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Parking futures: Preparing European cities for the advent of automated vehicles

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ABSTRACT

The introduction of automated vehicles (AVs) is a virtual certainty. Much less certain is the timing of their introduction and how rapid the transition to full automation will be. Various governments are already working to facilitate this shift by, for example, amending and elaborating regulations to support the introduction of AVs, or supporting tests in different urban environments. Meanwhile, urban and regional planners and decision-makers are still grappling with the uncertainties and differing opinions about the possible impacts of AVs on land-use changes and location choices, particularly in relation to the space available for vehicles, both moving (i.e. roadspace) and stationary (i.e. parking space). This paper uses a backcasting approach to identify critical policy decisions and measures to be taken before the implementation of AVs, so as to achieve a more desirable, attractive and high-quality city. These policy measures primarily relate to the reuse and reallocation of parking and roadspace. Two strategic decisions are found to be essential to meet the major goals of sustainable and liveable cities: a clear commitment to a shared mobility and the delimitation of Core Attractive Mixed-use Spaces (CAMS). In order to deliver these desired urbanisation patterns, a set of three policy paths, involving eight policy packages, is proposed for the next 20–30 years. This article provides urban and regional decision-makers with examples of interventions that can be implemented beyond and during the implementation of AVs.

1. Introduction

As with all advances in transportation technology, such as the first introduction of railways and cars, the future implementation of automated vehicles (AVs) will undoubtedly have a great influence on urban form and patterns of development. Literature on AV impacts related to urbanisation patterns points both to great opportunities and major threats. Optimistically, AVs could reduce parking needs, traffic volumes and road space, especially when shared, which could enable the redesign of these spaces, leading to a densification and an improvement of the attractiveness of city centres (Alessandrini et al., 2015; Begg, 2014; Cavoli et al., 2017; Dupuis et al., 2015; Fagnant and Kockelman, 2015; Heinrichs, 2016; Milakis et al., 2017b; Zhang et al., 2015). Conversely, the flexibility and comfort provided by AVs, added to their convenience for people without driving licenses, could cause reductions in the value of travel time and hence increases in distance travelled and sprawl intensification (Cavoli et al., 2017; Gruel and Standford, 2016; Milakis et al., 2017b; Thomopoulos and Givoni, 2015; Zhang and Guhathakurta, 2018; Zakharenko, 2016).

Despite being aware of the crucial relevance of AVs, few land-use or transport plans have considered their effects on future urban development in any detail.[1] According to Cavoli et al. (2017), US urban policymakers and planners stated that the uncertainties associated with AV deployment and use are the main reason for their disregard in planning schemes. Despite these uncertainties, attention to the issue is crucial, in order to avoid unwanted effects (Cohen and Cavoli, 2019).

Various authors emphasize the urgent need to identify desirable visions for future urban environments in the long term (e.g. Begg, 2014; Dupuis et al., 2015; Gruel and Standford, 2016; Guerra, 2016; Kane and Whitehead, 2017; Legacy et al., 2018; Lyons, 2018; Stone et al., 2018). This not only includes thinking about the way in which cities should adapt to the introduction of AVs but, perhaps more importantly, about how AVs should be developed to comply with the expectations attached to ideal future cities (Porter et al., 2018). The role of planning policies in promoting certain transport modes and choices is crucial, as evidenced in dense and public transport dependent cities such as Hong-Kong or Tokyo, cycling cities such as Amsterdam or Copenhagen, or more car-dependent cities such as Brisbane or Boston (Porter et al.,

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[1] According to Dupuis et al. (2015), only 6% of the most populated US cities have transport plans which take into account the effects of AVs in their development.

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2018). Hence, local governments and planners should start to prepare adaptive legal, urban and land-use regulations to accommodate such a disruptive transportation mode as AVs (Cohen and Cavoli, 2019; Legacy et al., 2018; Papa and Ferreira, 2018). In order to help and encourage urban decision-makers to take action, this paper attempts to contribute to the study of the potential role that AVs should play in contributing to future urban development by identifying the critical policy and planning measures that could better guide AV rollout. To this end, the backcasting methodology has proved especially useful.

This paper is divided into three main parts. The first part reviews the state of the art regarding development and timeline expectations of AVs, as well as their main potential impacts in urban form and land use, paying special attention to those related with parking space demands. The second examines the backcasting methodology in urban planning and then applies the procedure to AV implementation, exploring the steps and decisions to be taken to deliver desirable patterns of urban development. The third part summarises the main conclusions and discusses current limitations and future directions for further research.

2. Challenges and opportunities of automated vehicles for urban development

2.1. Automated vehicles: current status and timeline estimates

Although the first investigations and experiments related to Automated or Autonomous Vehicles began in the early 1980s (Anderson et al., 2014), most of the technological advances have taken place during the last decade. According to the Cologne Institute for Economic Research, 5839 patents related to Autonomous driving were filed between January 2010 and July 2017 (Bard, 2017). Nine of the world's leading automobile companies are responsible for most of these patents, led by Bosch (958), Audi (516) and Continental (439), although other large non automobile-supplier companies such as Google (338) are also competing to develop the first driverless car.

The widespread interest shown by private companies and public authorities, eager to provide the potential social benefits of AVs to citizens, is accelerating their development and implementation process. More and more cars equipped with advanced driver assistance systems (ADAS) such as cruise control or automated parallel parking (i.e. level 1 and level 2 AV, according to SAE levels[2]) are currently in use. Level 3 automated transit pods, buses, taxis and cars, or even level 5 ones (e.g. the Dutch WEpod), are being developed and tested in many countries, such as the US, The Netherlands, Sweden, the UK, Germany, and France (Hörl et al., 2016; KPMG, 2018). In the US alone, 163 AV-related companies have been launched and more than 7 million miles of road have been autonomously driven since 2009 (Ohnsman, 2018).

Because of the rapid technological development (as well as the desire of the AV industry to secure investment capital), many automobile companies claim that level 3 AVs could be commercialized by 2020–2025 (Hars, 2017). Regarding level 4 and 5 AVs, most timeline deployment estimates in the literature point to the period between 2027 and 2035 for them to be seen on public roads (Milakis et al., 2017a), or between 2040 and 2050 for widespread penetration (Hörl et al., 2016). This implementation could follow several phases or stages. After a testing period, the first introduction of level 4 shuttles or microtransit services and freight trucks is expected only on freeways, enabling freight platooning, between 2020–2027 (RPA, 2017). According to RPA (2017) there would then be a progressive autonomous conversion of vehicle fleets from 15% in 2030 to 75% in 2040, which would reduce the number of required traffic lanes. This would lead to the accommodation of AV circulation in urban streets beyond 2040, comprising flexible public Shared AV (SAV) services adaptable to different demand patterns.

Clearly, the estimated timeline for the introduction of AV technology is subjected to many uncertainties. Traffic limitations or the regulation of dedicated lanes in certain types of roads or environments are crucial to estimate the degree in which AVs are adopted more accurately (Röhrleef et al., 2015). Accounts by Begg (2014) and Litman (2018) warn that the process could easily be slower than expected, as with other technological or transport revolutions in the past. Indeed, the adoption of electric vehicles and the introduction of mass motorization took decades from the time when production first began. According to Litman (2018), even when technology becomes commercially available, the general use of privately-owned AVs could need another 20 or 30 years to become a reality. However, the implementation of shared (commercially-owned) AVs may accelerate the process.

These contrasting timeline estimates raise three key questions concerning the future development of cities: What happens in the meantime? How to deal with urban environments in which the existing car fleets operate alongside level 3 or level 4 vehicles? What are the urban and spatial planning implications of this transition?

2.2. Potential impacts of AVs in urban form and land use

Estimates of the potential implications of the implementation of AVs have increased rapidly in the academic literature over recent years, pointing to both optimistic and pessimistic valuations. These studies are mainly related with technological developments, use and transportation effects. Very few studies consider the consequences of this implementation on urban form and structure (Cavoli et al., 2017; González-González et al., 2018; Milakis et al., 2017b; Soteropoulos et al., 2018; Stead and Vaddadi, 2019), for which the key question is the dichotomy of density versus sprawl.

