditures of house-hold income Average income spent on transport Household income spent on energy Affordability of using mobility services Monthly ticket price for public transport Parking cost House prices/rents Share of adults with at least basic digital skills Young people neither in employment nor in education and training Long-term unemployment rate **Employment opportunities** Unemployment rate Youth unemployment rate Job creation Median gross earnings of newly contracted employees **City services** Growth of transport services sector Public Wi-Fi
Environment (17 indicators)	**City energy profile** Final energy consumption in the city (total, per capita) Primary energy consumption in the city (total, per capita) Renewable energy within the city Renewable electricity generated within the city **Transport energy profile & energy source of vehicles** Energy consumption of the mobility sector (total, per capita) Energy consumption of e-vehicles Fuel consumption Local freight transport fuel mix Percentage of renewable energy use in public transport **Air quality and Climate Change emissions** Nitrogen oxide emissions (NOx) Fine particulate matter emissions (PM2.5) Air quality index Air pollutant emissions

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	Ozone Green House Gases (GHG) **Noise** Noise pollution Exposure to noise population Hindrance of population by noise generated through urban transport
Land-use (30 indicators)	**Urban land use** Compactness Population density Land consumption Density of housing Density of employment and shopping Green areas Daily individual consumption of public space Urban functional diversity **Urban land use for mobility** Mobility space usage Length road network Kilometres of high capacity transport system Kilometres of high capacity public transport system Use of space for parking Public Transport Infrastructure Public Transport Network Public transport stops Share of urban space (for public transport, private/shared cars, cycling/scooter lanes, pedestrian) Pedestrian infrastructure Length of bike route network Extent of on-street cycle network Opportunity for active mobility Number of lanes Number of parking slots Release of land from transport to other uses Multimodal integration **Planning** Land use planning Urban Development and Spatial Planning Planning quality Space needed for road Space needed for transport and parking [km] of street sections with certain speed limits
Vehicles (36 indicators)	**Vehicles** Typology of vehicles Vehicle fleet per fuel type Number of autonomous/automated PT services on dedicated lanes Percentage of vehicle registered in the city that are autonomous vehicles Average age of vehicles **Clean-mobility (low emissions and non own vehicle)** Share of public transport Share of private car transport Share of car sharing transport Public transport use Public transport user Public transport trips Public transport service per head of population Car ownership Bike ownership Car share cars and stations per capita Bike sharing bikes and stations per capita Low-Carbon Emission Passenger Vehicles Number of e-vehicles (total, per capita) EV penetration rate in public transport EV penetration rate in sharing transport Number of shared e-scoters

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	Number of shared e-bikes Share of green deliveries EV public charging points Public charging points per eVehicle Number of e-charging stations for e-vehicles Number of e-charging stations for e-buses Number of slow charging stations Number of fast charging stations Use of public EV charging stations (energy) Use of public EV charging stations (number of chargers) Use of public EV charging stations (number of different users) Multimodal integration Percentage of commuters using a travel mode to work other than a personal vehicle Transportation Mode Share Users of mass transit (MT)
Network efficiency (46 indicators)	**Travel time** Total/average travel time Total duration of trips per week Commuting travel time Travel time by different modes Network-level journey time per week **Congestion** Travelling at peak hours Traffic density Average vehicle speed Percentage of vehicles speeding Peak speed related to car speed at peak times Vehicle occupancy rate Traffic calmed and car-free/pedestrianised streets Congestion Peak and off peak (travel time) Public transport trips in the peak **Efficiency, flexibility and reliability** Share of used road types per week Travel time reliability Delay Average Journey Delay Delays to freight distribution trips Waiting time Average waiting time at stops Waiting times at junctions Average vehicle speed Goods delivery frequency Flexibility in delivery services Urban functional diversity Average frequency of services Resilience of the road network to floods and other extreme weather conditions Barrier effect of roads and traffic on the mobility of pedestrians **ICT extent** City area not covered by telecommunication connectivity City area covered by municipally provided internet connectivity City area mapped by real-time interactive street maps Traffic monitoring Real time traffic information Intersection control Internet connectivity for commuters Percentage of public transport routes with municipally provided and/or managed. Percentage of city streets and thorough fares covered by real-time online traffic alerts and information Percentage of public transport lines equipped with a real-time ICT-based system

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	Percentage of public parking spaces equipped with real-time ICT-based availability systems Percentage of city area under a white zone/dead spot/not covered by telecommunication connectivity Share of passengers that use a smart method to pay for or validate a PT (public transport) ticket Share of PT vehicles that are equipped to provide real-time data that is released to passengers Percentage of local businesses contracted to provide city services which have data communication openly available
Equity (11 indicators)	**Accessibility for vulnerable groups** Accessibility for vulnerable groups to mobility services Accessibility of public transport for mobility-impaired groups Public transport offer adapted for persons with reduced mobility Accessibility of stations and stops to people with reduced physical mobility Accessibility of vehicles to people with reduced physical mobility Number of persons with disabilities that have real-time ICT-based interactive mapping applications per 100 000 population Inclusion of vulnerable groups in mobility services design **Affordability for vulnerable groups** Affordability of public transport for the poorest group Affordability of public transport for mobility impaired groups Gender income equity **Governance** Vulnerable groups targeted in policies
Accessibility (8 indicators)	**Accessibility** Access to mobility services Access to public transport Access to vehicle sharing solutions for city travel Population residing less 500 metres from a public transport stop Proportion of people with improved access to recreation and other services Number of jobs accessible Number of public services within 10-min walk and job opportunities within 30-min commute of residents Accessibility of lower density areas
Perceptions	**Individual features** *Personal values*: Social awareness towards the solutions deployed, Environmental awareness, Procedural justice, Distributional justice *Motives*: Cognitive enjoyment, Satisfaction with vehicle ownership **Social influence** *Perceived market:* Market orientation, Market demand **Perceived characteristic of technology** *Safety (trust):* Perceived safety on board and others sharing the road with AVs or while walking, sense of safety from injury caused by motorised transport or cycling *Security (trust):* Privacy preference, Improved cybersecurity, Improved data privacy *Quality:* Travelling reliability, Perceived comfort (e.g. sense of appropriate traffic speed, noise , etc), Quality of public transport, satisfaction with public transport *Ease of use & usefulness:* perceived usefulness, perceived ease to use **Perceived benefits / disadvantages** *Accessibility:* Improved access to basic health care services, Improved access to vehicle sharing solutions *Personal benefits:* Value of travel time savings, Encouraging a healthy lifestyle *Economic*: Cost, risk, benefit Aesthetic: Vehicle, Visual environment **Behaviour:** Intention to use, Willingness to pay to use, Willingness to invest, Willingness to recommend, Citizen-driven upscaling, Changing societal norms, Diffusion to other locations, Diffusion to other actors

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Final conclusions from the review of existing indicators are described below:

- More than 252 indicators have been found to measure the dimensions considered in this section. Additional indicators have been identified to measure perceptions.
- Indicators found correspond with qualitative and quantitative indicators and input, outputs, outcome and impacts indicators.
- Definitions of indicators provided by some of the documents reviewed are short and do not include the calculation procedure. Consequently, the evaluation to perform sometimes is not clear and generates doubts which is not desirable since definitions should not open for different interpretations.
- A same indicator can be appointed with different names or can be calculated with different formulas. The evaluation to establish must not include redundant indicators.
- The calculation of some indicators requires a high effort in the data collection. It is needed to think about the suitability of these for the case of CCAM project since the indicators must be measured with the tools established in the project and in the achievable timeframe and data must be available.
- Some of the definitions found are nowadays not applicable since it has produced a change (i.e. normative, etc).
- A detailed review of all indicators must be done in order to select those that are relevant for the project, allow the evaluation of the whole impacts identified to reach, be measurable, reliable, familiar, non-redundancy and independent.

Finally, for a best understanding of the mentioned gaps, some definitions of indicators found in the literature reviewed are shown in Table 53.

Table 52 Gaps in indicators definitions

Gap found	Indicator name	Indicator description	Evaluation procedure
Calculation procedure of indicator is not described	Noise pollution	Share of the population affected by noise >55 dB(a) at night time (% of people)	---
Same name of indicator but calculated through different procedure. Additionally, the procedure is not well established.	Congestion	Delays in road traffic and in public transport during peak hours compared to off peak travel (private road traffic) and optimal public transport travel time (public transport)	The indicator is evaluated with the information collected during monitoring period (i.e. once the solution has been deployed)
		Increase in overall travel times when compared to free flow situation (uncongested situation) (% in hours)	The indicator is evaluated after a comparison among the value of baseline (initial situation;_i.e. before technology solution deployment) and final situation (once technology solution has been deployed)
	Access to public transport	The extent to which public transport stops are available within 500 m (Likert scale)	**Likert scale:** No stops – 1 — 2 — 3 — 4 — 5 — Many stops *1. No stops* *2. Relatively few stops*

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			3. A relatively reasonable number of stops *4. A relatively sufficient number of stops* *5. Relatively many stops of public transport*
		Share of population with access to a public transport stop within 500m (% of people)	(Number of inhabitants with a transportation stop <500m/total population)*100% NB. It can be calculated as the sum of buildings with a point of access within 500m, multiplied by its inhabitants. A point of access is defined as the location where a mode of transportation can be accessed.
The calculation of the indicator is complex and requires a high effort	Public transport trips	Annual number of public transport trips per capita shall be calculated as the total annual number of transport trips originating in the city - "ridership of public transport" - (numerator), divided by the total city population (denominator). The result shall be expressed as the annual number of public transport trips per capita.	Transport trips shall include trips via heavy rail metro or subway, commuter rail, light rail streetcars and tramways, organized bus, trolleybus, and other public transport services. Cities shall only calculate the number of transport trips with origins in the city itself. Transport trips shall include trips via heavy rail metro or subway, commuter rail, light rail streetcars and tramways, organized bus, trolleybus, and other public transport services. Cities shall only calculate the number of transport trips with origins in the city itself.
Definition of indicator is nowdays not applicable: Indicator defined before the existence of the GDPR rule which has replaced the Directive on the protection of personal data (95/46/EG).	Data privacy	The level of data protection by the city	**Likert scale:** Not at all — 1 — 2 — 3 — 4 — 5 — Very high *1. City doesn't follow national regulations/laws on protection of personal data.* *2. City follows national regulations/laws on protection of personal data.* *3. City follows relevant national regulations on protection of personal data and the EU Directive on the Protection of Personal Data (95/46/EG).* *4. City follows all the relevant national and European regulations/laws related to data privacy and protection. If personal/private data is collected from citizens, proper authorisations with written agreements are made.* *5. Relevant national and European regulations on data protection and privacy are followed and written agreements are made for use of citizens' private/personal data. All the collected personal/private data, especially sensitive personal data, is accessed only by*

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			agreed persons and is heavily protected from others (e.g. locked or database on internal server with firewalls and restricted access).

5.4 Next steps

Project partners must design the evaluation framework to apply in the multi-systems impact assessment modelling tool considering the list of impacts, acceptance factors and indicators found during the literature review and reported in this deliverable. To this end, partners must define the components (i.e. dimensions and indicators) that better represent the potential effects. Exactly it must identify these components and provide a clear definition on what to evaluate. Additionally, co-creation activities must focus in this process.

Specific activities to be carried out with the outcomes of this section are shown below:

- Define the evaluation approach of the project and the indicators requirements.
- Selection of impacts and indicators taking into account the evaluation approach and project requirements as well as the criteria stablished in existing evaluation frameworks: be relevant, complete, measurable, reliable, familiar, non-redundancy and independent.
- Identification of new impacts and indicators to cover gaps found in the literature reviewed.
- Definition of indicators with the following items:
  - Indicator name
  - Dimension where the indicator is allocated which is linked with the impacts or technology acceptance factors
  - Indicator description which include a clear definition of what to evaluate and how to evaluate.
  - Unit of measurement
  - Reference document on which the indicator is based
  - CCAM solution to evaluate with the indicator
- Establish the relationships between impact categories.

6 CCAM in prototypical areas: Transport needs, current status and potential implementation of CCAM solutions

6.1 CCAM in prototypical areas: HELMOND

6.1.1 Main features of the prototypical area

Helmond is a medium-sized city - 95,000 inhabitants - located in the south east of the Netherlands (see Figure 10), 10 km from a bigger city, Eindhoven, the 5th largest city in the Netherland. After the crisis in the 1970’s, there has been a continuous increase in the number of inhabitants living in Helmond. Since the 1980’s, its population has nearly doubled, as well as the number of jobs. In the same time, the number of companies located has been multiplied by three and a half (more than 7500 in 2019). It is foreseen that the growth will continue in the years to come. Helmond anticipates to build 15 000 new houses (25% extra houses), 10 000 new working places and to create 20 000 new jobs. This growth generates a pressure both on housing and mobility. Helmond is based in Noord-Brabant, one of the three most important economic areas in the country. The region is known for its focus on R&D at the Eindhoven University of Technology (TU/e), TNO, the High-Tech Campus and the Automotive Campus (where over 35 companies work on innovative

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mobility solutions), which plays a role as a physical hotspot where the automotive world and mobility world meet.

Figure 10 Location of Helmond in the Netherlands

Helmond is a city well connected to external cities/ regions due to the existence and operation of four train stations. Helmond's train stations provide good public transport connections to the outside world. On average the number of train travellers during a workday in 2019 (before Covid) were the following (per train station in Helmond)[2]:

- Helmond central: 7833
- Helmond Brandevoort: 1727
- Helmond ‘t Hout: 1459
- Helmond Brouwhuis: 1839

[2] https://www.treinreiziger.nl/reizigersaantallen-in-2020-schiphol-grootste-daler-lansingerland-zoetermeer-kleinste-daler/):

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Figure 11 The four train stations in Helmond

However, as it is typical for many small and medium-sized cities, efficient last mile connections from/ to the train stations (covering a big part of the city as shown in Figure 11 and Figure 12) are currently lacking.

The bus network in Helmond is notably quite limited, both in terms of bus lines and in terms of frequency. There is one bus line with a high level of service (line 320), 4 regional bus lines (23,24,25 and 26), 1 bus line operating as an extension to the Automotive Campus from the main train station, only at peak hours (line 150), small minibus citybuses (8 seats : 23,24,25,26), one Buurtbus line (line 261 : a small bus driven by volunteers). The bus is mainly used by captive population, i.e. elderly and persons that do not have any alternative. The reliability of the bus service is an issue: the percentage of delayed bus services amounts to 13%.

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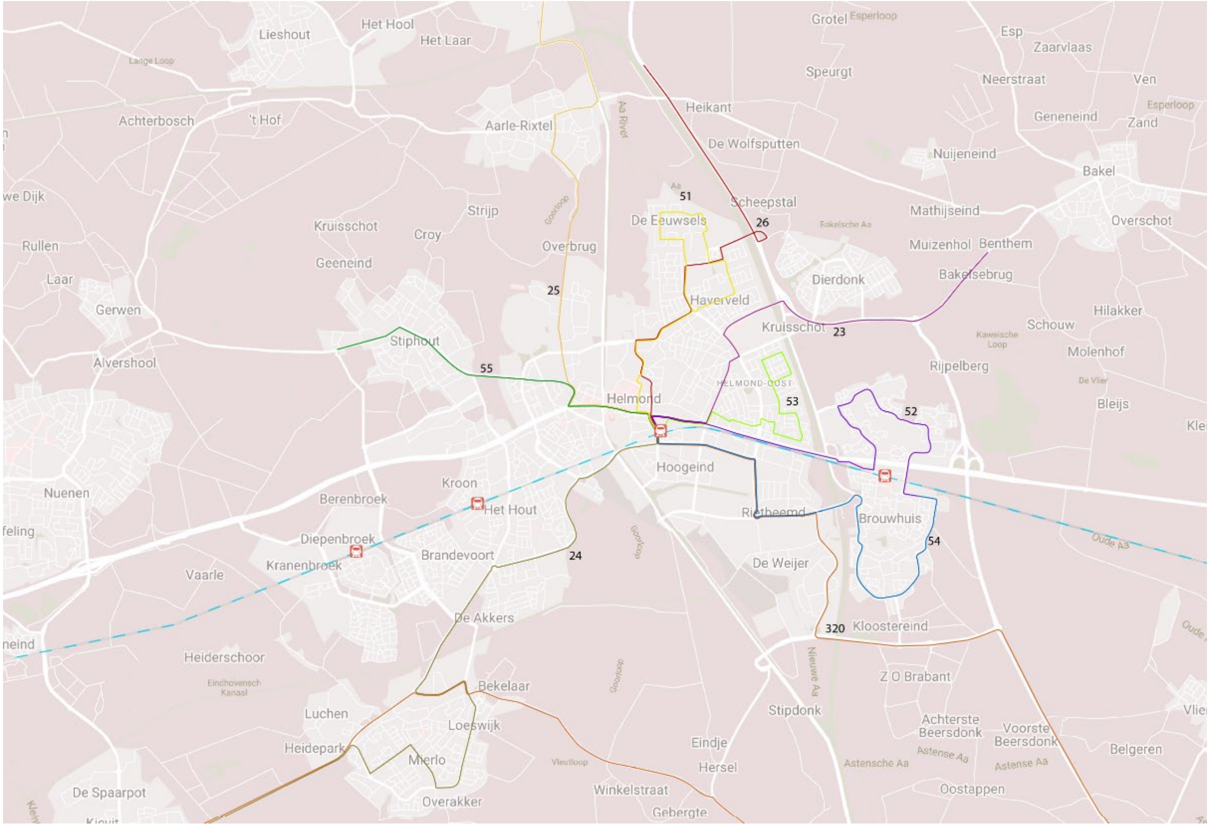

Figure 12 Helmond bus lines

A Demand Responsive Transport service called Taxbus as been added to the offer. But so far the use of this service has been limited and there is still a lack of awareness of the general public of the DRT option.

