



Review

# The Development of the Smart Cities in the Connected and Autonomous Vehicles (CAVs) Era: From Mobility Patterns to Scaling in Cities

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**Abstract:** Smart cities aim to integrate technological development with different functions/components such as mobility, management of energy, natural resources, water, and the waste cycle, air quality, land use, service network, construction, but also the economy, social participation, increased employment, and citizen safety. It includes a series of coordinated and integrated social, environmental and economic interventions to enhance human capital, reduce environmental impacts and solve ecological emergencies. The holistic approach is particular to smart cities, including several mobility aspects in the main European classifications. In particular, the development of smart cities depends on several factors related to transport supply (i.e., mobility service, infrastructure details, ICT) and demand (socio-demographic aspects), and the size of the city. This paper provides an overview of the development of smart cities by defining a methodology that allows the identification of criteria for determining the optimisation of urban mobility with a particular interest in the development of future autonomous mobility. The analysis of current literature on the concept of smart cities and new mobility technologies made it possible to analyse the compatibility between them and possible criticalities. The definition of criteria lays the groundwork for future research steps focused on the application of multicriteria analysis.

**Keywords:** smart city; CAVs; sustainable urban mobility; city dimension; intelligent transportation system



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## 1. Introduction

The smart city concept was born in the early 1990s [1]. American IT companies invented the term to describe new ICT tools aimed at responding to the problems of large metropolises, i.e., solving problems related not only to traffic and transport management but also to waste disposal, the efficiency of energy and water distribution networks, and the safety and health of citizens [2].

The smart city is often associated with the concept of an eco-city or sustainable city aiming to improve the quality of urban services or reduce their costs. The main feature is smart management, lifestyle, mobility, housing, and a smart economy. The main objective of smart cities is to reconcile technological innovation with the economic, social, and ecological challenges of tomorrow's cities. It must provide for a general improvement in the quality of life while respecting the environment.

Smart cities promote a sustainable and liveable urban future by making smart mobility an integral part of the smart city agenda. In terms of mobility, both the evolution of shared mobility [3], gendered or demand-responsive mobility [4,5], as well as the evolution of

electric mobility and related infrastructure [6], are strategies for optimising travel with a view to greater sustainability, especially if they are linked to the development of mobility as a service (MaaS) digital platforms for exemplifying mobility choices for users [7].

From the point of view of infrastructures and structures, the spread of design using tools such as the Infrastructures building information model (I-BIM) allows control over the various life stages of the project. Additionally, it enables information to be associated with safety [8] or the quality of the materials used or building evaluations [9].

The deployment of sensors in the urban environment enables the acquisition of all dynamic urban processes and the possible online transmission of data, processing by algorithms that also allow for automated management decision-making. Technological energy solutions and the spread of different modes of transport exemplify more liveable urban areas [10]. Therefore, automated control over dynamic urban processes is a universal principle that works for all areas of urban life, including transport and mobility [11].

Several strategies have been developed over the years and can contribute to the definition of smart cities, starting with the concept of smart mobility, e-mobility, smart parking, and autonomous mobility solutions. Indeed, for a city to be efficient, more liveable, and intelligent, it is necessary to move towards solutions that streamline traffic and reduce pollution. Technological development is applied through the deployment of 5G networks, broadband WiFi connections. Sharing networks linked to shared mobility, such as some applications that provide public cars that users can use for their journeys: bicycles and cars are accessible through special Apps that indicate where to find the vehicles and the rates of use. In smart cities that espouse the principles of the circular economy, there must be greater proximity between governance and citizens. The layout of cities will change, as will the way materials and products move around people and their needs.

## 2. Background on Smart Cities Benefit

Technology implemented in smart cities can help cities operate more efficiently, improving services to citizens and businesses. While the definition of a smart city is still evolving, some things have become clear: smart cities harness information and communication technologies to improve service levels, citizen well-being, sustainability, and economic development. The increasing development of technology can make cities more innovative and more efficient, given the rapid growth of the urban population in the coming decades. Therefore, the benefits associated with the development of smart cities are briefly described in the following sub-sections.

### 2.1. Cities with More Effective Decision-Making Based on Big Data

Significant technological innovation development has affected several communities in the last decade, facilitating and speeding up data and information exchange. Then, such a context implemented in cities led to the concept of the smart city. There are several definitions of a smart city; generally, it is a context where ICT (Information and Communication Technologies) can integrate traditional infrastructures through digital devices. Therefore, this definition highlights how smart cities represent routine function automation for citizens' issues and a planning tool to monitor cities' infrastructures [12]. The smart city concept began to spread since cities have been subjected to intense urbanisation. This situation led to the need for tools and methods to efficiently monitor and communicate systems to improve mobility and civil infrastructures or energy healthcare management.

Advances in big data and connected devices have given cities access to previously unavailable information. It gives them the ability to access and analyse a massive amount of information—and easily derive meaningful and actionable insights, especially in high-risk conditions. Notably, Big data and the Internet of Things (IoT) offer endless possibilities to enable stronger decision-making, which improves the lives of residents by cutting costs and improving services [13].

### *2.2. Greater Citizen and Government Engagement*

Collaboration tools, modern and intuitive websites, mobile applications, self-service portals, and convenient online accounts have become the standard in many aspects of life, and citizens expect no less from their city. The expansion of digital services in communities makes smart cities more attractive for residents and promotes a connected city experience. Together with a bottom-up planning approach, these intelligent technologies help increase civic engagement and trust in municipal officials [14].

### *2.3. Safer Communities*

A smart city is safer because it can take advantage of technological advances, and pursuing public–private partnerships helps reduce criminal activity. The use of sensors and 24-h cameras can prevail a sense of safety among the citizens [15]. Moreover, intelligent buildings could also provide complete health and safety monitoring for the users or inhabitants [16]. For instance, automatic alarm systems with cameras and smart locks ensure home security, and remote control systems give users more control over their living conditions.

### *2.4. Reduced Environmental Footprint*

With rising greenhouse gases, debris in our oceans, and rubbish on our streets, smart cities are fighting to reduce the adverse effects on the environment. Energy-efficient buildings, air quality sensors, and renewable energy sources give cities new tools to reduce their ecological footprint. Deploying air quality sensors around a city, for example, can provide data to track peak moments of low air quality, identify the causes of pollution and provide analytical data that officials need to develop action and mitigation plans, especially in the medical field.

### *2.5. Improving Transport*

Connected transport systems have great potential to improve efficiency throughout the city dramatically. From better traffic management to the ability of public transport passengers to track bus or train locations, smart technologies enable cities to better serve their citizens despite often rapidly growing populations. Technologies such as intelligent traffic signals optimise traffic flow, easing congestion during peak hours. Other intelligent transport technologies, such as smart parking management, allow cities to capitalise on additional revenue streams. The use of applications and sensors can also help during critical phases such as pandemics to manage the transport sector and the services offered to users [17].

### *2.6. Greater Digital Equity*

Smart city technology can create a more equitable environment for citizens if high-speed, low-cost services such as public WiFi hotspots strategically placed in a city are deployed [18].

### *2.7. New Opportunities for Economic Development*

By providing an open data platform with access to city information, businesses can make informed decisions through data analysis from integrated smart city technologies [19].

### *2.8. Efficient Public Services*

Smart sensors now allow cities to quickly identify leaks in pipes and repair damaged segments in a short time, reducing the amount of water lost. Smart electricity grids also enable two-way communication between electricity suppliers and consumers to help better identify peak usage times and outages [20,21].