On the one hand, the deployment of AVs could lead to denser and high-quality city centres, given that a large amount of space could be released due to reductions in parking demand, in the number of circulating vehicles, and in transport infrastructure due to the more efficient spacing and operation of vehicles. These spaces could be regenerated and transformed into new residential areas, economic centres, new urban facility districts or public green spaces, offering opportunities to improve urban quality standards and citizens' quality of life (Milakis et al., 2017b; Sousa et al., 2018). The relevance and amount of free spaces are directly affected by the preferred implementation of a shared use of AVs (SAV) over private ownership (PAVs).

Several authors have highlighted the potential of AVs to reduce car ownership and promote on-demand or sharing practices (Cavoli et al., 2017; Greenblatt and Shaheen, 2015; Stone et al., 2018; Zhang et al., 2015). These practices are already emerging in many countries, often due in part to their significantly lower costs when compared to owning a car (Burns, 2013). Sharing involves either sharing a vehicle or sharing a trip, which significantly influences impact estimates. For instance, Fulton et al. (2017) estimated the total number of circulating vehicles in the hypothetical case that all conventional cars would be replaced by PAVs and shared AV fleets. Their estimates suggested a total of 2.1 billion PAVs by 2050 compared to 0.5 billion SAVs by the same date. Similarly, the simulation carried out by the International Transport Forum in 2015 reported that equal levels of mobility could be achieved with a ca. 90% reduction in vehicles (65% at peak-hours) in a situation involving automated ridesharing services, with a combination of 8 and 16-seater vehicles, along with high-capacity public transport (Milakis et al., 2017b). Childress et al. (2015) also differentiated their travel demand estimates between PAVs and SAVs, obtaining a 20% increase

[2] Six levels of automation or development stages of Automated Vehicles, defined by the US Society of Automotive Engineers (SAE), are globally accepted (Cavoli et al., 2017; Litman, 2018): From Level 0-No automation to Level 2-Partial automation, driving tasks are performed by a driver. From Level 3-Conditional Automation to Level 5-Full Automation, driving tasks are performed by automated driving.

and a 35% decrease in demand, respectively. They justified the high decrease in SAVs as being the result of the high prices assumed.

Clearly, the willingness to share vehicles is very dependent upon the type of settlement. Mobility behaviour and preferences differ considerably between residents of metropolitan, urban, suburban and rural areas. Alessandrini et al. (2015) pictured a future city in which people in central areas would chose shared transport in up to 90% of their trips, in about 70% in inner suburbs, and in 50% in outer suburbs, complementing a high-tech public transport system. In this context, several authors warned about the potential negative effects of sharing practices for public transport (Cavoli et al., 2017; Meyer et al., 2017; Röhrleef et al., 2015). SAVs would be more competitive than public transport in rural and smaller settlements with low passenger demands and short distances, since they are faster, more comfortable and more economic (Meyer et al., 2017). Conversely, public transport within large urban areas and between urban centres could be efficient and complementary to SAVs. In fact, some studies in US cities point at an increase in the frequency of use of public transit, as well as in walking and cycling, by new carsharing users (Greenblatt and Shaheen, 2015). According to Milakis et al. (2017b) and Soteropoulos et al. (2018), the potential reductions in public transport associated with SAV implementation will have a bearing in the value of time, the operating costs and whether governments allow vehicles circulating with a low number of passengers. In a SAV low-cost scenario, SAVs could lead to reductions in public transport share of between 16 and 12% and larger reductions (26–20%) in non-motorized modes (Soteropoulos et al., 2018). Meanwhile, high operating costs and a ban of PAVs, could increase the public transport share between 13 and 17% and the walking share between 22 and 31% (Soteropoulos et al., 2018), and for short trips up to 140% and 50% respectively (Milakis et al., 2017b).

A decrease in the number of circulating vehicles and platooning in the city could lead to another range of benefits associated to fully automated SAVs, such as the reduction in the number and width of traffic lanes (Heinrichs, 2016) or the elimination of central reservations. In contrast, new charging stations and pick-up and drop-off points would be required. A high dispersion of these points throughout the city could enhance a greater use of single-occupant or small AVs, thus increasing the number of circulating vehicles. However, their location in transportation hubs or former 'park & ride' areas would promote the use of other public transit services, walking and cycling.

Parking demand will also be highly influenced by the rate of SAV implementation. Estimates of reductions in parking demand vary between 67 and 90% (Milakis et al., 2017b; Zhang et al., 2015). Dupuis et al. (2015) argued that at least 50% of street parking could be eliminated, a figure that would be higher if SAV penetration rates were significantly high. Zhang (2017) estimated a reduction of at least 20 parking spaces per SAV due to the reduction in vehicles and an increase in vehicle occupancy. Translating these estimations into land surface would mean that up to 1.4 million acres in the US (0.57 million hectares or 700,000 football fields) could be freed by 2040 (RPA, 2017).

Additionally, parking space could be reduced even further considering the improvement in efficiency of parking automation. Multistorey car parks and parking lots could increase their capacity up to 60%, since aisles, ramps and door opening space would no longer be necessary (Alessandrini et al., 2015; Begg, 2014; Heinrichs, 2016).

The spatial distribution of parking spaces would also be an important issue to consider. Firstly, large concentrations of parking lots in attractive parts of high-density city centres, such as shopping zones and mobility hubs, or collective garages in residential areas, are expected (Alessandrini et al., 2015; Heinrichs, 2016). Secondly, parking areas located outside the centre could accommodate around 97% of the daily parking demand (Zakharenko, 2016), given that AVs could pick up and drop off passengers at different points within the city and park far away when not needed (Begg, 2014).

Another possible effect of AV introduction is the increase in travel distance and frequency due to the changing cost of travel and value of time for passengers. According to Cavoli et al. (2017) the use of PAVs would lead to an increase in the distances travelled and a reduction in public transportation shares. Comfort, the possibility of performing leisure or working activities while travelling, piloted parking and faster trips due to platooning, would reduce the perceived value of time by users and therefore increase average commuting distances. Fagnant and Kockelman (2015) estimated an up to 26% increase in vehicle miles travelled (VMT) after a 90% adoption of AVs. These projections are similar to the ones made by Milakis et al. (2017a) for the Netherlands, who reported an increase in VMT of between 1–23 % by 2030 and between 10–71% by 2050, and to the 5–20% increase predicted by several US regional transport planning organizations (Guerra, 2016). SAV implementation and fares would again play a relevant role. Soteropoulos et al. (2018) point to a reduction in VMT of about 10–25% if ridesharing was chosen by a large share of travellers, and VMT increases between 35–60% for lower fares and additional empty trips, which could rise up to 89% if no public transport existed and SAVs replaced all private vehicles.

Zhang and Guhathakurta (2018) also suggest distinct changes in commuting VMT according to family types. The VMT for middle-aged families with younger children would increase (by 12%) with the introduction of SAVs, while VMT would decrease in the case of older families (by up to 7%). VMT increases could induce urban sprawl (Litman, 2018; Begg, 2014; Cavoli et al., 2017). According to Zakharenko (2016), cities could expand by 7% outside their centre, where land rents are 40% lower, while land rents within the city could increase up to 34% due to parking space removal in well-located areas. In population terms, a 3% increase in the outer suburbs and a 4% decrease in inner urban areas could be expected due to the reduction in the value of time for PAVs. Meanwhile, according to Soteropoulos et al. (2018), the introduction of automated public transport and the reduction in travel times could increase the population of large cities, while reducing the suburban population.

Very recent studies highlight a change in travel demand and mobility trends that should be considered in future vehicle estimates. Marsden et al. (2018) argue that commuting trips in England have experienced a 20% reduction since the mid-1990s. Also, young males between 18–30 years old, travel 50% fewer miles than in 1995, and on average, people travel 10% less than in 2002. These reductions, which occur in a variety of settlement types, from capital cities or metropolitan areas to rural ones, are associated with a range of influences including teleworking, on-line shopping, remote health treatment and diagnosis. These factors may play an even more important role in influencing travel patterns in the future.

The range of impacts of AVs on urban development is summarised in Table 1. Clearly, current settlement and transport structures play a decisive role in location choices and urban form (Soteropoulos et al., 2018). In this context, identifying strategic decisions and prioritizing key measures before and throughout the AV deployment process is crucial. This is the main purpose of the backcasting planning approach.

