Journal of Urban Mobility 9 (2026) 100194

Contents lists available at ScienceDirect

Journal of Urban Mobility

journal homepage: www.elsevier.com/locate/urbmob

Barriers to autonomous vehicles adoption in Europe: Insights from literature and interviews

Giuseppe de Leo *, Giovanni Miragliotta

Politecnico di Milano, Dipartimento di Ingegneria Gestionale, Via Raffaele Lambruschini, 4/B, Milano 20156, Italy

ARTICLE INFO

Keywords:
Self-driving cars
Adoption barriers
Regulatory challenges
Expert interviews
Mobility innovation

ABSTRACT

Autonomous vehicles (AVs) are expected to revolutionize mobility by improving road safety, efficiency, and accessibility. However, their diffusion in Europe remains limited due to a complex interplay of technological, regulatory, economic, and societal challenges. This study explores the main barriers obstructing the adoption of AVs in Europe, aiming to provide a multi-stakeholder perspective on the issue. Through a literature review grounded in high-ranking academic sources and complemented by 21 semi-structured expert interviews, we identify six interrelated categories of challenges: fragmented regulatory frameworks, unresolved ethical and legal liabilities, technological limitations and cybersecurity concerns, inadequate infrastructure and Vehicle-to-everything (V2X) integration, uncertain economic models, and low societal trust and cultural readiness. Our findings reveal a strong alignment between academic debate and practitioner insights, while also uncovering overlooked issues such as poor institutional coordination and the dynamic evolution of challenges across the AVs value chain. The analysis underscores the need for harmonized policy frameworks, collaborative innovation, and proactive public engagement to enable a gradual yet effective transition toward autonomous mobility in Europe. This paper contributes to both scholarly understanding and practical policymaking by offering a forward-looking roadmap for overcoming adoption barriers in the European AVs ecosystem.

1. Introduction

Autonomous vehicles (AVs), also referred to as self-driving or driverless cars, have emerged as a major innovation poised to reshape transportation (Bagloee et al., 2016; Fagnant and Kockelman, 2015; Huang et al., 2023; Talebpour and Mahmassani, 2016; Yigitcanlar et al., 2019). Proponents argue that AVs could drastically reduce traffic accidents, often attributable to human errors, improve mobility for those unable to drive, alleviate congestion through optimised driving patterns, and generate economic efficiencies in logistics and transit (Bajpai, 2016; de Leo and Miragliotta, 2025; Gruyer et al., 2021; Litman, 2020; Rahman and Thill, 2023). In Europe, where approximately 20,000 people still lose their lives in road crashes annually (European Commission, 2024), the potential safety benefits of automation are particularly significant. Beyond safety, AV technology aligns with broader European goals of digital innovation and sustainable mobility, promising more accessible transport services and integration with smart city initiatives. Major European automakers, technology firms, and research consortia have invested heavily in AV development, and several countries have hosted pilot projects of self-driving shuttles and automated highway driving. These developments underscore the high expectations for AVs as part of Europe's transport future.

Despite this promise, the rollout of autonomous driving in Europe has been cautious and incremental. Unlike in the United States and parts of Asia where testing and deployment have proceeded more freely, Europe's progress is tempered by numerous challenges spanning technological, regulatory, and societal domains. One key concern is regulatory fragmentation, due to jurisdictional differences among European countries which have led to a patchwork of laws governing AV testing and use, creating uncertainty for manufacturers and developers (Bardt, 2017). Technical challenges are also present because current AV systems still struggle to guarantee safety in all road situations, and high-profile setbacks have raised questions about their readiness for real-world deployment (Kalra and Paddock, 2016). Infrastructure limitations present another hurdle, as not all European roads are equipped to support Vehicle-To-Infrastructure (V2I) communication or even consistent lane markings and signage for machine vision (Duarte and Ratti, 2018; Liu et al., 2019; Rana and Hossain, 2023). Furthermore, ethical and legal

* Corresponding author.
E-mail addresses: giuseppe.deleo@polimi.it (G. de Leo), giovanni.miragliotta@polimi.it (G. Miragliotta).

https://doi.org/10.1016/j.urbmob.2026.100194
Received 22 July 2025; Received in revised form 27 December 2025; Accepted 27 January 2026
Available online 12 February 2026

issues remain unresolved. For instance, how AVs' algorithms should make moral decisions in crash scenarios (Martinho et al., 2021; Wu, 2020), and who bears liability if an autonomous car causes harm. Economic viability is uncertain as well: the costs of AV technology are high and immediate business models for recouping investments are unclear, especially as the automotive industry simultaneously invests in electrification and faces market fluctuations (Andersson and Ivehammar, 2019; Bösch et al., 2018; Litman, 2020; Martínez-Díaz and Soriguera, 2018). Finally, public acceptance is a pivotal factor, as European consumers have shown ambivalence and scepticism toward self-driving cars, often citing safety, trust, and privacy concerns (Othman, 2021; Rezaei and Caulfield, 2020). Without public trust and willingness to use AVs, even the most advanced technology may fail to achieve widespread adoption.

