



Exploring the implications of autonomous vehicles: a comprehensive review

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Abstract

Over the last few years, a large emphasis has been devoted to autonomous vehicles (AVs), as vehicle automation promises a large number of benefits such as: improving mobility and minimization of energy and emissions. Additionally, AVs represent a major tool in the fight against pandemics as autonomous vehicles can be used to transport people while maintaining isolation and sterilization. Thus, manufacturers are racing to introduce AVs as fast as possible. However, laws and regulations are not yet ready for this change and the legal sector is following the development of autonomous vehicles instead of taking the lead. This paper provides a comprehensive review of the previous studies in the transportation field that involve AVs with the aim of exploring the implications of AVs on the safety, public behaviour, land use, economy, society and environment, public health, and benefits of autonomous vehicles in fighting pandemics.

Keywords Autonomous vehicles · Implications · Public behaviour · Implications on society · Implications on land use · Pandemic

Abbreviations

AV Autonomous vehicle
SAV Shared autonomous vehicle
VKT Vehicle kilometre travelled
VOT Value of time

Introduction

Automation of vehicles has always attracted researchers: starting with the vehicle-to-vehicle communication system in the 1920s using radio waves [1], then the development of the vehicle's electromagnetic guidance in the 1930s and 1940s, or adding magnets to vehicles for the testing of smart highways during the 1950s and 1960s [2]. In 1980, Mercedes-Benz partnered with Bundeswehr University in Munich and invented the first autonomous vehicle in the world that opened the way towards thinking about legislation

adaptation [3]. Since this point in time, many companies have started working on developing autonomous vehicles [4].

Based on the National Highway and Transportation Safety Administration, there are 5 levels of AV functionality: level 0: no automation, level 1: automation of one control function such as lane keep assist or autonomous control, level 2: automation of two control functions, level 3: limited self-driving but expect the driver to take control at any time with adequate warning, level 4: drivers are not expected to take control at any time of the trip, and level 5: full self-driving with no human control [5, 6].

In the last decade, autonomous vehicles (AVs) have undergone tremendous improvement as both research and industry are putting significant efforts into developing AVs [7]. For example, Google launched the Google self-driving car project in 2009 with the vision of providing fully AVs by 2020 [8]. Uber partnered with Volvo and announced the development of the third version of its self-driving vehicle and they will start testing it by 2020 [9]. In 2014, Apple launched the AV project "Project Titan" with the vision of providing AVs by 2016; however, many issues such as leadership issue had an impact on the project and now it is expected that Apple car will be in the market between 2023 and 2025 [10]. Additionally, many start-up companies launched with the aim of developing AVs. In 2014, Zoox

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was founded to provide electric and autonomous vehicles and its value reached 3.2 \$ billion by 2018 [11]. Moreover, cities allowed testing and deployment of AVs on public roads. For example, in 2018, 29 of the US states allowed testing AVs on their roads. [12, 13]. Such pilot studies are mainly intended to test self-driving technology and public attitude and behaviour. However, till the moment there is no large-scale implementation of AV fleet in a given country. Additionally, there are many obstacles that might hinder the introduction of the AVs such as laws and regulations, public acceptance, ethical issues, and the development of the technology itself.

This paper reviews previous studies in the area of autonomous vehicles with the aim of revealing the implications of autonomous vehicles on safety, public behaviour, land use, economy, society, environment, public health.

Methodology and work cited

This state of the art reviews the existing literature on the topic of implications of automated vehicles. The databases and search engines used were Scopus, Web of Science, ScienceDirect, SPRINGER LINK, IEEE Xplore, and TRID. The keywords used were: implications of automated vehicles; autonomous vehicles; self-driving cars; road capacity and automated vehicles; autonomous vehicles and society; autonomous vehicles and economy; autonomous vehicles simulation; agent-based autonomous vehicles; autonomous mobility; and shared autonomous vehicles. Only reports in English were included from 2010 onwards. The obtained studies were screened based on their relevance and topics. Additional papers were obtained from the references of the screened papers. Scopus results indicated the sources, “Transportation Research Part C: Emerging Technologies”, “Transportation Research Record”, “Transportation

Research Part A: Policy and Practice”, and “Transportation Research Procedia”, as the most frequent resource used in this study.

Research contribution

Research in AVs has gained significant attention from researchers around the world and research in the implications of AVs is not an exception. There are a large number of studies in the literature that discuss the implications of AVs. Table 1 summarizes some of these studies. Most of these studies focus on the implications of AVs on one branch only, such as the implications of AVs on the environment, and ignore the other implications, which might be misleading. Thus, in this paper, a holistic review or a comprehensive review is conducted, and a holistic analysis is conducted in order to discuss the overall implications of AVs and reveal the intertwined relations between the studied factors. This holistic review provides the chance to explore the implications of AVs in new novel areas such as:

- Implications of AVs on the public transit.
- Implications of COVID-19 on the public attitude towards AVs.
- AVs in developing countries and the challenges that faces AVs in developing countries.
- Finally, this study provides a figure that holistically summarizes the strengths, weaknesses, opportunities, threats of AV technology (Figure-5).

Tables 2 and 3 summarize the results of previous studies that focus on the implications of AVs.

Table 1 Selected AV review papers and their scope

Study	Scope
Narayanan et al. (2020) [105]	Implications of shared AVs on multiple branches
Kopelias et al. (2019) [106]	Environmental impact of AVs
Spence et al. (2020) [107]	Implications of AVs on the public behaviour
Sohrabi et al. (2020) [108]	Implication of AVs on the public health
Hao and Yamamoto (2018) [109]	Implications of shared AVs on the public behaviour
Gandia et al. (2019) [110]	Scientometric and bibliometric review of AVs
Peng et al. (2020) [111]	Scientometric and bibliometric review of AVs
Faisal et al. (2019) [112]	Implications of AVs on the landscape
Rojas-Rueda et al. (2020) [113]	Implications of AVs on the public health
Sun et a. (2017) [114]	Implications of AVs on the travel behaviour and the current business models

Table 2 Implications of AVs on public behaviour

Study	Study area	Key assumptions	Replacement Factor	Average waiting time (min)	Vehicle utilization (%)	VKT increase (%)	Trip cost reduction (%)	Parking demand reduction (%)	Conclusion
Burns, Jordan, and Scarborough (2012) [17]	Ann Arbor, Michigan	Shared AVs replace private trips lower than 70 miles	One AV can replace 10 conventional vehicles	1	75%	-	90	-	Shared AVs highly reduce costs
Burns, Jordan, and Scarborough (2012) [17]	Babcock Ranch, Florida	Share AVs replace trips within the city only	-	1	-	-	Low trip cost	-	Low number of AVs can serve the city
Burns, Jordan, and Scarborough (2012) [17]	Manhattan, New York	Shared AVs replace the yellow taxicab trips	-	1	-	-	88	-	Shared AVs highly reduce costs
Kockelman and Fagnant (2014) [18]	Austin, Texas, USA	The study estimated the impact of AVs on the environment	12	0.3	High vehicle utilization and the life span will be short. As a result, newer AV generations might be more environmentally friendly due to the technological development	11% increase due to relocation to cheap parking areas during low demand	-	92% (Removal of 11 spaces for each AV)	Reduction on CO and VOC by 34% and 39% due to reduction in engine starts, fuel used to find parking spot and platooning
International transport forum (2015) [16]	Lisbon, Portugal	Study two scenarios 50% shared AVs and 100% AVs	10	3.7	60 to 75%	6% increase with 50% AVs and 89% increase with 100% AVs	-	80%	High reduction in the parking spaces
Azevedo et al. (2015) [32]	Singapore	Private vehicles are not allowed to access a 14Km2 restricted zone in the CBD in Singapore	-	Reduce with the increase in the AVs until 2500 AVs then stay flat at almost 3 min	-	Increase because of the restricted area	-	-	-
Zhang, Gubathakurta, Fang, and Zhang (2015) [19]	City of Atlanta, USA	-	14	0.12	-	-	-	90% reduction in the parking demand of the served population (serving 2% of population)	High reduction in the parking spaces

Table 2 (continued)

Study	Study area	Key assumptions	Replacement Factor	Average waiting time (min)	Vehicle utilization (%)	VKT increase (%)	Trip cost reduction (%)	Parking demand reduction (%)	Conclusion
Bischoff and Maciejewski (2016) [20]	Berlin, Germany	Autonomous taxis will replace private cars	11	2.5	32%	-	-	-	Every AV can replace 11 traditional vehicles
Hörl, Erath and Axhausen (2016) [33]	City of Sioux Falls, USA	-	-	10 to 15	-	60%	-	-	High increase in the VKT
Zhang and Guhathakurta (2017) [39]	City of Atlanta, USA	Simulate three parking scenarios: free parking, entrance-based charge, and time-based charge	-	-	-	5% increase in the entrance-based, 14% for the time based	-	90% reduction in the parking demand of the served population (serving 5% of population with 4.5% reduction in parking demand)	The parking strategy affect the VKT significantly
Moreno, Michalski, Llorca and Moeckel (2018) [22]	greater Munich metropolitan area, Germany	Simulation characteristics are based on a survey analysis with 24.5% shared AVs	2.5	5	-	Up to 8%	-	-	-
Zhang, Guhathakurta and Khalil (2018) [23]	Atlanta Metropolitan Area, USA	Vehicles are shared within the same household members	Reduce ownership by 18.3%	-	-	13.3%	-	-	Reduction in the ownership

Table 3 Implications of AVs on land use, economy, environment, and society

Study	Study approach	Congestion–VOT–VKT–Capacity–Delay	Equity	Market and jobs	Parking	Energy and Emissions	Economy	Conclusion
Brown, Gonder and Repac (2014) [44]	Estimate impact of AVs in environment using The Kaya Identity equation that determine the level of human impact on emissions	–	Increase the mobility for the elder and the disabled	–	Reduce need for parking which consumes 4% of the energy consumed searching for a parking spot. New developments would replace the parking spaces and garages. Platooning could save 20% of fuel. Smooth starts and stops would save 15% of fuel consumption	–	AVs have the potential to make dramatic impacts on the transportation energy	
Barth, Boriboonsinsin and Wu (2014) [35]	Study impact of AVs on the environment using a generalized energy/emission versus speed curve for typical traffic	AVs increase the potential for ride share and shift the personal transportation from personal use to shared use	–	–	–	AVs can reduce the emissions by: Reduce the congestion (by increasing the capacity and lower collision rate). Platooning effect due to reduction in the aerodynamic drag forces on the vehicles (10–15% energy saving) and traffic smoothing effect or reduce the sharp stop and go	–	AVs have the potential to reduce vehicle's emissions

Table 3 (continued)