3. Backcasting the city of tomorrow

3.1. Backcasting methodology

Long-term analyses (over 10 years or more) are commonly carried out by applying future studies based on scenario analysis (i.e. scenario planning, forecasting and backcasting studies). However, while scenario planning and forecasting focus on answering the question of what *could* or *will* (most likely) happen, backcasting tries to answer what *should* happen (or what is preferable) (Banister et al., 2007; Bribi, 2018; Vergragt and Quist, 2011; Wade, 2012).

In the case of scenario planning and forecasting, diverse development paths leading to various future scenarios are developed. While scenario planning considers a mix of qualitative and quantitative data trying to imagine diverse possibilities, forecasting uses mathematical

Table 1
Summary of contrasting implications of AVs' uptake: shared vs private AVs.

Likely impacts			PAVs	SAVs	Source
Densification	Reduction in number of Vehicles	In streets by 2050	2.1 billion cars (+60%)	0.5 billion cars (−33%)	Fulton et al. (2017)
		Replacement of conventional cars	1 conventional vehicle is replaced by 1 PAV	−12 to −14 vehicles each SAV	Fagnant and Kockelman (2015); Zhang et al. (2015)
		To satisfy current mobility levels	–	−90% vehicles (65% at peak-hours)	International Transport forum (cited by Milakis et al., 2017b)
	Reduction in Parking	Demand	−50%	−90% (at penetration rate of 2%)	Dupuis et al. (2015); Milakis et al. (2017b)
		Space		Each SAV −20 spaces	Zhang (2017)
Sprawl intensification	Increase in Vehicle Miles Travelled	Globally	+10% to +71% in 2050 35-89%	−35%	Milakis et al. (2017a); Soteropoulos et al. (2018)
		Commuting		−7 % to +12%	Zhang and Guhathakurta (2018)
	Expansion of the city	City surface		7% urban land	Zakharenko (2016)
		Increases in population	−4% population inner city +3% outer suburbs	+3% large cities -3% suburbs of smaller cities −2% non-urban regions	Soteropoulos et al. (2018)

models based on quantitative historical data and trend analyses to predict the future (Banister et al., 2007; Wade, 2012). These forecasting studies explore uncertainty under various conditions, such as sensitivity analyses of policies or the willingness of society to adapt to different futures (Dreborg, 1996). These approaches are commonly used in the investigation of technological developments based on predicting the future by extrapolating their current state of maturity (Jansen, 1994). Most of the AV implementation scenario literature is actually focused on such forecasting approaches (e.g. Fagnant and Kockelman, 2015; Milakis et al., 2017a; Zhang and Guhathakurta, 2018,) or scenario planning (e.g. Heinrich, 2016; Papa and Ferreira, 2018).

Backcasting approaches formulate a desirable image of the future, defining core policy goals and analysing the current situation in order to identify the priorities, actions and decisions necessary to achieve the desired future scenario (Banister et al., 2007; Broman and Robèrt, 2017; Carlsson-Kanyama, et al., 2003; Neuvonen and Ache, 2017; Phdungsilp, 2011). In this case, societal goals are first defined followed by consideration of how technological and societal development can be managed. Due to its goal-oriented and normative character, most recent studies related to urban sustainable futures employ backcasting (Bribi, 2018; Carlsson-Kanyama, et al., 2003; Eames et al., 2013; Höjer et al., 2011; Neuvonen and Ache, 2017; Phdungsilp, 2011).

Backcasting emerged in the 1970's in the field of energy studies as a response to the dissatisfaction with common forecasting approaches based on trend extrapolation. By the end of the 1980s it was transferred to sustainability studies (Vergragt and Quist, 2011). As a result, diverse types of backcasting approaches have been applied since then and classified in attention to the main focus of each study (Neuvonen and Ache, 2017; Vergragt and Quist, 2011; Wangel, 2011):

- Target-oriented backcasting, focusing especially on the creation of the visions of the future, as goal-fulfilling.
- Pathway-oriented backcasting, focusing on the achievement of preferred futures, and on the policy measures to be implemented, avoiding the explicit (quantitative) definition of goals.
- Action-oriented backcasting, focusing on identifying stakeholders and actors that should be involved in the process.
- Emancipatory backcasting, focusing on the perceptions and motivations of stakeholders.

The above classification is not meant to be exclusive, and many studies comprise a combination of two or more approaches (see Wangel, 2011). Among them, the combination of target-oriented and pathway-oriented approaches, where both the goals and the process of change are analysed, is the most commonly applied one in sustainable development studies, and was chosen for the purpose of this paper.

Another relevant backcasting classification is the one related to top-down versus bottom-up approaches. The first group refers to backcasting studies performed by interdisciplinary research teams, known as think-tank models, or by experts (expert-led backcasting), commonly used in early studies to inform policy and decision-making processes (Robinson et al., 2011), such as the present study. The analysis and definition of visions and measures are informed by experts', scholars' and scientists' views and literature reviews (Bribi, 2018). The second group involves participatory backcasting in which stakeholders, planners and the public are involved in some steps of the process, especially in the construction of future visions (Carlsson-Kanyama et al., 2003; Phdungsilp, 2011; Vergragt and Quist, 2011). Participative backcasting, which first started in 1990, has been used in various ways, particularly to convince citizens and stakeholders of the need to change behaviours and implement the identified policies (Robinson et al., 2011; Vergragt and Quist, 2011), and as a way of strengthening the participation process (Wangel, 2011). Nevertheless, participative approaches are not without contestation, but usually associated with specific interests that exert excessive influence on stakeholders' opinions (Quist et al., 2006; Vergragt and Quist, 2011; Wangel, 2011).

This diversity of backcasting approaches has led to a variety of methodologies and a number of steps, usually consisting of between three to five stages: problem statement or strategic problem orientation, visioning, pathway analysis or backcasting, action agenda, and implementation and follow-up (Broman and Robèrt, 2017; Eames et al., 2013; Quist et al., 2006). Here, in order to help urban decision and policy-makers understand the possible implications and benefits of proactive planning to lead the AV rollout, a three-step think-tank backcasting methodology comprising problem orientation, visioning and pathway analysis was used (Fig. 1).[3]

The first step of most backcasting analyses is to provide a detailed definition of the key concepts and features that comprise the optimal future framework (i.e. framing the problem). Planning should be flexible and adaptable to uncertain future situations, and selection of basic principles for the future city should accomplish several criteria. According to Broman and Robèrt (2017), these basic principles should be sufficient to cover all aspects, without overlapping or complicating the process. They should also be general but at the same time specific enough to enable a feasible application and be adaptable to properly guide the process. In this paper, the definition of the strategic problem

[3] The validation of the policy packages is explicitly not considered as part of the backcasting method in this paper but it could be included in follow-up research on the subject (as outlined in the conclusions). A range of other backcasting studies can be found which employ a similar methodological approach as the one adopted in this paper (i.e. they do not include a validation stage). Some examples include Banister (2000); Mont et al. (2013); Eames et al. (2013) and Neuvonen et al. (2014).

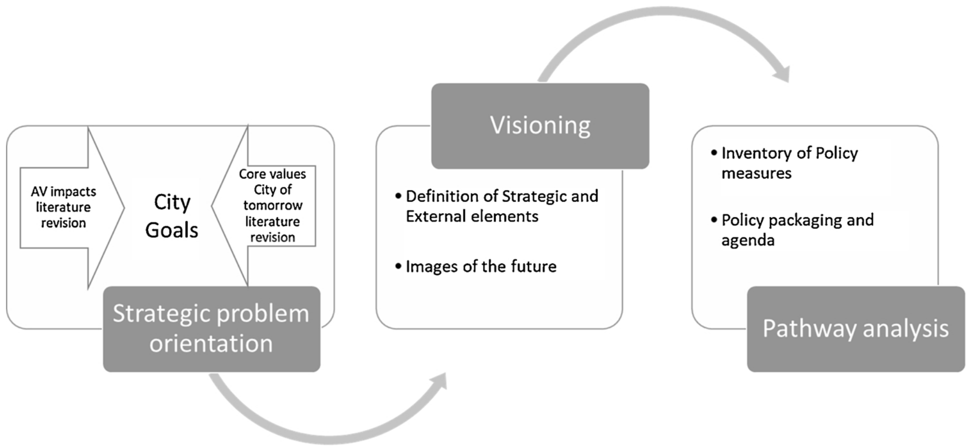

Fig. 1. Backcasting procedure used.

and the main policy goals to achieve a future driverless city were developed by comparing the likely AV impacts (outlined in Section 2) with a literature review of city's most cited core values (outlined in Section 3.2.1).