### 2.9. Improving Infrastructure

When correlated with advanced design and BIM (Building Information Modeling), smart technology can provide cities with predictive analysis to identify areas needing repair before infrastructure failure occurs (roads, bridges, buildings). It gives a massive opportunity for cities to save money on preventable infrastructure failures and better manage funds from the taxation of citizens [8].

### 2.10. Increased Workforce Engagement

A highly effective workforce is an essential criterion for achieving an efficient smart city. Implementing smart technologies helps ease the burden of manual tasks that many city employees face every day [22].

### 2.11. Transport Integration

The exemplification of the modal choice of transport is implemented through the dissemination of digital platforms such as Mobility as a Service (MaaS) [23] and Transport on Demand (TOD) [24] that allow the user to visualise the possible routes and the different modes of transport available and also to select the best modal choice considering sustainable and cost-effective solutions. These platforms allow several partners to exchange and share data to make decisions on mobility services, considering the recent spread of e-mobility [25]. The Figure 1 below, therefore, summarises the benefits of technology deployment and smart cities.

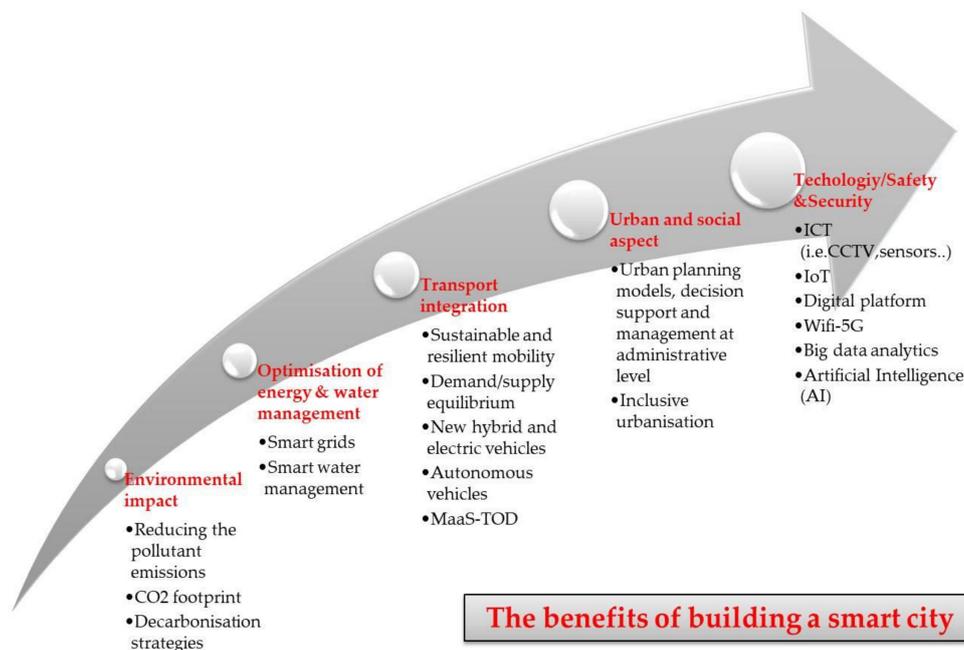


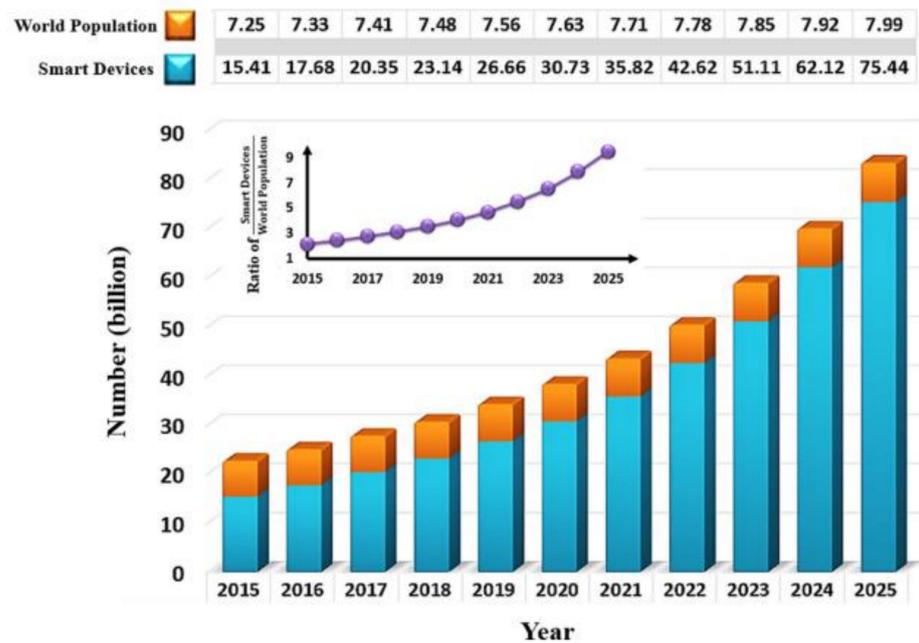
Figure 1. The benefits of the spread of smart cities.

Therefore, this paper outlines the factors that can shape the development of autonomous mobility in smart cities as the size of the city, the mode of transport, and the existing infrastructure change. Section 3 defines the evolution of smart cities in Europe. Section 4 outlines the development of CAVs. Section 5 describes the key factors that can influence the development of smart cities, starting from the implementation of urban planning and mobility tools. Finally, Section 6 provides a critical discussion over the topic and concludes the paper.

### 3. The Spread of Smart Cities in the European Context

Technology mainly spreading is represented by the Internet of Things (IoT), which consists of realising a massive global network of connected physical tools. The development

of cloud technology had a crucial role in IoT spread due to its high storage capacity. Ultimately, several projects of smart cities implementation have been activated from 2015 to 2025, as shown in Figure 2.



**Figure 2.** Quantity of projected smart devices connected to the Internet with the estimated world population [26].

Urban mobility is one issue that can obtain significant benefits from smart city implementation in terms of safety and traffic management. Such aspect is crucial considering that expected economic loss related to traffic congestion in just one country as the UK is estimated to be equal to GBP 307 billion until 2030. In this case, a crucial role for urban mobility improves as a smart city is represented by Intelligent Transport Systems (ITS) [26,27]. These devices can guarantee safer urban mobility due to Connected and Autonomous Vehicles (CAVs). Information exchange that occurs is identified as V2X (Vehicle to Everything) communication. Pieces of information can be classified concerning their data source: a geostationary dynamic, static and non-geostationary dynamic corresponding to IoT devices and maps, and vehicles, respectively [28]. The only limitations are physical obstructions of device processing systems; for instance, non-optimal lightning or reduced range, that is why a V2V (vehicles to vehicle) communication in addition to V2X is required. If detection systems cannot guarantee an efficient operation, CAVs can communicate with other AVs (Autonomous Vehicles) and ITS [28]. Anyhow, it has to be considered that a practical introduction of AVs did not still occur, then times required to implement a smart city context becomes longer. Moreover, AVs producers and researchers cannot refer to specific manufacturing and modelling standards [29]. Thus, to carry out a forecasting process of CAVs operation in a smart city, it is fundamental to analyse microsimulations to estimate potential fuel consumption and conflicts, considering an initial phase where CAVs will operate with the presence of conventional vehicles [30].