On an organizational level, it can be stressed that the City of Helmond is not the Local Transport Authority. The Province of Noord Brabant is responsible for the organization of Public Transport / Bus services on its territory. Through tenders, the Province selects a public transport operator and grants this operator the exclusive right to provide transport by bus. Hermes is the operator that was selected till 2026.

One ride hailing service, one car sharing service, one bike sharing service and one micromobility sharing service are also available in the city. The car ownership levels in the city are equivalent to 0.5 per capita and the city has a total of 59 EV charging stations.

The modal split shows that the public transport use is limited. On average, private vehicle trips in the city of Helmond have a share of 58% in the modal split, followed by bicycle trips which represent 38% of total trips and the remaining 4% are trips conducted by bus.

6.1.2 Overview of CCAM solutions in the area

Within 2021 and 2022, Helmond has tested two different automated shuttle systems:

- Within FABULOS EU project, Helmond has tested a shuttle (Navya) between Brandevoort railway station and the Automotive Campus. The context of this test is important: due to COVID restriction rules, notably social distance, only one passenger in addition to the steward could be transported on-board the automated shuttle. There has been however many lessons learned from this first experience with CCAM solution. It has been possible to assess what an autonomous shuttle is able to do and what is not yet technically possible.

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The conclusion we could draw is that additional developments are still required before the autonomous shuttles vehicles can become fully autonomous in mixed traffic without a steward on board and then become the transport service we can expect.

- Helmond also gained experience on the necessary (legal) procedures and approvals needed to get these new types of vehicles circulating on public roads.
- Smart Mobility and specifically C-ITS and CCAM are important pillars for Helmond to position itself even more firmly as a city of smart mobility. The political landscape in Helmond is therefore optimally organized for the development and application of smart mobility solutions. This is true not only in Helmond but as well in our Brainport region. This political support ultimately played a decisive role in making the field test in Helmond possible.
- It was hardly possible through Fabulos pilot – with one vehicle and only few persons that could be taken on board – to draw conclusions on what regards the modal split or the impact on the environment. However, once deployed, such automated shuttle can have less impact in terms of emissions and of noise as they are electric vehicles and collective transport which can be more flexible than the conventional ones (notably if on-demand), then more attractive.
- The (quite few) users of the shuttle nearly had unanimously a positive attitude towards the automated shuttle, as well as the other users of the road (pedestrians and cyclists). Some negative feedback came from car drivers that had to drive at a relatively low speed when the vehicle was in front of them
- Within LivingLAPT EIT Urban Mobility project, Helmond tested another automated shuttle (AuveTech) in a different context/ODD in September 2022. Indeed, due to the timeline of the project (one year project) and to the demanding process to obtain an authorization to circulate on public roads, it has been decided to organise a pilot on a private ground. The idea was to test the reaction of the vehicle in specific use-cases, to test the possibility of the vehicle to be remotely control in case of an expected event, to make citizens more aware of the possibilities offered by these vehicles and assess their reaction. The project will further look at the current legislation procedure permitting unmanned shuttles on public roads.
- Within ECSEL-SECREDAS, Helmond focused on integrated security, safety and privacy solutions for autonomous driving. It tested the mitigation actions that should be taken in case of an cyberattack on automated vehicles and/or a cyberattack of Helmond’s C-ITS infrastructure. The project has made a significant step to create a trusting environment - essential to connect the technologies to the lives and future of citizens.

6.1.3 Main challenges to overcome for the deployment of CCAM solutions

One of the main challenges that the city has to face is that the main road cuts Helmond in two halves. A lot of vehicles are passing on this road more than 30.000 per day, notably 2000 HGV/trucks (see Figure 13). It has a significant impact in terms of congestion noise and pollution. The intensity of the traffic makes it also complicated for the pedestrians and cyclists to cross this road. In order to smooth the traffic, to optimize the flows, to create more safety and to some extent to generate less emissions, Helmond has invested for years in (C-) ITS solutions and services resulting in the installation of 57 smart traffic lights being able to communicate with vehicles (through cellular and ITS-G5 communication). Hybrid C-ITS infrastructure in Helmond is available. Some C-ITS services, e.g. GLOSA (based on national Talking Traffic architecture (www.talking-traffic.com)) are provided by the City of Helmond.

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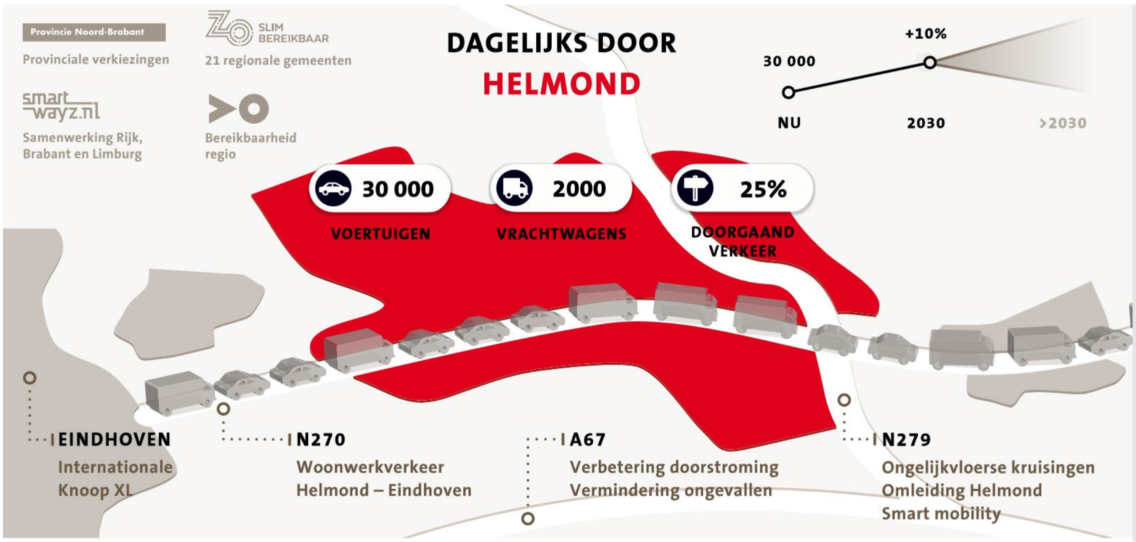

Figure 13 Traffic on Helmond main road

Helmond has a double challenge in the years to come: it needs both to build more houses and to provide people with a liveable city, with the objective of becoming a climate neutral and smart city.

This is why the City of Helmond and its stakeholders decided to design a new district called Brainport Smart district. In this new district (see Figure 14), 2500 houses and a small business park will be built by 2030. Brainport Smart district is close to Brandevoort Station - one of the four stations in Helmond. From the station, it takes 5 min by train to go to Helmond city centre. It takes 7 minutes to go to Eindhoven city centre.

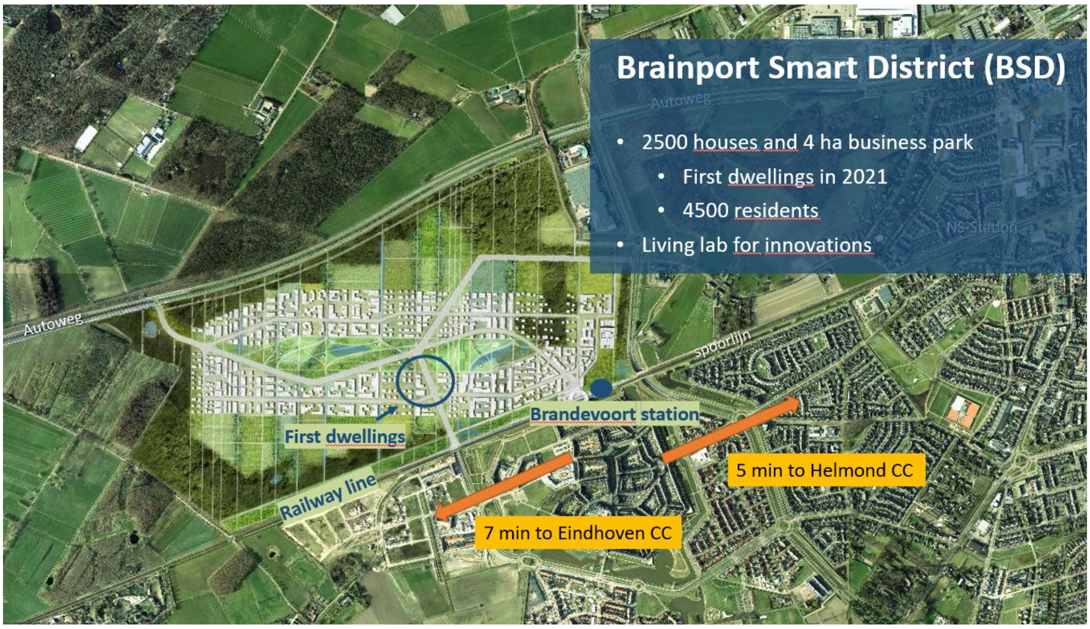

Figure 14 Brainport Smart District

Brainport Smart District intends to be a living lab for innovations. Companies, universities and citizens are encouraged to test innovative solutions in the district.

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As mentioned above, Helmond will face major challenges regarding accessibility, liveability, social inclusion, climate, road safety, economic prosperity in the years to come. People will have to adapt the way they live and move. Helmond is convinced that CCAM can play an important role in the mobility transition.

In the months and years to come, Helmond would like gradually to implement CCAM transport passenger and freight last-mile services that are complementary to the public transport network and that are useful for (and used by) the citizens. Our idea, that needs to be challenged with the ones of our citizens and stakeholders, is to focus on last-mile on-demand automated shuttles as they could be an efficient and flexible.

Helmond municipality knows that the process will be gradual as it will take some time before such services without a steward on-board (a condition if one wants to build a sustainable business model) can be operational on public road in mixed traffic. The needs and expectations of citizens and stakeholders need to be understood, including the most vulnerable ones and the ones that might be impacted the most by the mobility transition in progress.

The city can prepare the ground and aim at maximizing the positive impact while mitigating the potential negative impacts. As a city, a scenario in which the deployment of CCAM results in more vehicles circulating in the streets (and even in the air) must be avoided, and also other scenarios like a modal shift from active and shared modes to individual autonomous vehicles or more congestions in the streets due to the number of vehicles and kilometres driven (whether they be electric and autonomous). This would indeed impact negatively the health of the citizens and keep a significant part of our city dedicated to vehicles. On the contrary, shared CCAM can be a chance to dedicate urban space that is currently allocated to parking to greener and more useful and citizen-oriented purposes. CCAM solutions should contribute in a more liveable city. In terms of safety, the municipality of Helmond believes that CCAM solutions can result in less accidents and collisions in the cities. On the other hand, new risks possibly related to cybersecurity may occur. In terms of economy, Helmond intends to work in close cooperation with its stakeholders and economic partners to create CCAM products and services that are economically beneficial for the region. But the question of the loss of certain categories jobs (e.g. bus drivers) needs also to be well anticipated and taken into account. The city needs to listen to and understand the fears of the ones that are directly impacted by the changes implied by such a deployment. It is very important for Helmond to make sure that not only a few individuals can benefit from the CCAM solutions implemented, but that inclusion and equity aspects are carefully addressed, including the most vulnerable ones (elderly, disabled).

6.2 CCAM in prototypical areas: Gornoslasko-Zaglebiowska Metropolia (GZM)

6.2.1 Main features of the prototypical area

The GORNOSLASKO-ZAGLEBIOWSKA METROPOLIA [GZM Metropolis] is an association of 41 cities and communes with 2 335 883 inhabitants, located in Upper Silesia and Zagłębie in Poland. Metropolis GZM is situated on the main national and international routes, both road and rail ones. In the northern part of the Metropolis, there is an international airport of Katowice-Pyrzowice. Metropolis GZM is an economic centre, being a trade and service midpoint with a significant share of production activity. It is also the centre of concentration of specialist in medical services, academia, culture, religion and sports.

Metropolis GZM is located at the crossroads of a number of road traffic routes. Several Poland’s railway transport nodes are situated within Metropolis GZM, both for passengers and freight. Several dozen railway lines managed by PKP Polish Railways run through this interesting

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association of cities and communes. Metropolis GZM is located at the crossroads of two trans-European transport corridors.

The GZM Metropolitan Office is a public administration unit established by law. Among its most important tasks are the planning, coordination, integration and development of public transport and sustainable mobility. The GZM Metropolis acts as an integrator of the most urbanised and populated part of the Silesian Voivodeship. It therefore endeavours to design, implement and test innovative urban mobility concepts, linking densely populated urban centres (e.g. Katowice) with extensive public transport systems and shared services and sparsely populated suburban and regional areas, which are mainly accessible by car. Due to the region's high economic activity, a rapid transition to regional and urban transport and environmental sustainability is a priority in the conurbation. Understanding its polycentric and urbanised nature, the GZM is working on transport sustainability (SUMP) and data management (Open Data Store) solutions H2020 project partner: ASSURED-UAM Assured uam | Assured Uam (assured-uam.eu) and HARMONY Home - HARMONY (harmony-h2020.eu), as well as within the Urban Air Mobility Inititaive Cities Community Urban Air Mobility (UAM) | Smart Cities Marketplace (europa.eu).

As data on the number of private cars indicate: 1,508,515 private cars travel in the GZM area.

The public transport system organised by GZM through Metropolitan Transport Authority (ZTM) is the largest in Poland in terms of area served and number of transport lines. In 2020, 92,060,249 km were covered by buses and trolleybuses[3].

Functioning public transport system.

The bus fleet serving the bus transport network in the GZM area consists of ~1500 vehicles, with diesel-powered buses being the most numerous.

Transport lines:

- approx. 434 bus lines
- 8 trolleybus lines
- 31 tram lines

Low-emission vehicle fleet:

- 148 CNG buses
- 1182 ON buses
- 41 hybrid buses
- 23 trolleybuses
- 17 electric buses
- 311 tramcars

Vehicles using alternative fuels represent a small but growing percentage of the total number of vehicles - 11.78% in total.

The legislator, in the Act on Electromobility and Alternative Fuels, imposed an obligation on local government units, excluding municipalities and districts with a population of less than 50,000, to have a share of zero-emission buses in the fleet of vehicles used to provide public transport service at 30% from 1 January 2028 (see Figure 15).

[3] https://bdl.stat.gov.pl/bdl/dane/podgrup/tablica

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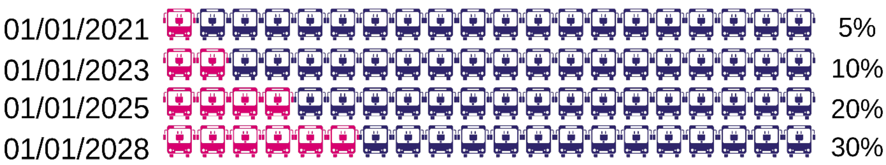

Figure 15 Progression on the share of zero-emission public transport buses - GZM

Table 54 shows the share of non-walking trips of inhabitants grouped by modes of transport (source: Transport Study of the Central Sub-region of the Silesian Voivodeship, Report 10, Stage 7[4]).

Table 53 Share of non-walking trips of inhabitants - GZM

modes of transport	share of non-walking trips of inhabitants of the analysis area
collective transport	23,5%
car	64,7%
bike	4,5%
combination of several modes	1,3%
other	6,0%

Number of journeys indicated in 2021 shows:
Total 272,492 thousand of which:

- By buses 201,315 thousand.
- Trams 66,800 thousand.
- By trolleybuses 4,377 thousand.

Concerning the development of electromobility in GZM public transport it is important to notice that the Metropolis is treating the purchase and operation of the first 20 hydrogen buses as a pilot, testing how they will cope in day-to-day operation and regular service and how they balance out cost-wise. Hydrogen and battery buses, although both electric, are complementary rather than competing with each other.

Due to different circumstances, in some situations it will be more beneficial to use battery buses, but when there are much longer distances to travel - hydrogen buses will prove unbeatable.

Intelligent Transport Management Systems (ITS)

Intelligent transport management systems are being introduced in selected cities of the GZM as a tool, among others, for the development of cooperative, connected and automated mobility. ITS services in general, and C-ITS (cooperative ITS) services in particular, along with the introduction of driving automation functionalities in vehicles are generally seen as converging paths: vehicles being connected to the mobility ecosystem in their immediate vicinity (other vehicles, infrastructure) and to the wider mobility ecosystem (central traffic management systems, other modes of transport, etc.), and to the internet.

ITS is operational in Gliwice (see Figure 16), Chorzów, Tychy and under construction in Katowice.