Once policy targets have been set, the second step is scenario-making or visioning, in which one or more Images of the future are created. Typically, a deductive approach is used in which two strategic elements are identified and their extremes are used to construct four scenarios or images of the future (Carlsson-Kanyama et al., 2003). A reference case (or business-as-usual scenario) is often also constructed, based on the extrapolation of current trends and assuming that no new policies are introduced (Banister et al., 2007; Stead and Banister, 2003). Each vision is described as a story line in which both strategic elements and external factors are considered (Banister et al., 2007). Strategic elements are factors that can be directly influenced by policy making and are critical to the developmental path. In this paper, strategic elements were identified from the revision of AV impacts, by selecting the two most influential or determinant impacts for urban form and land use changes. External factors are events or developments beyond the control of the study, such as population ageing, which are taken as given in the scenarios but also influence policy decisions.

Desirable images are meant to be creative and challenging, breaking with predominant trends, but at the same time relevant and plausible (Banister et al., 2000). They should respond to at least one, but preferably more, of these three criteria: being possible, probable and/or preferable (Banister et al., 2007). Creativity usually comes from brainstorming meetings involving research teams (think-tank approach) or experts, stakeholders, planners, and so on (participatory approach) (Broman and Robèrt, 2017; Carlsson-Kanyama et al., 2003; Phdungsilp, 2011). In this research, Images of the Future were created after a brainstorming meeting between the research team and a group of other researchers involved in AV and/or urban design and planning studies. Specifically, within this process, which served as a preparatory stage for images definition (Nevens et al., 2013), we selected a reduced interdisciplinary panel of skilled scholars from relevant disciplines (i.e. architecture, civil engineering and geography) with extensive scientific experience (more than 15 years on average), and familiar with the potential effects of AV implementation. After having been thoroughly informed about the objective of the study, they were asked to identify the strategic elements to configure the Images of the future, from their knowledge on the impacts of AVs on urban environments, and to discuss about the key elements of the potential images of the future. The results agreed upon after the discussion and reflection of the researchers were incorporated as expert knowledge and complemented by a review of the scientific literature to finally define the Images.

Once scenarios are created, the process turns to exploring the potential policies and paths to be applied. For each Image of the future, a list of single measures is usually produced and then creatively grouped into packages and those packages into paths (Banister et al., 2007). Policies should be adaptable to future uncertainties and therefore they should also identify potential risks. In this paper, the inventory of policy measures was developed from the revision of the academic literature, international urban planning guidelines, and real case studies. A very important outcome of the policy description was the identification of appropriate initial measures, intermediate goals and a timeline orientation, (i.e. the definition of an implementation agenda). To do so, the literature revision of AV timeline's rollout played a key role.

3.2. Envisioning the city of tomorrow

3.2.1. Core values for the city of the future

Over recent years, academic literature and urban policy have contained a great variety of new concepts for desirable urban development, mainly related with the traditional three dimensions of sustainability: social, economic and environmental. Khan and Zaman (2018) define ten sustainability dimensions to score the most popular conceptualizations of the desired future city, such as mobility, culture or safety. Similarly, Ortegón-Sánchez and Tyler (2016), Ratcliffe and Krawczyk (2011) and Williams (2014) have identified various dimensions of attractive and productive cities. A few examples include quality of life, accessibility to urban services, and social ecology.

International urban agendas have also introduced new priorities. For example, the New Urban Agenda, an outcome of the UN's Habitat III Conference held in 2016, refers to new goals such as economic innovation, affordable housing, cultural diversity, education, food security, public participation or urban resilience (UN, 2017). Meanwhile, the EU's Urban Agenda, also launched in 2016, introduces life quality improvement, urban area renaturing or brownfield regeneration, within the land use priority theme, and the emphasis on public transport, active mobility, local and regional connectivity and inclusive and equalitarian accessibility within the efficient urban mobility priority theme (EU, 2016).

As regards visions on future cities, Daffara (2011) has identified 6 vision goals comprising 73 strategies, which were widely validated by around 4000 local participants. The goals included a "valued natural environment; healthy, vibrant and inclusive learning communities; diverse transport infrastructures and mobility; responsible leadership, participatory decision-making and foresight; smartly managed rural and urban future; and innovative and diverse economies" (Daffara, 2011: 687). Likewise, in a study of city dweller aspirations for future cities carried out by Joffe and Smith (2016), respondents identified a range of important goals (city well serviced regarding cultural, retail and municipal facilities, associated with high levels of citizen well-being; green and blue city with parks, fields and free spaces of health,

Table 2
Summary of core values of the city of tomorrow.
Source: own work from Daffara (2011); EU (2016); Joffe and Smith (2016); Khan and Zaman (2018); Ortegón-Sánchez and Tyler (2016); Ratcliffe and Krawczyk (2011) and Williams (2014).

Dimension	Core Values
Social	- Social equity and inclusiveness - Healthy active society
Mobility	- Accessibility - Connectivity - Efficiency of the transportation system - Promotion of public transportation - Support of active mobility
Urban design	- Attractiveness - Urban quality - Liveability - Mixticity - Greening
Environmental	- Sustainable use of land - Sustainable use of resources
Cultural	- Identity Diversity
Safety	- Citizens' safety
Economic	- Profitability

relaxation and environmental wellbeing; sense of community and friendliness; city with an efficient transport, related to low-carbon transportation schemes; a well-designed, accessible and beautiful city which contains lively central areas; and a safe city).

In the light of all these studies and documents on core city values, a selection of the most relevant core values for the city of tomorrow have been made (Table 2). Each of these will be directly affected by the arrival of autonomous vehicles and planning development decisions.

3.2.2. Goals for the city of the future

After identifying the core city values, the major policy goals and targets to achieve the desirable city of tomorrow were developed by considering the likely AV impacts outlined in the previous section. As a result, the potential opportunities and threats that AVs may pose for urban planning were identified (Table 3). These address one of the research gaps identified by Legacy et al. (2018) who state that there has been little comprehensive examination of the specific impact of AV technologies on the efforts of citizens and governments to shape cities in productive and sustainable ways. A central guiding value for urban development is the shift from a vehicle-oriented to a citizen-centred perspective or, in other words, the shift or return from the "movement space" to the "living space" (see also Begg, 2014).

Goal 1 – Promote social equity and inclusiveness: this first goal aims to ensure the social core values of the city and supports cultural diversity. This goal, that would be supported by the increase in accessibility for all, is crucial when facing risks associated with the reduction in the use of public transport or the potential segregation of population due to the revaluation of real estate values corresponding to former parking lots within central areas.

Goal 2 – Reduction in the need for mobility: this goal aims to achieve a more citizen-centred city and is closely related to land use planning. It is decisive to face social, environmental, mobility and safety risks of AV implementation, such as sprawl intensification, unsustainable use of land and resources, and the increase in the number of circulating vehicles (PAVs or single-occupant SAVs).

Goal 3 – Encourage active mobility: walking and cycling are vital to ensure a healthy society (which could be threatened by the offer of door-to-door services), to promote a more sustainable mobility and to develop more attractive and liveable cities.

Goal 4 – High-quality multimodal public transportation system: this is the most relevant goal, affecting the social, environmental, mobility, urban design and safety dimensions. The implementation of a scalable public shared transportation system would minimise the risks associated with the substitution of inclusive massive public transportation systems by individual PAVs or single-occupant SAVs, or with the increase in the number of vehicles on roads, and the associated energy and land consumptions, potential accidents, and sprawl intensification. Moreover, it could improve inclusiveness and equity, promote active mobility from transportation hubs or stops to final destinations, improve transportation efficiency through platooning and connected services, and reduce the need for parking, enabling the renewal, attractiveness and liveability of core areas of the city.

Goal 5 – Reduce the number of circulating vehicles: this goal, directly linked to SAV over PAV implementation, aims to make the most of the potential benefits of AV, such as the release of large spaces within the city that could be transformed into new attractive, high-quality and liveable areas, as well as to control energy consumption, congestion and safety.

Goal 6 – More public, high-quality urban space for citizens: this goal is the most relevant one for urban planning. It directly affects urban quality and liveability conditions given that public spaces and urban facilities are one of the key elements of urban structure. This goal deals with the opportunities derived from the previous goal, the transformation of former parking lots and traffic lanes in well-located areas, and the incomes associated with their revaluation into new free areas. The main ambitions are: ensuring inclusive public spaces, renaturing urban areas, improving facilities and their accessibility, increasing city centre's attractiveness over peripheries, and avoiding segregation.