The goal of a smart city is to be more efficient, greener, more digital; therefore, more intelligent [31]. Smart is a city that manages resources intelligently, aiming to become economically sustainable and energetically self-sufficient. Moreover, it is attentive to the quality of life and the citizens’ needs, thanks to the level and type of services offered. In short, a smart city is an attractive and sustainable territorial space that keeps pace with innovations and the digital revolution.

The transformation of a city into a smart one involves investments and interventions in several areas, from economics to urban planning, from energy to mobility, with interdis-

ciplinarity to optimise resources and results. Smart City means energy saving and lower polluting emissions, efficient transport networks, greater use of digital infrastructures, better access for citizens to public administration, and safer and more usable public spaces. Consequently, the smart city also encompasses the concept of smart mobility closely linked to the green world and, therefore, infrastructures and solutions for mobility (parking, charging networks, cycle paths, electric cars, car-sharing, traffic reduction, creation of intelligent flows, to name a few) [32]. Hence, it is a more technological and more sustainable city, capable of wiser management of natural resources. Its intelligence is measured precisely to integrate the various features of sustainability, creativity, social inclusion, and cultural development.

Some European capitals have already cut CO<sub>2</sub> emissions by 25% for a few decades. Furthermore, they aim to reduce them by at least 40% by 2030 and, under the Paris Accords, aspire to become autonomous from fossil fuels by 2050 [33]. Many cities have distinguished themselves for their green vocation. They are currently engaged in strategic projects of various types and entities, aiming to be the most innovative city. Some have already achieved good results, especially in Northern European countries where people are more open to change, and innovation and investments have been made in the defence and protection of the environment for decades.

Anyhow, there is no single model of a smart city nor a better way to transform a traditional city into an innovative urban area based on new concepts of growth and development. Instead, several smart city cases are all good examples of how a city can be made more efficient, liveable, and functional. What makes the difference is the role assigned to citizens or social organisations, new technologies, bureaucracy, businesses, and public administration: in practice, what contributes to the development of the smart city together with design, and which can guarantee a prominent place for the social, technological and economic inclusion of all. Amsterdam, Vienna, Barcelona, Copenhagen, Paris, Stockholm, London, Manchester, Hamburg, Berlin are considered the most innovative European cities [34,35]. Among these, two examples of excellence are certainly Amsterdam and Barcelona.

Amsterdam has distinguished itself over the years for its initiatives in reducing CO<sub>2</sub> emissions with innovative mobility interventions, thanks to the culture and morphology of the territory that allow excessive use of the bicycle. In addition, it has undertaken green energy policies or energy-saving projects that affect various areas: from homes to public buildings, from logistical spaces to city and entrepreneurial spaces. Barcelona has instead focused on eco-sustainability by integrating Information Technology within the city with the use of sensors in public and private field (such as led lighting in parking lots, also with the involvement of car manufacturers that have developed ad-hoc models), connecting different sectors that, acting synergistically, generate transversal knowledge and cooperation. The goal has always been to achieve better efficiency and reduce costs and waste [36].

So a city in the North and one in Southern Europe, both smart but in a different way, as different and others can be the areas of action of all those cities that are turning into smart cities; each with its virtuous system, priority, targeted and limited projects and plans. Strategic plans that integrate new technologies, digital skills, connectivity, and big data with participatory democracy platforms involve citizens in managing public affairs and free access portals to learn about solutions, proposals, and services to improve citizens' lives. The technological innovation of startups and new coworking companies can encourage and develop the economy and progress [37].

#### **4. The Development of CAVs in Urban Mobility**

Connected and Autonomous Vehicles (CAVs) are vehicles equipped with various sensors to obtain information from the surrounding environment, which is then treated and processed by a computer incorporated into the vehicle, capable of making the vehicle move autonomously [38]. Autonomous driving is considered one of the significant innovations of these first decades of the 21st century, capable of revolutionising the urban and extra-

urban mobility system and transforming the lifestyle of people who move daily. In the last decade, the technology related to autonomous driving has accelerated thanks to Artificial Intelligence (AI) onboard vehicles. Thanks to the introduction of AI in driving systems, vehicles are becoming more and more “intelligent”, able to park themselves, change the speed or direction of travel, and react and predict obstacles while driving [39].

With the introduction of CAVs, more excellent road safety is expected for drivers and weak road users with greater accessibility and less environmental impact. However, many challenges still need to be overcome to reach this scenario, which is not without risks. Above all, the possibility of not decreasing road congestion instead of encouraging it. For self-driving cars to safely handle any traffic condition and any impulsive behaviour of other road users, such as cars, pedestrians, and cyclists, and thus ward off human intervention, millions and millions of test kilometres are needed in extreme situations, such as heavy rain, snowfall, other weather events [40].

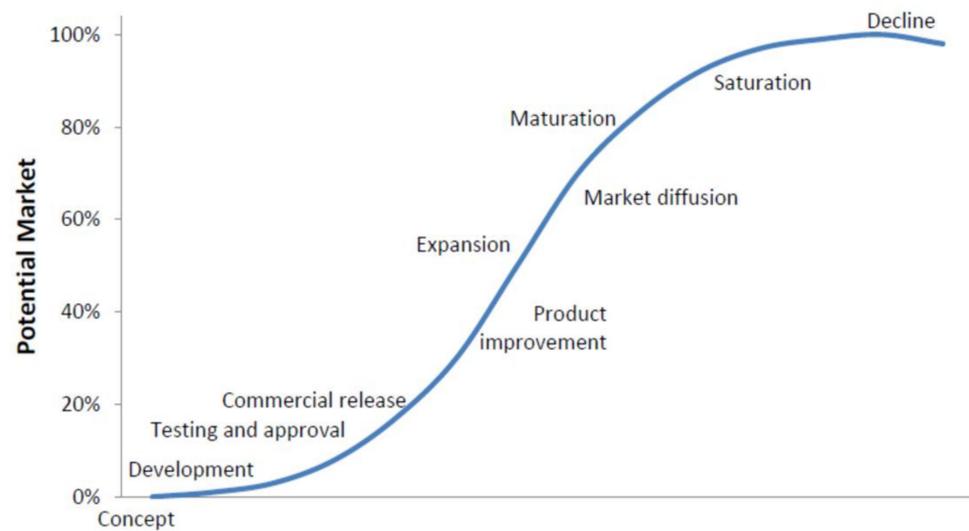
In a future in which CAVs will be widespread, there will always be a coexistence of private and shared use regarding the transport of people. The former will correspond to the private car without substantial differences from current vehicles, apart from the technological equipment present in the automation. On the other hand, will be vehicles intended for community use, in which users will find themselves on board, as is currently the case on collective transport vehicles, with the possibility of using the time in the way they prefer, not having to pay attention to driving and with the obvious advantage of not having to bear the costs of owning a vehicle for private use. In short, the difference between vehicles for personal use and shared use will be in the way of use compared to the usable technology present onboard the vehicles. This circumstance is an essential factor if the time onboard is used up for work activities. In this regard, it is estimated that with autonomous driving, the value of time (VOT) can be reduced by 30%, compared to manual driving, reaching the level of collective transport [41].