4 http://subregioncentralny.pl/transport/studium-transportowe-subregionu-centralnego-wojewodztwa-slaskiego

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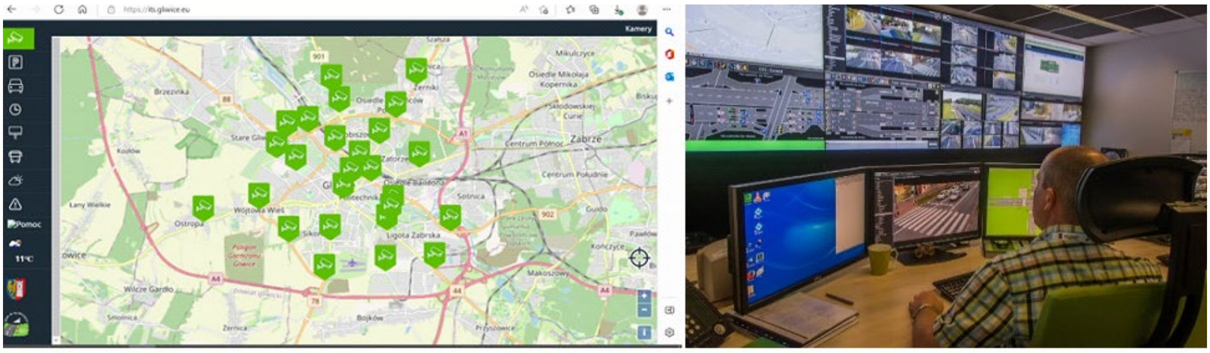

Figure 16 Gliwice ITS

The most advanced Intelligent Transportation Systems (ITS) solutions have been implemented in Gliwice since 2014. ITS collects and provides up-to-date information from the city's streets, which is processed in the Traffic Control Centre. Gliwice was the first city in Poland to have ITS cover all traffic lights. With the development of the system, functional improvements were also introduced. All modernised traffic lights have LED lamps, which not only consume over 8 times less energy than incandescent lamps, but are also more resistant to weather conditions and the light they emit is more visible in changing weather conditions. ITS, is also used by the city's police force. This is because the camera records help to settle disputes over the cause of traffic incidents and confirm the presence of wanted vehicles on the road. The system also allows the services to reach an incident threatening the safety of residents or other incidents quickly and without hindrance. It is invaluable for the smooth organisation of traffic flow in the city. The traffic control system is constantly being upgraded and updated. By coordinating the operation of control devices within more than 60 intersections simultaneously, Gliwice's ITS enables drivers to drive more smoothly and safely through the city. It facilitates the movement of buses and provides up-to-date information on the traffic situation. The most important information for drivers (including detours) is displayed on variable message boards located along the main routes entering the city. The main development areas of the system are the prioritisation of approx. 150 public transport buses to pass through junctions with traffic lights, as well as giving absolute priority to emergency vehicles (police, ambulance, fire brigade) to pass through junctions. Further signs providing dynamic information on the current traffic situation are also planned as part of the modernisation, as well as traffic measurement points providing data on traffic volumes in the city. The information displayed on the signs will be supplemented by an Internet service, which will mark the current obstructions occurring on our city's roads. A new feature in the field of street monitoring will be the automation of traffic incident recognition. Another innovation will be the introduction of a weight-based vehicle pre-selection system - all cars passing through the pre-selection points will be weighed and the details recorded in a system that will indicate vehicles with an overweight limit. There are also plans to build charging stations for electric cars.

The Silesian public services card

The Silesian Public Services Card (see Figure 17) [PL: Śląska Karta Usług Publicznych ŚKUP] - a project developed in the GZM since 2012 - serves to:

- encode season tickets
- payment of parking fees in Bytom, Chorzów, Katowice, Piekary Śląskie, Tychy and Zabrze,
- payment in cultural facilities (including museums, theatres and municipal cultural centres),

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- payment in leisure and sports facilities (e.g. swimming pools, ice rinks, tennis courts and sports halls),
- payments in libraries,
- making payments in city offices,
- logging on to city bike rental stations.

In the future, the Silesian Railways are to join the system.

Figure 17 Silesian Public Services Card

ŚKUP 1.5 as a component of ITS in cities

As of 2021, the Upper Silesian and Zagłębie Metropolis is developing 'Railway Sharing Contract 1.5 - Modernisation of the public transport fare collection system'. The following changes to the system are planned as part of the contract:

- online operation instead of offline operation,
- the card only as a data identifier and not as a data carrier,
- a mobile application as the basis of the system,
- automatic activation of purchased tickets,
- no need to visit a Customer Service Centre when creating accounts.

GZM open data sources[5]

The GZM Data Store project - Open Data of the Upper Silesian and Zagłębie Metropolis - is the creation of a common platform for open data about the Metropolis and making the data collected in the metropolitan union available to citizens. Between June 2020 and February 2022, the first task of the GZM Data Store project was in progress. 195 datasets on 5 (*.rdf) as well as 3 (*.csv) levels of openness from the 28 participating municipalities were made available and 119 visualisations of the datasets were produced. The datasets have been published on the GZM Open Data platform, which is available at: https://otwartedane.metropoliagzm.pl/.

Among the datasets made available are those relating to transport: Timetables and bus stop location (GTFS RT) and data on the exact location of buses from GPS receivers mounted on buses sampled approximately every 30 seconds. The datasets are provided by the Metropolitan Transport Authority in Katowice and the datasets are used by the maps.google.pl service. Using the maps.google.pl service, users can plan a journey taking into account the actual departure time / public transport vehicle and plan transfers. As part of the continuation of the data opening process, a further task is planned in 2022 to make available data sets held by municipalities, their organisational units and PKM Katowice, PKM Tychy, PKM Sosnowiec PKM Świerklaniec. Public administrations hold large amounts of valuable resources, such as mobility, transport, economic or financial data. This data can be successfully used to create products and services.

The metropolitan railway[6]

The Metropolitan Railway as the backbone of the entire public transport system in the Metropolitan area. The project envisages four options for the development of the railway - from the basic to the most extensive. The total cost of all variants has been estimated at more than PLN 16 billion. The implementation of the entire project is envisaged for the years 2019-2039. Each successive variant of the project includes all of the solutions indicated in the previous variants, as well as additional solutions.

[5] https://otwartedane.metropoliagzm.pl/
[6] Kolej Metropolitalna - Metropolia GZM

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From utilising existing infrastructure capacity by subsidising rail connections in its area, to building the first of the new tracks dedicated to the Metropolitan Railway. A total of almost 220 km of single track. In further stages of development, light rail is to be built and a monorail solution is to be considered, e.g. connecting Pyrzowice International Airport with Katowice and Sosnowiec. The development of the network assumes the addition of new passenger stops.

At the same time, the Upper Silesian and Zagłębie Metropolis also participates in the "Kolej+" (Rail+) programme, which aims to supplement the rail network in towns and cities with a population of over 10,000, which do not have access to passenger connections with voivodeship cities, or which have access to rail, but the existing connections need to be improved. A total of 15 projects worth PLN 1.7 billion have been submitted from the Metropolitan area. This includes six line projects designed to improve connections between several communes and the provincial city of Katowice, and nine point projects designed to improve the operation of the railway within a single commune. All projects are part of the concept of building the Metropolitan Railway.

The zero-emission transport network

Successive delivery of 32 new electric buses by the GZM, as well as the delivery and commissioning of 16 plug-in chargers with a power of min. 80 kW (2x40 kW), construction of 11 pantograph chargers with a power equal to 200 kW. The scope of the project also includes the development of a system that will manage the chargers and the settlement of energy consumption and payments between operators using the pantograph chargers.

GZM is also involved in a number of hydrogen technology market initiatives, including as a member of the European Alliance for Clean Hydrogen, under the Sectoral Agreement for the Development of the Hydrogen Economy in Poland, and through participation in the work of the Hydrogen Technology Committee of the Polish Alternative Fuels Association.

The metropolitan bike service

The Metropolitan Bike System is designed to equally satisfy the following tasks:

- to ensure seamless movement in conjunction with public transport systems within the framework of tariff integration and the use of interchanges (implementation of the MaaS concept);
- supporting movement between municipalities of the GZM - this applies in particular to spatially integrated localities or those connected by planned velostrades;
- support of changes in transport behaviour in favour of cycling;
- recreational use of bicycles in connection with metropolitan attractions (parks, tourist attractions).
- The above needs translate into the following assumptions of the Metropolitan Bik system in quantitative terms:
- high accessibility of the bike sharing system expressed in terms of number of vehicles and density of stations;
- zoning linked to population and user density;
- number of stations and bikes graded according to location and potential demand;
- overall distribution of the number of bikes and stations depending on the role of the centres in the metropolitan structure and the expected demand.

On the area of the GZM there is a need to ensure the possibility of efficient transfers and journeys, which is to be ensured by the introduction of public cycling, coordinated with other modes of transport. The present inter-municipal transport system requires support, despite the fact, that some communes of the GZM have their own bicycle systems, which, however, are not sufficiently compatible with other modes of transport.

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The planned undertaking will enable the planning of journeys and efficient billing thanks to integration with public transport tickets. The bike sharing system will also act as a complement to other modes of active mobility, e.g. UTOs (e-scooters), creating a common mobility "ecosystem".

In the designed system the bicycle will serve urbanised areas, located at a distance allowing to reach this means of transport (i.e. at a distance of 12-20 km), which allow such a spatial link (they have no fundamental barriers). Due to the parallel development of inter-municipal cycling infrastructure, priority will be given to the implementation of the system in municipalities linked by planned velostrades.

6.2.2 Overview of CCAM solutions in the area

In addition to the intermodal transport projects identified above, as well as tools including but not limited to ITS, no integrated activities nor pilots for CCAM solutions have been identified to date.

6.2.3 Main challenges to overcome in the area (improve air quality, exposure to noise pollution, traffic accidents…)

In addition to the integrated measures for the implementation of sustainable transport carried out by the GZM, the challenges of the individual cities and municipalities of the conurbation should also be pointed out.

The following are selected examples:

1. **City of Katowice**

In the assumptions of the "Strategy of development of the city of Katowice 30"[7] , Transport Katowice has set itself the goal of being a city implementing pro-environmental technologies in public and individual transport.

The "Update of the programme of environmental protection for the city of Katowice for the years 2021-2024 with perspective to 2026" [8].

presents the current state of the environment taking into account defined areas of intervention such as climate and air quality protection, noise pollution, electromagnetic fields, water management, water and sewage management, geological resources, soils, waste management and waste prevention, natural resources, threats of major accidents. The document indicates that the acoustic climate in the city is mainly shaped by noise associated with road, rail and air transport.

The document indicates that the acoustic climate in the city is mainly shaped by noise from road, rail and air transport, as well as from industrial activity. The strongest most influential source of noise is road transport.

The "Low-isoemisise management plan for the city of Katowice – update" indicates as one of the strategic objectives the reduction of pollutant emissions from installations used within the city, as well as from transport, aimed at meeting air quality standards.

2. **City of Bytom**

[7] https://www.katowice.eu/dla-mieszkańca/strategie-i-raporty/strategia-rozwoju-miasta-2030#:~:text=Strategia%20Rozwoju%20Miasta%20„Katowice%202030"%20jest%20najważniejszym%20dokumentem,obszar%20śródmiejski%2C%20Przedsiębiorczość%20i%20rozwój%20gospodarczy%20oraz%20

[8] https://bip.katowice.eu/UrzadMiasta/ZamierzeniaIProgramy/dokument.aspx?idr=125981

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The “Strategy for the development of electromobility in Bytom for the years 2020-2035” [9] assumes a decisive impact on the improvement of air quality by, among other things, the gradual elimination of combustion cars from the city centre area, the construction of transfer centres, the introduction of electric vehicles into public transport and the recommendation of electric cars in the private transport sector. The “City mobility plan for the municipality of Bytom” [10] assumes, among other things, a change in transport behaviour towards ecological means of transport by promoting integrated public transport and the so-called 'green mobility' of the inhabitants, improving accessibility to the city areas increasing the attractiveness of the urban environment, increasing the quality of life, the level of public health and transport safety among the addressees of the project.

In order to reduce noise in terms of the organisation of public transport, the document “Update of the programme of environmental protection against noise for the city of Bytom for the years 2019-2024 [11], supports for the replacement of tram and bus fleets with low-floor, ecological vehicles, and promotes the use of vehicles powered by gas and other "clean fuels" by bus operators is indicated.

The “Update of the low-emission economy plan for the municipality of Bytom” [12] identifies, as a strategic objective, the development of low-emission transport and electromobility through energy-efficient and cost-effective means of transport on the part of the municipality and public entities, as a result of the implementation of electromobility, including modernisation and replacement with low-emission vehicles. The document also points to the development of modern technologies in the field of electromobility, including, among others, intelligent traffic management, construction of charging stations for electric vehicles within the city.

3. City of Ruda Śląska

The “Low-emission economy plan for the city of Ruda Śląska” [13] identifies, inter alia, measures to reduce emissions from linear emissions (car transport) through the use of financial incentives as a means of replacing cars and other means of transport with cleaner and more environmentally friendly ones.

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[9] https://www.bing.com/ck/a?!&&p=e28e2dfe14f17ea5JmltdHM9MTY3MTQwODAwMCZpZ3VpZD0wOGYwNWE0YS0yM2Q0LTZmMzQtMTA0Yi01NGIyMjJjZDZlMWUmaW5zaWQ9NTE2MA&ptn=3&hsh=3&fclid=08f05a4a-23d4-6f34-104b-54b222cd6e1e&psq=STRATEGIA+ROZWOJU+ELEKTROMOBILNOŚCI+W+BYTOMIU+NA+LATA+2020-2035&u=a1aHR0cDovL3d3dy5rb25zdWx0YWNqZS5ieXRvbS5wbC9rb25zdWx0YWNqYS9wbGlrLzQ0NC9wcm9qZWt0LS1zdHJhdGVnaWEtcm96d29qdS1lbGVrdHJvbW9iaWxub3NjaS13LWJ5dG9taXUtbmEtbGF0YS0yMDIwLTIwMzUucGRm&ntb=1

[10] https://www.bytom.pl/bip/plany-programy-raporty/plan-mobilnosci-miejskiej

[11] https://www.bing.com/search?q=AKTUALIZACJA+PROGRAMU+OCHRONY+ŚRODOWISKA+PRZED+HAŁASEM+DLA+MIASTA+BYTOM+NA+LATA+2019-2024&cvid=5de3d625f98941fdb07de47c351cb0df&aqs=edge..69i57j69i11004.2139j0j1&pglt=41&FORM=ANNAB1&PC=W011

[12] https://www.bytom.pl/dla-mieszkanca/programy-w-zakresie-ochrony-srodowiska

[13] https://www.rudaslaska.pl/de/ruda-slaska/aktualnosci/2015/05/14/plan-gospodarki-niskoemisyjnej-dla-miasta-ruda-slaska/

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6.3 CCAM in prototypical areas: North Aegean Region

6.3.1 Main features of the prototypical area

The North Aegean Region includes ten inhabited islands and its total area, including many uninhabited islands and a large number of rocky islets, amounts to 3,832km². Five of the islands in the Region are large in area for the scale of the Aegean islands (Lesvos, Chios, Samos, Lemnos and Ikaria) and four smaller ones (Agios Efstratios, Inousses, Psara, Fourni), while two of the large islands, Lesvos and Chios are among the important islands of the European Area (see Figure 18).

Characteristic of the North Aegean Region is the great distance of all its islands from the mainland, forming the border of Europe. In close proximity from the east to the Turkish territory, while at the same time the distances between its islands are also large. The seat of the Region is the city of Mytilene.

The terrain of most of the islands in the Region is mountainous and semi-mountainous, with mountainous areas covering about 33% of the total area of the island of the Region. In particular, Samos is characterised by its mountainous terrain, with a mountainous area covering the entire territory of the island of its terrain compared to the other islands, while Lemnos is characterised by its semi-mountainous and lowland. The slopes of the terrain also show significant differences between the islands, with the highest in Ikaria and the lowest in Lemnos.

The islands of the North. Aegean islands, as Mediterranean ecosystems, have to show a complex mosaic of ecosystem types on the very limited surface area that they cover. A set of terrestrial and aquatic ecosystems, rich in endemic and rare species of flora and fauna. In terms of the ecosystem, the North Aegean Region brings together more than 5,000 different species animals and about 1,000 species of plants, some of which are in danger of being extinct under the pressures on the marine environment, and particularly on the marine ecosystem. The coastal ecosystem, which is by its nature the most productive and the most important for maintaining ecological balances.

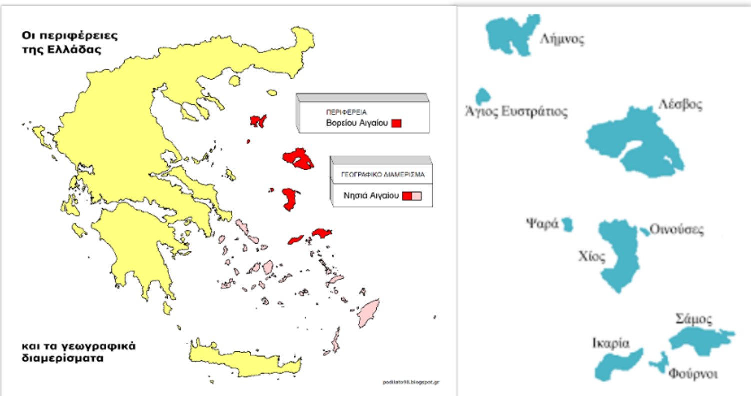

Figure 18 Geographical map of the North Aegean Region

The North Aegean Region represents 2% of the total population of Greece with a general population of 229.519 inhabitants (Greek statistical authority 2020). The territorial area of Lesvos with its main town Mytilene is 1.636 km² and according to the demographic data of 2011 the population is 86.312 inhabitants. The area of Chios is 842.796 km² and the population is 51,269. Next, the territorial area of Samos is estimated at 477.942 km² and its population at 33,335 inhabitants. While the territorial area of Lemnos with its capital Myrina reaches a territorial area of 476,288 km² and a population of 16.743 inhabitants. The territorial area of Ikaria with its capital Agios Kirikos consists of 255,32 km² and its population of 8.431 inhabitants. Agios Efstratios has a territorial area of 43.325 km² and a population of 249 inhabitants. The territorial area of Psara reaches 40,467 km² and the population of inhabitants to 408. The Fourni its territorial area amounts to 30.5 km² and the number of inhabitants to 1,199. Inousses is 14,382 km² with a population of

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796 inhabitants. Finally, Thymena has a territorial area of only 10,071 km² and a population of 142 inhabitants.