Study	Study approach	Congestion–VOT–VKT–Capacity–Delay	Equity	Market and jobs	Parking	Energy and Emissions	Economy	Conclusion
KPMG (2015) [15]	Estimating the impacts of AVs in the UK economy using the publicly available information, interviews, and the use of the green book economic model	–	–	AVs will open up new opportunities in other fields such as: decision-making software, vehicle cybersecurity and data opportunities. AVs open up Additional 320,000 jobs by 2030 in the UK	–	–	Increase in the GDP by 1% in 2030 with 51 £ billion benefits by 2030 and 121£ billion by 2040	AVs will provide huge social, industrial, and economic benefits
Friedrich (2016) [40]	Study the effect of the AVs on highways and intersection capacity using the macroscopic traffic flow models	AVs might provide 1.78 of the capacity of conventional vehicle. Lane capacity might reach 3900 veh/hr for 100% AVs compared to 2200 veh/hr today. At intersections, AVs would increase the capacity by 40% to 1120 veh/hr/lane compared to 800 veh/hr/lane for conventional vehicles	–	–	–	–	–	Significant increase in the capacity is expected using AVs

Table 3 (continued)

Study	Study approach	Congestion–VOT–VKT–Capacity–Delay	Equity	Market and jobs	Parking	Energy and Emissions	Economy	Conclusion
Miller and Heard (2016) [36]	Discuss the effect of the AVs on the environment	AVs increase the potential for ride share and shift the personal transportation from personal use to shared use. AVs would enable passenger to benefit from the travel time. However, the ability to benefit from the time might increase the VKT and in turn the emissions	AVs have the potential to improve the mobility for elder and disabled	–	AVs have the potential to reduce the parking spaces required especially in central areas	Improvement in the fuel economy due to the reduction in the collisions, the reduction in the congestion due to the optimized vehicle operation, platooning effect of AVs. On the other hand, the reduction in the collisions and congestion might lead to higher travel speed and higher emission	Not all potential AV-related behavioural shifts are environmentally favourable	
Kockelman and Clements (2017) [38]	Synthesizing existing literature and evaluating cost and sales changes (Economic analysis)	AV occupants will be able to use that time, which might increase the VKT and increase the fuel consumption	AVs have the potential to decrease opportunities for employment of millions of truck drivers	New business opportunities in the digital media industry as people will be engaged more in it during the trip	Reduction in parking spaces (40% reduction in urban areas)	Trucks will be controlled by the lead driver. It is expected that this system will reduce the fuel consumption by 15%	Shared AVs have great impact in the US economy (1.2\$ trillion in total or 3800\$ per person per year)	Individual businesses that do not adapt to this change may be hurt by the rise of AVs
Clark, Larco and Mann (2017) [48]	Argument/discussion on the social Impacts of AVs	–	Increase accessibility for aged and disabled individuals. However, create social gap based on the educational level	AVs will replace people with lower level education	Almost 90% of the parking spaces will be removed	–	–	Governments must begin to incorporate the changes to take advantage of the AVs and protect themselves from AV drawbacks

Table 3 (continued)

Study	Study approach	Congestion–VOT–VKT–Capacity–Delay	Equity	Market and jobs	Parking	Energy and Emissions	Economy	Conclusion
The Polis Traffic Efficiency and Mobility Working Group (2018) [34]	Discussion on the implications of AVs	The time spent in the vehicle cannot be considered as economic loss as people will be able to be engaged in productive activities. On the other hand, this will motivate people to make longer trips and move further from their work. Consequently, AVs might not solve the congestion problem	AVs will increase the accessibility for people with limited transportation accessibility	Many jobs will disappear, while new jobs professions will be available	–	AVs could enable the traffic to flow more efficiently and smoothly due to the ability to travel in platoons. However, it is not clear in the city centre where AVs interact with other road users	The passenger time will not be considered as economic loss	Even if the AVs prove to be technically and commercially viable, it might be necessary to limit the use of AVs for policy reasons
Metz (2018) [37]	Discussion on the implications of AVs	Drivers will be able to benefit from the time spent in vehicle, but this might increase the VKT. Shared AVs will reduce the number of vehicles in operation and in turn the congestion. However, this might attract more trips and the AV low cost might attract public transportation passengers. As a result, the impact on the congestion might be minor	AVs will increase the demand as it will enable new users (such as old people and disabled) to use the AVs	–	AVs will reduce the number of parking places especially in the CBD areas, which will permit for new development opportunities and will reduce the congestion of vehicles in search for a parking space	–	AVs will increase the demand for sharing trips as it will reduce the travel costs dramatically	To reduce traffic congestion substantially, it would be necessary to limit car ownership to within the capacity of the road network

Table 3 (continued)

Study	Study approach	Congestion–VOT–VKT–Capacity–Delay	Equity	Market and jobs	Parking	Energy and Emissions	Economy	Conclusion
Compass Transportation and Technology (2018) [42]	Discussion on the economic and social impacts of AVs	–	Increase the accessibility for elder, disabled and employees	Although there will be significant employment displacement, AVs will create new employment	Reduce the required parking spaces which use	–	–	AVs will provide new market opportunities and increase the industries productivities
Securing America's Future Energy (SAFE) (2018) [14]	Estimating the economic benefits of AVs using consumer surplus	Increase the capacity with 50% AVs and 3.2 times increase with 100% AVs. AVs have the potential to reduce congestion with economic benefits of 71 \$ billion	AVs would increase the accessibility in the depressed regions	AVs open up new business opportunities	–	Reduce fuel by 20% with 3.4\$ billion per year. AVs can substantially reduce America's reliance on oil with a social benefit of 58 \$ billion by 2050	800\$ billion by 2050 form reduction in collisions, value of time, consumption and environmental benefits	It is highly likely that AVs will revolutionize the American economy in ways that have not been seen before

Implications of AVs on vehicle ownership (fleet size) and vehicle utilization

The adoption of AVs promises many changes. One of these changes is the reduction in the vehicle ownership or increase in the vehicle utilization. Results of previous simulation models show that every single AV can replace a significant number of conventional vehicles, especially if it is used as a shared mode of transportation, which means that a lower fleet size can serve the same population with higher vehicle utilization [14, 15]. Studies show significant increase in vehicle utilization from 5% in conventional vehicles [16] up to 75% [17]. This increase in vehicle utilization is beneficial as it means shorter life span and adaption of newer and better technology [18]. Simulations of AVs as a shared mode showed that every AV can replace more than 10 conventional vehicles [16–21]. However, using AVs privately showed a slight reduction in the overall vehicle ownership. For example, the simulation model in Germany by Moreno, Michalski, Llorca, and Moeckel (2018) showed that every AV can replace 2.5 conventional vehicles. This is because of the difference in assumptions between this study and all other studies [22]. All the previous studies assumed that all trips will be made by SAVs, but Moreno, Michalski, Llorca, and Moeckel (2018) study [22] mimicked the results of a survey that showed that 24% of respondents would use shared AVs. Consequently, it is more reasonable to rely on the later results (AV = 2.5 conventional vehicles) because it is not realistic to assume that 100% of the trips will be made by shared AVs (SAVs). Over time, the percentage of trips made in shared AVs might change as AV penetration increases and shared AVs prove their high performance and gains for society then the percentage of shared trips might increase and become closer to the percentages stated in the first studies (AV > = 10 conventional vehicles). Similarly, Zhang, Guhathakurta, and Khalil (2018) showed that sharing AVs between the same household members reduces the vehicle ownership by 20%, which is also a significant reduction, but modest when compared to other studies [23].

In brief, AVs have the potential to reduce vehicle ownership significantly, even if it used privately. On the other hand, using AVs as a shared mode shows promising results with a significant reduction in the required fleet size to serve the same population. This reduction in fleet size is beneficial for the society and environment because it means lower emissions, better traffic conditions, much higher vehicle utilization, and shorter life span, which in turn means the adoption of newer and cleaner technology quickly.

Singapore provides a realistic example of the potential of AVs to reduce vehicle ownership. Pilot studies in

Singapore started in 2015 and the city is known as the world's most AV-friendly country. The city allowed for tests in a wide range of autonomous vehicles for private and public use, that more than 10 companies are testing their vehicles in the city. Results showed that by 2018 (in three years) vehicle ownership reduced by 15% [24].

One major factor that influences the vehicle ownership is regulations. Regulatory action will be a significant determinant of how AVs could affect the ownership. For example, cities might allow AVs as shared mode only and prevent the private use. Currently, cities focus on testing AVs as a shared mode. For example, the following cities are testing autonomous shuttles or autonomous buses: Texas—USA, Wageningen—the Netherlands, Helsinki—Finland, Paris—France, Shenzhen—China, Sion—Switzerland, Edmonton—Canada. Using AVs as a shared mode of transportation guarantees the maximum benefits.

Quality of the service (waiting time and travel cost) provided by shared AVs (public transit vs. AVs)

Although shared AVs reduce the required fleet and significantly increase the vehicle utilization, it provides high-quality service for the public. One important factor for travellers in shared transportation modes is the average waiting time because people perceive their waiting time considerably much longer than the actual time. Different surveys provided different waiting time to in-vehicle time ratios [25].

For example, Wardman (2004) found that one-minute waiting is equivalent to 2.5 min of in-vehicle time [26]. Horowitz (1981) found that the ratio is 1.9 [27]. Abrantes and Wardman (2011) found that one-minute waiting is equivalent to 1.4 min in vehicle [28]. Consequently, any reduction in passenger waiting time has a significant influence on customer satisfaction. Currently, the average transit waiting time in the USA is approximately 40 min (31% of their commuter time) [29, 30]. The average waiting time in Toronto, Canada, is 20 min [31].

For the case of shared AVs, results show that shared AVs can provide significantly lower waiting time (5 min on average) when compared with the current transit waiting time and with significantly lower trip costs as shown in Table 4.

In conclusion, shared AVs have the potential to significantly reduce the average waiting time and trip costs when compared with the current transit service, which means that shared AVs will be a strong competitor to the transit service and might attract public transit users. Thus, transit agencies should be aware of this new coming disruption to the transportation system or else they will incur significant losses; in particular, AVs will be available sooner or later.