However, it is necessary to take into account an ambiguity deriving from a lack of traffic reduction, since if people used the time in the car to work or carry out activities in the same way as they would do at home or in the workplace, the time spent would become irrelevant. Queuing from the vehicle and therefore the problem of road congestion would take a back seat. Nevertheless, this problem is currently secondary, as it will take many more years to see the large-scale spread of CAVs.

#### *4.1. CAVs Development and Distribution Forecasts*

Many of the technologies applied in CAVs are currently under development and will have to go through several steps to become reliable, affordable, and, therefore, commercially available in most markets. Hence, like all new technologies, even those related to CAVs, it can be assumed that it should generally follow an S-shaped development curve, according to Rogers’ law [42], as shown in Figure 3 below.

From an initial concept, it is evident that there are numerous evolutionary steps, such as the initial stages of development and testing, approval, commercial release, product improvement, expansion and diffusion in the market, maturation and possibly saturation, and finally, the decline. Once level five of autonomous driving technology is fully functional and reliable, additional time will be required for testing and regulatory approval. As automatic vehicles can impose high external costs, including accident risks and delays for other road users, they will have higher testing and regulatory standards than most other technological innovations. Additionally, for this reason, it will take many years longer than other technological innovations to reach such a level of maturity to be spread throughout the territory.



**Figure 3.** Predictable distribution pattern of innovations often called S-curve according to Rogers’ law [42].

Under favourable conditions, testing and approval will only take a few years, but the technology could prove unreliable and dangerous. Different jurisdictions are likely to require additional testing, permissions, and regulations, resulting in uneven implementation and deployment rates. It is essential to recognise how the management of a vehicle on public roads is complex due to the frequency of interactions with other objects, often unpredictable, such as vehicles, pedestrians, cyclists, animals, to name a few [43]. Due to these continuous and unexpected interactions, CAVs will require even more complex software than those on board aircraft, which must “only” follow a route without worrying about constantly monitoring the surrounding area and avoiding sudden obstacles.

The data in Table 1 estimate the percentage of diffusion concerning automatic vehicles on total sales, on the car fleet in circulation, and trips made by users [42]. It is estimated that market penetration will occur from 2030, when vehicles with level 5 autonomous driving could be available for purchase but with obvious high costs and performance limits. Due to these constraints, only a minority of new vehicles will be fully autonomous over the first decade under consideration. Market shares increase due to the resulting drop in prices, improved performance, and increased consumer confidence. It is expected that, in about 2050, half of the vehicles sold and 40% of journeys could be made using autonomous driving. Market saturation is likely to take several decades, and some motorists may continue to choose “traditional” vehicles due to lower purchase costs and personal preferences.

Table 1 represents only future estimations based on the current evolution of technologies and tests carried out on the road. Therefore, the implementation of self-driving vehicles may be slower and less complete than the more optimistic forecasts. The innumerable technical, political, and social challenges could prevent autonomous vehicles from being fully reliable and cost-effective from around 2030, extending the time to diffusion beyond 2040 or 2050. Their costs could be higher and the benefits smaller than expected. It will also be required consumer acceptance, which could be influenced by doubts, privacy concerns, or a preference for traditional driving. A significant portion of vehicle travel will remain human-driven even after market saturation. Therefore, there could be slowdowns or accelerations in the diffusion of CAVs in the next few years, and probably this diffusion will not be the same in all countries and continents [44].

**Table 1.** Timing estimation concerning the introduction and diffusion of CAVs in the car market.

Diffusion Stages of C.A.V.s	Decade of Diffusion	% on New Sales	% on the Car Fleet in Circulation	% of Trips Made
Available with a very high price	2030	2–5%	1–2%	1–4%
Available with a moderate price	2040	20–40%	10–20%	10–30%
Available at an affordable price to many	2050	40–60%	20–40%	30–50%
Autonomous driving as a standard feature included in most new vehicles	2060	80–100%	40–60%	50–80%
Market saturation and full availability for everyone	2070	?	?	?
Autonomous driving function for all new and operating vehicles	?	100%	100%	100%

However, considering private cars, other vehicles are intended to be automated, such as, for instance, fleets of automatic minibuses for integration with the local public transport service [45]. Emerging shared mobility services, such as car-sharing and ride-hailing, also reduce vehicle ownership and parking demand in some situations. In this regard, the autonomous vehicle could accelerate these trends, even outside the dense urban areas, increasing accessibility and dependence on the private car [46].

#### 4.2. Potential Distribution Scenarios and Corresponding Urban Impacts of CAVs

The connection between land use and the transport system is indisputable. For this reason, since the mid-1900s, leading to an ever-greater growth and expansion of cities, public and private transport has become a fundamental part of human life, affecting all its features such as work, free time, and education and services. Cities are also expanding given the combined effect of increasing the well-being of the people, a change in lifestyles, and reduced transport costs. These peculiarities allow, for instance, to live further away from the workplace [47]. Therefore, the introduction of CAVs in urban environments must be planned from a global perspective. By 2040, fully autonomous transport systems will appear in the largest cities in the world [48].

Consequently, cities will have to face this challenge. The introduction of the CAVs will lead to a change in movement modalities and the planning and management of urban spaces. In this global approach, densities, urban structures, and land use need to be considered so that new mobility models resulting from vehicle automation provide the desired accessibility while promoting sustainable land use. Self-driving car technology will change the urban environment, and these changes will be irreversible. Hence, it is vital to know the consequences of its application, avoid adverse developments, and get the maximum benefit from the introduction of CAVs.

Like all innovative technologies, automated vehicles also have advantages and disadvantages deriving from their use and diffusion [49]. The main benefits include increased accessibility for all population groups (from young people to the elderly to the disabled), entrance to areas of cities currently not served by public transport, and increased travel safety for all road users [50]. The widespread introduction of CAVs is expected to reduce travel time, thanks to a uniform travel speed of all road users with a faster passage of intersections (thanks to the coordination between vehicles with V2X technologies) and an automatic selection of optimal paths using cloud technologies [51]. Furthermore, the introduction of self-driving technology combined with electric cars will significantly reduce the toxic emissions into the atmosphere of cities [52]. The CAVs could lessen the demand for parking in cities because the vehicle fleet will decrease, and parking spaces could be moved to more peripheral areas. Since the human presence in the parking areas will be negligible and not considered, their configuration could also change to optimise the available space [53].

Regarding the disadvantages, first of all, there is the possibility, given by the widespread distribution of self-driving cars and access to them by a broader segment of the population, to strengthen the current trend towards expanding cities. If autonomous vehicles turn

out to be mainly privately owned, the resulting increase in road traffic will negate the time savings described above in the positive features. A further negative impact is that on human health due to a sedentary lifestyle. The travel priority will be driving a car rather than walking or using a bicycle for short trips [54].

#### 4.2.1. Conceivable Spread Scenarios

Leaving aside the obstacles that could slow down the diffusion of CAVs, both economically (given a high initial purchase cost, at least in the first years of diffusion) and socially, there are currently several scenarios concerning the apparent safety and regulatory issues introduction of automated transport. Depending on ownership, there are two main ones: private ownership of the vehicle and public ownership of fleets of cars and autonomous vehicles [48].

No significant changes are expected in the first scenario, where the cars will still be privately owned. In fact, in a private house, where a parking space is usually located adjacent to the house, a standard car is replaced by a car that drives itself. In areas with greater population density, it can be supposed that during the construction of a multi-story condominium, rather than the integrated underground parking, large independent garages located in more external and accessible places will be built because it will be possible to call the car directly from home through an application installed on the smartphone [55].