Recent research has converged on the notion that autonomous vehicle adoption is hindered by a multifaceted set of barriers spanning technological, regulatory, and societal domains. Prior studies - from survey-based analyses (Wishart et al., 2023) to expert-driven decision models (Raj et al., 2020; Shahedi et al., 2023) and large-scale literature syntheses (Mahdavian et al., 2021; Ullah et al., 2025) - have consistently highlighted obstacles such as technical limitations and safety concerns, high costs, regulatory uncertainty, deficient infrastructure, and societal resistance. Studies focused on rural contexts (Prioleau et al., 2020) or global policy overviews (Bezai et al., 2021; Fagnant and Kockelman, 2015) further underscore how these challenges are compounded by demographic, spatial, and policy heterogeneity. Notably, the lack of standardization (Raj et al., 2020), poor ICT infrastructure (Shahedi et al., 2023), and public trust deficits (Bezai et al., 2021; Wishart et al., 2023) emerge as recurring themes. These findings are summarized in Table 1, which compares methodological approaches, geographic scopes, key barriers identified, and limitations across the selected studies.

However, much of this literature is either non-European in focus or treats barriers in isolation without triangulating perspectives across stakeholders. In contrast, the present study contributes by grounding its analysis in the European context and integrating insights from both academic literature and expert interviews with key actors in the AV ecosystem, including policymakers, industry representatives, and mobility users. By doing so, we move beyond sectoral or geographic silos to construct a holistic framework that captures the interdependence of technical feasibility, governance readiness, and public acceptance. This integrative approach responds directly to existing research gaps, offering an empirically grounded, context-sensitive perspective on how Europe can address its specific adoption barriers.

Given this intricate context, there is a need for a comprehensive examination of the barriers impeding autonomous vehicle adoption in Europe. While various studies have investigated individual issues such as technical performance, legal frameworks, or user acceptance, fewer works have integrated these perspectives to provide a holistic view of the socio-technical challenges involved. Bridging this gap between scholarly research and practical experience is essential for developing realistic strategies to advance autonomous vehicle deployment.

Accordingly, this paper addresses the following research question:

What are the main challenges for Europe in transitioning toward autonomous driving?

To answer this question, we conducted a narrative literature review of recent high-quality studies, focusing on peer-reviewed European and international publications from the last decade, selected for their relevance to the regulatory, technological, and societal dimensions of AV deployment (see Section 2.1 Literature review approach for methodology) and complemented this with 21 expert interviews, through which we systematically identified six key categories of AV adoption barriers. This mixed qualitative approach ensured that the barriers highlighted are grounded in a broad base of scholarly evidence and expert insight, and are clearly defined from the outset.

Regarding the structure of the paper, Section 2. Methodology outlines the methodology of this research, which combines a literature review with expert interviews conducted with professionals in the automotive field. Section 3. Key Findings present the combined findings from the literature review and the expert interviews, organized around six key thematic barriers. In this results section, academic evidence is integrated with illustrative quotes from industry experts (formatted in italics) to provide both scholarly and practical insights on each barrier. Section 4. Discussion is refocused to synthesize and compare these findings, integrating also a systematic cross-country comparison, juxtaposing the findings from Europe with international benchmarks, particularly from the United States and China. Section 5. Conclusions concludes by summarizing the implications of our findings and offering recommendations for policymakers, industry, and future research. Through this structure, we seek to provide a well-rounded understanding of the obstacles hindering autonomous driving in Europe and how these challenges might be addressed moving forward.

2. Methodology

This study adopted a two-parts research design comprising a narrative literature review and a set of expert interviews. The narrative literature review provided a broad foundation of existing knowledge on autonomous vehicles' adoption challenges in Europe, while the expert interviews captured in-depth insights from practitioners and stakeholders. Together, these complementary approaches ensured that the analysis integrated both established scholarly perspectives and current real-world expertise.