According to the statistics of the Hellenic Statistical Authority in the North Aegean Region, the age distribution for 2020 is 24% for residents aged 65 and over, 27% for those aged 45-64, 19% for those aged 30-44, 6% for those aged 25-29, 4% for those aged 20-24, 5% for those aged 15-19 and finally 15% for those aged 0-14.

However, after the refugee crisis of 2015, the islands of the North Aegean Region Lesvos, Samos and Chios have a strong multicultural element. According to the statistics of the Ministry of Immigration and Asylum in September 2022, the islands of Lesvos, Samos and Chios hosted 1,727, 1,117 and 392 refugees accordingly.

The North Aegean Region represents only 2% of the economically active population of the country, whereas the percentage of the economically active population of. Regarding the percentage distribution for the North Aegean Region according to the Hellenic Statistical Authority, it is observed that the majority of the employed persons are found in the agricultural and livestock farming and tourism sectors (88% in 2020), while the shares in the hospitality sector (10% in 2020) and accommodation (2% in 2020) are smaller.

Regarding the percentage distribution of the unemployed, we note that the North Aegean Region accounts for 2% of the country's unemployed, according to the Hellenic Statistical Authority, with a decrease of -10% in the period 2019-2020 (14 thousand in 2020). At the same time, in 2020 it has the 3rd lowest unemployment rate at 16%, in relation to the economically active population of the 13 regions of Greece.

In relation to the aviation infrastructure, the North Aegean Region has 5 airports, one in each Unit. Specifically, the airports of the Region are Mytilene International Airport "Od. Elytis", the State Airport of Chios "Homeros", the State Airport of Lemnos "Ifestos", Samos International Airport "Aristarchos Samios" and Ikaria State Airport "Ikaros".

Port infrastructure

Concerning port infrastructure, the North Aegean Region has 5 main port infrastructures ports, the port of Samos, the port of Myrina, the port of Chios, the port of Agios Kyrikos Port and the Port of Mytilene.

The port of Myrina mainly serves the commercial and passenger traffic to islands of the Northeastern Aegean, Piraeus, Kavala, Lavrio, Mykonos, Patmos and Syros. It also has a tourist port where cruise ships and private yachts.

The port of Chios has a commercial/passenger terminal where it serves the connection of Chios with the islands of the Northeastern Aegean, Piraeus, Chios and Northern Greece. It also has a tourist port where both cruise ships as well as smaller vessels, which transport passengers from Chios to Cesme, Turkey, as well as private yachts.

The port of Samos (Vathi) has a commercial/passenger terminal where the passenger ships of the Samos connection line with Piraeus, the islands of Samos and the islands of the North-Eastern Aegean and Northern Greece. It also has a tourist port where both cruise ships and smaller boats, which carry passengers from Samos to Kusadasi in Turkey, as well as private boats private yachts.

The port of Ikaria (Agios Kyrikos) has a commercial/passenger terminal where passenger ships of the line connecting Ikaria with Piraeus, the islands of the Northeast Aegean, Syros and Mykonos. The port of Mytilene has a commercial/passenger station serving the Mytilene's connection with the islands of the North-Eastern Aegean, Piraeus and Northern Greece. It also has a tourist port where both cruise ships as well as smaller vessels, which transport passengers from Chios to Aivali, Turkey, as well as private yachts.

Road networks

The road network and land transport are necessarily limited to a local level island's scale and their importance is always proportional to the size of the island. It should be noted that in addition to the

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number of cars of the resident inhabitants, the road network of the North Aegean Region is burdened with a high number of cars of tourists in the summer season. More specifically, the road network per Regional Unit is as follows:

Regional Unit of Samos

The road network of the Unit is in very good condition.

All settlements are connected to each other and to the main road. The main roads and the main routes between the main roads of the region are all interconnected.

Regional Unit of Lemnos

The island's road network is tarred in largely tarred and in a moderate condition. The main road axis is in very good condition, starting from Myrina approaches the airport and ends at Moudros. Branches of the main axis leading to the other settlements of the island, the most important of which are:

- Provincial roads Myrinas - Kallitheas
- Provincial road Plaka-Romanou
- Provincial road Katalakko-Kornos
- Provincial road Mudros-Skandali

Regional Unit of Lesvos

The main road network of the island, connecting the two ports of Lesvos Mytilene and Sigri. Branches of the main roads leading to the airport and the tourist resorts. The town of Mytilene has 3 exits. The northern exit leads to the northeastern part of the island and through the old port and the industrial zone, the Southern exit leads to the south of the island the Gulf of Gera and the Airport and the Western exit leads through the international road to all other settlements. In general, the road network is of good passability, with the exception of the mountainous areas of the area of Mount Olympus and the north-western side of the island.

Regional Unit of Ikaria

The road network is limited and requires extensive works and improvements. Provincial roads, are tarred and in relatively good condition.

There are only in the north-eastern part of the island, which connecting the peripheral settlements of Armenisti and Evdilos with the Regional Unit of coast and the port of Agios Kirykos. The rest of the south-western part of the island lacks infrastructure since the settlements are connected to non tarred roads.

Regional Unit of Chios

The main network connects the town of Chios with the main cities of Chios. The main city of Chios is the main centre of the island. The majority of the roads are tarred and in very good condition. Problems are encountered in the northern part of the island due to landslides. The secondary road network consists of dirt roads, while the sections that are tarred are in poor condition due to poor maintenance.

The use of public transport in the North Aegean Region is limited only to urban and intercity bus services depending on the Regional Unit.

Urban services

In the **Regional Unit of Lesvos**, urban bus services are provided by the private company Mytilene City Busses S.A. which operates 12 routes a day from morning to evening at regular intervals in all areas of the Municipality of Mytilene. The intercity bus of Lesvos covers the other municipalities of the Regional Unit of Lesvos with 19 destinations and 14 routes, multiple schedules during the day. Specifically, the routes with destinations:

- Agia Paraskevi

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- Agiasos
- Arganos
- Vatera
- Eresos
- Thessaloniki
- Kalloni
- Mandamados
- Mesotopos
- Molyvos
- Mytilene
- Papados
- Pelopi
- Petra
- Plomari
- Polihnitos
- Sigri
- Skala Eressos
- Skala Kalloni
- Ypsilometopo

The **Chios Intercity Bus** Station was founded in 1952 with its headquarters in the town of Chios, together with all the Prefectural Bus Stations of Greece (Law 2119/52). In 2003 it was transformed into a Public Limited Company by leasing the buses of the shareholders that were part of the Chios Intercity Bus Station.

The task of Y/KTEL Chios S.A. is the transport service of the long-distance lines of the Prefecture of Chios. The aim is to provide a better service to passengers and students of primary and secondary education in the Prefecture of Chios.

There are 27 destinations in the Prefecture of Chios and some of them on a daily basis with multiple scheduled services.

In the **Regional Unit of Samos**, bus lines are provided for the whole island, with 16 daily scheduled routes covering the areas:

- Kokkari
- Chabou
- A. Konstantinos
- Karlovassi
- Pythagorio
- Mytileneans
- Chora
- Potokaki
- HOPEON
- Peacock
- Mills
- Blacksmiths
- Tower
- Bourlionians
- Pebbles
- Kallithea
- Drakontioi
- Airport

In the **Regional Unit of Lemnos**, public transport is not separated into urban and interurban and there are daily bus services from and to the capital Myrina with the rest of the villages of Lemnos.

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In **Ikaria** the bus services operate during the summer months, throughout the tourist season and cover the areas of Raches, Evdilos, Nash, Armenistis and Agios Kirikos, Slagia, Airport, Chrysostomos and Xylokyris.

About the others Regional Units Furni, Thymena, Aghios Efstratios, Inousses, Psara there are no any bublic bus services or any other public transportation.

Low and zero emission vehicles

In the North Aegean Region, we find low and zero emission vehicles. In the Regional Unit of Lesvos, electric scooters have been installed in the town of Mytilene. They have been installed in two busy places, in Sapphous Square and on the waterfront. The Scoot Company has installed the electric scooters which can be easily "hired" for transportation by downloading an app from the mobile phone.

In addition, in most of the islands of the North Aegean Region, the use of bicycles is very common for the movement of citizens through the central cities, as well as the use of skates. Statistics for which it is difficult to record, as their purchase and acquisition does not require registration with the Ministry of Transport, thus making their use easier and more frequent by citizens.

Finally, in recent months the use of electric motorcycles has begun to be observed in the North Aegean Regional Unit. However, the number of individuals who have acquired them is very small, and vehicle charging facilities have not yet been constructed, making them difficult for users to use.

Other issues

Concerning ICT deployment, and unfortunately, in the North Aegean Region, no form of ICT deployment is implemented in any Regional Unit.

With the influx of additional people from rural areas, it is vital to consider sustainable urban planning, which will contribute significantly to the development of the urbanised area in several major cities. The concept of mobility and the way in which it is articulated with urban planning and the transportation of people will undergo drastic changes in the coming years. With an ever-increasing population and vehicles on the roads, authorities need to reduce congestion and design new route optimizations with a reduced ecological footprint.

In the Larger Regional Units such as Lesvos, Chios and Samos during peak hours, congestion in the city is particularly noticeable. Moreover, in these cities the ring system found in large urban centres, a measure to limit the circulation of vehicles in the city centre, based on the rotation of most of them and designed to reduce traffic congestion in the city centre and thus reduce air pollution due to the emissions of pollutants during the operation of vehicles, cannot be implemented due to its size.

As mentioned above, during peak hours, the daily congestion in city centres contributes to air pollution and air quality in both the city centres and the wider areas of these districts.

Moreover, in the islands of the North Aegean Region, the most frequent way of transport of citizens is the use of motorbikes and scooters. Means of transport which strongly contribute to the creation of noise pollution in the city centres. This creates an extremely dangerous situation for public health, causing hearing problems, anxiety and psychosomatic illnesses.

In conclusion, as mentioned above, in the North Aegean Region, the use of motorbikes and scooters is the main form of transport for citizens. Making drivers particularly exposed and making driving very dangerous. According to the Greek Police data for the North Aegean Region, during the month of October 2020, there were a total of -8- road accidents, compared to 14 in the corresponding month of 2019. Also, the data recorded by the Hellenic Home Statistics reported for the North Aegean Region in the period 2021 and 2022, 34 traffic accidents in the Regional Unit of Lesvos, 13 in the Regional Unit of Samos and 4 in the Regional Unit of Lesvos.

As automated transport evolves, public transport organisations in the North Aegean Region can consider the fair implications of integrating autonomous vehicles and buses into current transport

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systems. Per capita and operating costs for automated mobility modes managed by public transportation agencies are unknown at this time, given the limited number of pilots.

Automated public transport includes the automation of conventional forms of public transport that operate on fixed routes and schedules. This form of mobility is mainly publicly funded and includes high-speed rail (HSR), heavy rail (HRT), light rail (LRT), metro, bus rapid transit (BRT) and traditional buses. In the present case, in the North Aegean Region, traditional bus/bus services are mainly found. These services consist of high occupancy vehicles with a capacity of around 30 passengers and passengers are picked up and set down at fixed stops and transfer stations. The automation of conventional public transport improves punctuality and allows for increased frequency of services both during and outside normal operating hours, making more efficient use of infrastructure. The expected increases in service frequency are mainly due to lower marginal operating costs, as human operators are no longer required to operate the vehicles. When not in use, the vehicles are stored in a warehouse located in the city of the North Aegean Region's Regional Units.

6.3.2 Overview of CCAM solutions

The Regional Unit of North Aegean has not implemented any CCAM solutions. The main actions funded from the resources of the Operational Programme NORTH AEGEAN 2014-2020 approved by the European Commission in December 2014 through the Priority Axes are:

- Strengthening the competitiveness of enterprises
- Research, technological development and innovation
- Climate change adaptation, prevention and risk management
- Environmental protection and resource efficiency
- Transport infrastructure
- Strengthening employment
- Social inclusion and the fight against poverty
- Social infrastructure for education, health and social welfare.

6.3.3 Main challenges to overcome for the deployment of CCAM solutions

Improving the connectivity of the North Aegean islands with the mainland is imperative, as it will exploit their strategic position as part of the trans-European maritime transport networks and strengthen the local economy by increasing entrepreneurship and tourism.

In order to achieve the above objective, as far as the entry & exit gates of the islands are concerned, it is necessary to expand/improve the existing infrastructure to meet the new conditions (new types of ships, new demand, etc.).

During the previous programming periods, efforts were made to meet these needs by creating port and/or connecting roads, but in each period these were small-scale and covered immediate needs, according to the transport conditions at the time. Many of these interventions, particularly in the current period, have not been completed or have not been initiated. So it is imperative to complete a transport system in order to optimize the connectivity of the Aegean islands with the mainland & the islands with each other in combination with the improvement of the entry/exit gates. Also a particularly important factor for the well-being of the inhabitants & for the development of the islands' economy (attracting population, business, tourism development) is the promotion of combined transport, the improvement of accessibility and the reduction of the risk of the road network linking productive and tourist-cultural resources with entry/exit gates of the islands as well as with administrative, business centres and public health infrastructures.

As automated transport evolves, public transport organisations in the North Aegean Region can consider the fair implications of integrating autonomous vehicles and buses into current transport systems. Per capita and operating costs for automated mobility modes managed by public transportation agencies are unknown at this time, given the limited number of pilots.

The immediate future situation, given the present situation, is as follows:

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Environmental: Urban transport has a direct impact on air pollution and noise, but of fundamental importance for citizens and businesses

By 2030, a 50% increase in annual passenger traffic & a 70% increase in annual freight traffic is projected. By 2050, an estimated 1.2 billion more cars will be on the roads. ½ of the world's population is now middle class, radically changing lifestyles & mobility expectations

Air pollution is the biggest environmental risk to human health, causing an average of 400,000 premature deaths per year in Europe alone. Noise pollution, caused by motor vehicle traffic, is the cause of around 8 900 premature deaths in Europe every year. The total cost of traffic congestion to the economies of EU countries is estimated at more than €240 billion per year, or around 2% of EU GDP.

There are remain problems and negative impacts caused by the increase in the number of vehicles, such as traffic congestion and high vehicle speeds, demand for parking in city centres and illegal parking, increased energy consumption, increased road accident casualties, air and noise pollution, greenhouse gas emissions and the occupation of open spaces.

There are still mobility problems in the municipalities of the North Aegean Region, which are largely due to the lack of an integrated network of accessible routes and soft forms of mobility (e.g. green routes, pavements with free access of at least 1.5 m) and infrastructure for people with disabilities (routes for the blind, appropriately designed ramps, etc.).

With regard to public transport, the bus lines of the bus company serving the two largest municipalities of the North Aegean Region, Mytilene and Chios, operate with deficiencies (frequencies insufficient to serve the large number of users, unreliable routes, limited opening hours).

In line with the general trends of development, as well as the modern directions for sustainable urban mobility, the existing problems are perpetuated and extended to all areas of city life.

Interventions needs to be implemented, priority is given to accessibility for vulnerable groups, with particular provision for ramps for the disabled at intersections and blind routes on the pavements

to connect the hinterland with the gateways to/ from the islands as in the present situation it is a field that is ignored. Projects to improve road safety.

Car manufacturers are gradually equipping their vehicles with partially automated features, while policy makers are developing rules to facilitate the development of highly automated vehicles. However, the widespread deployment of automatic means of transport introduces new risks, thus creating a barrier to their acceptance. According to one report, evaluating safety through road testing may take hundreds of years to eliminate uncertainties from citizens' minds. As a result, authorities will need to try to create a flexible regulatory framework that can address these risks and thus support successful technology adoption.

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a transport system in order to optimize the connectivity of the Aegean islands with the mainland & the islands with each other in combination with the improvement of the entry/exit gates. Also a particularly important factor for the well-being of the inhabitants & for the development of the islands' economy (attracting population, business, tourism development) is the promotion of combined transport, the improvement of accessibility and the reduction of the risk of the road network linking productive and tourist-cultural resources with entry/exit gates of the islands as well as with administrative, business centres and public health infrastructures.

In the new Programming Period 2021 - 2027 the programme focuses on the interconnection of the North Aegean Region through the strengthening of mobility and regional connections. Focusing on the accessibility of connectivity to the mainland, interconnection of islands with each other, connection of island interiors with entry-exit gates. Improving road transport, port transport and air transport.

Smart cities are a recent innovation that is seen as a winning strategy to tackle some serious urban problems such as traffic, pollution, energy consumption, waste treatment. This concept is attracting considerable interest in the world of technology and sensors. Governments can streamline the way cities operate, saving money and making them more efficient. Rapid urban developments, sustainable transport solutions are needed to meet growing demands for mobility, while mitigating potentially negative social, economic and environmental impacts.

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Automated public transport includes the automation of conventional forms of public transport that operate on fixed routes and schedules. This form of mobility is mainly publicly funded and includes high-speed rail (HSR), heavy rail (HRT), light rail (LRT), metro, bus rapid transit (BRT) and traditional buses. In the present case, in the North Aegean Region, traditional bus/bus services are mainly found. These services consist of high occupancy vehicles with a capacity of around 30 passengers and passengers are picked up and set down at fixed stops and transfer stations. The automation of conventional public transport improves punctuality and allows for increased frequency of services both during and outside normal operating hours, making more efficient use of infrastructure. The expected increases in service frequency are mainly due to lower marginal operating costs, as human operators are no longer required to operate the vehicles. When not in use, the vehicles are stored in a warehouse located in the city of the North Aegean Region's Regional Units.