However, a new type of mobility appears in the second scenario, linked to an autonomous robotaxi and minibus system and local public transport. Autonomous taxis can be considered the logical continuation of the car-sharing system, which already exists in cities [56]. These taxis do not operate on certain times or routes but are concentrated on demand to be more widespread and efficient than a typical public transport line. The public transport system, integrating with the possibility of combined use with robotaxis or automated minibuses, will solve the problem of covering the last mile. Public transport will move passengers, over long distances, to a hub, where a robotaxi or minibus will pick up and deliver the passengers to their destination. All this could lead to a radical transformation of the public transport system.

The impact on the urban environment following the spread and use of CAVs will be significant [43]. It will be necessary to completely rethink public areas and those destined to parking lots, as there will be less and less need in central or residential areas. The parking lots adjacent to the houses can be converted into additional private spaces or other pedestrian paths or cycle paths. For instance, the elimination of the private garage may favour the expansion of the airspace of the house, where granted, thus leading to better exploitation of the building lot. A similar situation to that expected with private buildings could occur with public ones. The car park will still exist but will be redesigned as a charging station for vehicles. It could be placed in an area adjacent to the building without going too far, thus avoiding increasing the kilometres travelled by cars to return from the destination to the car park and then return to pick up the passenger to bring it home.

Common to both scenarios is the impact on the urbanisation of the territory and road infrastructures. It is possible that with the coming of the CAVs, interest in suburban residential areas will increase. Autonomous vehicles will give greater access to outdoor areas, with lower market prices for housing, but being far from the centre, leading to an increase in urban sprawl. In addition, well-connected rural areas will gain accessibility in an automated driving environment [47]. The positive effects of automation on the territory are subject to more sustainable mobility models. Above all, private owners and companies should aim to share vehicles to obtain higher vehicle utilisation.

#### 4.2.2. Impacts on the Territory

It is possible to highlight three main categories of CAVs' influence on the urban form: urbanisation, road infrastructure, and impact at the local level [48]. The first group includes the factors that influence the structure of the city. As depicted in Figure 4, the introduction of autonomous vehicles can lead to urban sprawl and lower building density. Nevertheless,

on the other hand, it can increase the accessibility of some previously inaccessible areas (red arrows in Figure 4).

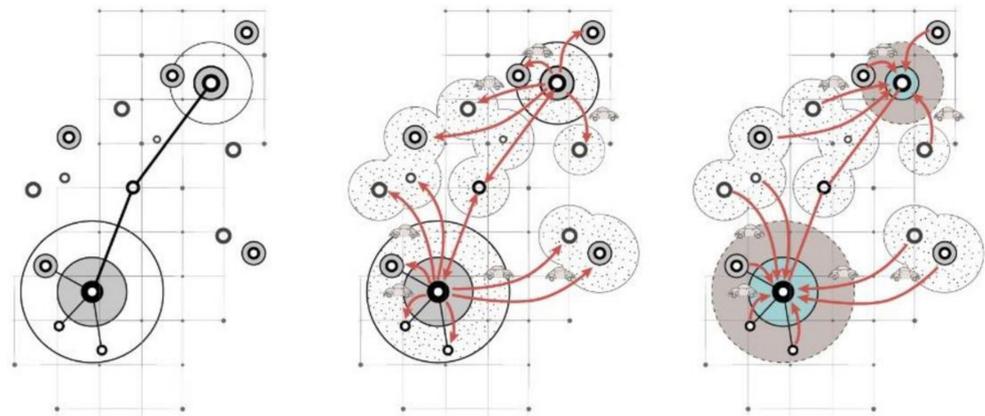


Figure 4. CAVs’ effect on building density [48].

The public transport system can also notice improvements, notably in suburban areas. As previously mentioned, the introduction of autonomous transport systems can solve the last mile issue, thanks to a widespread diffusion proportionate to the demand for the various autonomous transport services (Figure 5).

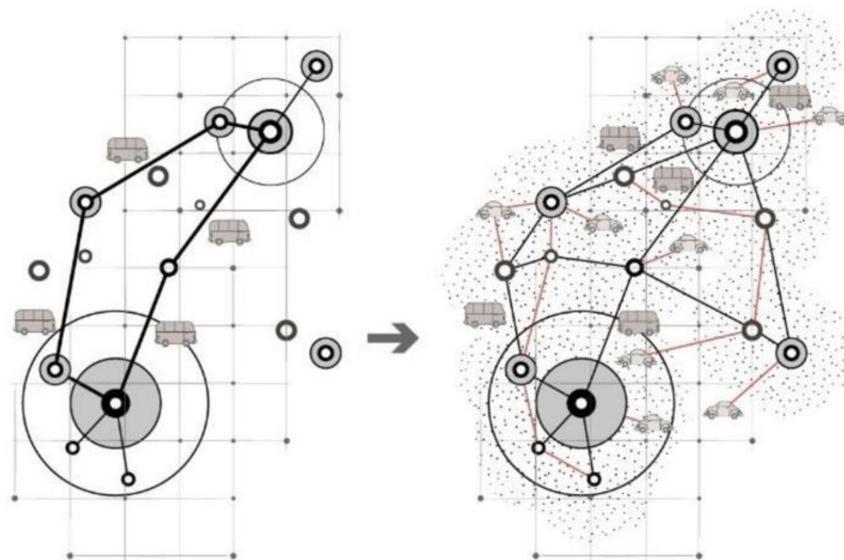


Figure 5. CAVs’ effect on the urban transport system [48].

The second group (impact on road infrastructures) includes the factors that influence road space use and physical change. The introduction of CAVs will improve road safety, eliminating the current disagreement between the vehicle driver and pedestrians, and other road users (Figure 6). In a scenario in which there will be a progressive complete replacement of conventional vehicles with autonomous ones, not only the space intended for pedestrians will tend to expand, but the physical separation between cars and pedestrians could be eliminated on urban roads. Furthermore, the introduction of CAVs will reduce the lanes’ width and essentially eliminate the parking areas along the sidewalk (Figure 7).

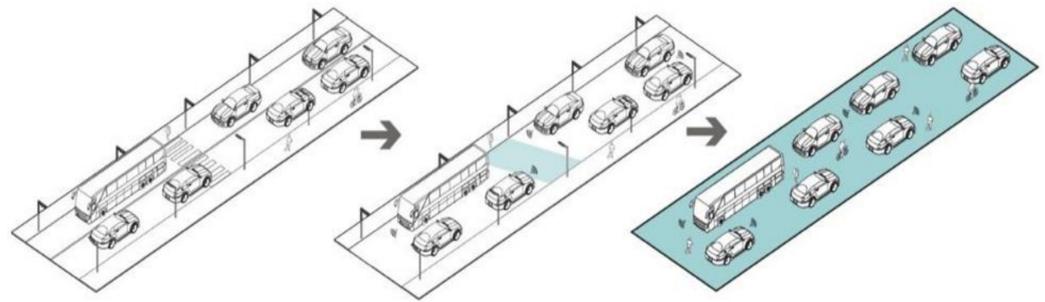


Figure 6. Supposed transformation regarding the road section after the diffusion of the CAVs [48].