2.1. Literature review approach

To build a robust theoretical foundation for this study, a narrative literature review was conducted following established guidance for narrative and semi-systematic approaches (Baumeister and Leary, 1997; Snyder, 2019). Unlike systematic reviews, which are highly structured and aim to exhaustively capture all relevant publications within predefined parameters, narrative reviews allow for a more flexible and iterative exploration of literature, particularly useful for complex, interdisciplinary topics such as the adoption of autonomous vehicles in Europe.

This review aimed to identify, map, and synthesize the main barriers discussed in the academic discourse concerning the European transition to autonomous driving. As Snyder outlines, narrative reviews are particularly suitable when research questions are broad, topics are studied across multiple fields (e.g., transportation engineering, economics, law, psychology), and when conceptual definitions vary widely (Snyder, 2019). These are all conditions that clearly apply to the AV domain. This approach was chosen considering the goal to integrate diverse lines of research and reveal thematic patterns, rather than to assess effect sizes or conduct meta-analysis.

The literature review began with exploratory keyword-based searches conducted in Scopus and Google Scholar, using terms such as "autonomous vehicles", "self-driving cars", "automated driving" combined with "Europe", "European Union", and "barriers", "adoption", "deployment", "regulation", "public acceptance", "infrastructure", and similar variants. This initial phase provided a core set of relevant publications, primarily journal articles published in high-ranking journals across transportation studies, innovation policy, law, and mobility systems.

To ensure relevance and academic rigor, only peer-reviewed journal articles listed in the 2022 Australian Business Deans Council (ABDC) Journal Quality List (Rahaman, 2023) were included. This provided an objective and widely recognized benchmark for journal quality. Preference was given to papers published from 2010 onward, as this period corresponds to the acceleration of AV research and pilot deployment in Europe. Additionally, papers were included only if they directly addressed barriers or challenges to the development, regulation, or

Table 1
Comparative summary of nine key academic studies examining barriers to autonomous vehicle adoption.