Implications of AVs on the public behaviour

One of the biggest advantages of AVs is that passengers will be able to be engaged in other activities, which in turn means that the trip time will not be considered as economic loss [34]. Additionally, AVs have the potential for ridesharing

Table 4 Summary of the studies investigating the waiting time and trip costs of SAVs

Simulation study	Results
Burns, Jordan, and Scarborough (2012) [17]	The simulation model for Ann Arbor, Michigan, USA, to achieve a customer waiting time of two minutes or lower shows high-cost reduction from 21 \$ to 2 \$ (90% reduction) per day due to reduction in the ownership cost, operating expenses, parking fees and value of time
Burns, Jordan, and Scarborough (2012) [17]	Two simulation models for Babcock Ranch, Florida, USA, and Manhattan, New York, USA, showed radically low trip cost with a waiting time less than two minutes. In Manhattan, results show high-cost reduction from 7.8 \$ per trip (using the traditional yellow taxi) to 0.8 \$ per trip (88% reduction) due to the reduction in the ownership cost, operating expenses, and central coordination. For the Babcock Ranch case, the mobility service cost would be less than 3\$ per day per person or 1\$ per trip
International Transport Forum [16]	The simulation model for Lisbon, Portugal, shows that AVs can provide an average waiting time of 3.7 min
Zhang, et al. (2015) [19]	A simulation model for the City of Atlanta, USA, shows that AVs can provide an average waiting time of 0.12 min
Azevedo L, et al. (2016) [32]	The simulation model for Singapore shows that AVs can provide an average waiting time of 3 min
Bischoff, and Maciejewski (2016) [20]	The simulation model for Berlin, Germany shows that AVs can provide an average waiting time of 2.5 min and up to 5 min during the peaks
Hörl, Erath, and Axhausen (2016) [33]	The simulation model for the City of Sioux Falls, USA, shows that AVs can provide an average waiting time of 5 min during the off-peak and an average waiting time of 10 to 15 min during the peak periods
Moreno, et al. (2018) [22]	The simulation model for greater Munich metropolitan area, Germany shows an average waiting time of 5 min with 95% of the waiting time is lower than 10 min

and shifting the personal transportation from personal use to shared use [35, 36] as discussed in Sect. 4 (Implications of AVs on Vehicle ownership (Fleet size) and vehicle utilization). This reduction in fleet size means better traffic conditions and mitigation of congestion. On the other hand, AVs will motivate people to make longer trips, travel further, and make additional trips which in turn increase the VKT [34, 37]. The increase in the VKT increases the emissions [36] and fuel consumption [38]. Results of AV simulation models show that AVs have the potential to significantly increase the VKT for a variety of reasons as shown in Table 5.

Additionally, while the mentioned simulation models show that AVs have the potential to increase the VKT, all these studies do not take into account the possibility that AVs might motivate people to make additional trips. Thus, it must be mentioned that the low waiting times and low trip costs of AVs might attract people to make additional trips (induced demand) and might discourage people from making trips using public transportation [37], which in turn means a significant increase in the VKT, and emissions. Moreover, this additional demand besides with the increase in the VKT might worsen the traffic conditions. Thus, AVs might not solve the congestion problem, but as mentioned before the time spent in the vehicle will not be considered as an economic loss [34] as passengers will spend their time in productive activities. In conclusion, while AVs have the potential to allow people to be engaged in productive activities during their trips (good influence from the economic perspective), AVs have the potential to motivate people to make additional trips which significantly increase the VKT and emissions (bad influence from the environmental perspective). Thus, while AVs might enhance the economic condition, they might destroy the environment. One major factor that has an impact on the public behaviour is regulations. Regulatory action will be a significant determinant on controlling the change in the public behaviour and in turn

the impact of AVs. For example, regulations might allow AVs as a first mile-last mile solution to support public transit service, which guarantees the maximum benefits of AVs.

Implications of AVs on capacities of roads and intersections

AVs have the potential to reduce the distance between the vehicles (distance ahead) and to reduce the lane width [40] due to the high level of communication between vehicles and the elimination of human factors from the driving process, which in turn means a significant increase in capacity of roads as shown in Table 6.

In conclusion, AVs have the potential to increase roads and intersection capacities. On the other hand, it is not expected that this increase can be achieved until a high level of market penetration [37] as with conventional driving the human factor will dominate for safety issues or for human feeling of safety as people will be scared to see the vehicle drive close to the vehicle ahead or the vehicle beside. However, in AVs, people might be involved in other activities (sleeping, watching movies, or any other activity) and probably they will not see the surrounding roads, which might allow vehicles to drive close to each other.

Implications of AVs on the land use

AVs will change more than our streets, over time they could change the structure of cities, towns, and neighbourhoods. For example, AVs have the potential to reduce the number of parking spaces needed to serve the population. These freed-up spaces can be used for other purposes and allow for the construction of new developments. Results of the previous simulation models show that AVs have the potential to

Table 5 Summary of the studies investigating the impact of AVs on the public behaviour

Study	Results
Fagnant and Kockelman (2014) [18]	The simulation model for Austin, Texas, USA, shows an increase in the VKT by 11% due to vehicle relocation searching for cheap parking lots during the low demand periods
International Transport Forum [16]	The simulation model for Lisbon, Portugal, shows an increase of 6% in the VKT with 50% AVs and 89% increase in the VKT with 100% AVs
Hörl, Erath, and Axhausen (2016) [33]	The simulation model for the City of Sioux Falls, USA, shows 60% increase in the VKT [33]
Zhang, and Guhathakurta (2017) [39]	Zhang and Guhathakurta (2017) studied the impact of parking prices on the VKT for the City of Atlanta, USA, using simulation models for three scenarios: free parking (as a baseline), entrance-based charge, and time-based charged. AVs were programmed to reduce their overall costs (travel or fuel costs and parking costs). Results showed 5% increase in the VKT for the case of entrance based and 14% increase in the VKT for the time-based parking [39]. Thus, the parking strategy has a significant impact on the VKT
Zhang, Guhathakurta, and Khalil (2018) [23]	The simulation model for the Atlanta Metropolitan Area, USA, based on the assumption that Vehicles will be shared within the same household members shows an increase of 13.3% in the VKT

significantly reduce the parking demand and required parking lots as shown in Table 7.

Furthermore, AVs might change the design of parking lots. Theoretical speaking, AVs will park themselves without the need for the door space which could enable 20% more free spaces. Moreover, AVs can block each other and let each other out when necessary as shown in Fig. 1. A study by Audi suggested that a parking space can take 2.5 times the conventional vehicles using this blocking method [43]. Thus, AVs have the potential to significantly reduce the number of parking places required in the CBD areas [36], which reduces congestion of vehicles in search

for a parking space [37], that consumes 4% of the energy (fuel) consumed [44]. Additionally, the freed-up parking spaces can be used for other purposes. For example, using the parking areas in the real estate industry can increase the value of land use by 5% [38]. In addition, AVs will not rely on on-street parking but will travel to the nearest off-street parking. Thus, AVs can increase the road capacity as these parking lanes can be used to serve the traffic. Moreover, this reduction in the parking demand might be also associated with changes in houses design as the end house parking spaces might not be needed anymore and can be used for other purposes. In other words, AVs can indirectly increase the areas of houses.

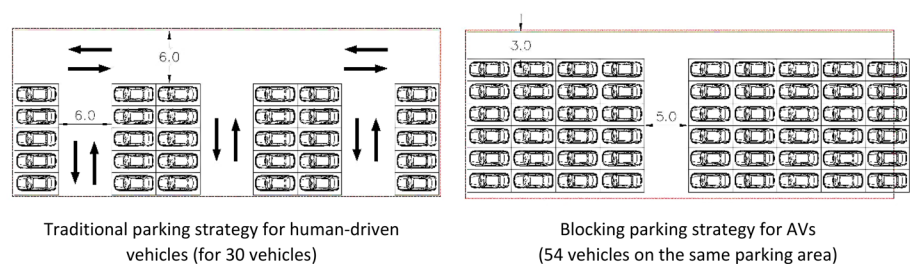
Table 6 Summary of the studies investigating the impact of AVs on the road and intersection capacity

Study	Results
Friedrich (2016) [40]	The study analysed the impact of AVs on road capacity using the macroscopic traffic flow models. Results showed that AVs with 100% market penetration might provide 1.78 of the capacity of the traditional vehicles with a lane capacity of 3900 veh/hr compared with 2200 veh/hr for conventional vehicles. Additionally, AVs might increase the intersection capacity by 40%
Wagner (2016) [41]	This study estimated the impact of AVs at the intersection level in Braunschweig, Germany using a simulation model for intersections and a simulation of a green wave. Results showed that AVs can double the capacity at intersections and AVs can improve the delay times in the case of sub-optimal coordination because the number of vehicles leave a signal is much more when compared with the case of human drivers. Consequently, AVs can reduce the delays dramatically up to 80%
Securing America's Future Energy (SAFE) (2018) [42]	This study estimated that AVs can increase the capacity by 50% to 70% with 50% AV market penetration and 320% increase with 100% AV market penetration

Table 7 Summary of the studies investigating the impact of AVs on the land use

Study	Results
Fagnant and Kockelman (2014) [18]	An agent-based model for Austin Texas, USA, shows that each AV can remove 11 parking spaces compared with the case of conventional vehicles
Zhang et al. (2015) [19]	The simulation model for the city of Atlanta, USA, which is based on the assumption that 2% of the population are using AVs shows 90% reduction in the parking demand for the served population
International Transport Forum [16]	The simulation model for Lisbon, Portugal, shows that AVs can alter the need for the on-street parking and free up an area of almost 1,153,000 m ² which represents almost 20% of the overall area of streets in the city of Lisbon. Moreover, AVs might make it possible to remove 80% of the off-street parking
Zhang and Guhathakurta (2017) [39]	The simulation model for the city of Atlanta, USA, which is based on the assumption that only 5% of the residents would use AVs instead of their conventional vehicles shows 4.5% reduction in the parking demand which can be translated into 90% reduction in the parking demand for the served population

Fig. 1 Traditional parking strategy for human-driven vehicles vs. the blocking parking strategy for AVs



Implications of AVs on the energy consumption and emissions

Transportation is the main source of pollution on our planet. Transportation contributed to 29% of greenhouse gas emissions in the USA in 2017. It was found that the transportation sector generates the largest share of greenhouse gas emissions that are primarily generated from the following sources: burning fossil fuel for cars, trucks, ships, trains, and planes. More than 90% of the fuel used in transportation is petroleum-based, which includes primarily gasoline and diesel [45]. Additionally, it was estimated that road transport contributes to 72% of the total transportation pollutions. Cars alone contribute to 44% of the 72% [46]. In Canada, transportation contributes to 25% of the total emissions [47]. Consequently, transportation is the main source of pollution and the search for a sustainable transportation system became critical, and a wide area of research. Previous simulation models show that AVs have the potential to provide a sustainable transportation system and significantly reduce energy and emissions as shown in Table 8.

In summary, AVs enable high levels of communication between vehicles, which allow vehicles to travel in platoons. Platoons can reduce 15% of the fuel used [35, 38] or up to 20% [14]. Additionally, AVs make it possible to apply the vehicle optimal traffic assignment to minimize the total travel time and in turn optimize the fuel

consumed and reduce the emissions [36]. Moreover, AVs smooth starts and stops can save 15% of fuel consumption.

Implications of AVs on the economy

It is expected that the impact of AVs will extend beyond the simple crash, and fuel saving into every aspect of the economy. Businesses companies that are unable to adapt to this change may be hurt by the introduction of AVs. For example, AVs will increase the demand for sharing trips and so it will reduce the travel costs dramatically [37]. In the worst case, AVs might not solve the congestion problems as the additional demand and increase in VKT might offset the increase in the capacity. However, the drivers' time will not be considered as an economic loss anymore as drivers can spend their trips in productive activity [34, 38].