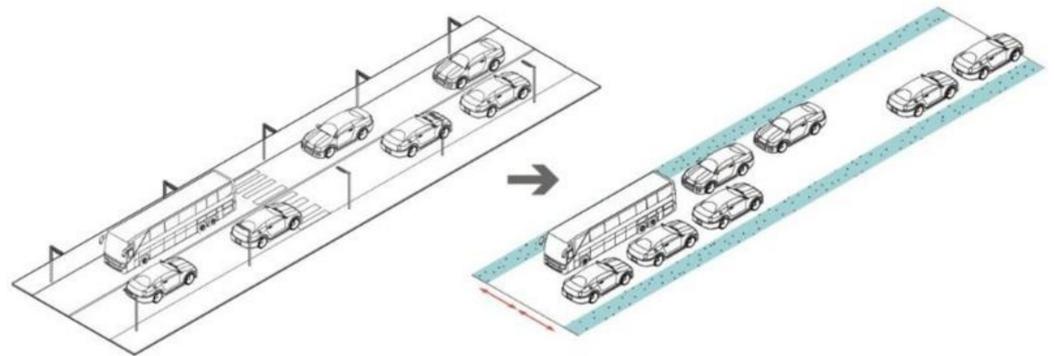


Figure 7. Supposed more efficient utilisation of the carriageway given by the development of CAVs [48].

Concerning local changes, CAVs can impact residential development in the city centre and the suburbs. With the coming of autonomous vehicles, it will be possible to free many areas currently used by cars, which will have to be adapted and reused for other functions (Figure 8). For instance, the conversion of parking areas with the construction of new buildings for offices, homes, shops, or recreational spaces will lead to a consequent increase in the density of buildings. Some spaces currently occupied by private garages will be freed up (Figure 9).

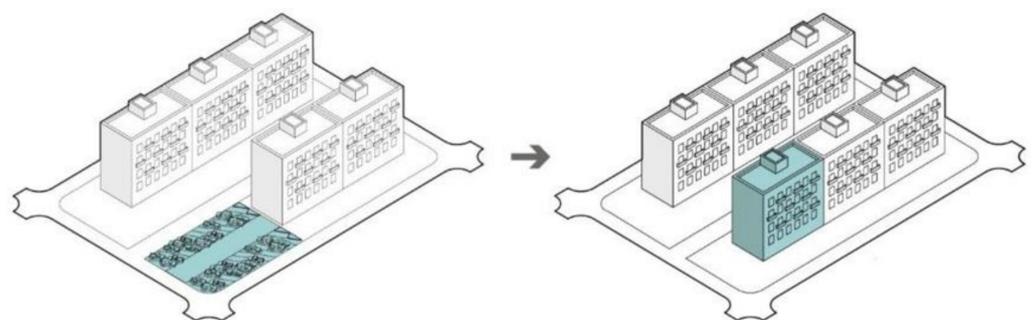
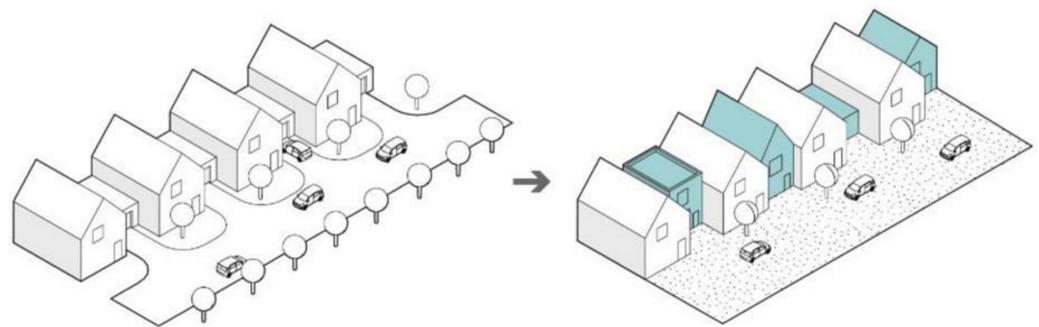


Figure 8. Supposed CAVs' effect on high-density residential areas [48].



**Figure 9.** Supposed CAVs’ effect on peripheral areas with lower density [48].

Ultimately, the introduction of self-driving vehicles will be slow and progressive and will undoubtedly have a different impact on the territory, depending on the type of vehicle and ownership. From the technological point of view, legislative and economic changes, the first scenario is the simplest to perform, in which a self-driving car replaces a simple one. From the urbanisation and spatial planning perspective, it is crucial to promote the introduction of the second scenario, which will exclude, or limit, the private ownership of vehicles, consequently reducing their number. The CAVs technology will lead to a progressive and irreversible change of the urban environment. Therefore, to avoid the negative consequences of introducing these new technologies, it is necessary to foresee changes to the urban environment to meet future needs.

**5. Definition of the Factors That Influence the Spread of CAVs in the Smart Cities**

Today, around 75% of Europe’s population lives in cities. This percentage is set to rise worldwide. According to United Nations reports, 70% of the global population will live in cities by 2050. At the same time, and despite occupying 2–3% of the total land area, cities are responsible for 70% of carbon dioxide and pollutant emissions and significant energy consumption due to this concentration of people and activities. For this reason, the smart city model of modern society must go hand in hand with energy efficiency goals (which include the energy efficiency of buildings and businesses) following Agenda 2030. All forms of sustainable and innovative mobility are vital players in the transport sector within Smart Cities. In particular, sharing mobility services (car sharing, bike sharing, carpooling, and sharing electric micro-vehicles) and electric vehicles are particularly appreciated by citizens because they are efficient and sustainable, reducing traditional urban traffic and harmful emissions. Table 2 shows the definition of the smart cities concept in different parts of the world [57].

**Table 2.** The definition of the smart cities concept in different parts of the world [57].

Smart City	American Model	Asian Model	European Model
Main axis	research	testing	sustainability
	Technology	Automation	urban regeneration
	Globalisation	New Town	social inclusion
Urban scale	metropolis/megalopolis	megalopolis/gigalopolis	cities/metropolis
Identity	global	global	global/European/local
Citizens participation	medium-low	low	medium/medium-high
main promoters of urban smartness	private: ICT companies/academic innovation centres	private: ICT companies/Building society/Finance	public: U.E./cities network/Universities/Local Authorities
		public: national Government	

The acquisition of data through sensors operating in real-time and/or through the dissemination of questionnaires and interviews allows for scaling, i.e., it allows for the analysis of the dependency that correlates a city with specific socio-economic and structural indicators. It is shown that there are correlations between the dependence on the population size of the total number of miles travelled daily, the total length of the road network, the total traffic delay, the total petrol consumption, the amount of CO<sub>2</sub> emitted, and the relationship between area and population of cities and all correlations refer to a possible increase in the congestion factor as the size of the city increases [58].

Mobility planning within cities and the organisation of the various forms of mobility cannot fail to consider two fundamental parameters of the context in which one lives, namely demographic size and the extent of the territory in which one moves. Thus, to identify the size of the city, it is helpful to refer to the following parameters:

1. The territorial surface area in square kilometres
2. Population density (inhabitants per square kilometre)
3. Resident population
4. Commuting population

A more significant difference in territorial size indicates a greater difficulty in managing space and the organisation of a capillary network capable of connecting centre and periphery and periphery and periphery.

The same reasoning can be applied to the number of residents so that if more people gravitate to the area, the greater the range of services must be to guarantee the same travel opportunities for everyone. Knowledge of the commuter population gravitating in a city is essential to plan dedicated services according to the different users (students, workers, tourists).