Goal 7 – Re-densification, regeneration and renewal of core areas: This goal focuses on guaranteeing cultural identity and urban high-quality standards in central core areas of the city. The release of large parking areas could support cultural identity, by recovering the character and morphology of central neighbourhoods, as well as their urban attractiveness and liveability, thus promoting high-quality standards in deprived core areas. The creation of more cycling and walking paths, green areas, and needed urban facilities would also contribute to these goals.

Goal 8 – Avoid VMT increase and sprawl: This goal is associated with the social and environmental dimension, given that sprawl has been described as one of the most inefficient and unsustainable urban patterns of development due to its high land and resource consumption, as well as a segregation enhancer.

Goal 9 – Safety: This goal deals with ensuring citizen's safety during the transitional period of AV implementation. It could be achieved by several types of measures associated to other goals such as the reduction in the need for mobility and circulating vehicles.

3.3. Envisioning the city of tomorrow

3.3.1. Strategic and external elements

Underlying the development of the Images of the future presented below is the belief that addressing issues of liveability, sustainability and social justice in the city requires more than simply replacing current conventional private cars with privately-owned automated ones. Furthermore, the contrasting results obtained in several studies regarding reductions in parking demand, the number of circulating vehicles, vehicle miles travelled and sprawl, as indicated before, have demonstrated AV's great potential. As a consequence, one of the two strategic elements when envisioning Images of the city of the future is Sharing.

However, encouraging sharing is not enough (Clewlow and Mishra, 2017). Other strategies related to urban planning to reduce motorized mobility needs are also needed, as mentioned before. The priority should be a major shift or return from the modern urban paradigm of 'movement space' to the one of 'living space' (Begg, 2014). With this in mind, the second strategic element is the restriction of AV access within the city. Unlimited access would enhance the provision of door-to-door services, in which passengers could be picked-up at the very front door of their houses and dropped-off at their destination, thus reducing

Table 3
Core city values, AV implications and Policy goals for the city of tomorrow.

Core values for the city	AV Opportunities	AV Threats	G1- Social equity & inclusiveness	G2- Reduction need for mobility	G3-Encourage active mobility	G4- High-quality multimodal public transportation	G5- Reduce number of circulating vehicles	G6- More free public, high-quality & equipped space for citizens	G-7 Re-densification, regeneration & renewal of core areas	G8- Avoid VMT increase & sprawl	G9-Safety
Social equity & inclusiveness	Increased mobility for elderly, children, disabled and unlicensed people	Reduction of public transportation	x			x					
		Expansion of the city-Sprawl could cause segregation		x						x	
	Creation or increase of inclusive public spaces	Revalorization real estate values in the centre could cause segregation	x				x	x			
Healthy - Active society	Less vehicles imply less pollution and less illnesses	Door-to-door services imply less walking and cycling, causing health problems		x	x	x	x				
Economic profitability	Revaluation and profitability of well-located new free areas	Reduction of public incomes related to traffic taxes, fines, fees, and so on	x					x			
	Reconversion of former parking lots into economic areas			x	x		x		x	x	
Land-use Sustainability	Renaturing urban areas due to the reduction of parking demand	Inefficient land use due to city-Sprawl				x		x		x	
Sustainability of Resources	Less vehicles imply less energy consumption	Increase of VMT implies high energy consumption		x	x	x	x			x	
		Inefficient resource use due to city-Sprawl		x				x		x	
Transport Accessibility	Increased mobility for elderly, children, disabled and unlicensed people		x			x					x
Transport Connectivity	Platooning in segregated lanes means more free space	Need to locate new hubs to interchange between modes				x	x				x
Transport Efficiency	More efficient vehicles and platooning lead to more free space	Congestion PAVs vs Reduction vehicles SAVs				x	x				x
Promotion public transportation	Increase of public transportation use for interurban trips	Reduction of public transportation				x					
Active mobility	Increase of cycling and walking paths in new free spaces	Door-to-door services imply less walking and cycling			x		x		x		
Cultural Identity	Recover the character and morphology of core areas								x		
Cultural Diversity		Revaluation of real estate values in the centre could cause population segregation	x					x			
	Reconversion of former parking spaces into			x		x	x	x	x		

(*continued on next page*)

Table 3 (*continued*)

Core values for the city	AV Opportunities	AV Threats	G1- Social equity & inclusiveness	G2- Reduction need for mobility	G3-Encourage active mobility	G4- High-quality multimodal public transportation	G5- Reduce number of circulating vehicles	G6- More free public, high-quality & equipped space for citizens	G-7 Re-densification, regeneration & renewal of core areas	G8- Avoid VMT increase & sprawl	G9-Safety
Attractiveness Urban quality and liveability	attractive and high-quality areas	Need for more large parking lots in peripheral areas									
	Increased and improved urban facilities in new free areas	Need for dispersed pick-up and drop-off points			x			x	x		
Green Public spaces: greening	Reconversion of former parking lots into green public areas			x		x	x	x			
Citizen's safety	Less and more efficient vehicles imply less accidents and reduce the need for segregated lanes	Accidents caused by the interaction with conventional vehicles, pedestrians and cyclist during transition		x		x					x

walking and cycling needs almost to zero. In contrast, restricted access refers to an urban planning policy that regulates pick-up and drop-off areas and eliminates parking spaces in core areas. Access would be restricted to certain areas within the city with the exception of emergency services, disabled or reduced mobility passengers. These restrictions would allow the development of more free, public, high-quality and equipped spaces in those areas restricted to AVs, encouraging a healthy mobility and enhancing citizens' quality of life.

Some relevant external factors associated with urban development and AV implementation are the following: demographic trends, such as ageing or urban population growth; technological development, such as electricity generation and distribution or digitalization; cultural aspects, such as preferences on housing location, urban design (e.g. attractiveness of urban living), and land price. Among them, electricity generation and distribution are the most crucial ones for the deployment of AVs, assuming that AV development is linked and combined to vehicle electrification and that other types of AVs (e.g. diesel AVs) would lead to sub-optimal scenarios (Kane and Whitehead, 2017). In this context, the amount of available electric energy is key to the use of more or less private or shared AVs. Similarly, the distribution of electricity could be a limiting factor for the location of charging stations.

3.3.2. *Images of the future*

Taking into account these strategic elements, four Images of the future were created (Table 4). The distinguishing features of the four images are related to the basic forms of mobility in the city (individual or shared) and the levels of access granted to vehicles in the urban fabric (unlimited access or constrained access). The images described below consider impact estimates derived from the literature and the effect of external factors in contrast with the goals and targets set for the future city.

- *Image 1–The hyper-mobile city:* this scenario involves a city in which all vehicles are shared and have access to all areas of the city. SAVs of several sizes have replaced other public transport services, providing ad-hoc services which are mostly used as single-occupancy-vehicles, especially by wealthier citizens, thus increasing the number of vehicles within the city and worsening congestion. Society has become more car-dependent. Citizens do not walk or cycle for daily transit, and there is a huge problem of public health, especially related with obesity.
- *Image 2–The liveable shared city.* SAVs of different sizes are deployed and adapted to each settlement type, complementing a high-quality public transport service. Pick-up and drop-off points are located at attractive points of the city, such as public service buildings, commercial areas and transportation hubs, in which bicycle rental services are also offered. Citizens walk from their homes to the nearest SAV station and from the multimodal station to their destination. A great amount of public space has been freed: former parking lots and buildings have been transformed into attractive green parks, playgrounds, cultural and community buildings, urban facilities, new affordable residential areas or urban farming lands. Additionally, parking lanes have been transformed into new shared lanes, gardens and parklets, thereby increasing the densification of the city centre and attracting a more diverse population in a vibrant and liveable city.
- *Image 3–The unlimited individualistic city*. The city faces electricity shortages to charge the enormous number of private AVs. The city's area has expanded farther away from the centre, providing high-quality houses for the wealthiest population in the outer suburbs, segregating them from the poorer people who live within deprived neighbourhoods of the city centre and have no access to a motorized mobility (AV). Parking demand has decreased in commercial areas but has increased in residential areas due to the incorporation of more vehicles owned by the elderly, disabled and people without a driving license. Additionally, the increase in vehicles has worsened

Table 4
Images of the future.