Study (Year); Authors	Methodological Approach	Geographic Focus	Key AV Adoption Barriers Identified	Notable Limitations/Gaps
Autonomous vehicles: What are your intentions? (2023); Darren Wishart, Shelly Weaver, Anna Apuli	**Survey (Theory of Planned Behavior)** Online questionnaire of 254 Australian drivers assessing attitudes, norms, control, perceived barriers, and adoption intent.	Australia (general population drivers)	**Safety/Technical:** Fear of operating errors; equipment or system failure. **Economic:** Cost concerns (interestingly, cost worry was positively associated with intention). **Regulatory:** Need for legislative and infrastructure readiness noted. **Social:** Public trust and acceptance debates (safety concerns more influential than cost).	Convenience sample (not fully representative); focused on term "autonomous" without specifying level or timeframe (potentially causing varied interpretations). Did not measure participants' detailed knowledge of AV technology.
Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations (2015); Daniel J. Fagnant & Kara Kockelman	**Conceptual Policy Analysis** Literature synthesis and back-of-envelope cost–benefit estimates; identifies hurdles and recommends policies for AV deployment.	United States (national policy level)	**Economic:** High initial vehicle costs. **Regulatory:** Patchwork state-by-state licensing, lack of federal standards. **Legal:** Undefined liability in crashes. **Privacy & Security:** Data privacy concerns; cybersecurity risks. **Technical/Societal:** Uncertain interactions with transportation system; public perception challenges.	Broad overview based on early projections; does not empirically test public opinion. Primarily U.S.-focused and centered on policy/ regulatory issues (technical feasibility treated only qualitatively). Assumes technology will mature; "Missing research" noted on unknown impacts.
A multicriteria decision making approach to study barriers to the adoption of autonomous vehicles (2020); Alok Raj, J. Ajith Kumara, Prateek Bansalb	**Expert-Based Multi-Criteria Analysis** Identified 10 barriers via literature and expert input; applied Grey-DEMATEL to map causal relationships; created causal loop diagram.	United States (context for analysis)	**Social:** Lack of customer acceptance (found to be the most critical barrier). **Regulatory/Institutional:** Lack of industry standards; absence of regulations and certification frameworks. **Technical:** Safety and reliability concerns. **Economic:** Initial cost and equity (social inequality in access). **Other:** Privacy/security risks; liability uncertainty; infrastructure inadequacy; potential job losses. Barriers are interdependent (feedback loops rather than isolated issues).	Relied on opinions of 18 experts (limited sample), all within U.S. context. Results may not generalize globally. Did not capture "community acceptance" explicitly (only individual acceptance). Focuses on macro-level expert views rather than mass consumer data.
Future cities and autonomous vehicles: Analysis of the barriers to full adoption (2021); Nacer Eddine Bezai, Benachir Medjdoub, Amin Al-Habaibeh, Moulay Larbi Chalal, Fodil Fadli	**Critical Literature Review** Mixed-method integrative review of recent research, yielding a conceptual framework categorizing barriers into two overarching groups (user/government perspective vs. ICT/technical systems).	Global (Urban "smart city" focus; authors UK/ Qatar)	**User/Government Perspectives:** (i) User acceptance and behavior – public skepticism, user readiness; (ii) Safety – trust in AV safety performance; (iii) Legislation – lagging laws and regulations. **ICT/Technical Systems:** (i) Computing hardware/software limitations; (ii) Connectivity (V2X communication infrastructure); (iii) Accurate mapping and positioning challenges. Also noted secondary factors such as cost barriers, cybersecurity/privacy issues, and need for physical infrastructure upgrades.	Not an empirical study; synthesizes literature with possible selection bias toward recent debates. Does not quantify barrier importance. Primarily addresses urban implementation, so findings may not directly generalize to rural contexts. Some factors (e.g. cost, privacy) appear in discussion but were not core categories in the initial framework.
Assessing the barriers and implications of autonomous vehicles: Implementation in sustainable cities (2025); Irfan Ullah, Jianfeng Zheng, Alessandro Severino, Arshad Jamal	**Bibliometric Analysis & Review** Used bibliometric mapping (Scopus, VOSviewer) to identify research trends, then qualitatively discussed key challenges and implications for AVs in sustainable urban transport.	Global (sustainable cities focus; authors in Asia/ Europe)	**Technical:** Ensuring AV safety and reliability under real-world conditions. **Infrastructure:** Need for extensive smart infrastructure investments (e.g. sensors, charging, connectivity). **Social:** Public acceptance and trust deficits; potential travel behavior changes (e.g. induced demand). **Regulatory:** Governance and policy lag (regulation not keeping pace). **Economic/Societal:** Employment shifts (job losses for drivers), ethical concerns (decision-making in dilemmas). Emphasizes multi-faceted impacts on city sustainability (traffic flow, emissions, accessibility).	Relies on published literature and bibliometric data, no primary stakeholder input. Bibliometric scope limited to Scopus-indexed sources (potential regional/language bias). Primarily an overview of broad challenges; lacks granular case studies. Acknowledges need for more diverse data and on-ground evidence to validate conclusions.
Barriers to the Adoption of Autonomous Vehicles in Rural Communities (2020); Diandra Prioleau, Priya Dames, Kiana Alikhademi, Juan E. Gilbert	**Conceptual Analysis (Position Paper)** Discusses how current rural transport struggles (finance, infrastructure, policy, demographics) might impede AV	United States (Rural areas)	**Financial:** Low income and high cost – affordability of AVs and AV-based services (ride-share) for rural residents. **Infrastructure:** Sparse, poor-quality transportation infrastructure and	Not based on new empirical data (no rural user surveys or trials). U.S.-centric and focused on broad issue areas rather than specific case evidence. Highlights problems but does not provide quantitative weight

(*continued on next page*)

Table 1 (*continued*)