The density of inhabitants per square kilometre, on the other hand, describes the degree of occupation of an area, so for example, an area with a higher density will present problems linked to a high concentration of demand for mobility, and therefore it will be necessary to guarantee greater service activity to dispose of more intense flows of movements more quickly. In comparison, in areas with a lower density, the main difficulties will be optimising and diversifying services to avoid, for example, empty lines or excessive waiting times.

As far as the modal choice is concerned, it is helpful to define the different forms of mobility according to the distance to be reached, i.e.,

1. Short distance (<2 km): the preferred choice for walking or cycling (classic or pedelecs, micro-mobility)
2. Medium distance (2–5 km): the preferred choice for public transport (bus, tram), shared transport (car), on-demand transport (taxi or DRT)
3. Long-distance (>5 km): preference for public transport (metro-train), shared transport, demand-responsive vehicle.

Several factors can influence these distances, such as personal factors and factors related to the built environment. According to [59], distances travelled in long-distance and daily trips are influenced by socio-demographic data in much the same way, while spatial effects influence distances travelled in daily and long-distance trips mainly in different directions. Residents of small towns and low-density neighbourhoods make fewer and/or shorter long-distance trips than those living in large cities and high-density neighbourhoods, but the latter travel shorter distances in their daily lives. Increasing urban accessibility is closely related to the definition of short, medium, and long distances to measure walkability and the effectiveness of car-sharing based on parking distances or the distance of charging stations in electric vehicles [6,60].

The diffusion of urban planning forms such as the 15-min cities can reduce travel distances and promote activities and technological development on an urban neighbourhood scale. As well as the diffusion of the concept of the compact city develops buildings vertically and uses small spaces for the implementation of services and technologies.

The new identification of weak demand areas refers to peripheral regions and those due to the recent pandemic. This identification also includes areas characterised by a reduced transport offer due to the current pandemic. It allows the diffusion of complementary forms of mobility, such as on-demand mobility, while respecting social quotas and distancing, reducing private vehicles. One of the essential aspects of the smart city is that it is equipped with intelligent adaptive systems which, through the spread of the so-called Internet of Things (IoT), i.e., networks and sensors, can optimally manage urban flows (e.g., by increasing or decreasing the duration of red lights, showing free parking spaces available in real-time, monitoring city traffic, energy networks, pollution and so on). On the mobility front, the most advanced challenge is represented by electric vehicles with autonomous driving, which means a real leap forward in automotive technology, albeit within an evolutionary path that has been underway for some time.

Large and small cities have already been carrying out smart city transformation processes for years, changing their physiognomy, social, economic, and urban fabric. The recent COVID-19 pandemic has also shown that new technologies benefit the safe mobility of people and goods [61].

The recent restrictions on mobility with the simultaneous development of remote interactions (smart-working, e-learning, e-health, etc.) propose a different way of interacting with the city system and, more generally, with its aggregate forms (Province, Region). It is necessary to develop the urban system to benefit from these changes imposed by contingent situations. It also derives the opportunity, in the future, of a more efficient and effective set of interactions that could improve the quality of life. From an infrastructural point of view, the development of smart roads, together with the evolution of the use of Big Data and the implementation of dedicated apps for smartphones and tablets, are the main actions to be developed starting from the urban context to allow the execution of autonomous mobility and at the same time guarantee 24-h monitoring and a reduction in environmental noise emissions. The spread of recharging infrastructures (especially fast ones) and electric mobility allows a general decrease in environmental impacts and provides an incentive to abandon internal combustion engine vehicles.

From a regulatory point of view, two main planning tools have been defined in Europe to develop local strategies integrating electric mobility, namely Sustainable Energy Action Plans (SEAPs) and Sustainable Urban Mobility Plans (SUMP) [62]. A SEAP is a crucial document within the Covenant of Mayors in which cities define activities and measures to reduce CO<sub>2</sub> emissions by 2020 according to targets, while SUMP are strategic plans that aim to reduce congestion. It builds on existing planning tools and is based on integration, participation, and evaluation principles to meet the mobility needs of people and goods today and tomorrow to improve the quality of life in and around cities. The policies and measures defined in a SUMP must cover all modes and forms of transport in the entire urban agglomeration, public and private, passenger and freight, motorised and non-motorised, traffic and parking, and therefore the introduction of electric mobility and autonomous vehicles within these planning tools will allow for a better and rational design of future mobility.

Sustainable Urban Mobility Plans (SUMP), Sustainable Energy Action Plans (SEAPs), and Sustainable Energy and Climate Action Plans (SECAPs) are the main instruments promoted by the European Union to foster local policies for sustainable mobility, energy, climate change adaptation, and mitigation [63,64]. According to [65], these instruments must be harmonised and thus improve the planning, implementation, and monitoring of their sustainable energy and mobility plans like described on Figure 10.

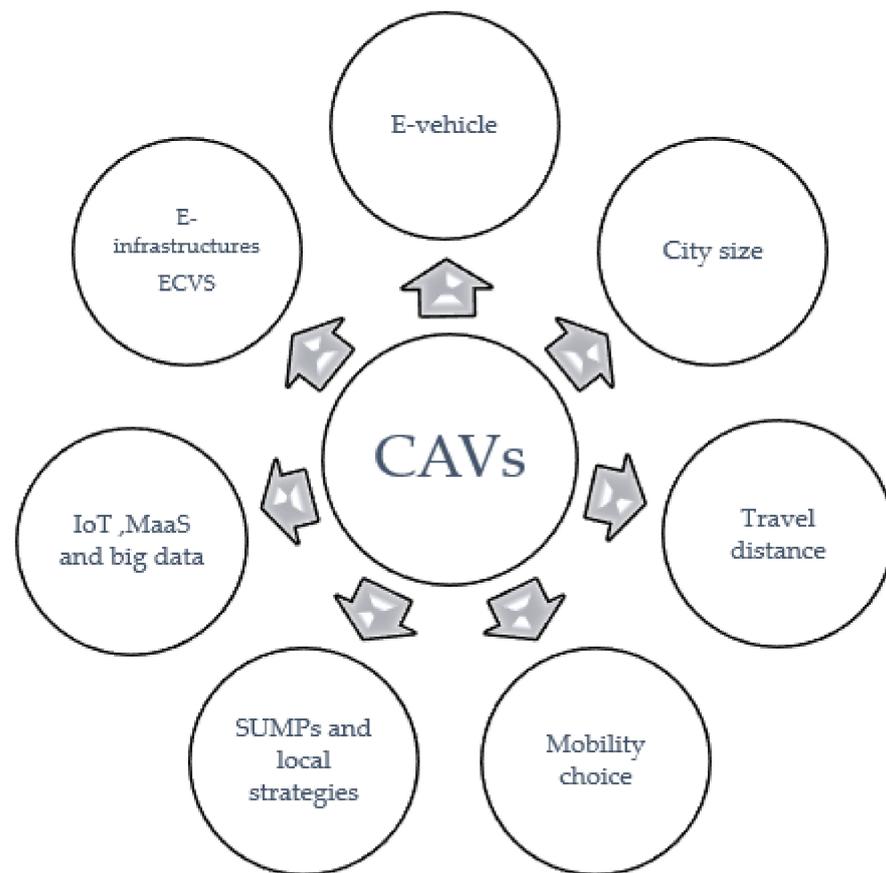


Figure 10. Proposal future works scheme.