Kockelman and Clements (2017) studied the impact of AVs on the economy of the USA. For software and technology companies, AV software technology is expected to grow from 680\$ million in 2025 to 15.8\$ billion in 2040. Also, the required mapping process is expected to grow from 530\$ million to 10.6\$ billion in 2040. This contributes to revenue of 26.4\$ billion in 15 years. Moreover, the impact on health care will be enormous. Based on NHTSA 2015, accidents account for 23\$ billion as medical expenses in the USA. As a result, assuming 90% reduction in collision rate (due to the elimination of the human error) means a reduction of 20.7 \$ billion each year, a reduction in the need for supplies and

Table 8 Summary of the studies investigating the impact of AVs on the environment

Study	Results
Barth, Boriboonsomsin, and Wu (2014) [35]	This research studied the impact of AVs on energy consumption and emissions using the generalized energy or emission versus speed curve for typical traffic which state that the lowest emissions level and the lowest fuel consumption level occur at a speed range between 35 and 55 mph. Results shows that AVs can reduce emissions and energy through three main factors: first, reducing congestion (by increasing the capacity and reducing collision rate) and in turn increase the speed. Second, vehicle platoons which reduce the aerodynamic drag forces on vehicles as a separation of 4 m can achieve 10–15% energy saving. Third, traffic smoothing effect that reduces the sharp stop and go. The smooth operating can reduce the fuel consumption by 15%
Fagnant and Kockelman (2014) [18]	The simulation model for Austin, Texas, USA, shows 34% reduction in the CO2 emissions and 49% reduction in the volatile organic compounds (VOC)
Miller and Heard (2016) [36]	Results shows that AVs can enhance the fuel economy dramatically due to: platooning effect, reduction in collisions, and reduction in congestion due to the optimized vehicle operation as AVs will allow for the application of system optimal traffic assignment which reduces the total travel time in the entire network. On the other hand, reducing collisions and congestion might increase the travel speeds, which means higher emission
Kockelman and Clements (2017) [38]	This study estimated that AV platooning can improve safety and reduce the fuel consumption by 15%
Securing America's Future Energy (SAFE) (2018) [42]	Results of this study show that AVs can reduce the fuel consumed by 20% with an economic benefit of 3.4\$ billion per year. Additionally, AVs can substantially reduce America's reliance on oil with a social benefit of 58 \$ billion by 2050

doctors, and better allocation of personnel to provide better services. Additionally, AVs will increase the value of land use as the land used as parking before can be converted into houses, parks, or other developments. The average value of a parking place in the USA is 6300\$ with a total value of all parking spaces of 4.5 \$ trillion. However, using the parking areas in the real estate industry will increase the land use value by 5%. The study concluded that Shared AVs have a great impact on the economy (1.2\$ trillion in total or 3800\$ per person per year) [38].

Compass Transportation and Technology (2018) evaluated the impact of AVs on the economy of the USA. Results show that the benefits to cost ratio of the AVs is 8:1. Additionally, an improvement of 10% in the transportation network is associated with a two per cent (or a bit more) improvement in overall economic productivity or improvement in GDP [42]. Securing America's Future Energy (SAFE) (2018) studies that the impact of AVs on the economy of the USA. Results show that the reductions in collisions, the value of time, fuel consumption, and environmental benefits will contribute to benefits of almost 800\$ billion by 2050 [42]. Additionally, KPMG (2015) examined the impact of AVs on the UK economy. Results show that the economic and social benefits of the AVs can reach 51 £ billion by 2030 (1% increase in GDP) and 121£ billion by 2040 [15].

Implications of AVs on the society (equity)

AVs have the potential to increase coverage and accessibility for aged and disabled individuals [14, 36, 42, 44, 48]. Additionally, AVs can increase the accessibility for people with limited transportation accessibility [34] such as rural areas or depressed regions [14].

AVs have the potential to radically change the conventional market. Many jobs will disappear, while new job professions [34] and new business opportunities [14] will be available. AVs open new opportunities in a variety of fields such as decision-making software, vehicle cybersecurity, and data opportunities. AVs will provide new opportunities for the digital media as commuters who are used to watch the road will switch to use the digital media features in their automobiles during their trips. Additionally, Internet shopping could receive a large bump from this added free time. It is estimated that AVs will provide 320,000 additional jobs in the UK [15]. On the other hand, this increase in entertainment flexibility for passengers might reduce the use of radio as people might prefer other activities to do while in the vehicle [38].

On the other side, people are likely to be replaced by AVs, which have a potentially significant impact on individuals with lower levels of education and income and

consequently implications and concerns for equity [48]. AVs can cause serious loss for truck drivers as the technology would reduce the opportunity for the employment of millions of drivers [38]. On the other hand, a recent study by Gittleman and Monaco (2020) shows the risk on truck drivers is real, but the projections touted are overstated because companies will not be able to abandon all drivers as drivers do more than just driving and not all the tasks can be automated [49]. For example, checking for safety problems can be performed by sensors, but AVs cannot fix these issues so dealing with these detected issues requires human interaction.

Implications of AVs on the public health

Implications of AVs on public health could vary depending on many factors such as the type of use or ownership, automation level, and the type of engine such as internal combustion, and hybrid engines. While AVs might increase some risks such as pollution and sedentarism, AVs might reduce morbidity and fatalities from vehicle collisions and might help reshape cities to promote healthy environments. Public health can benefit from the proper regulations if these regulations are implemented before the introduction of AVs in the market. This section explores the benefits and risks of AVs on the public health.

Physical activity

Physical activity related to transportation has been suggested as a main source or strategy for increasing the daily physical activity level [50–52]. The benefits of this active transportation have been recognized in many cities around the world and have shown direct and indirect benefits such as the reduction the noise level and the improvement in the air quality. While it is difficult to predict the impact of AVs on the travel behaviour and their impact on the physical activities, AV simulation models suggest that AVs could increase the VKT to pick up passengers from their location and in turn reduce the physical activity [53]. Additionally, privately owned AVs might lead to a more dispersed urban growth pattern (sprawl), which in turn increases the average trip length and discourages people from walking or cycling [54]. On the other hand, if people are willing to share their trips, shared AVs could reduce the VKT when compared to private AVs. Thus, shared AVs are likely to increase the physical activity more than privately owned AVs because this approach needs to be complemented by walking, cycling, or using public transportation.

Air pollution and emissions

It was estimated that around 95% of the world's population lives in areas that exceed the healthy air requirements provided by the World Health Organization (WHO) [55]. Motorized vehicles are one of the main sources of air pollution [56, 57]. In 2015, it was estimated that 250,000 deaths were related to air pollution from road transportation [58]. Emissions related to transportation can be classified into two categories: exhaust emissions and non-exhaust emissions.

Exhaust emissions

Three main factors have a strong influence on the implications of AVs on the air pollution as follows: the implications of AVs on the VKT, the reliance on gasoline engines or electric vehicles, and the integration between AVs and public transportation or active transportation modes [51]. Simulation models show that AVs have the potential to increase the VKT and thus increase the air pollution exposure. Additionally, as gasoline and diesel engines pollute more than electric vehicles do, if AVs are not fully electric, travellers would be exposed to higher pollution levels, and higher air pollution exhaust emissions would then affect the public health. Finally, AVs can increase the air pollution level if AVs use patterns do not facilitate walking, cycling, and transit use. Regulations can play an essential role in the implications of AVs on the air pollution and account for these issues to reduce the negative externalities of motorized transport.

Non-exhaust emissions

Other sources of air pollution sources include brake and tyre wear, road surface wear, and resuspension of road dust. These emissions together might exceed the tailpipe emissions at least in terms of particulate matter [56]. Additionally, brake and tyre wear have higher oxidation potential when compared to other traffic-related sources, which can be translated into worse environmental conditions. Moreover, as the weight of electric vehicles is more than the weight of non-electric vehicles, electric vehicles have the potential to emit more non-exhaust emissions [59]. Thus, AVs have the potential to increase the non-exhaust emissions, even with a shift to electric vehicles, because of the increase of the VKT [60].

Noise

Noise associated with traffic has been addressed as a source of multiple health issues such as including sleep disturbance, annoyance, cardiovascular disease, and hypertension [61, 62]. In Europe, it is estimated that noise causes 10,000 premature deaths per year [63, 64]. AVs using internal

combustion engines similar to conventional vehicles could continue to contribute more to road traffic noise. As in the case of air pollution, if AV use results in increasing the VKT, then the noise exposure level would increase [53]. On the other hand, the use of electric vehicles would reduce the noise level considerably. However, at speeds higher than 50 km/hr electric vehicles and conventional vehicles produce the same noise levels. For example, a Dutch study estimated that a fleet of fully electric vehicles could reduce the urban noise levels significantly by 3–4 dB and reduce annoyance effects by more than 30% [65]. Thus, electric AVs can reduce the noise level significantly.

Electromagnetic fields

Electric and magnetic fields (EMFs) can be defined as invisible areas of energy (also called radiation) that are generated by electricity. Low- to mid-frequency EMFs are in the non-ionizing radiation part of the electromagnetic spectrum and are not known to damage DNA or cells directly. Previous studies evaluated the relation between the exposure to non-ionizing EMFs and the risk of cancer with no conclusive results [66]. On the other hand, a recent study by the US National Toxicology Program on male rates showed a clear relation between the exposure to high levels of radiofrequency, such as that used in 2G and 3G cell phones, and the development of heart tumours [67]. AVs rely on multiple technologies that would increase the exposure to the EMFs, which in turn might worsen the public health.

Substance abuse

In 2019, almost 9.9 million people were reported driving under the influence of drugs [68]. Laws prohibit driving under the influence of drugs or alcohol. These laws together with the social norms have increased the public awareness and discourage people from abusing these substances while driving [69]. It is possible that the widespread of AVs would cause laxity in the public attitude towards drugs. In 2017, Australia's National Transport Commission linked AV passengers with taxi passengers and showed that there might be exemptions from the legal restrictions for AV passengers [70]. Thus, a clear definition of the capabilities and requirements of AV passengers will need to be addressed and aligned with the future policies. Additionally, the efforts against alcohol and drug abuse should be maintained.

Stress

Driving has been addressed as a source of health issues. Recent studies show that driving for long hours causes a high level of stress [71]. It was found that stress has adverse impacts on the immune, cardiovascular, and nervous systems, among others

[72]. AVs have the potential to decrease the mental workload and stress, thereby producing a more positive set of emotional responses. Thus, AVs could reduce the stress of driving, and enhance the public health.

AVs and pandemics

The global COVID-19 has made radical changes in our world, as people had to adapt to a new lifestyle. Experts believe that this pandemic is a turning point that will accelerate the new digital revolution. Although the pandemic has halted many AV pilot studies [73, 74], it is expected that this crisis will accelerate the introduction of AVs as AVs can be useful in emergencies and pandemics as follows:

During the COVID-19 pandemic, China used autonomous vans for food and medical supplies delivery and sanitize streets [75]. In Beijing, a partnership between Neolix and Apollo was established with the aim of delivering food and medical supplies [76]. Similarly, in Florida, USA, the Mayo Clinic has started using the AV developed by Beep to transport COVID-19 tests from the testing site to the processing laboratory [77]. Thus, AVs have proved their value in fighting pandemics so, in the future, AVs can be used as a transportation mean to transport people to grocery stores, healthcare, and pharmacies, while maintaining isolation and sterilization [74, 75].