The immediate future situation, given the present situation, is as follows:

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By 2030, a 50% increase in annual passenger traffic & a 70% increase in annual freight traffic is projected. By 2050, an estimated 1.2 billion more cars will be on the roads. ½ of the world's population is now middle class, radically changing lifestyles & mobility expectations

Air pollution is the biggest environmental risk to human health, causing an average of 400,000 premature deaths per year in Europe alone. Noise pollution, caused by motor vehicle traffic, is the cause of around 8 900 premature deaths in Europe every year. The total cost of traffic congestion to the economies of EU countries is estimated at more than €240 billion per year, or around 2% of EU GDP.

Economics: Bicycle use is equivalent to a reduction of 16 million tonnes of carbon dioxide (CO_2) equivalent per year in Europe alone. This reduction corresponds to the annual CO_2 emissions of

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an entire country (such as Croatia). This reduction saves up to €5.6 billion per year. At current levels of bicycle use in the EU, fuel savings amount to 3 billion litres of fuel per year, which is equivalent to the fuel consumption for the entire road transport of an entire country, such as Ireland. The value of these fuel savings amounts to almost €4 billion. Illegal parking adds 30% to the traffic burden, parking "for five minutes" can increase the consumption of following cars fivefold, and emissions soar (up to 79% increase in carbon monoxide). The car occupies 80% of Public Space and is stationary 22 out of 24 hours a day. The choice of a private vehicle results in the degradation of the urban environment and social alienation from the city.

Objects of Sustainable Mobility:

- Collective means of transport
- Non-motorised means of transport
- Combined transport
- Road safety
- Parking/mobility traffic management
- Intelligent transport systems
- Incentives / disincentives
- Access to ports/airports
- Electromobility
- Bioclimatic design of public space
- Network of free, public spaces
- Green infrastructure/water networks

The existence of electric vehicles (cars, taxis, public transport with buses, bicycles, skates, etc.). The existence and wide distribution of charging infrastructure (in public, semi-public, private spaces)

Emerging mobility solutions aim at moving from a human-led vehicle ecosystem to a computerised ecosystem environment through the development of autonomous on-road technologies). Autonomous vehicles have the potential to offer a variety of societal benefits, including fewer accidents, less congestion, reduced vehicle emissions.

However, there remain problems and negative impacts caused by the increase in the number of vehicles, such as traffic congestion and high vehicle speeds, demand for parking in city centres and illegal parking, increased energy consumption, increased road accident casualties, air and noise pollution, greenhouse gas emissions and the occupation of open spaces.

There are still mobility problems in the municipalities of the North Aegean Region, which are largely due to the lack of an integrated network of accessible routes and soft forms of mobility (e.g. green routes, pavements with free access of at least 1.5 m) and infrastructure for people with disabilities (routes for the blind, appropriately designed ramps, etc.).

With regard to public transport, the bus lines of the bus company serving the two largest municipalities of the North Aegean Region, Mytilene and Chios, operate with deficiencies (frequencies insufficient to serve the large number of users, unreliable routes, limited opening hours).

In line with the general trends of development, as well as the modern directions for sustainable urban mobility, the existing problems are perpetuated and extended to all areas of city life.

On streets where on-street parking is permitted, architectural designs with parking spaces are proposed. Redevelopment of existing sidewalks and improvement of technical/geometric features throughout the city to facilitate pedestrian movement of users. In the interventions proposed to be implemented, priority is given to accessibility for vulnerable groups, with particular provision for ramps for the disabled at intersections and blind routes on the pavements. Reduction of vehicle speeds in residential areas. Replacing illegal parking with widening of pavements and - where

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feasible - creating cycle lanes, even on sections of the hierarchical road network. Expanding the Controlled Parking System. Strengthening the use of bicycles by building a network of cycle paths and developing bicycle infrastructure (parking, bike sharing, etc.), so that bicycles can be an alternative means of transport and at the same time act as a complementary means of public transport.

In order to implement a radical scenario, a change of attitude towards urban transport, changes in infrastructure and the transport network are needed.

The new "Regional Development Partnership 2021-2027" ("NSRF 2021-2027") largely reflects the new priorities of the European Commission and the new development priorities of Greece for the coming years. With Sustainable Urban Development Strategies (covering the largest urban centres of the North Aegean Region, Mytilene and Chios) aiming to address economic, environmental, demographic, climate change and functional organisation challenges of urban centres.

Road Network:

- Development/upgrading of existing road network
- Construction of new road sections
- Active passive road safety interventions
- Improvement of road surface condition
- Road safety upgrading

Coastal:

- Modernisation/extension of port infrastructure
- Development of systems and applications for ports and maritime safety
- Environmental management and monitoring of ports
- Increasing frequency of services
- Improving ship quality
- Reduction of ticket costs
- Increasing inter-island connectivity

Air navigation:

- Upgrading air navigation systems
- Reducing ticket costs
- Increase inter-island connectivity

Use of alternative fuels & Implementation of environmentally friendly modes of operation such as:

- Electrification
- Charging infrastructure
- Use of Renewable Energy Sources (wind, solar, Agios Efstratis)

Improved connectivity between islands is foreseen. Upgrading of barren line vessels and passenger reception facilities. Completion of tourist and mixed-use port facilities. Developing and strengthening sustainable, climate-resilient, smart and intermodal national, regional and local mobility, with better access and cross-border mobility. Expansion/upgrade projects in the main port infrastructure of the Region. Projects for upgrading/improving and/or extending road infrastructure in the islands, national and/or provincial roads, to connect the hinterland with the gateways to/ from the islands. Projects to improve road safety.

As interventions of strategic importance of the North Aegean Programme for the programming period 2021-2027, the following are envisaged:

- Improving the mobility and functionality of the two urban centres of the Region, in the context of spatial strategies for sustainable urban development, involving a combination of various interventions such as urban transport, cycling infrastructure, electromobility, public open space redevelopment and energy efficiency measures and in the two major urban

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centres of the Region, Mytilini and Chios. The Pythagorio Bypass road project on the island of Samos.

- Car manufacturers are gradually equipping their vehicles with partially automated features, while policy makers are developing rules to facilitate the development of highly automated vehicles. However, the widespread deployment of automatic means of transport introduces new risks, thus creating a barrier to their acceptance. According to one report, evaluating safety through road testing may take hundreds of years to eliminate uncertainties from citizens' minds. As a result, authorities will need to try to create a flexible regulatory framework that can address these risks and thus support successful technology adoption.
- Case studies of the scenario of replacing conventional buses with automated public transport help to demonstrate that the benefits of automated vehicles are particularly successful when used together, but the replacement scenario would require rapid and significant changes in legislation and traveller behaviour. Develop regulatory and legislative processes as to levels of liability in the event of an accident, wrong way trips, inability to fully respond to passenger needs.

One possible solution to be considered that is proposed concerns low-speed electric autonomous buses as a common autonomous mobility solution. The buses operate at lower speeds and their predictability reduces the risks that act as a barrier to private autonomous vehicles. Some pilot projects for buses include serving the existing public transit system in the form of first and last mile transit access. Overall, these studies and pilot programs further advance galvanize the positive benefits of shared autonomous mobility solutions over private vehicles, but uncertainty over costs and a lack of information around the equity impacts of automated buses prevent progress towards a regulatory path to widespread deployment. The costs associated with the operation of shared autonomous vehicles are an important factor in decision making regardless of whether the operation is publicly or privately managed. Numerous studies have been conducted to date to evaluate the operating costs of automated vehicles and buses under a range of shared-use scenarios. These findings are limited, as automated technology is still being developed, and thus the relative costs vary over time and between studies.

In conclusion, automated buses can contribute to the provision of high-quality urban mobility to provide opportunities for efficient movement of people and assets in urban environments, campuses and large facilities such as airports and ports in the North Aegean Region. The use of automated public transport, combined with accessibility improvements (inherent in the design), address both socio-economic and disability equity, safety, energy efficiency, cost-effectiveness, urban land and space management and scalability.

The North Aegean Region has a prototype implementation area in combination with the "Sustainable Urban Mobility Plan of the Municipality of Mytilene and Chios", in order to establish environmentally friendly modes of transport, so that they become places that offer an excellent quality of life, attractive destinations for residents and visitors and are a gateway to the island worthy of its hinterland and its history. To transform the whole of the islands into a world-class alternative tourism destination offering visitors the opportunity to immerse themselves in their rich local heritage. This will promote economic development that does not threaten the pillars on which the islands' attractiveness is based: nature and its unique gifts, landscape and agricultural products. These outputs are grouped under the following themes:

- Efficiency
- Liveable Streets -Efficiency
- Environment
- Equity and Social Inclusion
- Safety
- Economic Growth

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In the field of Environmental Protection, the reduction of energy consumption related to transport and the protection of the natural and built environment and the improvement of the health of the population.

In the Social Sector, emphasis is placed on promoting the use of sustainable means and modes of transport over the car, improving accessibility for vulnerable users, improving public health, improving the level of road safety, integrating new technologies to promote shared transport and for optimal mobility management and enhancing participation in transport planning, and finally interpersonal direct socialization of citizens.

In the economic sector, the gains are related to transport system functionality, better management of tourist seasonality in travel and improved freight transport.

More precisely, in the reduction of energy consumption related to travel by combining the integration of alternative fuels in the public/municipal fleet vehicles with the use of alternative fuels or electricity, the increase of cycle paths and cycle-friendly roads as well as walking and reduction of car use. It is planned to use alternative fuels or electricity by 30% of the public/municipal fleet, increase by 10% the kilometres of cycle path networks, increase walking by 20% and reduce by 10% for the first 5 years. From 70% of the public/municipal fleet, increase by 20% of the kilometres of cycle path networks, 50% of walking in the next 10 years and decrease by 20% in the next 10 years until the use of alternative fuels or electricity is realised from 100% of the public/municipal fleet, increase by 40% of the kilometres of cycle path networks, increase in walking by 100% and decrease by 35% for the next 15 years. In addition, the implementation will facilitate the creation of favourable conditions for the use of electric vehicles by creating 58 charging stations at the level of the Municipality of Mytilene and 52 at the level of the Municipality of Chios.

It is also agreed to increase the number of mild traffic roads in neighbourhoods and areas around schools with a speed limit of 30 km/h as the Automated Public Transport tends to make routes at this speed for safer travel, and to increase the number of green routes connecting important public spaces in the municipalities of Mytilene and Chios, improving the efficiency of the transport system.

It includes a contribution to increasing the level of service of public transport, projected in total coverage area: 80% for the next 5 years, 90% for the next 10 years and 99% for the next 15 years. Reducing the rate of illegal parking by 20%, 40% and 70% and increasing the use of active travel (walking and cycling) as the main means of daily commuting by 20%, 30% and 45% in corresponding timeframes.

As a result, a reduction in the number of road traffic incidents with casualties and an increase in the level of perceived road safety and the safe movement of citizens within the Municipalities of Mytilene and Chios.

Participation in transport planning is enhanced through the implementation of traditional and innovative ways of involving residents and visitors in the traffic, urban and environmental planning of the area.

It is envisioned that freight transport will be improved through the development of a smart and cooperative feeder system for the intervention area which will be served by the smart feeder system.

In addition, it is envisaged that the transport system will be directly operational by increasing the punctuality of the public transport system during peak hours and increasing the level of satisfaction of commuters with the operation of the system. Contributing to the optimal management of tourist seasonality in travel by enhancing the efficiency of the transport system promoting walking and cycling tourism.

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7 Methods for the co-creation and assessment of CCAM solutions

7.1 Introduction

This section identifies methods that can be applied in activities involving citizens and organization, to co-create CCAM use cases, scenarios, business models, and Key Performance Indicators. It also sets out the requirements for these methods to be used within the Move2CCAM project activities. The methods were identified from the review of user perceptions in Section 4 of this deliverable and from the wider literature on the experience of car and public transport travellers (including academic papers and reports).

7.2 Focus groups

Focus groups involve bring together a small group of individuals who answer questions and discuss with each other about a specific topic. The discussion is prompted by (oral, textual, or visual) information provided by the facilitator. Focus groups result in different, and possibly richer, insights than individual interviews because each participant's input to the discussion is influenced by the input of others. In many cases, several focus group sessions are run, each with a group with a different age, socio-economic group, or combination of these.

This method has been used in several studies to understand perceptions about automated mobility (Etminani-Ghasrodashti et al 2021, Dichabeng et al 2021, Duboz et al 2022). The method can also be used, more broadly, to understand the perceptions, needs, and preferences of citizens and organizations about CCAM solutions and their likely impact.

Focus groups are usually structured around a fixed set of topics introduced by the facilitator. The output can be analysed with formal methods (e.g. content analysis) or examined in terms of what participants agreed and disagreed with, or of other criteria. In the context of CCAM solutions, the list of relevant topics to discuss in focus groups can include:

- Mobility needs
- Awareness of CCAM technologies (e.g. type of vehicles)
- Views on how the technologies will develop and their adoption by society
- Suggestions of possible applications of these technologies
- Perceptions about the benefits and concerns about the negative impacts of CCAM technologies, at the individual and societal level
- Concerns for specific groups (e.g. people with restricted mobility) and locations (e.g. rural)
- The role of different stakeholders (including public authorities) in the development of solutions and in making sure they bring benefits for society

7.3 Deliberative dialogues

Deliberative dialogues involve bringing together a small group of individuals who are provided with key information about a problem and then discuss with each other, with the aim at arriving at a consensus. This can lead to the co-creation of solutions, while also providing researchers with insights about the participants' perceptions of the problem. The dialogue can include elements of other qualitative and quantitative methods (e.g. questionnaires, stated preference questions). The method differs from focus groups as participants learn from the information provided by the facilitator, expert contributions and from the other participants' points of view, in order to reach a common goal (consensus). Dialogues have been used, for example, by Chng et al. (2021b) to understand perceptions about automated mobility.

Participatory scenario planning is a dialogue-based method suited for the purposes of co-creation activities involving citizens and organizations. In this method, a group of individuals identifies a set

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of alternative scenarios for the future, discussing their benefits and costs. This has been used mostly to look at environmental climate change impacts, but can be adapted for the case of CCAM solutions. As with other deliberative dialogue methods, the aim is to achieve a consensus. In this case, this consensus is the co-creation of a set of CCMA use cases and business models, and associated scenarios for both

The dialogues can have the following steps:

Step 1: Initial short questionnaire answered by participants

This can cover current travel behaviour, unsatisfied travel needs, awareness of CCAM solutions, perceptions of benefits, concerns, willingness to use those solutions, type of intended use (e.g. vehicle ownership, public transport, shared solutions), and opinion about their likely impact at the individual and societal level

Step 2: Presentation of key facts about urban and regional mobility and about CCAM solutions

The facilitator presents the range of CCAM technologies that have been tested or will be tested, and examples of trials of those solutions

Step 3: Consensus (co-creation activity)

Participants discuss to reach a consensus about the most beneficial applications of the technologies presented. These should consider current and future needs for travel, taking into account possible changes in future conditions (e.g. population ageing, urbanization). The scenarios should specify: types of technology used, geographical and temporal reach (i.e. where and at what times will the solution be available), and types of ownership.

Consensus can be achieved through discussion, with prompts from the facilitator (Strömberg et al 2021). An alternative is to use an activity leading to co-created solutions. For example, Belton and Dillon (2021) used 'collaborative storytelling' where participants generated scenarios for autonomous flights as stories, after agreeing on the beginning and end of the story.

Step 4: Final short questionnaire

This covers the same topics as the initial questionnaire, to assess possible changes in opinions and perceptions.

7.4 General surveys

Surveys have been the most common method to analyse people's perceptions, acceptance, and intention to use automated mobility. This includes surveys implemented in several countries with several thousand participants (e.g. Nordhoff et al 2020, Potoglou et al 2020). Some surveys asked participants about their perceptions and satisfaction after trying a real-life autonomous vehicle (Salonen 2018, Zoellick et al 2019, Rombaut et al 2020).

The surveys can include all the topics mentioned in Section 8.2 for focus groups. They can include a mix of:

- Closed questions - participants choose from a fixed set of possible options
- Rating questions - participants indicate a level on a scale (e.g. level of agreement with a statement, level of satisfaction)
- Open questions - participants provide comments on issues not covered in other questions, or provide more detail or justify the reasons for the answers in the closed and rating questions)

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7.5 Stated preference surveys

Stated preference surveys are a special type of surveys where participants choose their preferred option from a number of alternatives. Each alternative is defined by several characteristics ("attributes"), which can assume different values ("levels"). Each participant answers several choice questions, where the attribute levels of each alternative are systematically varied. This allows for the estimation of the marginal effect of changing each attribute level. This method has been used in several studies to assess preferences for CCAM scenarios (Alessandrini et al 2014, Paddeu et al 2021, Jabbari et al 2022). Stated preference exercises can be a component of larger surveys.

In the case of the assessment of citizens' CCAM requirements and impacts, the alternatives that participants choose from could be a CCAM solution vs. another solution (e.g. conventional vehicles) or different types of CCAM solutions (e.g. different scenarios for a certain use case - see Section 2 of this deliverable).

- The set of attributes of each alternative can include
- Cost of using mobility services (or buying a vehicle)
- Time savings and travel time reliability
- Comfort and convenience
- Use of time on board
- Safety
- Availability (e.g. at certain times of day)
- Type of space used (e.g. dedicated road lanes)

7.6 Virtual reality and physiological measures

Two methods are particularly promising for the assessment of user reactions to CCAM technologies, within the context of drive trials or lab-based experiments. Virtual reality and collection of physiological measures.