	Shared Mobility	Individual Mobility
Unlimited access	Image I - The hyper-mobile city	Image III - The unlimited individualistic city
Restricted access	Image II - The liveable shared city	Image IV- The restricted individualistic city

congestion in the city's main streets, especially at peak hours. A large part of the population does not walk or cycle, leading to health problems.

- *Image 4–The restricted individualistic city*. Daily mobility needs are mainly serviced by PAVs, although these vehicles do not have access to all parts of the city, thereby encouraging walking or cycling in specific areas. Much of the city and its population does not have access to motorized transit. However, congestion is still a great problem on major roads, and a larger amount of land is dedicated to parking, both in peripheral parking lots and residential areas. Electricity shortages are also a problem due to the huge demand imposed by PAVs.

Among the four images of the future briefly presented above, only *Image 2 (The liveable shared city)*, is considered worth pursuing, given its potential to accomplish a greater number of urban policy goals, and the fact that it is more desirable from the liveability, sustainability and social justice perspective. The other images would cause problems and fail to accomplish one or more of the policy goals for the city of tomorrow. For example, Image 1 would fail to accomplish the equality and healthy society goal, Image 3 the efficient use of resources (energy), the inclusiveness, sense of community and equality of aspirations, and health goals; while Image 4 would fail to achieve the equality and efficient use of energy goals.

3.4. Planning and policy strategies and agenda setting

3.4.1. Inventory of policy measures

Based on a review of the academic literature, international urban planning guidelines, and case studies, an inventory of policy measures which could contribute to the achievement of *Image 2 – The liveable shared city* was identified (Table 5). These measures were grouped into the four main types of policy instruments most commonly used in the literature (Banister et al., 2000, 2007; Givoni et al., 2013; Hood, 1983; UN, 2016):

- Market-oriented policies: involve financial, fiscal and tax-revenue measures aimed at encouraging or discouraging one type of urban development or transport model above others.
- Regulation-oriented policies: including ordinances, norms, technical standards, government reforms, administrative mechanisms, aimed at establishing the desired typology of urban form, land use and mobility.
- Public infrastructures or services: referring to the provision of infrastructures and services such as public transport stations, cycle routes, parks, educational, medical, sports and cultural buildings and places.
- Educational and awareness-oriented policies: their aim is to change societal attitudes and awareness about new development patterns and new mobility arrangements in order to increase public support for other *a priori* controversial policy measures.

3.4.2. Policy packages, paths and agenda

The second step of policy setting was assembling measures into groups in order to improve the effectiveness and efficiency of the policy actions. Policy packages were created based on the relationships between policies and the opportunity they provide to address one or more policy targets. According to Givoni et al. (2013), there are three types of interrelationships between policy measures:

- pre-condition relations: a measure requires a previous successful implementation of another measure to be applied
- synergetic relations: the efficiency of a measure is enhanced by its combination with other measures
- contradictory relations: the presence of contrasting measures jeopardizes the positive effect of either one or both measures.

Thus, policy packages require combinations of policies whose interrelations fall into the first two types. Combinations of policies that fall into the third category should be excluded. An iterative process was used to evaluate and combine the measures. Then policy paths were created by combining some policy packages, or even packages with single measures (following Banister et al., 2000).

A policy agenda was set by prioritizing the selected measures in attention to their relevance and estimated time framework. The first measures to be implemented were the less controversial ones, those which are crucial for the achievement of goals but that could have a long-term effect, those introducing dynamism into the process and the more adaptable ones (Banister et al., 2000; Stead and Banister, 2003). In order to reduce public resistance to certain policies (e.g. the imposition of taxes), additional or complementary "revenue-generating" measures, such as the improvement of public services due to these new taxes, were simultaneously implemented into the packages (Givoni et al., 2013).

According to these principles, three policy paths and eight policy packages were developed which, due to the variety of potential AV impacts and diversity of urban development goals, are complementary and consecutive (Fig. 2).

3.4.2.1. Policy path 1: safe and shared transition (2019–2030). AVs will be progressively implemented. Shared shuttles and automated freight transport will be implemented first on highways and interurban transit lanes and then on urban streets where they will share traffic lanes with conventional vehicles. Besides, the initial rollout of AV will promote SAV over PAV in order to dissuade people from using the more attractive PAVs from the beginning. Therefore, this path comprises two policy packages: (i) safe transition; and (ii) initial transition to shared mobility.

Package 1 was created under the assumption that it is essential to ensure a safe interaction between currently circulating vehicles, pedestrians, cyclists and new AVs during the transition to automation. A key safety measure is the segregation of traffic lanes, by regulating lanes dedicated to AVs (both passenger and freight) transit. In the case of interurban transportation, the coordination between local and regional administrations is necessary. In the case of urban streets, there are currently several dedicated lanes in major cities used by public transportation services (bus, shuttles, taxis) that could be reconsidered for SAV transit.

It is also crucial to restrict access to specific areas of the city for new pods/vans, freight AVs and conventional cars. Core Attractive Mixed-use Spaces (CAMS) will be delimited by local administrations. The restriction imposed on both SAVs and conventional cars will have a threefold aim: to ensure safer, more liveable areas for citizens, pedestrians and cyclists, to avoid/reduce citizens' inclination to use private cars by reducing their current, convenient unlimited access and to release well-located parking spaces. The reduction or elimination of car and parking

Table 5
Inventory of policy measures.

Policy Measures		Policy Goals	G1- Social equity & inclusiveness	G2- Reduction in mobility needs	G3- Encourage active mobility	G4- High-quality multimodal public transportation	G5- Reduce number of circulating vehicles	G6- More free public, high-quality & equipped space for citizens	G7- Re-densification, regeneration & renewal of core areas	G8- Avoid VMT increase & sprawl	G9-Safety	Source of policy measures
Market-oriented	M1	Incentives to developers, residents and businesses to redevelop city centres	x	x	x		x	x		x		Kalkuhl et al. (2018); Gruel and Standford (2016); Litman (2015; 2018); Razin (1998)
	M2	Higher fees for housing development farther away from the city centre	x				x			x		
	M3	Subsidies for promoting new collaborative small activities in new free public spaces	x	x	x			x				
	M4	Incentives to develop adaptable and flexible SAVs	x			x	x	x				
	M5	Incentives to major companies to provide SAV fleets to workers and develop Sustainable Mobility Plans (SUMP)		x		x	x					
	M6	Subsidies for SAV use for dependent and lower-income people	x			x	x					
	M7	Car-ownership tax				x	x					
	M8	Higher fees for single-occupant vehicles					x					
	M9	Higher fees of empty-cruising trips					x				x	
	M10	Mileage-related taxes				x				x		
Regulation-oriented	R1	Mixed land uses: residential, working, services and commercial areas	x	x	x		x	x		x	x	Bohl (2002); Brown et al. (2018); Grant (2002); Gruel and Standford (2016); Litman (2015); Röhrleef et al. (2015)
	R2	Minimum urban density standards	x	x	x		x	x		x	x	
	R3	Decrease space for cars and parking	x		x	x	x	x	x		x	
	R4	Delimitation of Core Attractive Mixed-use Spaces (CAMS) in the city		x	x			x	x		x	
	R5	Dedicated lanes to SAVs, to freight platooning, public transport				x	x				x	
	R6	Higher priority for walking and cycling	x		x		x	x			x	
	R7	Relocation of working places closer to public transportation interchanges	x	x		x	x		x	x	x	
	R8	Reducing number and width of traffic lanes and eliminate medians			x	x	x	x	x			
	R9	Relocation of parking lots			x	x		x	x	x		
	R10	Restriction access for SAVs to CAMS	x		x		x	x	x		x	
	R11		x		x	x	x	x	x	x		

(*continued on next page*)

Table 5 (*continued*)