Vayyar, which is a start-up company, is working on developing new smart vehicles that monitor the cleanliness and air quality that measure airborne contaminations for infected passengers. This feature is very useful as it helps in the early detection of infections and diseases [75].

Finally, AVs can be used for the transportation of people during pandemics and replace the public transit service which is a major source for the outbreak of diseases and viruses. In 2018, Goscé and Johansson studies how public transit affects the spread of viruses in London, and they found a correlation between the use of public transport and the spread of diseases [78].

As a result, AVs have proved their ability in addressing some of the biggest challenges confronting societies in pandemics. Thus, the previous use cases show that AVs represent a major tool in the fight against pandemics that AVs can provide effective, and safe mobility to help people to move to their essential activities.

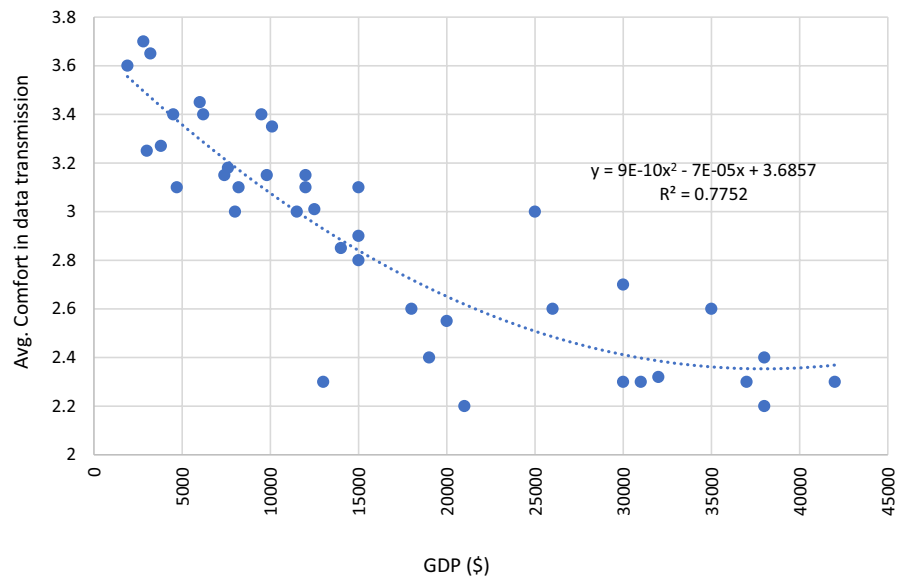
Autonomous vehicles in developing countries

While most of the previous work focuses on studies from developed countries, this section sheds light on the implications of AVs and the challenges that face AV deployment in developing countries. However, it must be mentioned that rare studies discuss AVs in developing countries and most of these studies focus only on the public attitude towards AVs (discussed in detail in Sect. 14.2). For example, there is no simulation study for AVs in any developing country. One of the main reasons for this lack of studies is the poor infrastructure that does not support the navigation of AVs, which requires huge capital costs or investments to provide a safe infrastructure that supports AV navigation. In this section, a detailed analysis of the infrastructure challenges that face the deployment of AVs in developed countries will be discussed and analysed.

Public attitude towards AVs in developed countries and developing countries

One of the main studies that tested the public attitude towards AVs in an international level is the study by Kyriakidis, et al. (2015) [79]. This study used an Internet-based survey with 5000 responses from 109 countries to investigate the public acceptance, worries, and willingness to buy partially, highly, and fully automated vehicles. Comparing the results across different countries (in terms of accident statistics, education, and income) shows that people from developed countries are more pessimistic than people from developing countries towards AV adoption. Specifically, respondents from more developed countries are more worried about data transmitting as shown in Fig. 2 that shows the relationship between the Gross Domestic Product (GDP) and the level of comfort towards data transmission. This difference can be explained in terms of the perceived threat level. In general, people from developed countries have more sophisticated computer infrastructure for data misuse that these countries have multiple widely publicized cases, such as some Google cases [80, 81] and Facebook cases [82, 83], that makes citizens of developed countries may realistically believe that the threat of data misuse exists and is harmful to them. On the other hand, the fatality rates in developing countries are much higher than in developed countries that the current trends indicate that road traffic injuries will become the fifth leading cause of death by 2030, with the difference between high- and low-income countries further magnified [84]. Thus, according to Maslow's hierarchy of needs [85], people in low-income countries are mostly concerned with basic

Fig. 2 Average level of comfort in transmitting data to tax authorities versus gross domestic product (GDP) for different countries (adopted from [79])



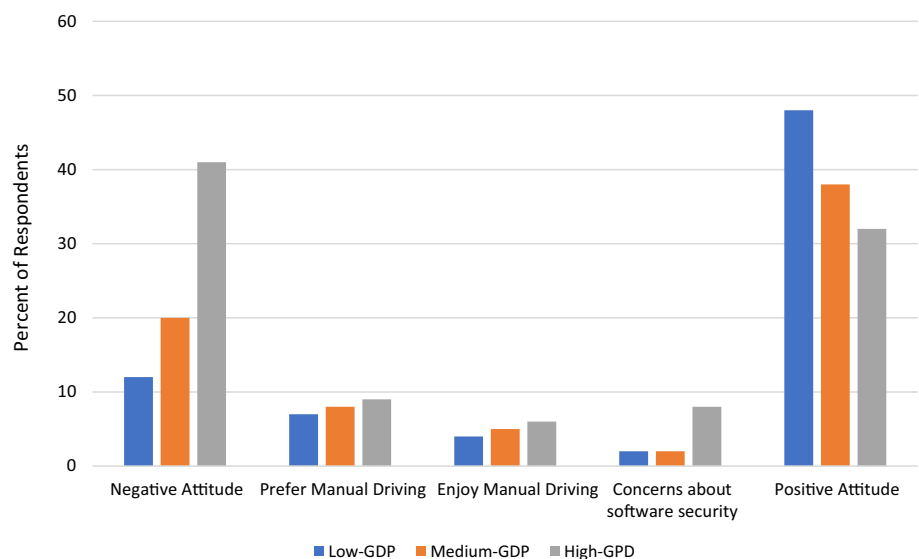
physiological and safety needs that make data privacy or transmission a least priority issue for them.

Another study by Bazilinskyy et al. (2015) investigated the public attitude towards AVs by analysing textual comments resulting from three international previous surveys with 8,862 respondents from 112 countries and these responses were analysed to understand the difference in the public attitude across different countries. In this study, responses were categorized according to the GDP into three different categories: high-GDP, low-GDP, and medium-GDP. Figure 3 summarizes these results and as shown in the figure people from high-income countries

were more likely to express a negative comment and less likely to express a positive comment about automated driving [86] which is compatible with the result of the previous survey by Kyriakidis, et al. (2015) [79].

A third and recent international survey by Moody et al. (2019) with 33,958 respondents from 51 countries investigated public perceptions of AV safety across a diverse sample of individuals from a wide variety of countries. Results show that although respondents from developed countries are more aware of AV technology, they are more pessimistic about the present and future safety of AVs [87]. Figure 4 shows the level of awareness and the public acceptance of AVs in the surveyed countries.

Fig. 3 Percentage of positive and negative comments for different GDP levels (adopted from [86])



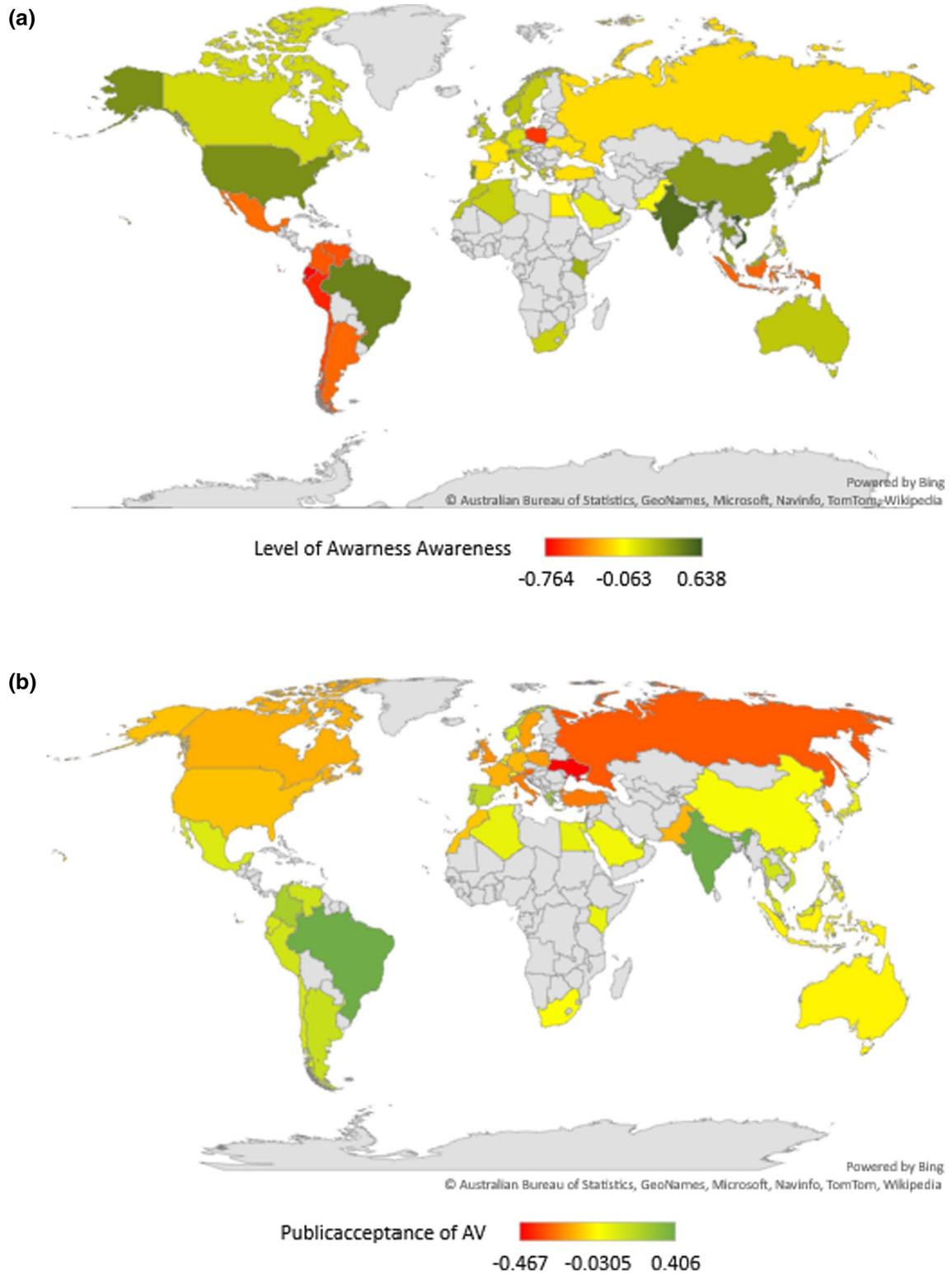


Fig. 4 Different (a) level of awareness and (b) public acceptance of AVs in different countries (adopted from [87])