Study (Year); Authors	Methodological Approach	Geographic Focus	Key AV Adoption Barriers Identified	Notable Limitations/Gaps
	adoption; presented at IEEE symposium (short paper).		limited broadband/connectivity in rural areas. **Policy/Governance:** Limited focus on rural needs in AV policies; funding limitations for rural transit. **Demographic/Social:** Older and disabled populations need accessible AV designs; skepticism or low tech-literacy delaying acceptance. **Equity/Ethical:** Risk of bias in AV technologies (e.g. facial recognition) against rural minority groups.	or timeline for barriers. Calls for including rural stakeholders in design and policymaking, but implementation of this remains untested.
Drivers and Barriers to Implementation of Connected, Automated, Shared, and Electric (CASE) Vehicles: An Agenda for Future Research (2021); Amirsaman Mahdavian, Alireza Shojaei, Scott McCormick, Timothy Papandreou, Naveen Eluru, Amr A. Oloufa	**Systematic Critical Literature Review** Reviewed 130+ sources (academic studies, government and industry reports) covering all CASE dimensions; identified implementation drivers and barriers; outlined future research needs.	Primarily United States (with global trends noted)	**Technological:** Need for mature vehicle AI and sensor reliability; unresolved performance issues (e.g. AVs in bad weather). **User Attitudes:** Cognitive biases favoring the status quo; low trust due to safety fears (high-profile AV crashes) and lack of firsthand experience. **Economic:** High cost of AV technology and uncertainty in cost–benefit for consumers. **Legal/ Policy:** Privacy and data security concerns; unclear liability in crashes; inconsistent regulations and lack of uniform testing standards across jurisdictions. **Coordination:** Collaboration gaps among stakeholders (tech firms, government, public) - need for unified policies and infrastructure investment.	Focuses on broad "CASE" concept, so some findings are generalized across connected, shared, electric aspects in addition to automation. U.S.-heavy regulatory context (e.g. state policy differences) may limit applicability elsewhere. No primary data collection; instead aggregates known issues. Suggests many open research questions (agenda), indicating that empirical evidence on several barriers is still lacking.
Barriers to the sustainable adoption of autonomous vehicles in developing countries: A multi-criteria decision-making approach (2023); Alireza Shahedi, Iman Dadashpour, Mahdi Rezaei	**Hybrid Expert Elicitation & MCDM** Comprehensive lit review to identify barriers, then employed Rough Best–Worst Method and IR-MABAC to weight and rank 23 barriers, with input from industry and transport experts (eight experts).	Developing Countries (illustrative case: Iran)	**Economic:** Macroeconomic instability (e.g. *high inflation* rates) and low purchasing power hindering AV affordability. **Infrastructure:** Poor ICT infrastructure - e.g. *lack of quality internet connectivity* and smart road equipment. **Social:** *Learning and usability challenges* for users (education/ training needed to use AVs); cultural and psychological resistance to new tech. **Regulatory/Governance:** Weak regulatory frameworks, lack of local standards and policies; institutional readiness issues. **Technical:** Technology not adapted to local conditions (road quality, traffic mix); safety and security concerns (similar to global issues). **Environmental:** (Implicitly considered under sustainability, though top-ranked barriers were economic/technical in nature).	Only 8 experts, all from one country (Iran), were consulted - a small and geographically limited sample. This may bias the barrier prioritization toward that context. Assumes developing countries face similar barrier patterns. Results emphasize certain factors (inflation, internet) that might evolve; a broader international sample could change rankings. Despite using rigorous MCDM, the approach is only as good as the expert input and may not reflect end-user perspectives directly.
A systematic literature review of the factors influencing the adoption of autonomous driving (2020); Mohamed Alawadhi, Jumah Almazrouie, Mohammed Kamil, Khalil Abdelrazek Khalil	**Systematic Literature Review** Reviewed 85 papers to distill critical factors for successful AV adoption. Categorized 14 key factors into four "readiness" categories required for mass adoption.	Global (studies from multiple countries; authors UAE)	**Technology Readiness:** Vehicle technology maturity; proven safety; ethical programming of AV decision-making. **Infrastructure Readiness:** Robust V2X communication networks; road infrastructure tech (smart signals, signage); and considerable investment (cost of infrastructure). **Legal Readiness:** Clear liability frameworks; data privacy protections; cybersecurity measures in place. **User Acceptance:** Consumer willingness to adopt – influenced by awareness/education (marketing and	Literature up to 2019 covered - rapidly evolving developments post-2020 are not included. The 14 factors were qualitatively derived; no new empirical validation was performed. Some factor definitions overlap (e.g. "safety" spans tech and social domains), requiring ongoing refinement. The study emphasizes broad categories; context-specific nuances (e.g. differences between regions or urban vs rural) are not deeply explored.

(*continued on next page*)

Table 1 (*continued*)

Study (Year); Authors	Methodological Approach	Geographic Focus	Key AV Adoption Barriers Identified	Notable Limitations/Gaps
			public outreach), trust in the technology, and affordability (cost of AVs). All four areas must advance in parallel for successful adoption.	

societal adoption of AVs in a European context or included comparative insights involving Europe. Studies focused exclusively on technical components without reference to broader deployment challenges were excluded. Candidate studies were evaluated by screening titles and abstracts (and full texts when needed) against these criteria to ensure a direct thematic focus on AV adoption barriers. Ultimately, 38 journal articles meeting the above inclusion criteria were reviewed.