Policy Measures		Policy Goals	G1- Social equity & inclusiveness	G2- Reduction in mobility needs	G3- Encourage active mobility	G4- High-quality multimodal public transportation	G5- Reduce number of circulating vehicles	G6- More free public, high-quality & equipped space for citizens	G7- Re-densification, regeneration & renewal of core areas	G8- Avoid VMT increase & sprawl	G9-Safety	Source of policy measures
		Restriction of single-occupant vehicles allowed to enter the centre (CBD)										
	R12	Restriction of SAV services for large distances to the city centre				x				x		
	R13	Restriction of empty-cruising trips					x	x		x	x	
Public infrastructures or services	P1	Creation of new high-quality green public spaces, public educational, medical, sportive and cultural infrastructures and buildings within the centre	x	x	x		x	x		x		Litman (2018); Wiseman (2017)
	P2	More spaces for walking and cycling paths	x		x		x	x			x	
	P3	Improve cycle and walking paths	x		x		x	x			x	
	P4	Improve public transport infrastructures (high-tech system)	x			x	x				x	
	P5	Improve public transport services (frequencies, itineraries…)	x			x	x					
	P6	Provision of adaptive / flexible public transportation	x			x	x			x		
	P7	Provision of public transport or public SAV fleets to large working places (Technological parks, Commercial areas, Industrial Estates…)	x			x	x			x		
	P8	Creation of pick-up and drop-off points/stations in specific locations (at the edge of CAMS)			x	x	x	x	x	x	x	
	P9	Local transportation logistics centres (click and collect points at the edge of CAMS)		x	x		x	x	x		x	
	P10	Improvement of parking lot capacity with electric vehicle charging stations					x	x	x		x	
	P11	Reconversion of fuel stations into pick-up and drop-off areas or charging stations			x			x	x		x	

(*continued on next page*)

Table 5 (*continued*)

Policy Measures	Policy Goals		G1- Social equity & inclusiveness	G2- Reduction in mobility needs	G3- Encourage active mobility	G4- High-quality multimodal public transportation	G5- Reduce number of circulating vehicles	G6- More free public, high-quality & equipped space for citizens	G7- Re-densification, regeneration & renewal of core areas	G8- Avoid VMT increase & sprawl	G9-Safety	Source of policy measures
Educational & awareness	E1	Promotion of leisure and cultural activities in former curbs or parking areas	x	x	x		x	x	x			Kim (2015); Pojani and Stead (2015); Roth (2003)
	E2	Campaigns about the benefits and suitability of public and shared mobility	x	x		x	x				x	
	E3	Campaigns focused on changing the vision of privately-owned vehicles as a symbol of socio-economic status	x			x	x			x		

space within these regulated CAMS is also important to dissuade citizens from using private cars and shift to public transport and new SAVs. Motorized access will be limited to specific sites: pick-up and drop-off points and transport interchanges. Walking and cycling infrastructures will be improved in all city areas. Giving higher priority to pedestrians and cyclists, along with improvements in the quality and quantity of cycling lanes and walking itineraries within these restricted zones will also guarantee a safer transit, and a more active/ healthy mobility.

Due to the delimitation of CAMS, road space and parking areas will be reallocated. For this reason, one of the major measures of this package is the firm commitment to promote a mix of uses in these areas and the rest of the city centre. Mixing land-uses has become one of the main tools to ensure urban sustainability, since it provides greater economic vitality, social equity, healthy and safer urban environments, and pedestrian-oriented neighbourhoods (Grant, 2002; Hirt, 2016; Talen, 2012). The R1 regulatory tool refers to planning policies enabling local authorities to decide over the type, intensity and location of uses and activities. These policies establish which uses are permitted or prohibited, as well as the form and size of land units in every portion of the city (Brown et al., 2018; Chung, 1994). Additionally, R1 also considers administrative instruments such as TDR (Transfer of Development Rights), which are very useful to encourage urban redevelopment. These regulatory measures are complemented with other financial or market-oriented tools such as incentives to promoters, residents or businesses, to refill urban centres.

Package 1 - Safe transition

R5. Separate lanes to accommodate SAVs, freight platooning, public transport

R4. Delimitation of Core Attractive Mixed-use Spaces (CAMS) of the city

R10. Restriction access for SAVs and private cars to specific CAMS

R3. Decrease space for cars and parking within restricted areas

P8. Creation of pick-up and drop-off points/stations at specific locations (edge of CAMS)

P9. Local transportation logistic centres (click and collect points such as at the edge of CAMS)

R1. Mixed land uses: residential, working, services and commercial areas

M1. Incentives to developers, residents and business to redevelop the city centre

R6. Higher priority for walking and cycling

P2. More spaces for walking and cycling lanes

P3. Improve cycling lanes and walking itineraries

;1;

Package 2 focuses on another relevant strategy for this transition, consisting of taking advantage of the first deployment of shared systems over PAVs. To achieve this, the implementation of SAVs should be characterized by adaptable and flexible vans or pods that provide comfortable and attractive services to citizens. Measures such as incentives to companies from national governments to develop such vans and the public provision of these types of vehicles are necessary.

To enhance the acceptance of measures related with the reduction and restriction of car use, the creation of new high-quality public services and spaces within these restricted CAMS, as well as involving public participation on the selection of these potential attractive urban interventions will be very helpful.

Package 2 - Initial transition to shared mobility

M4. Incentives to develop adaptable and flexible SAVs

P6. Provision of adaptive / flexible autonomous public transportation

P1. Creation of new high-quality green public spaces, public educational, medical, sportive and cultural infrastructures and buildings

P2. More spaces for walking and cycling lanes

P3. Improve cycling lanes and walking itineraries

;1;

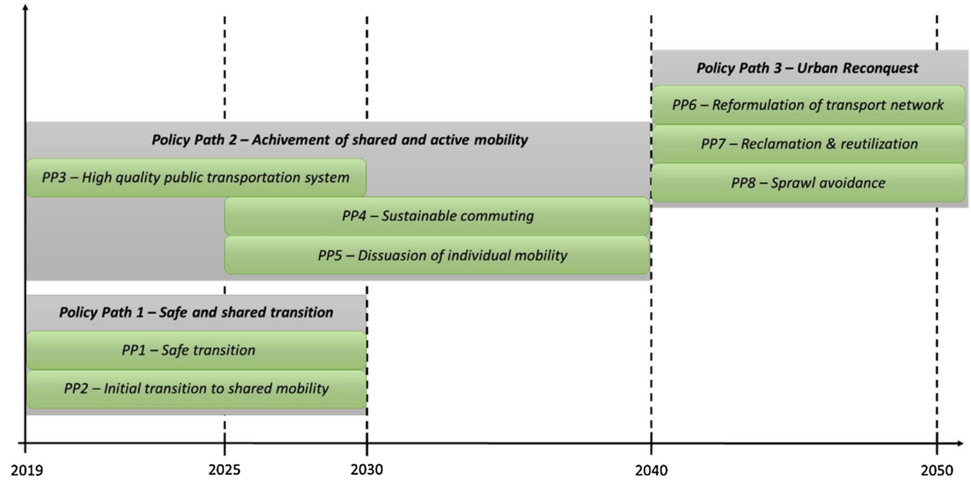

Fig. 2. Policy packages and path agenda.

3.4.2.2. Policy path 2: achievement of a shared and active mobility (2019–2040). The goal of this policy path is to urge the shift from an individual mobility pattern to a shared and active mobility as quickly as possible. To do so, three packages were created and assembled: *High quality public shared transportation system (Package 3); Sustainable commuting (Package 4); Dissuasion of individual mobility (Package 5)*.

Package 3 focuses on encouraging the use of a high-tech shared multimodal transportation system. The main emphasis is on improving the quality, flexibility, affordability and reliability of automated public transportation and shared mobility. This improvement is associated with an increased digitalization and management of services based on ICT development, a redesign of itineraries, and an enhancement of infrastructure provision, such as stations, and vehicles. Coordination between local and regional administrations to define the most efficient connections is essential. It is also necessary to favour the access of lower-income people to these new services and dissuade people from using private vehicles or single-occupant vehicles. Here, education measures such as campaigns about the benefits and suitability of public and shared mobility and market-oriented measures such as higher fees are also crucial.

Package 3 - High quality public shared transportation systems (2019–2030)

P4. Improve public transport infrastructures (high-tech system)

P5. Improve public transport services (frequencies, itineraries…)

M4. Incentives to develop adaptable and flexible SAVs

M6. Subsidies for SAV use for dependent and lower-income people

P6. Provision of adaptive / flexible autonomous public transportation

R1. Mixed land uses: residential, working, services and commercial areas

E2. Campaigns about the benefits and suitability of public and shared mobility

M8. Higher fees for single-occupant vehicles

;1;

Package 4 focuses on the attention that should be paid to commuting, which constitutes the majority of daily trips. Encouraging workers to use more shared and public transportation services is decisive to provide specific public services associated with SAV fleets to large working places such as Technological parks, Universities, Commercial areas, Industrial Estates, and so on, and/or to economically incentivize major companies to provide these fleets and develop their own sustainable mobility plans. Measures regarding the relocation of working places closer to public transport interchanges and urban policies encouraging more mixed land use planning are also relevant to reduce the need for mobility or to encourage shared mobility practices. These measures are also related with a close coordination between local and regional administrations.