Surveys from developing countries

In general, the studies that focus on the public acceptance of AVs in developing countries are rare. A recent survey in Pakistan that evaluates the public attitude towards AVs by Shafique et al. (2021) shows that a small proportion of the respondents are not aware of this new technology. Additionally, the main concern of the respondent was not privacy, such as data transmission, but sharing the road space with driverless trucks was the main concern with 70% of the respondents were highly concerned about the idea of sharing the road with driverless trucks. On the other hand, 15% of the respondents were highly concerned about the privacy of the vehicle such as the continuous vehicle tracking [88]. Again, these results indicate that safety is the main concern for people in developing countries and privacy is not an issue for them similar to what the previous international surveys show. Additionally, respondents were very optimistic towards AVs as when the respondents were asked about the expected benefits of AVs, 98% of the respondents believe that AVs can reduce the number of accidents and 99% believe that AVs can reduce the severity of the crashes. Thus, this high level of trust in AVs' ability to improve traffic safety combined with the non-concerned opinions regarding the privacy or data transmission makes people from developing countries very optimistic towards AVs. The previous statement can be concluded from an earlier survey by Sanaullah, et al. (2017) in Pakistan that shows that Pakistanis are highly interested in AVs. This survey shows that 75% of the respondents are highly interested in AVs and the level of interest in AVs increase with the increase in the level of automation as 5% of the respondents are interested in level-0 automation, 8% are interested in level-1 AVs, 27% are interested in level-2 AVs, 34% are interested in level-3 AVs, and 26% are interested in level-4 AVs. Additionally, this survey shows that most Pakistanis believe that AVs are safe and will improve the level of safety as 75% of the respondents believe that AVs will improve traffic safety and reduce fatalities [89], which is consistent with Shafique et al. (2021) survey results [88] mentioned above. Additionally, Escandon-Barbosa et al. (2021) survey investigated the impact of the risk perception on the willingness to pay AVs in Vietnam and Colombia. The results show that traffic safety is the main factor that affects the willingness to pay AVs followed by the financial risk [90].

Benefits of AVs for developing countries

The fatality rates in developing countries are much higher than in developed countries that the current trends indicate that road traffic injuries will become the fifth leading cause of death by 2030, with the difference between high- and low-income countries further magnified [84]. Statistic

on fatal accidents in developing countries shows that the human factors are the main factor behind most of these accidents [91], which can be eliminated by AVs. Additionally, the deployment of AVs will be associated with a reduction in the vehicle ownership, accidents, emissions, and pollution. All these advantages will help people in developing countries to have healthier lives. Thus, AVs might be more critical for developing countries than developed countries as AVs will save the lives of many people. These benefits are associated with a high level of acceptance and interest in AVs [6] in developing countries than in developed countries as shown in all previous international surveys. However, AVs face multiple issues that might make it hard to test AVs in developing countries. These issues will be discussed in the next section.

Challenges for AV deployment in developing countries

Road signs and marking

AVs need highly visible curves, speed limits, and other signage in order to safely complete the tasks of driving, navigation, and parking [92–94]. However, the current marking and signing technique does not support AV navigation. For example, the two major issues facing AV navigation are the faded road marking and the non-standard road signs [95, 96]. These two issues are commonly found in developing countries and will confuse AVs.

Road marking is essential for AV navigation and localization especially for camera-based localization techniques [93]. Previous filed studies on AVs show that missing road marking might cause unsafe navigation of AVs. However, in many developing countries there is a lack of the necessary marking as shown in the study by Huq et al. (2021) in India [97]. This study shows that many roads in India lack the stop lines, pedestrian crosswalks, lane marking, and edge marking. This lack of marking makes it challenging for AVs to operate safely on these roads.

The variation in the road signage, which is normal in the roads of developing countries, is the second challenge facing AVs, so coding is a main principle for sending information in a recognizable and standardized way. Standard colour, shape, font, line spacing, and luminance contrast are major factors that should be considered even for human drivers. However, the historical standards for coding have changed but outdated signs remain on the road network. Thus, this variety in the signage standards introduces new challenges for AV navigation. In general, there are many factors that impact the process of detection and recognition of the signs for AVs such as [21, 98]:

Inconsistent signs: the lack of consistency in the application of signs, and sign location can be problematic and causes uncertainty on how the vehicle will react in these conditions.

Obscured signage: in many scenarios, signs might be Obscured partially or fully because of many factors such as other vehicles, vegetation, and the existing roadside infrastructure. This issue requires research in order to ensure the adequate detection of the signs in all conditions.

Varying illumination: many factors might affect the visibility of AVs such as the weather conditions, the low lighting conditions, and low sun angle. Additionally, the degraded retroreflective material will affect the visibility of AVs during night.

Lack of signage.

Developing countries suffer from all the previous signage issues. For example, the study by Huq et al. (2021) in India shows that most roads in India do not have stop signs, pedestrian crossing signs, lane merging signs, and lane split signs, and in many cases, traffic signals are not used at the intersections, which is confusing for AVs [97].

Traffic management:

AVs are expected to depend on accurate road mapping to complete their journey safely [99]. However, traffic incidents are stochastic events that change the road layout and AVs must be able to navigate safely in all cases. Additionally, roadway maintenance work is expected, which results in changing the road layout and the locations where the vehicles are expected to travel. As a result, depending on accurate mapping might not be enough as lane closures, and traffic incidences might add new risks [100]. While there are multiple websites that provide accurate information regarding traffic incidents in developed countries, such as waze.com in the UK, there is no such website in any developing country. Even more complex, these information from the websites only contains details reading the incidence cause and time without accurate information on the incidents' on-site conditions, which makes it hard for AVs to navigate safely even in developing countries [101]. As a result, this lack of real-time information might be problematic for the safe navigation of AVs where traffic incidents occurred in developing countries.

Parking

Research studies on the parking of AVs show that AVs can significantly reduce the number of the required parking lots, especially in the context of shared AVs as vehicles will be serving customers at different times, which reduces the

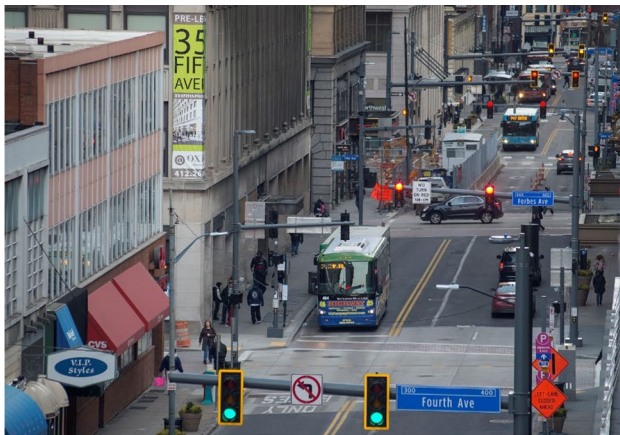
number of required parking spots [15, 101]. Additionally, the autonomous valet parking system will allow vehicles to park closer to each other, and thus, the parking lots will be able to serve more vehicles. This provides new opportunities for both the users and the infrastructure provider as the user will not have to search for a space to park and increase the number of vehicles using the parking area due parking owners. AVs have the potential to free up significant parking spaces and allow these spaces to be used in other activities, AV parking faces multiple issues in developing countries. Firstly, AV parking requires remote control of the vehicle by the parking operator which might expose the vehicle to cybersecurity threats also safeguards might be required if the vehicle does not respond. Secondly, AV parking will need an electronic payment method as no occupant will be in the vehicle. Thirdly, a major issue in the current parking lots is that most of them are privately owned and do not have a consistent marking system so the AVs will struggle in such an environment. Finally, the current parking lots do not support AV safe operations as most of the current parks are underground parks where the GPS signals are lost or weak, which causes confusion for AVs [102].

Safer harbour area

In the future, when AVs will operate on the roads, passengers will be able to participate in other activities. However, this introduces new issues and risks in case of vehicle malfunctioning or deterioration in the surrounding environment. This case might need some human interaction and ask the passengers to take control of the vehicle, but it is possible that the driver is not ready to take control of the vehicle so AVs will need a safe area to use until the driver takes control. As a result, the use of safe harbour areas is important for AVs to offer the vehicles a safe area in case the AV cannot operate safely in the current surrounding environment or in case of any malfunctioning [103]. In developed countries, the hard shoulder area is used along the road as the emergency refuge area (ERA) and can be used as a safe harbour area for AVs [100, 103]. In developed countries, the hard shoulder is usually used for serving the running traffic, which makes it dangerous to be used as a safe harbour area for AVs.

Traffic Heterogeneity

As shown above, AVs have the potential to increase the lane capacity in developed countries without any infrastructure improvements. However, in developing countries, the lane capacity is greatly reduced by the heterogeneity of traffic as shown in Fig. 5-b. Non-motorized and motorized vehicles pass together through the same lane creating a haphazard situation and reducing the effective lane width. This heterogeneity of traffic will confuse AVs.



(a) Road with intersections (from the USA)



(b) Congested heterogeneous traffic conditions (from India) [104]

Fig. 5 Homogenous and heterogeneous traffic conditions [103]

Summary of the challenges for the deployment of AVs

The deployment of AVs in developing countries faces many issues such as the absolute lack of standardization in road infrastructure, poorly planned road network, lack of directional, informational and warning signals, and poor mapping of roads. All the currently existing algorithms which are being used and under research in the field of AV require a structured set of road infrastructure to work properly as in developed countries where everything is well structured. However, such a well-structured infrastructure network does not exist in most developing countries. Thus, it can be concluded that while people in developing countries are more optimistic towards AVs, the infrastructure challenges represent a major obstacle for the deployment of AVs.

Impacts of the public perception on the adoption of AVs

As mentioned before, public acceptance of AVs is considered a major factor for the success of AVs. Thus, this section briefly summarizes the impact of the public attitude and cultural dimensions on the adoption of AVs.

Impact of previous experience with AV features (awareness)

In order to investigate the impact of previous experience with AV features, Piao et al. (2016) conducted a survey and telephone interview in La Rochelle, France, after the end of a pilot AV project (autonomous shuttles) in the city. The results show that around 90% of the respondents are familiar with AV technology. Additionally, more than 65% of the respondents preferred AVs than human-driven vehicles. Additionally, 73% of the respondents with previous experience with AVs were optimistic about the adoption of AVs, while 55% of the respondents without previous experience with AV technology were optimistic about this new technology. Thus, previous experience with AVs has a significant influence on the public acceptance of AVs. A second approach to investigate the impact of previous experience with AV on the public attitude towards AVs is driving simulators [114]. Thus, Wintersberger, Riener and Frison (2016) used a driving simulator to understand the impact of previous experience with AVs on the public acceptance and questionnaires were conducted twice for every participant; one before and another after the trip to analyse the participants' attitude towards AVs. This study concluded that respondents with previous experience with AV are more optimistic about adopting this technology [115].