Virtual reality provides an immersive experience that can realistically replicate the reality, while introducing variations that cannot always be found in reality (Jones et al 2022). It also allows for the representation of realities that do not yet exist (e.g. future scenarios). Virtual reality can simulate a trip using an autonomous vehicle in a variety of conditions (e.g. busy vs. quiet traffic, urban vs. rural, different number of pedestrians and cyclists, different weather conditions, straight vs. non-other routes, moving vs. parking). As an alternative, simulated trips can be compared with trips with different levels of automation.

The reaction of study participants to various aspects of autonomous vehicle use can be assessed with physiological measures. This includes brain activity (recorded using electroencephalograms), heart activity (using electrocardiogram or photoplethysmography sensors) and skin conductance (also known as galvanic skin response). The data can be complemented with questionnaire data (asking the participants' opinions before and after the simulation).

Review methods

We conducted a review of studies that have used visual reality and/or physiological measures to analyse reactions of users of fully autonomous (i.e. Level 5) vehicles (solely or compared with vehicles with other levels of autonomy). Only empirical studies involving human participants were reviewed. A search was conducted in Scopus, PubMed, and Transportation Research International Documentation with the following search string, combining keywords for technology, application of this technology, outcome (i.e. effect on user of the technology), and research method (virtual reality or physiological measures, with the latter disaggregated into various possible data collection methods)

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Technology	*(automat* OR autonomous)*
Application	*AND (mobility OR transport* OR vehicle)*
Outcome	*AND (percept* OR perceiv* OR experience OR reaction OR response OR feeling OR accept* OR intention OR attitude OR behavi*)*
Research Method	*AND ("virtual reality" OR physiological OR eeg OR electroencephalogram OR ecg OR electrocardiogram OR "skin conductance" OR galvanic OR "heart rate" OR ppg OR photoplethysmography)*

The searches returned 842 unique results. We read all abstracts and excluded:

1) Studies that did not analyse use reactions to fully automated road vehicles including studies about

- driving non-autonomous or partially autonomous vehicles
- the perspective of other road users (e.g. pedestrians)
- autonomous personal mobility devices (e.g. wheelchairs),
- autonomous water or air passenger vehicles
- reactions to autonomous vehicles as inferred by reactions of passengers to vehicles driven by humans

2) Studies that did not collected data from human participants (i.e. theoretical studies, reviews, position papers).

3) Studies that did not use virtual reality or physiological measures, including studies that:

- labelled their methods as virtual reality but that did not use immersive environments (with headsets or screens covering the participants' whole field of vision)
- analysed the use of virtual reality while riding in real autonomous vehicles

After these exclusions, a total of 54 studies remained. 20 of these studies were then removed because they could not be located or because, after reading the full paper, it was determined that they were not in scope, were not studies collecting data from human participants, or did not use virtual reality or physiological measures. 34 studies were retained for further analysis.

Studies were split into three groups: those using virtual reality and physiological measures (4) and those only virtual reality (16) and only physiological measures (14)

We then extracted the following information from each study:

- Type of comparisons made (e.g. different characteristics of autonomous vehicles or comparisons with partially or not autonomous vehicles)
- Context in which autonomous vehicle was used (i.e. characteristics of the virtual reality or other environment or device)
- Road and traffic condition
- Autonomous driving style
- Duration of the experiment for each participant
- Outcome i.e. which user reaction was measured (physiological or other)
- Which variable was measured
- Data collection method (how the variable was measured)
- Country where data was collected
- Sample recruitment
- Sample size
- Sample balance (according to age, gender, and other relevant characteristics)

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- Data analysis method
- Methodological issues encountered (related to virtual reality or physiological measures only)
- Ethical issues addressed or encountered
- Key result (related to physiological measures only)

The variable, data collection method, data analysis method and results fields were not extracted in the case of studies using virtual reality but not assessing outcomes with physiological measures.

An additional field was collected: type of autonomous vehicle. However, all the studies reviewed were about autonomous cars (not shared vehicles, buses, or other types of public transport vehicles). This is a gap of existing research.

The collected information is in Annex III, which contains three tables, for studies using virtual reality AND physiological measures (Table 73), studies using virtual reality ONLY (Table 74) and studies using physiological measures ONLY (Table 75).

Technologies

The objective of some studies using virtual reality and/or physiological measures is to compare user reactions for fully automated vs. partially or not automated drives. Those that focus on fully-automated drives compared aspects of these drives that were found to be significant in determining user reactions, including:

- types of messages (e.g. warnings) provided by the vehicles to the passenger (e.g. text only, audio)
- vehicle interior configuration
- driving style and events
- day/night, visibility
- trip characteristics

Other comparisons focused on the influence of research methods on results. For example, Zou et al (2021) compared on-road vs. laboratory experiments, and the use of headsets vs. screens.

Experiment set-up

Most of the studies using virtual reality involved participants using head-mounted headsets showing an immersive environment containing a road, other vehicles, the road surroundings. The environment could also contain pedestrians. The immersive environment was in some cases created with 360º videos. In the experiment of Ferrier-Barbut et al. (2018), these videos were recorded from a real autonomous vehicle. In some cases, the experiment used a motion simulator, to create the sensation that the virtual vehicle was moving. Audio was also included as part of the environment. The interior of the vehicle was also represented in some studies. In most cases, participants could also see information provided by the vehicle (for example, about driving conditions). In the study of Ihemedu-Steinke et al. (2018), there was a split screen, showing the road, and a virtual tablet used by the passenger to read an e-book – to emphasize the possibility of engaging in leisure activities while the vehicle drives itself. The virtual environment in the Morra et al (2019) study also included the hands of the participants.

A variety of road and traffic conditions has been tested, including motorways, urban environments, residential neighbourhoods, rural and mountain roads, and environments with different complexity and risks. Djavadian et al. (2019) compared roads familiar and unfamiliar to the user. Driving style also has influence on results, as shown by studies comparing safe vs. risky styles.

In terms of research methods, the duration of the experiments varies from a few minutes to more than an hour (including several scenarios).

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Outcomes (user reactions)

The type of user reactions analysed in studies using virtual reality and/or physiological measures has been described with a variety of overlapping concepts, including stress, anxiety, mental state, emotional state, emotional response, arousal, trust, discomfort, acceptance, user uncertainty, user experience, perceived safety, and cognitive workload.

Within the set of studies using virtual reality, some studies analysed user behaviour, including:

- choices or preferences of autonomous drive vs. manual drive (Manawadu et al 2015, Djavadian et al. 2019)
- moral behaviour in case of dilemmas (Benvegnu et al. 2021)
- head movements (Derakhshan et al. 2022)

Another relevant user reaction is motion sickness, which can occur when passengers of autonomous vehicles engage in activities (e.g. reading) (Venkatakrishnan et al. 2020).

Studies collecting physiological measures used a variety of variables:

- Heart rate
- Heart rate variability
- Skin conductance response
- Electroencephalogram band combinations and ratios

These measures were collected by sensors placed on hands or fingers, headsets, or wearable devices (e.g. wrist bands). Data analysis methods included analysis of variance, inspection of time series data in relation to driving events, mean comparison, regression, and deep neural networks.

Participants

Surprisingly, few studies mentioned the country where data was collected. There is even less information about how participants were recruited.

The samples are small although in some studies the sample size was determined by a power analysis, which ensures that the methods used can detect the hypothesized effects of autonomous driving on users, if these effects are indeed present.

Nevertheless, the major problem is the demographic imbalance in the sample, in comparison with the population. In almost all studies, the sample is composed 100% of students (or in some cases, students and researchers). As a result, the mean age of participants is 20-30. To compound this age imbalance, in most studies, the sample is overwhelmingly composed of men. In addition, in most studies the sample is composed of individuals who have a driving licence. There is a clear issue of potential self-selection in the sample (students who are more enthusiastic about autonomous vehicles are more likely to offer themselves as volunteers to experiments announced in their universities). Another implication of sample imbalance is the lack of representativeness of the population, which limits any attempt for generalization. The available evidence on user responses to automated drive is only representative of the population of male young students who have a driving licence. The reaction of some of the main potential beneficiaries of autonomous vehicles (older people who cannot drive anymore, people without driving licences) is unknown.

Issues

Few studies mentioned methodological issues encountered, or acknowledge methodological limitations. The few issues reported about virtual reality include:

- Perception of speed not same as in real drive (due to vibration, air flows, and other aspects)
- Difficult in accounting for activities that travellers engage with while travelling
- Short time of the experiments may not represent real-world drives

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The few issues reported about the use of physiological measures include:

- Parameters for detection of emotional changes may differ in short and long-term situations
- Difficult to account for activities that travellers engage with while travelling
- Difficult to account for all real-world distractions
- Difficult to account for all confounding driving variables, external factors influencing responses (e.g. parked vehicles, weather), and participant boredom
- Tension felt by some participants related to the first-time use of driving simulator
- Electrodermal activity measured with wrist bands depends on tightness of the band, hand movements, and sensitivity of outer side of wrist
- Difficulty and time required to classify data
- Participants are familiar with human drivers, not with automated vehicles, which conditions results comparing drives with both

Ethics

Both virtual reality and physiological measure collection have potential ethical issues that need to be addressed prior to the experiment. Surprisingly, the majority of the studies reviewed do not mention any ethical aspects. The few that do (e.g. Zou et al 2021, Van et al 2018, Beggiato et al 2019) give only perfunctory information, stating that the study received ethical approval, and that participants gave informed consent.

Other aspects

Most of the studies reviewed were published in conference proceedings in the Engineering or Computer Science fields. There are almost no studies looking at the problem from a transport, mobility, or social perspective. In many cases, the message of the study is unclear for readers unfamiliar to the topic, as the description of methods and results is obscured by the use of an excessive number of acronyms specific to the paper. This limits the potential for interdisciplinary collaborations and the use of research to inform policy and practice.

7.8. Conclusion on co-creation and data collection methods

A variety of methods can be applied in activities involving citizens and organization to co-create CCAM use cases, scenarios, business models, and Key Performance Indicators. These methods can be qualitative (focus groups, deliberative workshops) or quantitative (general surveys, stated preference surveys, virtual reality, collection of physiological measures). We reviewed studies using virtual reality and physiological measures in detail. These studies found that the experience of users of automated vehicles depends on a wide range of variables. However, the studies leave several gaps and have issues such as small unbalanced samples and lack of details on ethical aspects of the experiments and on methodological problems encountered

8 Conclusions and future steps

As stated before, now that all the information contained in this deliverable is clear within the project, it will be used as a basis to continue working on the rest of scientific and technical work packages of the project, mainly in order to define the co-creation activities that will be soon started.

Concerning the information given about CCAM technologies, use cases and scenarios, multiple scenarios have been analysed related to both connected and autonomous (or partly-autonomous) vehicles, and taking into account both passengers and freight transport. It is important to notice that this deliverable does not cover water transport nor air passenger transport as they are outside the scope of the project.

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Nine scenarios have been defined in the scope of CCAM solutions for passenger transport and seven scenarios for CCAM solutions for freight transport. For each scenario, a table is given in order to describe the user needs around it, the technologies and stakeholders involved, and also its main challenges and potential impacts.

Once the main scenarios to be considered have been addressed, an insight of the cost-structure of CCAM solutions and existing or potential business and financial models to ensure their implementation has been included. For each business model, an initial description of CCAM solution analysed is presented, and then a description of the business model (using the "four-box" approach) is given. Besides, the financial model applied is described, followed by an overview of the stakeholders involved and a brief description of the available CCAM solutions in this sense. As a conclusion from this section, it can be stated that, although the technology included in CCAM solutions has advanced and evolved fast during the past years, its implementation (specially at scale) is still in its infancy. Most of the reviewed solutions are being tested all over the world, but the business models connected to them are quite immature since they have not been tested in a commercial way or at scale. Based on the addressed CCAM solutions and their business models, a list of the most promising applications with more potential to create positive impact and business models has been included in section 2, where the following applications can be remarked: automated freight trucks, autonomous shuttle bus in rural areas, MaaS, robot delivery and drone delivery. More conclusions concerning business models are available in section 2.

Besides, a review has been done about the perception and needs of organizations and citizens regarding CCAM solutions, carrying out a systematic review procedure in order to find relevant studies since the volume of the literature on this topic is quite large. As main conclusions, it can be said that the literature suggests that people perceive CCAM solutions as useful, releasing travel time and some of the stress associated with driving. However, they also have a lot of concerns. For example, and in relation to passenger land transport, the main concern is safety, especially in the case of fully automated vehicles with no human operators (despite the fact that, in general, people think that automated vehicles can be safer than conventional ones). Other main concerns are security (e.g. hackers and/or other passengers), and privacy. Specific groups, such as the elderly and people with disabilities, see CCAM technologies as a potential enhancer of their mobility and accessibility, but have some concerns, such as the physical accessibility of the vehicles. See section 3 for more information around CCAM perceptions and needs.

Concerning Transport System Dynamic Models, information around SDM in general has been provided in section 4, and the use of SDM in the transportation sector has been also addressed, making clear that the use of these kind of systems to support the decision making processes offers the benefit of examining the impacts within each case both in themselves as well as in relation to their related systems.

An overview of the evaluation frameworks to measure mobility solutions impacts and technology acceptance has been also provided in this document. The outcome of this review is a list of dimensions and indicators considered by the literature after an exhaustive review of documents developed by experts in this field. Additionally, the indicators found have been classified in those dimensions that can be relevant for the multi-systems impact assessment modelling tool to be deployed in the project. Also, gaps found in the literature related to this topic has been provided as well as the next steps to carried out in the project for the final selection and definition of indicators, impacts and acceptance factors.

Information about the prototypical areas is also available in this document, including the main features of each prototypical area, an overview of CCAM solutions on it and the main challenges to overcome for the deployment of CCAM solutions in each particular area. Two of the three

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prototypical areas have already deployed some kind of CCAM solution, while GZM has not deployed any CCAM solution up to now.

The last chapter of this document is devoted to methods that can be applied in activities involving both citizens and organisations in order to co-create CCAM use cases, scenarios, business models and KPIs. Besides, this section has also set out the requirements for these methods to be used within the Move2CCAM project activities. Those methods have been identified from the review of user perceptions and needs in section 3, and also from the wider literature. Focus groups, deliberative dialogues, general surveys, stated preference surveys and simulation using virtual reality are the main methods that have been described in this section 7.

9 References

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10 Annex I: Literature reviewed related to evaluation frameworks and indicators

Initiatives, projects and papers considered in the review process of chapter 5 related to impacts, acceptance factors and indicators are described briefly in this annex. Exactly, it is described their purpose of these initiatives/projects/papers and the approach and scope of the document developed (i.e. evaluation framework). All this information is compiled in tables below.

Table 54 Initiatives and projects on smart and sustainable cities

Initiative	Evaluation framework name	Evaluation framework description
International Organization for Standardization (ISO) *This International Standard is applicable to any city, municipality or local government that undertakes to measure its performance in a comparable and verifiable manner, irrespective of size and location.*	**ISO 37120** Sustainable Cities and Communities. Indicators for city services and quality of life (2014)	International Standard which defines and establishes methodologies for a set of indicators to steer and measure the performance of city services and quality of life.
	ISO 37122 Sustainable Cities and Communities. Indicators for Smart Cities (2019)	This International Standard defines and establishes methodologies for a set of indicators to steer and measure the progress towards a smart city.
United for Smart Sustainable Cities (U4SSC) initiative *It is a global UN initiative coordinated by ITU, UNECE and UN-Habitat, and supported by CBD, ECLAC, FAO, UNDESA, UNDP, UNECA, UNESCO, UNEP, UNEP-FI, UNFCCC, UNIDO, UNOP, UNU-EGOV, UN-Women, UNWTO and WMO. U4SSC provides an international platform for information exchange and partnership building to guide cities and communities in achieving the UN Sustainable Development Goals.*	Collection methodology for Key Performance Indicators for Smart Sustainable Cities (2017)	The document aims to provide cities with a consistent and standardised method to collect data and measure performance and progress to achieving the Sustainable Development Goals (SDGs) becoming a smarter city becoming a more sustainable city
United Nations Industrial Development Organization (UNIDO) This organization has been exemplary in promoting and implementing industrial development projects globally since its inception as a specialized agency of the United Nations in 1966. In response to the global issue of ensuring sustainable industrial development, UNIDO's landmark Lima Declaration, adopted by Member States on 2 December 2013, first put forward the concept of inclusive and sustainable industrial development (ISID).	Bridge for cities. Belt & Road initiative: Developing Green Economies for Cities (2017)	The objective of this report is to develop a framework of indices that can provide an overview of trends on inclusive and sustainable urban-industrial development. Using these indices, cities could be assessed and compared to reveal their comparative advantages and disadvantages, in order to better establish their respective development trajectories for the promotion of smart, sustainable and inclusive urban and regional growth.
Sustainable development in the EU (EUROSTAT) Monitoring report on progress towards the SDGs in an EU	Sustainable development in the European Union Monitoring report on progress towards the SDGs in an EU context (2022)	The document provides a quantitative assessment of the progress of the European Union (EU) towards reaching the SDGs through indicators stablished to