As the literature was reviewed, six major themes emerged inductively based on recurrent topics and points of concern across multiple sources. These themes represent consistent clusters of barriers frequently discussed in the academic world, and they include: (1) Regulatory and legislative challenges, (2) Technological and safety challenges, (3) Infrastructure and connectivity requirements, (4) Ethical and legal issues, (5) Economic and market challenges, (6) Societal acceptance and cultural barriers.

Each of these six themes corresponds to a distinct dimension of AV adoption barriers. For example, regulatory and legislative challenges refer to policy and legal hurdles (such as lagging regulations or unclear liability laws); technological and safety challenges involve technical limitations, reliability issues, and safety risks of AV systems; infrastructure and connectivity requirements concern the need for supportive physical and digital infrastructure (e.g. road sensors, V2X communication networks); ethical and legal issues encompass moral dilemmas (like decision-making algorithms in crash scenarios) and questions of liability and data privacy; economic and market challenges pertain to cost barriers, investment and business model uncertainties, and market readiness; and societal acceptance and cultural barriers include public trust, user readiness, and cultural attitudes toward autonomous driving. While these categories are analytically distinct (each addressing a unique barrier domain), they are interrelated in practice. For instance, technological improvements can alleviate safety concerns and thereby bolster public acceptance, just as robust regulatory frameworks can enhance consumer trust and stimulate market investment. Thus, the six themes provide conceptual clarity for analysis, even as we acknowledge their real-world interdependence.

These six categories were not pre-established but emerged organically during the review process through iterative reading, note-taking, and comparison across studies. This aligns with recommendations by Braun, Clarke and Snyder on using thematic analysis in literature synthesis (Braun and Clarke, 2006; Snyder, 2019).

Throughout this inductive coding process, we continually revisited and refined the emerging themes to ensure each represented a conceptually distinct barrier and that the issues grouped within each category remained closely related, reinforcing internal consistency.

The review findings were subsequently structured according to these categories, providing a coherent synthesis that integrates diverse insights from various academic traditions.

Because the source literature spanned engineering, social science, and policy domains, the themes were defined at a sufficiently broad level to capture common issues across disciplines. By aligning on widely cited barrier concepts (e.g., safety, regulation, public acceptance), we maintained consistency in interpretation, ensuring that findings from different fields could be mapped appropriately onto the same thematic categories.

This thematic structure also formed the analytical lens for interpreting and comparing the expert interview data presented in later sections of the paper.

To enhance transparency and traceability, Table 2 provides a structured overview of the six barrier categories identified through the literature review, along with representative supporting references for each category. This synthesis makes explicit how each thematic cluster is grounded in prior academic work and allows readers to verify the evidence base from which the barriers were derived.

By adopting a narrative literature review approach, this study was able to comprehensively map the state of academic knowledge on the barriers to AV adoption in Europe. This method allowed for flexibility in navigating interdisciplinary literatures while maintaining transparency and academic rigor in article selection and thematic synthesis (Tranfield et al., 2003). The findings from this literature review serve as a benchmark for evaluating and contextualizing the insights gathered through the expert interviews.

2.2. Expert interviews

To complement the literature findings with real-world perspectives, we conducted a series of interviews with experts involved in the development, regulation, or deployment of autonomous vehicles in Europe. The goal of the interviews was to gather qualitative insights into how the challenges identified in literature are perceived on the ground, and to uncover any additional issues that practitioners consider important. We used a semi-structured interview format, which allowed us to cover specific topics of interest while also giving interviewees the freedom to introduce and elaborate on issues they found most pertinent (Fig. 1, inspired from (Ziegler and Abdelkafi, 2023)).

A purposive sampling strategy (Ahmad and Wilkins, 2024) was employed to identify key informants capable of providing strategic and operational insights into the European AV ecosystem. Experts were selected according to three main criteria: (1) demonstrable professional experience in autonomous driving, connected mobility, or related regulatory and innovation domains; (2) active involvement in the European market; and (3) willingness to participate in an in-depth, one-hour interview. The study focused on Europe because of its leading role in sustainable mobility innovation and its complex regulatory and industrial landscape, which make it an ideal context for exploring AV adoption barriers.