The emergence of CAVs encourages increasing the flexibility of transport services, reducing accidents caused by alcohol abuse, and reducing human error or distraction. These systems also allow the optimisation of the efficiency of vehicle flows, the reduction of pollution, and increase the opportunities for social inclusion for people with disabilities, social inclusion opportunities for people with physical, cognitive, or motor disabilities.

In the European context, many historical centres limited traffic zones and pedestrian areas have been introduced to reduce traffic congestion. These areas have been introduced to reduce pollution and make it easier to gently use public space (on foot, bicycle, etc.) of public space. These new autonomous mobility systems could become tools to facilitate access to historic urban space without building expensive infrastructures such as subways, costly infrastructures such as underground metro systems, tram lines, etc., without developing a new vehicle.

## 6. Discussion

Looking ahead to 2050, the possibilities offered by CAVs seem limitless. In many ways, next-generation technologies can be an essential ally in achieving our sustainability goals. Electrification is a crucial step towards reducing emissions to zero by 2050. Removing exhaust fumes from roads will dramatically improve air quality in cities. Moreover, the evolution of smart cities could manage resources intelligently to become economically sustainable, energy self-sufficient, and attentive to its citizens' quality of life and needs, evolving in step with innovation and the digital revolution, but remaining a sustainable and attractive reality.

Connectivity is the key to promoting autonomous and sustainable mobility. Mobility is not seen as a goal in itself but as a means of providing access to essential services. Adopting connected autonomous vehicles will increase road capacity and reduce congestion even in the most densely populated areas. The roads with self-driving cars, intelligent traffic lights

to regulate traffic, information exchange between objects, but above all large green spaces, fluid traffic, and sustainable mobility with bike-sharing and car-sharing of electric and/or hybrid cars.

By 2030, it is estimated that Level 5 automated vehicles (the highest in the SAE classification) will be a reality, i.e., vehicles capable of driving on any type of road, in any weather condition, and the passengers onboard can completely disregard driving during the journey. A self-driving vehicle continuously and automatically makes decisions about its behaviour and, therefore, the machines must capture every detail: pedestrians, cyclists, trucks, animals and, in general, every smallest obstacle around them, whether stationary or in motion, is fundamental in determining whether to brake, turn, slow down, accelerate or continue.

The evolution of these vehicles is closely correlated to the development of technology and sensors, and mechanisms outside the cockpit with which the vehicle communicates with the road infrastructure (so-called smart road), also becoming a useful tool for providing information on traffic and safety. The advantages of autonomous driving include:

1. greater safety when moving around, and therefore a reduction in accidents, given that the driving system is not subject to fatigue or distraction and is less subject to risks linked to environmental conditions (low light, fog, rain)
2. the possibility of getting around more easily for the elderly and disabled
3. the reduction of traffic and pollution (thanks to smart roads, traffic should be smoother with a consequent reduction in polluting emissions)
4. reducing driver stress
  - a. The disadvantages of this technology are numerous and ethically significant:
5. the reduction of jobs
6. the possibility that the software that governs the cars could be affected by errors
7. like any electronic device connected to a network, the self-driving car is also attackable by hackers
8. the safety risk of personal data of drivers, passengers, and third parties

Adopting connected autonomous vehicles will increase road capacity and reduce congestion even in the most densely populated areas. The roads with self-driving cars, intelligent traffic lights to regulate traffic, information exchange between objects, but above all large green spaces, fluid traffic, and sustainable mobility with bike-sharing and car-sharing of electric and/or hybrid cars.

## 7. Conclusions

Self-driving vehicles also offer new opportunities for people with motor problems, including the elderly (a growing population), people with disabilities, and marginalised groups. It is estimated that mobility as a service will make the cost of a ride less than the price of a public transport ticket, thus helping to break down the barriers of social inequality. Similarly, the evolution of CAVs can bring several benefits to the community. It can be measured both directly and indirectly. Critical indicators for optimising the service of CAVs in urban areas include (1) traffic volume traffic accidents, (2) transport costs, (3) total parking space, and (4) energy consumption and travel time.

A liveable city should be safe, clean, and full of green areas. Cars, as we know, harm each of these aspects. When autonomous driving technology reaches high levels, safety on the roads and environmental sustainability will increase radically. The AV revolution could create a future of smooth and predictable traffic and more efficient public transport. As a result, city dwellers will have more free space to use. In addition, there will be fewer risks for pedestrians and cyclists, who have many concerns in urban areas. All the benefits of autonomous vehicles and smart cities could improve the quality of life for millions of people while taking care of the environment to a higher level. The cities of the future will therefore have to become digital hubs.

Notably, the development of smart cities in the CVAs could potentially guide long-term urban planning. The question is whether CAVs can transform cities into better places to live with a future time horizon? Urban space planning will have to consider that self-driving vehicles do not need parking spaces in city centres, so these spaces can be converted to facilities that make cities more pleasant places to live.

Some of the urban planning strategies being implemented, even in light of the recent pandemic, are related to the concept of the “15-min city”, a contemporary idea whereby all citizens should be able to access essential services within 15 min on foot, by bicycle or by using public transport. Note that this concept does not consider cars at all, primarily privately owned cars. It is likely that self-driving cars, as a public and shared service, will fulfil journeys by eliminating private vehicles.

There is a significant gap between the direction in which the automotive sector is moving and what cities aspire to. However, there is also good reason to say that sustainable cities can benefit from better collaboration. First of all, cities will still need cars in 2050. Although there is convincing evidence to show that “the city in 15 min” works for densely built-up centres such as Paris, in cities such as Gothenburg, with considerably more urban sprawl, it is likely that cars will continue to be an essential means of transport. On the other hand, the automotive sector also needs the cooperation of cities. The adoption of new technologies depends mainly on the policies and willingness of cities to facilitate it.

Although each city has a unique structure, it can be sorted into a category of cities with similar characteristics that make certain forms of transport more suitable than others. Planners can identify and analyse these indicators to support future developments in transport systems. Similarly, planning makes it possible to develop an intelligent urban system and optimise its benefits through various strategies. Often, this planning is part of years of municipal investment and attention to the local impacts of digital technology. It must consider the following as implementation tools:

1. City leadership and democratic planning: cities that have made the smart city-equity connection often because elected officials prioritise it.
2. Community awareness and related buy-in promotion: cities actively reach out to all community segments to educate them about innovative city technologies, get feedback from citizens, and create a co-creative process that allows the smart city to be equitable.
3. The definition and constant monitoring of critical system issues and fundraising: cities need resources for digital inclusion and smart cities, and some places have raised funds for inclusion through local franchise agreements with telecommunications and cable companies for infrastructure development.

The manuscript therefore lays the foundations for the definition of strategies that can be implemented in the various types of cities of today and the next few years, encouraging the development of specific, operational components that can adapt the development of CAVs to smart cities (e.g., through the dissemination of induction technologies for recharging electric cars and various devices, the dissemination of educational campaigns that allow a drastic reduction in the use of private vehicles and greater attention to shared mobility, and also continuous research related to the ethical and social aspect of the use of CAVs). Several cities, after small-scale experimentation, have already planned and introduced a better development of sensor networks throughout the city, capable of making humans interact with cars and the environment (e.g., smart intersections, smart roads, autonomous parking and electric vehicle charging points).

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