Impact of the economic conditions on public acceptance of AVs

In order to investigate the impact of the economic conditions on the public acceptance of AV, Bazilinskyy, Kyriakidis and De Winter (2015) conducted an international survey with 8862 respondents from 112 countries. Results of this study show that people from low-income countries are more optimistic towards AVs than people from medium- or high-income countries. The survey shows that 40, 20, and 23% of the respondent from low-, medium-, and high-income countries are optimistic about the adoption of AVs. Additionally, a large proportion of the respondent from high-income countries were concerned about the data transmission (privacy) and the software failure [86]. These results are consistent

with the results of the other international surveys mentioned in Sect. (15).

Willingness to pay:

The willingness to pay is a key factor for the success of any new technology, especially in the initial state where the cost of the new technology is night hawked, previous surveys show that most respondents are not willing to pay more for AVs as summarized in Table 9.

Precepting of AVs for different age groups:

Although most studies arbitrarily assume that AVs have the potential to increase accessibility for aged individuals and consider this segment as the early adaptor of AVs [14, 36, 44, 118, 119], results of previous surveys that investigated

the impact of the respondents' age on the public attitude towards AVs as summarized in Tables 10. Thus, the assumption that the aged will be of the early adaptors of AVs contradicts with the results of previous surveys and younger people might be the early adopters of AVs.

Perception of males and females:

Previous surveys show that males are always more optimistic towards AVs than females as summarized in Table 11.

Summary of the impact of the demographics on the public attitude towards AVs

Figure 6 summarizes the results of previous surveys mentioned in this study. (Table 12) The figure shows the minimum, maximum, and average percentages of the different

Table 9 summary of the selected studies that investigated the willingness to pay for AVs

Survey	Results
Schoettle and Sivak, (2014) [116]	60% of the respondents are not willing to pay more for AV technology, while 10% are willing to pay much more
Kyriakidis, Happee and de Winter (2015) [79]	AVs are more attracted to travellers who make long trips and to people who live in countries with high accident rates Only 5% of the respondents are willing to pay more for AV technology
Cunningham, Ledger, and Regan (2018) [117]	66% of the respondents are not willing to pay more for AVs

Table 10 Summary of the selected studies that investigated the perception of AVs for different age groups

Survey	Results
Piao et al., (2016) [114]	56% of respondents whose age is more than 65 would be optimistic towards AVs, compared to 62% and 61% for people aged between 18 and 34, and 35–64
Abraham et al., (2017) [120]	40% of the respondents aged 25–34 years old prefer AVs, while only 12% of the respondents aged 65–74 years old consider making trips in AVs
Richardson and Davies (2018) [121]	people become discouraged about AVs with the increase in the number of years driving

Table 11 Summary of the selected studies that investigated the perception of AVs for males and females

Survey	Results
Schoettle and Sivak, (2014) [116]	Males are more positive towards AVs
Schoettle and Sivak, (2015) [99]	40% of the female respondents are concerned about fully AVs, while 30% of the male respondents are concerned about fully AVs
Piao et al., (2016) [114]	64% of the male respondents agreed to make trips using AVs, while 55% of the female drivers agreed to make trips in AVs
Abraham et al., (2017) [120]	53% of the male drivers trust AVs and agree to let the vehicle to take control, while 40% of the female drivers trust AVs and would let the vehicle to take control
Richardson and Davies (2018) [121]	Females are more concerned about the risks of AVs 60% of the male respondents believe that AVs can improve the safety of traffic, while 47% of the female respondents agree that AVs improve traffic safety

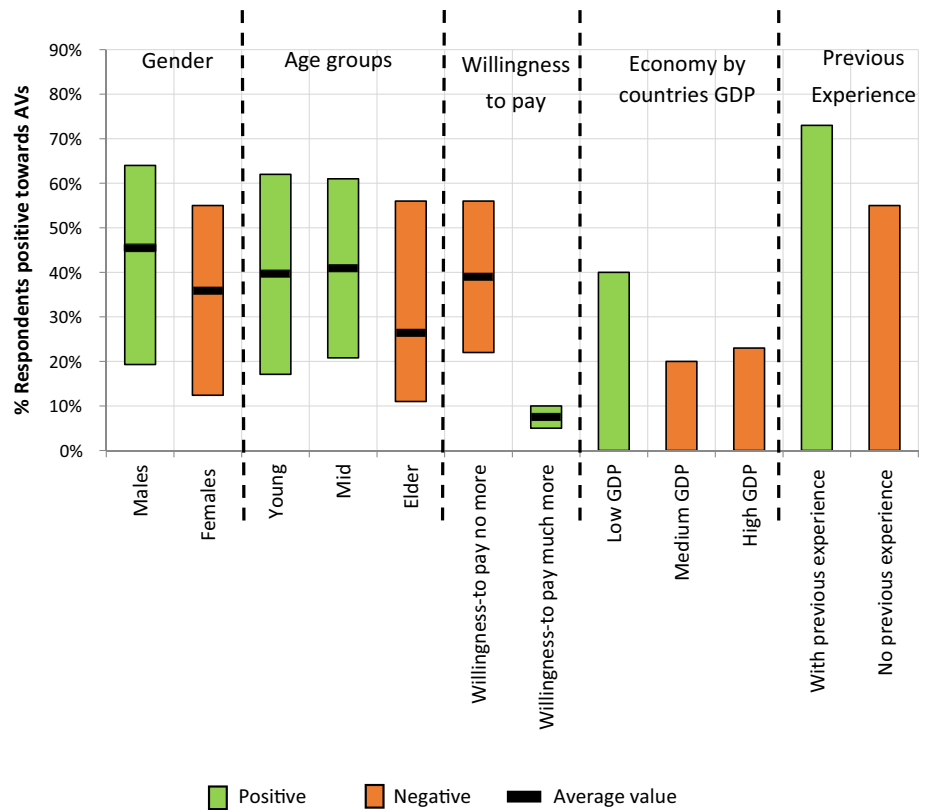
Table 12 Risks and benefits of AVs

Implication of AVs on	Benefits	Risks
Safety	AVs have the potential to increase the traffic safety due to the elimination of the human error that contribute to 90% of the overall accidents	Vehicular failure might replace the human error and contribute more to accidents because of the complexity of the sensors, and the information processing process. Another issue is that the behaviour of AVs is unknown in different environmental conditions such as fog, snow Recent studies show that AVs perform much worse than human drivers and that AV safety is still in early stages of development
Ownership	AVs have the potential to reduce the vehicle ownership significantly, even if it used privately. However, using AVs as a shared mode shows promising results with a significant reduction in the required fleet size to serve the same population. Results show that every shared AV can replace up to more than 10 conventional vehicles. This reduction in the fleet size is beneficial for the society and environment because it means lower emissions and better traffic conditions. Additionally, this reduction on the fleet means size much higher vehicle utilization and shorter life span, which in turn means adoption of newer and cleaner technology quickly	–
Waiting time, and trip costs	Shared AVs have the potential to provide much better service when compared to public transit as AVs can reduce the average waiting time and trip costs significantly, which means that shared AVs will be a strong competitor to transit service	Low trip costs of AVs might attract more people to make trips (induced demand) and might attract public transportation users and discourage people from using public transit, which in turn worsen the traffic conditions, increase the required fleet size, VKT, emissions, and energy consumption
Public behaviour	One of the biggest advantages of AVs is that passengers will be able to be engaged in other activities, which in turn means that the trip time will not be considered as economic loss Additionally, AVs have the potential for ridesharing and shifting the personal transportation from personal use to shared use. This reduction in fleet size means better traffic conditions and mitigates congestion	On the other hand, AVs will motivate people to make longer trips and travel further which in turn increases VKT. The increase in VKT might mean increase in emissions and fuel consumption Simulation models show that AVs will increase the VKT significantly depending on their operating strategy, and mode (private or shared mode)
Roads and intersections	AVs have the potential to reduce the distance between the vehicles (distance ahead) and reduce the land width due to the high level of communication between vehicles and the elimination of human factors from the driving process, which in turn means a significant increase in capacity of roads	On the other hand, it is not expected that AVs can increase the capacity until high level of market penetration as with conventional driving the human factor will dominate for safety issues or for human feeling of safety as people will be scared to see the vehicle drive close to the vehicle ahead or the vehicle beside

Table 12 (continued)

Implication of AVs on	Benefits	Risks
Land use	<p>AVs have the potential to significantly reduce the number of parking places required in the CBD areas by 80% to 90%, which reduces congestion of vehicles in search for a parking space that consumes 4% of the energy (fuel) consumed</p> <p>Additionally, AVs will not rely on on-street parking but will travel to the nearest off-street parking. Thus, AVs can increase the capacity of roads as these parking lanes can be used to serve the traffic</p> <p>Additionally, this reduction in the parking demand might be also associated with changes in houses design as the end house parking spaces might not be needed anymore and can be used for other purposes. In other words, AVs can indirectly increase the areas of houses</p> <p>Furthermore, AVs might change the design of parking lots. Theoretical speaking, AVs will park itself without the need for the door space which could enable 20% more free spaces. Moreover, AVs can block each other and let each other out when necessary. It was estimated that a parking space can take 2.5 times the conventional vehicles using this method</p>	<p>–</p>
Economy	<p>AVs have a great influence on the economy. It is expected that the impact of AVs will extend beyond the simple crash, and fuel saving into every aspect of the economy</p>	<p>AVs might not solve the congestion problems as the additional demand and increase in VKT might offset the increase in the capacity. However, the drivers' time will not be considered as economic loss any more as drivers can spend their trips into productive activity</p>
Society and equity	<p>AVs have the potential to increase coverage and accessibility for aged and disabled individuals. Additionally, AVs can increase the accessibility for people with limited transportation accessibility such as rural areas or depressed regions</p> <p>AVs open new opportunities in variety of fields such as decision-making software, vehicle cybersecurity, and data opportunities</p>	<p>AVs have the potential to radically change the conventional market. Many jobs will disappear, while new job professions and new business opportunities will be available</p> <p>Additionally, people are likely to be replaced by AVs, which have a potentially significant impact on individuals with lower levels of education and income and consequently implications and concerns for equity. AVs can cause serious loss for truck drivers as the technology would reduce the opportunity for the employment of millions of drivers</p>
Public health	<p>Thus, electric AVs can reduce the noise level significantly</p> <p>AVs could reduce the stress of driving and enhance the public health</p>	<p>AVs might discourage people from walking or cycling, which means reduction in the daily physical activity level</p> <p>Thus, AVs have the potential to increase the exhaust and non-exhaust emissions, even with a shift to electric vehicles, because of the increase of the VKT</p> <p>AVs rely on multiple technologies that would increase the exposure to the Electric and magnetic fields, which in turn might worsen the public health</p> <p>AVs might cause laxity in the public attitude towards drugs and alcohol</p>

Fig. 6 Summary of the of the public perception of AVs



demographic studies in this section. The figure shows that females are more concerned about AVs than males. Additionally, younger people are more optimistic towards AVs than older people. Furthermore, most people are not willing to pay more for the new technology. Moreover, people from high-income countries are more concerned about the security and privacy of AVs than people from low-income countries. Finally, previous experience with AVs increases the level of acceptance of AVs and attracts people towards AV technology.