Participants were recruited through a combination of professional networks, academic collaborations, and LinkedIn searches. Approximately 120 potential participants were initially identified and contacted via a standardized invitation email outlining the research objectives and confidentiality conditions. Thirty individuals expressed preliminary interest, and 21 confirmed and completed the interview process. The final sample size was determined by thematic saturation, which was reached after approximately 19 interviews, with the last sessions providing confirmatory rather than novel insights - consistent with the 12-to-30 participant range suggested in qualitative research guidelines (Galvin, 2015; Guest et al., 2006).

The final sample included experts from five European countries: Italy (15), Belgium (2), the United Kingdom (2), Spain (1), and Germany (1), covering a balanced mix of industry, consultancy, and research backgrounds. Participants represented small ($<$ 50 employees), medium-size ($<$ 250), and large enterprises ($\geq$ 250), and operated in a range of business areas such as Research and Development (R&D), technology management, general management, and sales or innovation functions. This diversity ensured that both corporate and entrepreneurial

Table 2
Six key autonomous vehicles' adoption barriers identified from the literature review, with representative supporting sources and their classification according to the ABDC Journal Quality List.

Barrier Category	Reference	Journal	ABCD Rating
Regulatory and legislative challenges	Fagnant and Kockelman, 2015	Transportation Research Part A: Policy and Practice	A*
	Brodsky, 2016	Berkeley Technology Law Journal	A
	Taeihagh and Lim, 2019	Transport Reviews	A
	Lee and Hess, 2020	Transportation Research Part A: Policy and Practice	A*
	Mordue et al., 2020	Transportation Research Part A: Policy and Practice	A*
Technological and safety challenges	Petit and Shladover, 2015	IEEE Transactions on Intelligent Transportation Systems	A
	Kalra and Paddock, 2016	Transportation Research Part A: Policy and Practice	A*
	Sheehan et al., 2019	Transportation Research Part A: Policy and Practice	A*
	Guo et al., 2020	IEEE Transactions on Intelligent Transportation Systems	A
	Liu et al., 2020	Transportation Research Part F: Traffic Psychology and Behaviour	A
	Wang et al., 2020	Journal of Advanced Transportation	A
	Eskandarian et al., 2021	IEEE Transactions on Intelligent Transportation Systems	A
	Jin et al., 2022	Journal of Safety Research	A
Infrastructure and connectivity requirements	Abboud et al. 2016	IEEE Transactions on Vehicular Technology	A
	Gandia et al., 2019	Transport Reviews	A
	Babić et al., 2020	Journal of Advanced Transportation	A
	Tengilimoglu et al. 2023a	Transport Policy	A
	Feess and Muehlheusser, 2024	Transportation Research Part B: Methodological	A*
	Tengilimoglu et al., 2024	Journal of Transport Geography	A
Ethical and legal issues	Li et al., 2019	Transportation Research Part A: Policy and Practice	A*
	Santoni De Sio, 2021	Ethics and Information Technology	C
Economic and market challenges	Nazari et al., 2018	Transportation Research Part C: Emerging Technologies	A*
	Fritschy and Spinler, 2019	Technological Forecasting and Social Change	A
	Kaplan et al., 2019	Applied Economic Perspectives and Policy	B
	Amis and Janz, 2020	The Journal of Applied Behavioral Science	B
	Nunes and Hernandez, 2020	Transportation Research Part A: Policy and Practice	A*
	S. Wang et al. 2020	Transportation Research Part F: Traffic Psychology and Behaviour	A
	Mahmoodi Nesheli et al., 2021	Case Studies on Transport Policy	C
	Nordström and Engholm, 2021	Transportation Planning and Technology	B
	Alvarez León and Aoyama, 2022	Technological Forecasting and Social Change	A
	Krammer, 2022	Technovation	A
	Wu et al., 2025	Communications of the ACM	A
Societal acceptance and cultural barriers	Hohenberger et al., 2017	Technological Forecasting and Social Change	A
	Adnan et al., 2018	Transportation Research Part A: Policy and Practice	A*
	Buckley et al., 2018	Transportation Research Part F: Traffic Psychology and Behaviour	A
	Kaur and Rampersad, 2018	Journal of Engineering and Technology Management	B
	Xu et al., 2018	Transportation Research Part C: Emerging Technologies	A*
	Shariff et al., 2021	Transportation Research Part C: Emerging Technologies	A*

perspectives were captured. Table 3 summarises the participants' segment, company size, business area, and position.