Package 4 - Sustainable commuting (2025–2040)

P7. Provision of public transport or public SAV fleets to large working places (Technological parks, Universities, Commercial areas, Industrial Estates…)

M5. Incentives to major companies to provide SAV fleets for workers and develop sustainable mobility plans

R7. Relocation of working places closer to public transportation interchanges

;1;

In parallel with the commercialization of PAVs, dissuasive measures to avert their use should be implemented, and this is the main target of Package 5. This package also aims to prevent the large-scale use of single-occupant SAVs, that can otherwise have similar negative impacts as PAVs. In this case, educational, market-oriented and regulative measures are needed. National campaigns aimed at separating vehicle ownership from socio-economic status may be helpful. However, ownership taxes and higher fees (Wiseman, 2017) or local access restrictions for single-occupant vehicles are expected to be much more effective and efficient. The latter measures are more aggressive but, since they would be implemented later, and after a successful use of public automated services, they are not expected to face a very strong citizen rejection.

Package 5 - Dissuasion of individual mobility (2025–2040)

E3. Campaigns focus on changing the vision of privately-owned vehicles as a symbol of socio-economic status

M7. Car-ownership tax

M8. Higher fees for single-occupant vehicles

R11. Restriction of single-occupant vehicles allowed to enter the centre (CBD) (RPA, 2017)

;1;

3.4.2.3. Policy path 3: urban reconquest (2040 and beyond). Once high AV sharing rates become a reality, urban and land use transforming measures will be introduced to promote an urban renaissance: a shift from cities dominated by cars, to citizen-centred urbanism. Three packages would support the achievement of this major goal: *Reformulation of the transport network (Package 6)*; *Reclamation and reutilization of free areas (Package 7)*; *Sprawl avoidance (Package 8)*.

Package 6 focuses on regulatory and public transportation infrastructure intervention measures as a result of the deployment of platooning transit of multi-sized SAVs, the reduction in circulating vehicles, the reduction in vehicle size, the efficiency and benefits of parking automation and the conversion to a de-carbonized transportation system. Such measures are the reduction in the number and width of interurban and urban traffic lanes and the elimination of medians and the reduction, improvement and relocation of parking spaces and lots, equipped with charging stations. In addition, penalizing empty-cruising by higher fees or restrictions will help to reduce the number of vehicles and therefore to reduce traffic lanes, although this could also increase the need for parking spaces.

Package 6 - Reformulation of the transport network

R3. Decrease space for cars and parking

R8. Reduce number and width of traffic lanes and eliminate medians

R9. Relocation of parking lots

P10. Improvement of parking lot capacity with electric vehicle charging stations

P11. Reconversion of fuel stations into pick-up and drop-off areas or charging stations

M9. Higher fees to empty-cruising trips

R13. Restriction of empty-cruising trips

;1;

Package 7 comprises the reclamation and reutilization of urban space by reconfiguring the transport network. Package 6 measures predetermine the development of major urban interventions which could be progressively implemented, such as the creation of high-quality public green spaces, the creation of new public facilities, affordable housing, the improvement and increase of walking and cycling itineraries throughout the city; the transformation of former curbs and parking areas into leisure and cultural areas; or the promotion of new collaborative economic activities in new free public spaces such as local food production or selling, among others, encouraged by public subsidies.

Package 7 - Reclamation and reutilization of free areas

P1. Creation of new high quality green public spaces, public educational, medical, sportive and cultural infrastructures and buildings

P2. More spaces for walking and cycling lanes

E1. Promotion of leisure and cultural activities in former curbs or parking areas

M3. Subsidies for promoting new collaborative small activities in new free public spaces

;1;

Finally, Package 8 seeks the reduction of vehicle miles travelled and sprawl. The most efficient measures comprise minimum urban density standards, higher fees or taxes over housing developments farther away from the city centre and over mileage travelled, and the restriction of SAV services for large distances to/from the city.

Package 8 - Sprawl avoidance

R2. Minimum urban density standards

M2. Higher fees for housing development farther away from the city centre

M10. Mileage-related taxes

R12. Restriction of SAV services for large distances to the city centre

;1;

4. Conclusions

It is impossible to disengage the vision of the city of tomorrow from the configuration of future transport systems (Alessandrini et al., 2015) and *vice versa*. Accordingly, the role of urban planning in the transition to the use of AVs has been emphasized in the literature, urging local governments and decision-makers to start preparing adaptive legal, urban and land use regulations to accommodate such a disruptive transportation mode (Papa and Ferreira, 2018). In such a context of long-term planning, backcasting approaches are essential to anticipate the type of planning measures that could make the most of potential benefits while eluding possible adverse outcomes (Stead and Banister, 2003) of new technologies or systems such as AVs.

This paper has reviewed timeline estimates and potential impacts of Autonomous Vehicles, emphasizing those effects that are directly related with urban form and spatial distribution, and comparing them with the key values of the city of tomorrow, so as to understand the strategic elements that define the Images of the future and policy goals for urban development. Our findings clearly point to the high relevance of adopting sharing mobility strategies and the need for a restricted access to the city to avoid an excessive use of AVs and to ensure a significant release of public space that is currently devoted to parking, to promote a real transition to more attractive, efficient and liveable cities.

Under these two assumptions four Images of the Future were created, but only one was elaborated due to its ability to deliver core goals: a city in which a flexible high-tech, public, shared transportation system is deployed, and walking and cycling in several Core Attractive Mixed-Use Spaces (CAMS) are favoured. This type of inclusive and sustainable transportation system would promote a city renaissance, more citizen-centred than car-dependent, with a re-densification of the city centre. It would also stimulate the creation of new, large, public, open, green areas, parks, playgrounds or public buildings where leisure, cultural, new economic and community activities could be developed, through the liberation of a large amount of road and parking space.

In order to guide the AV implementation process, a first attempt to identify critical policy measures was carried out, resulting in an inventory of market-oriented, regulation-oriented, public infrastructure related and educational and awareness oriented recommended measures. These measures were then assembled into three complementary and consecutive policy paths in relation to timeline estimates and major policy targets. The first path, named Safe and shared transition, aims to ensure a safe coexistence between AVs and other mobility options (i.e. conventional vehicles, pedestrians and cyclists) during the implementation phase, and to promote the rollout of SAVs over PAVs, mainly through regulatory measures related to the restriction of access and parking and the delimitation of traffic lanes. The second path, named Shared and active mobility, seeks to promote high quality and sustainable public transport and the distancing from individualistic forms of mobility by means of infrastructure-related measures such as the improvement of public transport services, more connections to major attractive nodes, market-related measures such as incentives to companies, higher fees for single-occupant vehicles and regulatory measures such as relocation of working centres. Finally, the Urban reconquest path aims to improve the fabric of new urban areas, by redefining the urban space with the aim of reusing roadspace and parking space, for example with regulatory measures (e.g. the reallocation of parking lots, reducing traffic lanes), and the provision of new public facilities, high-quality public green spaces, sportive or cultural areas. At the same time, the third path tries to avoid sprawl, through regulatory or market-oriented measures such as minimum density standards or mileage-related taxes.

Clearly, further research should be conducted to validate and identify potential policy measures in specific case studies and compare the ideal driverless cities of the future in different countries around the world (north Europe, south Europe, USA, Asia), considering different policy procedures, measures and acceptability. To this end, participatory backcasting, involving diverse stakeholders within the process (Carlsson et al., 2003; Givoni et al., 2013; Neuvonen and Ache, 2017; Phdungsilp, 2011) or including new evaluation and decision-making tools such as the use of multi-criteria analyses (Soria-Lara and Banister, 2018), would be very useful. This paper merely opens the debate on how urban policies should start to include AV related measures in their planning schemes and provides a first insight into appropriate tools to push policy and decision-makers to take a step forward in the implementation of AVs.

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