Implications of AVs on traffic safety

Safety of AVs is essential to their success in the market and society [122]. The main advantage of AVs is their quick response when compared to the human driver [123]. Moreover, AVs are programmed so that they can obey the rules of the roads, cannot be distracted by the phone [124]. For example, Papadoulis et al. (2019) investigated the impact of different levels of penetration of AVs on the safety of traffic using Vissim simulation models and evaluated the safety of every penetration rate using the Surrogate Safety Assessment Model (SSAM). Results of this study show that AVs can significantly improve traffic safety and the level of safety increase with the increase in the level of penetration of AVs. Specifically, the results show that AVs reduce traffic

conflicts by up to 47, 80, 92 and 94% with 25, 50, 75 and 100% AV penetration rates, respectively [125]. Similarly, Ye, and Yamamoto (2019) investigated the impact of AVs with different penetration rates on the safety of traffic using a simulation model. The impact of the different penetration levels of AVs on the safety was assessed based on the frequency of dangerous situations and the value of time to collision in the mixed traffic flow under different AV penetration rates. Additionally, the acceleration rate and speed difference distribution of the traffic were used to understand the evolution of the network dynamics under different AV penetration rates. The results of this study show that traffic safety can be significantly improved with the increase of AV penetration rate. Additionally, the simulation models show that the portion of smooth driving increases with the increase in AV penetration [126]. Aside from simulation models, AVs are usually programmed to make decisions using machine learning and artificial intelligence (AI) techniques. The use of AI to improve the safety and make decisions in AVs has achieved some progress; however, this progress is not significant because of the complexity of the vehicle in terms of electrical and mechanical components and the variety of external conditions such as weather, road conditions, topography and traffic pattern [122, 123]. Additionally, an important factor that has contributed to recently reported crashes in AVs is the transition from the conventional mode to the AVs [with its various levels]. Another

behavioural aspect that is indirectly related to safety is the normal eye contact–feedback–proceed two-way communication between drivers in adjacent cars in conflicting situations; a behavioural component that is either absent in full AV penetration; or more confusing in conventional vs AV mixed conditions [123]. These challenges forced Waymo CEO John Krafcik in November 2018 to state that he does not believe that AV technology will ever be able to operate in all possible conditions without some human interaction [127, 128]. Consequently, solving the safety issue requires a multidisciplinary effort between science, technology and manufacturing. Typically, an AV contains more than 50 processors and accelerators that run millions of codes to support the vision of the vehicle in order to make the appropriate decision. Additionally, the behaviour of AVs is unpredictable in all scenarios unless it is trained for these problems in real work; however, there are hundreds of scenarios that the vehicle might face [122]. Therefore, it is fair to state that the level of development and data to support the safety of autonomy is still in the early stages [129]. The data collected between 2014 and 2017 by the research team at the University of Illinois for 114 AVs that travelled almost 1.1 million kilometres showed that the human drivers are 4000 times less likely to have an accident [122]. One of the

proposed solution is the approach followed by Tesla as in 2016 when Tesla announced that their vehicles are able to travel autonomously; however, this feature will operate in the shadow mode. In the shadow mode, the vehicle can make decisions but these decisions are not executed but the human driver’s decisions are the decisions executed instead [130]. This approach helps in gathering information about the decisions of the vehicles and compares these decisions with the human driver actions in order to train the vehicle to take the actions that mimic the human driver’s actions. Additionally, this approach helps the manufacturer of AVs to understand how AVs learn and improve over time.

Conclusions

It has been three decades since Mercedes-Benz and Bundeswehr University in Munich invented the first AV in the world. Over the last decade, AV technology has seen rapid improvement as both research and industry are putting significant efforts into the development of AVs. This paper reviews the current state of the art of AV implications on public behaviour, land use, economy, society and environment, and public health. While AVs hold many benefits, they



Fig. 7 SWOT analysis for AV technology

also hold many risks as summarized in Table 9 and Fig. 7 which summarizes the strengths, weaknesses, opportunities, and threats (SWOT analysis) of AV technology mentioned in this study. This paper shed the light on many strengths and weaknesses of AVs and the intertwined relationships between them as follows:

- AVs have the potential to reduce vehicle ownership. The pilot studies in Singapore emphasize this ownership reduction, as results show 15% reduction in the vehicle ownership due to the spread of AVs in 2018 [24].
- Shared AVs have the potential to provide excellent service to the public as AVs can significantly reduce the average waiting time and trip costs, but this might encourage people to make additional trips (induced demand) and might attract transit users, which in turn increases the VKT, emissions, and energy used. One positive sign is that most of the cities testing AVs are testing autonomous shuttles or autonomous buses with the aim of solving the first mile and last mile problem and increase the reliance on public transit.
- AVs allow passengers to be engaged in other activities, which means that the trip time will not be considered as an economic loss. On the other hand, this will motivate people to make longer trips and travel further which in turn increases VKT, emissions, and energy consumed.
- AVs have the potential to significantly reduce the parking demand by 80 to 90% as reported in the previous studies [16, 19, 39], which in turn reduces congestion of vehicles searching for a parking space. Additionally, the freed-up parking spaces can be used for other purposes. For example, using the parking areas in the real estate industry can increase the value of land use. Additionally, this reduction in the parking demand might be also associated with changes in house design as the end house parking spaces might not be needed anymore and can be used for other purposes.
- AVs have the potential to reduce emissions and energy due to the platooning effect, smooth start and stops, reduction in the number of engine starts because of the reduction in required fleet size. Additionally, AVs open the way towards the application of the system optimal traffic assignment.
- AVs have a great influence on the economy. It is expected that the impact of AVs will extend beyond the simple crash, and fuel saving into every aspect of the economy. It is expected that AVs will revolutionize the economy in ways that have not been seen before.
- AVs open new opportunities in variety of fields such as decision-making software, vehicle cybersecurity, and data opportunities. On the other hand, people are likely to be replaced by AVs, which have a potentially significant impact on individuals with lower levels of education and consequently concerns for equity. AVs can cause a serious loss for truck drivers as the technology would reduce the opportunity for the employment of millions of drivers.
- AVs have the potential to increase coverage and accessibility for aged, disabled individuals, and people with limited transportation such as people in rural areas.
- Implications of AVs on public health could vary depending on many factors such as the type of use or ownership, automation level, and the type of engine such as internal combustion, and hybrid engines. While AVs might increase some risks such as pollution, sedentarism, and exposure to the electric and magnetic fields, AVs might provide some benefits such as the reduction in the stress of driving, and the reduction in the noise level. Public health can benefit from the proper regulations if these regulations are implemented before the introduction of AVs in the market.
- In pandemics, AVs can be used for food and medical supplies delivery and sanitize streets. Additionally, AVs can be used as a transportation mean to transport people to grocery stores, healthcare, and pharmacies, while maintaining isolation and sterilization.
- The fatality rates in developing countries are much higher than in developed countries that the current trends indicate that road traffic injuries will become the fifth leading cause of death by 2030, with the difference between high- and low-income countries further magnified. The main source of accidents in developing countries is the human drivers which can be eliminated by AVs. Thus, the value of AVs in developing countries is higher than the value of AVs in developed countries as AVs will save more lives. This high value of AVs is associated with a high level of acceptance and interest in AVs in developing countries than in developed countries as shown in all previous international surveys. However, AVs face multiple issues and challenges that might make it hard to deploy or test AVs in developing countries soon. These challenges include but not limited to: the poor signage and marking standards, the lack of most basic marking and signage, the poor parking design that does not support AV navigation in terms of marking or signage consistency and the required navigation technology in case of underground parking, and traffic Heterogeneity that might confuse AVs.
- Although residents of developing countries are more optimistic towards AVs than residents of developed countries, the infrastructure and behavioural challenges will force developing countries to delay the adoption of AVs.
- The broader implications of AVs will be dependent on how the technology is adopted in various transportation systems. Regulatory action will be a significant determinant of how AVs could affect our lives, as well as how

AVs influence the public behaviour, land use, economy, public health, environment, and society.

Direction for future research

Although there is a large number of studies that focuses on AVs, there are multiple research gap that requires further studies and analysis as follows:

Induced demand: AVs will allow people to be engaged in other activities during their trips, which will motivate people to create additional trips and travel further. Thus, the assumption that the travel demand is unchangeable, as stated in all simulation studies, is not true as AVs will be less expensive (as a shared public mode of transportation) and thereof induced demand is inevitable; the magnitude of which is yet to be succinctly and evidently studied/estimated by transportation planners. This gap is more important to be addressed now than ever as the anticipated travel demand implications might offset some of the perceived benefits of AVs as the added trips generated besides with the VKT increase might offset the benefits of AVs and cause a high level of congestion and emissions, which means that AVs might represent a huge risk on the network and the public health. Thus, further research studies are required to understand the impact of AVs on the travelling behaviour and estimate the expected increase in the trips generated because of the attractiveness of AVs.

Public behaviour: Further studies are required to understand the change in public choices. For example, is it realistic that people might prefer to live further from work and spend their trip sleeping? If so, how far or what is the increase in the trip length and total VKT? What is the impact on the origin–destination matrices? For example, what is the impact on the distribution of people in urban and rural areas?

Elder and disabled accessibility: AVs are expected to increase the accessibility for the elders and disabled. While the disabled are considered to be one of the early adaptors of the AVs, no study surveyed this group to understand their acceptance of the AVs. As a result, future studies are required for this group instead of making assumptions. Similarly, the elders are considered of the early adaptors of the AVs as AVs will increase their accessibility. However, previous surveys show that the elder group is the most pessimistic group towards AVs [114, 120, 121] which contradicts the theories that the elder will benefit more from the AVs. In other words, it is noteworthy that, although accessibility to the elderly and disabled was among the key drivers/benefits of AV selling point, little to no research focused on the disabled group to understand their acceptance of AVs. Addi-

tionally, although the elders were thought to be among the early adaptors of AVs to improve their accessibility; results showed that younger people are more interested in AVs which questions the hypothesis that the elder would benefit more from AVs.

Implications of AVs on developing countries: Further studies are required to understand and quantify the implications of AVs on the land use, public behaviour, emissions, and roads and intersection capacity of developing countries. To the moment, there is no single simulation model developed in any developing country to understand how AVs will affect people of developing countries. Additionally, further research studies are required to propose solutions for the issues and challenges facing AV deployment in developing countries.

Authors' contributions KO took part in literature search and review, research methodology, data preparation, data analysis, and manuscript writing and reviewing.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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