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context Sustainable development through European statistics		measure the progress already reached.
	CITYKEYS project CITYkeys indicators for smart city projects and smart cities (2017)	Project funded as a horizontal activity of the Smart Cities and Communities call to develop an indicator framework for smart city project evaluation. Indicators defined allow to evaluate the impact of a smart city project comparing before and after situations or comparing expected impact with a reference situation, monitor the progress of the city as a whole towards smart city goals and assess how the project has contributed to the objectives at city level.
	Smart Cities Information System (SCIS) Key performance indictors guide (2017)	SCIS focuses on the development of indicators to measure technical and economic aspects of energy and mobility related measures applied in LH projects
Lighthouse projects initiative (LH projects from Horizon 2020) *Projects funded by the EC through Horizon 2020 to test integrated innovative solutions at district scale to achieve environmentally-friendly, economically viable and socially desirable urban environments in lighthouse cities that should act as exemplars for their region helping to plan the replication of these solutions, adapted to different local conditions.*	**MAtchUP project** D1.1: Indicators tools and methods for advanced city modelling and diagnosis (2018)	Describe the methods and tools selected to carry out the Advanced City Diagnosis that allow to: Identification of needs and challenges of the cities as well as their strengths and weakness to help city managers in the decision-making process of the city Be aware how close a city is to become a sustainable and smart city. Monitor the progress of the city to show to what extent sustainability and smart goals have been reached. Set a reference methodology for benchmarking and comparison of different aspects of cities and to compare cities with other.
	MAtchUP project D5.1 Technical evaluation procedure (2019)	The main objective of these documents is to define a strong evaluation framework in the three lighthouse cities, with the aim to assess the effectiveness of the proposed interventions, deployed in the associated individual actions, under three perspectives: technical-environmental, economic and social
	MAtchUP project. D5.2 Economic evaluation framework (2019)	
	MAtchUP project D5.3 Social evaluation framework (2019)	
	mySMARTLife project D5.1 Integrated Evaluation Procedure (2019)	
	REMOURBAN project • D2.1_EvaluationFramework • Development of an Evaluation Framework for Smartness and	The framework developed considers two levels of evaluation: city level, to assess both sustainability and smartness of the city as a whole from a comprehensive and integrated perspective, and project level, to

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	Sustainability in Cities (Antolín, 2020)	provide a clear identification of the impact of implementation of technologies and solutions on three key priority areas (sustainable districts and built environment, sustainable urban mobility and integrated infrastructures and processes) aimed at achieving the city high-level goals.
SunHorizon project (Horizon 2020) SunHorizon aims to be a breakthrough demonstration to market project focusing its activities on "reducing system costs and improving performance as well as optimising existing technologies for Heating &Cooling applications"	• D7.1. SunHorizon Technologies social and market acceptance (2020) • Peñaloza, D. et al (2022): Social and market acceptance of photovoltaic panels and heat pumps in Europe: A literature review and survey.	The deliverable and associated paper aim at exploring the social and market acceptance of the innovative SunHorizon technology (solar energy coupled with heat pumps) with the purpose of identifying which aspects need more focus for the replicability of the solutions to a wider audience. Previous studies (scientific papers and EU projects) on social and market acceptance of similar technologies have been considered for the design of the survey delivered to stakeholders from energy sector and potential users of the technologies.

Table 55 Initiatives, projects and papers on mobility

Initiative	Evaluation framework name	Evaluation framework description
CIVITAS initiative *One of the flagship programmes helping the EC achieve its ambitious mobility and transport goals, and in turn those in the European Green Deal. It does this by acting as a network of cities, for cities, dedicated to sustainable urban mobility. Through peer exchange, networking and training, CIVITAS fosters political commitment and boosts collective expertise, equipping cities to put mobility at the centre of decarbonisation.*	**CIVITAS CAPITAL.** Advisory Group 5. City level Sustainable Mobility Indicator Descriptions (2016)	This document provides a simple, easy to use set of indicators that cities can use to measure how well their transport and mobility system is performing. Data gathered regularly can show that objectives are achieved, that what is supposed to function, does function, and to show politicians and citizens that their city is improving.
EIT Urban Mobility *Initiative of the European Institute of Innovation and Technology (EIT) working from 2019 to encourage positive changes in the way people move around cities in order to make them more liveable places.* *Co-funding of up to € 400 million (2020-2026) from the EIT*	Innovation pathway (KAVA 20061) Impact Assessment Framework (2020)	The document describes the impact assessment framework to identify the policy measures (or 'solutions') that enable cities to meet their vision and objectives, taking into account the local context

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SUMI PROJECT *SUMI project selected by the European Commission – DG MOVE to support the testing of Sustainable Urban Mobility Indicators (SUMI) within the "Service Contract: Technical support related to sustainable urban mobility indicators" (MOVE/B4/2017-358).*	Sustainable Urban Mobility Indicators (SUMI). Harmonisation Guideline (2020)	The starting point for the SUMI project were the "SMP2.0 Sustainable Mobility Indicators"1 developed by WBCSD, the World Business Council for Sustainable Development. These have subsequently been revised by the SUMI consortium for use by European cities. The goal of this document is to proactively handle and prevent possible data harmonisation problems when collecting data.
SPROUT project (EU project) *Project funded to provide a new city-led, innovative, and data-driven policy response to address the impacts of emerging mobility patterns, digitally enabled operating and business models, and transport users' needs*	Methodology for Consequence Analysis of Future Mobility Scenarios: The SPROUT Framework. (Xenou, E. (2022)	The SPROUT consequence analysis framework presents the main components and the process followed for identifying the future mobility state of the five SPROUT cities
MORE project (EU project) *H2020 project that aims to develop and implement procedures for the design of urban corridor roads*	Deliverable 1.2. Urban Corridor Road Design: Guides, Objectives and Performance Indicators	A comprehensive compilation of objectives and performance indicators for the design of urban roads and streets.
Urban agenda for the EU	Urban Mobility Indicators for walking and public transport (Urban Agenda for the EU, 2019)	A common set of urban mobility indicators and best practice case studies on the walkability of cities and access to public transport.
Federal Transit Administration from United States	Mobility Performance Metrics for Integrated Mobility and Beyond (2020). FTA Report No. 0152 (Federal Transit Administration)	The objective of this research is to develop new mobility performance metrics to supplement existing, traditional public transit-oriented ones due to emerging mobility services such as bikeshare, carshare, ridesourcing, ridesharing, and on-demand transit, coupled with trip planning, scheduling, transfer, and navigation platforms, are changing the way people get around. The goal the new supplemental mobility performance measures was to improve decision-making.
Papers	Key performance indicators as element of assessment and towards the development of sustainable mobility (Tundys B. 2015)	

Table 56 Initiatives and projects working on MaaS and CCAM solutions

Initiative	Evaluation framework name	Evaluation framework description

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The Trilateral EU-US-JP Automation in Road Transportation Working Group Group established in 2012 to support the cooperation between Europe, United States and Japan on the topic of Automation. The Working Group is an important reference group for the work of the CARTRE action.	Trilateral Impact Assessment Framework for Automation in Road Transportation (2018)	Framework to analyse the impacts of automated vehicles and create recommendations of the KPIs for expressing the impact of automation in road transportation
Harmony **project (Horizon 2020)** EU project to develop a new generation of harmonised spatial and multimodal transport planning tools to enable metropolitan authorities to lead the transition to a low carbon new mobility era in a sustainable manner.	D1.1 Review of new forms of mobility, freight distribution and their business models; gaps identification in KPIs and SUMPs (2021)	The deliverable includes a review of the KPIs for regional spatial and transport planning.
AVENUE project (Horizon 2020) It aims to design and implement full-scale demonstrations of autonomous minibuses in the urban transport of European cities.	• D8.11. Sustainability Assessments (2019) • How to measure the impacts of shared automated electric vehicles on urban mobility. (Nemoto, 2021)	Documents aim to integrate and interconnect the sustainability dimensions – social, environmental, economic and governance - with the technological impacts of autonomous driving.
CATRE project "Coordination of Automated Road Transport Deployment for Europe" Coordination and Support Action from H2020 Programme which consists of a network of European experts in the area of automated driving that represent industry, research and road authorities. CARTRE aims to accelerate development and deployment of automated road transport by increasing market and policy certainties.	D5.3. Societal impacts for automated driving (2018)	A structured approach that provides insight into what is expected from ongoing studies in Europe in terms of socio-economic impacts of vehicle automation. The framework suggested by the Trilateral ART WG was utilized in the societal impacts of automation in this study.
LEVITATE (Horizon 2020) Project to build tools to help European cities, regions and national governments prepare for a future with increasing levels of automated vehicles in passenger cars, urban transport services and urban logistics.	D3.1. A taxonomy of potential impacts of connected and automated vehicles at different levels of implementation (2019)	This deliverable presents a taxonomy of potential impacts of connected and automated transport systems at different levels of implementation. A distinction is made between direct, systemic and wider impacts.
PAsCAL project (Horizon 2020)	D7.1 – Impact areas and paths (2019)	This document intends to identify the different impact areas and pathways that

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It aims to develop a multidimensional map of public acceptance of higher levels of Connected and Autonomous Vehicles, pointing out any critical issues on the matter, particularly investigating the new "driver" needs considering different modes and mobility services		allow to measure impacts in the different areas.
SUaaVE project (Horizon 2020) The project aims to improve public acceptance rates of CAVs using a human-driven design approach. The project brings together thousands of passengers, drivers and stakeholders to actively co-create concepts about CAV technology. The project is expected to help improve the safety perception, attitudes and emotional evaluation of CAV.	Deliverable 1.1. Identification of potential psychological factors influencing the passenger and road user acceptance of CAV (2019)	Literature review on psychological factors affecting acceptability and acceptance of CAV.
Trustonomy project (Horizon 2020) The project aims to raise safety, trust and acceptance of automated vehicles through the investigation, set up, test and assess relevant technologies and approaches in autonomous driving and request to intervene scenarios. This is done taking into account key considerations such as types of users, road transport modes and driving conditions.	Deliverable D1.3 Trustonomy Framework Definition (2019)	The context of trust is presented, and methods for measuring and assessing trust and acceptance are identified
Others	System-level impacts of self-driving vehicles: terminology, impact frameworks and existing literature syntheses (2018) This research was funded by Trafikverket under Grant TRV 2017/22806. The report is one deliverable for the research project "Systemeffekter av Självkörande Fordon".	The first aim of the report is to summarize knowledge to enable future design of a high-level conceptual framework for impacts from self-driving vehicles from a systems perspective. The second aim is to summarize knowledge on impacts from self-driving vehicles in a selection of the available literature.
	Measuring System-Level Impacts of Corporate Mobility as a Service (CMaaS) Based on Empirical Evidence (Vaddadi, 2020)	The paper aims to contribute to the research gap by introducing a framework for evaluating CMaaS impacts, applying the framework to a CMaaS pilot, and discussing how the findings can be generalized to other MaaS systems.
	A review on the factors influencing the adoption of new mobility technologies and services: autonomous vehicle, drone, micromobility and mobility as a service (Zhang, 2022)	The paper conducts a systematic review of the new mobility technologies and services, especially on autonomous vehicles, drones, micromobility and Mobility as a Service (MaaS) to gain a deeper insight into the factors that affect the adoption or preferences of these technologies and services and thus

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		provide policy implications at the strategic level.

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11 Annex II: Review on Social and Environmental life cycle assessment

This annex describes the output of the literature review related to social and environmental life cycle assessment.

Exactly, the section covers the following issues:

- Structure of the evaluation frameworks reviewed and indicators considered in the literature reviewed and considered as relevant for the performance of life cycle analysis in the project.
- How extent the initial categories are considered by the reference documents.
- Indicators considered in each initial dimension and reference document where they are included.

11.1 Structure of the evaluation frameworks

This section is about the indicators included in each evaluation framework reviewed and considered as relevant for the performance of life cycle analysis in the project.

Table 57 Evaluation framework Ecoinvent 3.0

Environment	
Air quality	
Emission intensity of Mercury Emission intensity of Chromium VI Emission intensity of PAH, polycyclic aromatic hydrocarbons Emission intensity of Selenium Emission intensity of Cadmium Emission intensity of Chromium Emission intensity of Lead Emission intensity of Nickel Emission intensity of Zinc Emission intensity of Copper Emission intensity of Benzene Emission intensity of Ammonia	Emission intensity of Xylene Emission intensity of Dinitrogen monoxide Emission intensity of Toluene Emission intensity of Methane, fossil Emission intensity of Sulfur dioxide Emission intensity of Acetaldehyde Emission intensity of Particulates, > 10 um Emission intensity of Particulates, > 2.5 um, and < 10um Emission intensity of NMVOC, non-methane volatile organic compounds Emission intensity of Carbon monoxide, fossil Emission intensity of Nitrogen oxides Emission intensity of Carbon dioxide, fossil

Note: It is considered only the use phase of the vehicles and exhaust (tailpipe) and non-exhaust pollutants

Table 58 Evaluation framework Environment Footprint

Environment		**Health**		**Land use**
Global warming potential	*Ecosystem quality*	*Air quality*	*Use of resources*	*Soil quality*
Climate change	Acidification Eutrophication, freshwater Eutrophication, marine Eutrophication, terrestrial Ecotoxicity, freshwater	Ozone depletion Ionising radiation Photochemical ozone formation Particulate matter Human toxicity, non-cancer Human toxicity, cancer	Water use Resource use, fossils Resource use, minerals and metals	Land use

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Table 59 Evaluation framework Gompf, K. et al (2022)

Mobility behaviour						
Accessibility	*Convenience*	*Privacy*	*Feedback mechanism*	Urban development	Supplier relationships	
Number of transport points Number of passengers	Punctuality of deliveries	Data privacy	Consumer complaints	Urban development plans	Purchasing behaviour	
Equity						
Employment	*Community engagement*	*Inclusiveness*	*Discrimination*	*Child labour*	*Work-life balance*	
Percentage of employees hired locally	Degree of population participation	Inclusive design (ageing and disabled)	Prevention of discrimination	Prevention of child labour	Healthy work-life balance	
Equity						
Forced labour	*Fair competition*		*Promoting social responsibility*		*Collective bargaining*	
Prevention of forced labour	Fair competitive activities		Social responsibility support Percentage of audited suppliers		Freedom of association and collective bargaining	
Environment	**Land use**		**Safety**	**Economy**		
Noise pollution	*Public space*	*Space occupancy*	*Social*	*Affordability*	*Tax income*	*Employment*
Noise pollution greater than 65 dB Average emissions of noise (noise index)	Green and open space per capita	Infrastructure efficiency Infrastructure space occupancy Space occupancy in relation to green and open space	Fatal and non-fatal traffic accidents Fatal and non-fatal injuries	Trip fare	Taxes per pkm	Percentage of employees hired Remuneration Minimum wage paid

Table 60 Evaluation framework Vaddadi, B. et al (2020)

Mobility behaviour		**Economy**			
Travel behaviour	*Quality of travel*	*Travel costs*	*Business models*	*Economic*	*Employment*
Nº of multimodal trips % of multimodal trips Overall adoption of Move2CCAM solutions	Satisfaction of transport services for work related travel	% travel costs / monthly income	Business opportunities for CCAM solutions Move2CCAM solutions scalability Move2CCAM solutions profitability	Taxes from Move2CCAM solutions operation	New job opportunities generated by Move2CCAM services Total new Move2CCAM corporates
Equity			**Land use**		
Accessibility			*Infrastructure*		
Perceived accessibility to transport services for work related travel Accessibility to Move2CCAM solutions for different user segments and user groups			Land area used for bus stops, roads, electric charging points, parking lots, etc.		

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Table 61 Evaluation framework Jones E.C et al (2019)

Traffic efficiency	Environment	Economy
Use of resources	*Use of resources*	Economy performance
Fuel consumption during driving	% renewable electricity generation in the electricity country mix	Nº of privately-owned vehicles (POVs) avoided circulating

Table 62 Evaluation framework Gudmundsson, H. (2004)

Mobility behaviour	Environment	Land use
Waste from road vehicles	*Waste from road vehicles*	Space consumption
Number of used tyres	Treatment of used tyres	Daily individual consumption of public space involved in parking

11.2 Initial dimensions in the literature

This section provides an overview of how the initial dimensions considered in project are deal in the literature reviewed and considered as relevant for the performance of life cycle analysis in the project.

Table 63 Focus areas from DoA in the literature (life cycle approach)

Evaluation framework name	Focus areas							
	Equity	Mobility behaviour	Safety	Health	Economy	Environment	Land use	Network efficiency
Gompf, K., Traverso, M., & Hetterich, J. (2022)	X	X	X		X	X		
Vaddadi, B., Zhao, X., Susilo, Y., & Pernestål, A. 2020.	X	X			X	X	X	
Gudmundsson, H. (2004)		X				X		
Fazio, S., Castellani, V., Sala, S., Schau, E. M., Secchi, M., Zampori, L., & Diaconu, E. (2018).				X		X	X	
E. C. Jones; B. D. Leibowicz. 2019					X	X	X	X
Ecoinvent 3.0 database						X	X	

11.3 Indicators linked with initial dimensions

This section provides the list of indicators categorized under each of the initial dimensions considered in the project in the literature reviewed and considered as relevant for the performance of life cycle analysis in the project.

Table 64 Indicators from Equity dimension (life cycle approach)

Equity dimension
Gompf, K., Traverso, M., & Hetterich, J. (2022) Percentage of employees hired locally Degree of population participation

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Inclusive design (ageing and disabled) Prevention of discrimination Prevention of child labour Healthy work-life balance Prevention of forced labour Fair competitive activities Purchasing behaviour Social responsibility support Percentage of audited suppliers Freedom of association and collective bargaining **Vaddadi, B., Zhao, X., Susilo, Y., & Pernestål, A. (2020)** Perceived accessibility to transport services for work related travel Accessibility to Move2CCAM solutions for different user segments and user groups

Table 65 Indicators from Mobility dimension (Social and Environmental life cycle approach)

Mobility dimension
Gompf, K., Traverso, M., & Hetterich, J. (2022) Number of transport points Number of passengers Punctuality of deliveries Data privacy Consumer complaints Urban development plans **Vaddadi, B., Zhao, X., Susilo, Y., & Pernestål, A. (2020)** Total travel / individual / month Nº of multimodal trips Overall adoption of Move2CCAM solutions **Gudmundsson, H. (2004)** Waste from road vehicles

Table 66 Indicators from Safety dimension (life cycle approach)

Safety dimension
Gompf, K., Traverso, M., & Hetterich, J. (2022) Fatal and non-fatal traffic accidents Fatal and non-fatal traffic injuries

Table 67 Indicators from Health dimension (Social and Environmental life cycle approach)

Health dimension
Fazio, S., Castellani, V., Sala, S., Schau, E. M., Secchi, M., Zampori, L., & Diaconu, E. (2018). Ozone depletion Ionising radiation Photochemical ozone formation Particulate matter Human toxicity, non-cancer Human toxicity, cancer

Table 68 Indicators from Economy dimension (life cycle approach)

Economy dimension
Gompf, K., Traverso, M., & Hetterich, J. (2022) Trip fare Taxes per pkm Percentage of employees hired Remuneration Minimum wage paid **Vaddadi, B., Zhao, X., Susilo, Y., & Pernestål, A. (2020)** % travel costs / monthly income Business opportunities for Move2CCAM solutions

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Move2CCAM solutions scalability
Move2CCAM solutions profitability
E. C. Jones; B. D. Leibowicz. (2019)
Nº of privately-owned vehicles (POVs) avoided circulating

Table 69 Indicators from Environment dimension (life cycle approach)

Environment dimension
Ecoinvent 3.0 database
Emission intensity of Mercury
Emission intensity of Chromium VI
Emission intensity of PAH, polycyclic aromatic hydrocarbons
Emission intensity of Selenium
Emission intensity of Cadmium
Emission intensity of Chromium
Emission intensity of Lead
Emission intensity of Nickel
Emission intensity of Zinc
Emission intensity of Copper
Emission intensity of Benzene
Emission intensity of Ammonia
Emission intensity of Xylene
Emission intensity of Dinitrogen monoxide
Emission intensity of Toluene
Emission intensity of Methane, fossil
Emission intensity of Sulfur dioxide
Emission intensity of Acetaldehyde
Emission intensity of Particulates, > 10 m
Emission intensity of Particulates, > 2.5 m, and < 0 m
Emission intensity of NMVOC, non-methane volatile organic compounds
Emission intensity of Carbon monoxide, fossil
Emission intensity of Nitrogen oxides
Emission intensity of Carbon dioxide, fossil
Environment Footprint methodology & Fazio, S., Castellani, V., Sala, S., Schau, E. M., Secchi, M., Zampori, L., & Diaconu, E. (2018)
Climate change
Acidification
Eutrophication, freshwater
Eutrophication, marine
Eutrophication, terrestrial
Ecotoxicity, freshwater
Water use
Resource use, fossils
Resource use, minerals and metals
Gompf, K., Traverso, M., & Hetterich, J. (2022)
Noise pollution greater than 65 dB
Average emissions of noise (noise index)
E. C. Jones; B. D. Leibowicz. (2019)
% renewable electricity generation in the electricity country mix of the Netherlands
% renewable electricity generation in the electricity country mix of Poland
% renewable electricity generation in the electricity country mix of Greece
Gudmundsson, H. (2004)
Treatment of used tyres

Table 70 Indicators from Land use dimension (life cycle approach)

Land use dimension
Environment Footprint methodology & Fazio, S., Castellani, V., Sala, S., Schau, E. M., Secchi, M., Zampori, L., & Diaconu, E. (2018)
Land use
Land area used for bus stops, roads, electric charging points, parking lots, etc.
Daily individual consumption of public space involved in parking

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Table 71 Indicators from Traffic efficiency dimension (life cycle approach)

Traffic efficiency dimension
E. C. Jones; B. D. Leibowicz (2019)
Fuel consumption during driving

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12 Annex III: Studies using virtual reality and/or physiological data to assess CCAM user responses

Table 72 Studies using virtual reality and physiological data to assess reactions of users to autonomous vehicles

Study	Comparison	Context	Road and traffic	Driving style	Duration	Outcome	Variable	Data collection method	Data analysis method	Country	Sample recruitment	Sample size	Sample balance	Methodologicl issues	Ethics	Results
Tomita et al 2017	No	Virtual reality (headset)	2 lanes, sidewalk, some pedestrians poles	Various speeds, speed change, sounds	90 minutes	Anxiety	Heart rate	Heart rate sensor	Heart rate not analysed	Japan	Unknown	16	All students	Perception of speed not same as in real drive (due to vibration, air flows)	Consent	Heart rate results not reported
Park et al 2018	No	Virtual reality simulator (showing 360º video) and motion simulator, 3D audio effect	Motorway vs. residential neighbourhood	Safe vs. risky driving	4 minutes	Emotional state	Beta/alpha ratio	Electro encephalogram	Analysis of time series data in relation to driving events	Unknown	Unknown	1	Only 1 participant	Difficult and time-consuming to manually classify data	Unknown	More negative emotional states in risky driving scenario
Morra et al 2019	Different types of warning to passenger	Virtual reality (headset), with platform. Sounds, interior of vehicle, user's hands, warnings	Urban, environments with different complexity and risks	Unknown	12 minutes	Trust	Skin conductance response	Sensor on fingers	Analysis of time series data in relation to driving events, ANOVA	Unknown	Unknown	38	66% male, mean age 24, all have driving licence	Unknown	Unknown	Differences in skin response linked to differences in warning systems to passenger
Park and Nojoumian 2022	No	Virtual reality (headset), with 360º video; motion simulator	Unknown	Different styles, from moving slowly/predictably, to erratically	Unknown	Emotional response	beta/alpha power ratio	Electro encephalography	Mean comparison	Unknown	Unknown	50	Unknown	Parameters for detection of emotional changes may differ in short and long-term situations	Unknown	Correlation between real-time trust in autonomous drive and emotional

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Study	Comparison	Context	Road and traffic	Driving style	Duration	Outcome	Variable	Data collection method	Data analysis method	Country	Sample recruitment	Sample size	Sample balance	Methodologicl issues	Ethics	Results
																responses

Table 73 Studies using virtual reality (and no physiological data) to assess reactions of users to autonomous vehicles

Study	Comparison	Context	Road and traffic	Driving style	Duration	Outcome	Country	Sample recruitment	Sample size	Sample balance	Metho dologicl issues	Ethics
Ferrier-Barbut et al 2018	No	Virtual reality (headset), based on 360^0 recordings on a real autonomous car	Various scenarios related to pedestrians near the vehicle	Unknown	Unknown	Discomfort	France	Unknown	19	79% men all student/research centre staff, age unknown	Unknown	Unknown
Helgath et al 2018	Manual and partial automated driving	Virtual reality (headset)	Urban	Unknown	Unknown	Acceptance and experience	Unknown	Unknown	17	65% female, all aged 20-28, most students and drivers	Unknown	Unknown
Ihemedu-Steinke et al 2018	No	Virtual reality simulator with motion simulator. Split screen showing road and a tablet	Motorway, little traffic	Unknown	12 minutes	Motion sickness	Unknown	Unknown	14	Gender-balanced, age 28-55, mean 37, 85% frequent drivers, all have university degree	Unknown	Unknown
Djavadian et al 2019	Manual driving	Virtual reality (headset)	Familiar vs unfamiliar roads, low vs high traffic volume	Unknown	Unknown	Choice of autonomous drive vs. manual drive	Canada	Unknown	17	65% male, aged 18-39, 82% student, 18% research centre staff	Unknown	Unknown
Koilias et al 2019	Virtual reality	Passenger next to driver showing different levels of engagement with driving	Urban, other vehicles and pedestrians	Unknown	<60 minutes	Anxiety	Unknown	Unknown	75	All students, mean age 24.	Unknown	Unknown
Shahrdar et al 2019	No	Virtual reality (headset), based on 360 video	Unknown	Safe vs. risky driving	10 minutes	Trust	Unknown	Unknown	50	84% male, age 18-30	Unknown	Unknown
Von Sawitzky et al 2019	No	Virtual reality (headset)	Straight 4-lane roads different situations at junctions, 120km/h base speed, vehicles close to each other	Unknown	50 minutes	Trust	Unknown	Unknown	30	1/3 male, man age 29, all students and university staff, all have driving licence	Unknown	Consent
Venkatakrishnan et al 2020	Manual driving	Virtual reality (headset), with sounds	Urban	Maximum speed 35mph	Less than 30 minutes	Motion sickness	USA	Unknown	63	60% male, all students, mean age 24.1	Unknown	Informed consent
Benvegnu et al 2021	Manual driving	Virtual reality (headset)	Unknown	Unknown	Unknown	Moral behaviour	Italy	Unkown	15	Mean age 24, all students, gender-	Unknown	Consent

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Study	Comparison	Context	Road and traffic	Driving style	Duration	Outcome	Country	Sample recruitment	Sample size	Sample balance	Metho dologicl issues	Ethics
										balanced, all have driving licence		
Colley et al 2021a	No	Virtual reality with simulated motion (movable seat)	City centre	Unknown	80 minutes	Reaction to motion, task performance	Unknown	Mailing lists of university and online media	18	83% male mean age 26, 72% students, 28% researchers	Unknown	Unknown
Colley et al 2021b	Different types of notification	Virtual reality (headset)	Urban	Unknown	60 minutes	Trust, perceived safety, acceptance	Unknown	Unknown	20	Mean age 32, 50% students, gender balanced, all had driving licence	Unknown	Consent
Schneider et al 2021	Different types of notifications	Virtual reality (unclear characteristics)	Single-lane, urban area	30 km/h	60 minutes	User experience	Unknown	Unknown	22	Mean age 28, mostly students, gender-balance, all had driving licence	Did not account for activities while travelling	Unknown
Wintersberger et al 2021	No	Virtual reality (unclear characteristics)	Urban, square blocks	Unknown	10 minutes	Trust and simulator sickness	Unknown	Mailing lists	21	Mean age 31, gender-balanced, mostly university staff, all have driving licence	N/A	Consent
Zou et al 2021	On-road vs lab, headset vs. not	Virtual reality (headset)	Low traffic	Unknown	Unknown	User experience	Australia	Individuals registered in database, advertised to students	28	Age 19-57, mean 28.	Unknown	Consent, ethics approval
Colley et al 2022	Manual drive	Virtual reality	Motorway	More or less ecological	6 minutes	Choice of driving style	Unknown	Unknown	19,	68% male, all student or research centre staff all have driving licence	Unknown	Informed consent
Derakhshan et al 2022	Manual drive	Virtual reality (headset)	Unknown	Unknown	90 seconds	Head movement	Germany	Visitors to an exhibition	26750	Unknown	Duration of experiment too short	Provision of information to participants

Table 74 Studies using physiological data (and not virtual reality) to assess reactions of users to autonomous vehicles

Study	Context	Comparis on	Road and traffic	Driving style	Duration	Outcom e	Variable	Data collection method	Data analysis method	Country	Sample recruitm ent	Sam ple size	Sample balance	Metho dologicl issues	Ethics	Results
Waytz et al 2014	Driving simulator (unknown characteri stic)	Manual drive	Unknown	Unkown	12 minutes	Trust	Heart rate	Electroencep halogram	Orthogon al contrasts	Unknow n	Unknow n	100	Gender-balanced , age unknown	Unknown	Unknow n	More trust in vehicle with anthropomorp hic features
Manawad u et al 2015	Driving simulator (2D)	Manual drive	Various (motorway, urban, rural/reside ntial,	Unknow n	Unknown	Preferre d driving method	Heart rate	Wrist-based optical rate monitor	Simple average	Unknow n	Unknow n	12	All 21-24 years old students 92% male	Unknown	Unknow n	Novice drivers prefer autonomous driving

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Study	Context	Comparison	Road and traffic	Driving style	Duration	Outcome	Variable	Data collection method	Data analysis method	Country	Sample recruitment	Sample size	Sample balance	Methodologicl issues	Ethics	Results
			parking area													
Wintersberger et al 2016	Driving simulator	Manual drive	Various (urban with dense traffic, mountains, forests)	Unknown	9 minutes	Mental states	Heart rate variability	Electrocardiogram	ANOVA, Kruskal-Wallis	Unknown	Unknown	48	All students, mean age 23 gender-balanced	Tension related with first-time use of simulator, no account for possibility to perform side activities	Unkown	No effect on heart rates
Morris et al 2017	Driving simulator	Manual drive	55mph speed, no or light traffic	Safe vs. risky driving	Unknown	Stress	Skin conductance, trapezius muscle tension	Surface electromyography	Mean comparison	Unknown	Unknown	28	79% female mean age 19	Unknown	Institutional review board, consent	More stress in autonomous drive
Van et al 2018	2D driving simulator with environmental sounds	Manual drive, stationary	Various (1 lane 70km.h limit, 2 lanes 100km/h)	Unknown	120-150 minutes, including questionnaire	Awareness of auditory signals	Electroencephalography Event-Related Potential response	Electroencephalography	ANOVA, heat maps	Netherlands	Opportunity sampling	18	All students, aged 20-25, all have driving licence	Does not account for all real-world distractions	Ethics approval, informed consent.	Response lower in autonomous drive vs. stationary, higher vs. manual drive
Beggiato et al 2019	2D driving simulator	Manual drive	Unknown	Participants own style vs. defensive vs dynamic style	Unknown	Discomfort	Heart rate, electrodermal activity	Wrist band	Analysis of time series data in relation to driving events	Unknown	Unknown	40	63% male, age 25-84, all have driving licence	Electrodermal activity depends on tightness of the band, hand movements, sensitivity of outer side of wrist	Ethics approval, informed consent.	Heart rate decreased during uncomfortable situations, no effect on electrodermal activity
Hu et al 2019	2D driving simulator	No	Urban roads, day vs. night	Normal vs. abnormal braking	Unknown	Mental state	Unclear	Electroencephalography, electrocardiogram	Unclear	Unknown	Unknown	15	80% male, mean age 22, all with	Unknown	Unknown	Unclear

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Study	Context	Comparison	Road and traffic	Driving style	Duration	Outcome	Variable	Data collection method	Data analysis method	Country	Sample recruitment	Sample size	Sample balance	Methodologicl issues	Ethics	Results
													driving licence			
Pollmann et al 2019	Stationary driving simulator surrounding big screens covering whole field of vision, no headsets	Different vehicle interior configurations	Urban, night-time	Maximum 30km/h	6 minutes	Cognitive workload	Theta/alpha ratio	Electroencephalography	ANOVA	Unknown	Unknown	23	Gender-balanced. Mean age 29	Did not account for motion	Ethics approval	Large, bright, blue car interior, less visual and auditory stimuli reduce cognitive workload
Dillen et al 2020	Real autonomous vehicle	Driving style and events	Test track no other vehicles	Various longitudinal and lateral thresholds of acceleration and distance	Unknown	Comfort and anxiety	Galvanic skin response, heart rate, heart rate variability	Wearable device	Regression	Canada	Unknown	20	Age 19-64, mean 34, gender unknown	Confounding driving variable, external factors influencing responses (parked vehicles, weather) participant boredom	Unknown	Presence/proximity of lead vehicle raised physiological responses
Eimontaite et al 2020	Pod-like driving simulator and large screens, with sounds	Visibility, trip characteristics, type of notifications	2-way rural road with cars and buses in other direction, pedestrians, and animals	Unknown	Unknown	Arousal	Electrodermal activity, heart rate, skin transmission	Wristband	ANOVA	UK	Unknown	15	73% male, age 61-81 mean age 70, all have driving licence	Unknown	Ethics approval, consent, workshop to inform participants	Greater arousal for trips with no audio notifications and a stop
Mühl et al 2020	2D driving simulator	Manual drive	Motorway through rural/wooded landscape	150m or 80m from leading vehicle when overtaking	Unknown	Trust and preferences	Skin conductance	Sensors attached to tips of index and middle fingers	ANOVA	Unknown	Unknown	24	All students, mean age 24, 2/3 female	Participants familiar with human drivers, not with automated vehicles	Informed consent	No effect of automated vs. manual drive, only effect of driving style
Trende et al 2020	Fixed driving simulator with	No	Urban (50km/h limit) and	Unknown	Unknown	User uncertainty	Heart rate, interbeat interval	Wrist band	Deep neural network	Unknown	Unknown	50	Age 20-43, mean 26. Gender	Unknown	Unknown	Uncertainty varied widely between participants

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Study	Context	Comparison	Road and traffic	Driving style	Duration	Outcome	Variable	Data collection method	Data analysis method	Country	Sample recruitment	Sample size	Sample balance	Methodologicl issues	Ethics	Results
	vehicle interior and 180o field of view		rural (100 km/h limit)										balance. All have driving licence			
Palatinus et al 2022	Test of real vehicle	Manual drive	Test in airport runway and service road	Unknown	Unknown	Acceptance	Frontal alpha asymmetry, (beta+gamma)/alpha	Electroencephalography	ANOVA	Hungary	Unknown	38	Mean age=31, 2/3 male	Sample of volunteers can impact neural responses and attitudes	Consent, consistent with Declaration of Helsinki, ethics approval	Autonomous drive: less positive affectivity, same arousal
Su and Jia 2022	2D driving simulator with moving platform	No	Urban roads, motorways, mountain/rural roads	Gentle vs. normal vs. aggressive	Unknown	Comfort	Unclear	Headset and wristband	Unclear	USA	Unknown	10	90% male, mean age 27, all students and researchers, all had driving licence	Unknown	Consent	Unclear

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