We identified candidates through our professional network and recommendations, aiming for a balance between different industries and between different European countries or regions. Invitations were sent via email outlining the research purpose, and the interviews were scheduled with those who agreed to participate. To encourage frank discussion, we ensured interviewees that their responses would be anonymized; in our reporting, we refer to them by generic descriptors or codes (e.g., "Interviewee 5, an automotive R&D director").

All interviews were conducted via Microsoft Teams between May and November 2024. Each session lasted approximately 60 min (range: 45–60 min). Interviews were carried out in Italian for 15 participants and in English for 6. Table 4 provides detailed information on the date, duration, and language of each interview.

All expert interviews were conducted in person by the first author, which ensured consistency and rapport throughout the data collection (Lachonius et al., 2023). We followed a semi-structured guide with open-ended questions. This flexibility allowed us to probe deeper into topics that each expert was most familiar with, while still covering the common ground of challenges across all interviews.

The interview protocol was structured around a semi-structured guide developed from recent literature reviews on the theme. This approach is commonly used in qualitative research to ensure that the questions are grounded in academic discourse while allowing flexibility to explore practitioner perspectives (Donovan et al., 2024).

The interview protocol was structured around six major thematic blocks, each encompassing open-ended questions aimed at eliciting deep and diverse insights:

1. Introduction and warm-up
   Background, organizational role, market scope (i.e., Can you briefly introduce yourself and your role within your society? How long you have been working in your company? What is the size of your company?).
2. Automotive in general
   Perceptions of the mobility market's transformation and the technological advancement at the moment (i.e., How would you describe the technological advancement at the moment in the mobility market? What are the important transformations in the mobility market right now?).
3. Perspectives on AVs
   Perception of the AVs, expected changes in the value chain, the role of OEMs and suppliers, monetization strategies, and the emergence of service platforms (i.e., How would you define the AVs? Do you perceive AVs as standalone entities or as integral components of a broader mobility ecosystem? Why? How will AVs change the

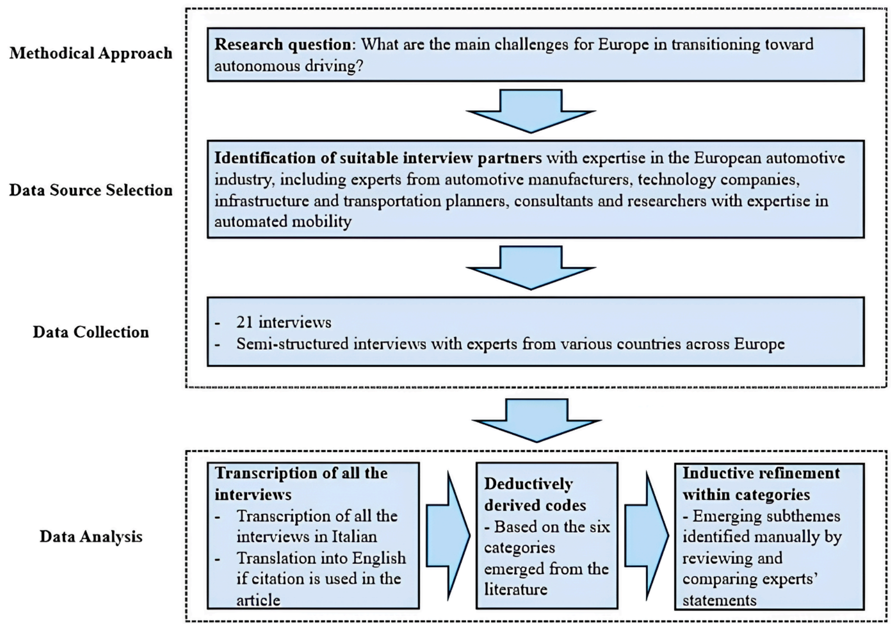

Fig. 1. Overview of research methodology | Experts interviews.

automotive value chain? How do you think that your role as a company will change in the automotive value chain? What will be the role of mobility service providers evolving with the advent of AVs? Do you envision some changes in the roles of the suppliers? Of the manufacturers? To what extent will the products and services change? How to monetize these products and services?).

4. Policy and regulatory considerations

   The evolving role of regulators, liability frameworks, and enabling environments for AV deployment (i.e., What will be the role of policymakers to enable this transformation? How might regulatory frameworks need to adapt to accommodate the deployment of AVs, particularly in terms of safety and liability?).

5. Environment/society/safety

   Contributions to environmental goals, public acceptance, safety perceptions.

6. Industry vision and innovation

   Pathways to market diffusion, required innovations, and potential business model configurations (i.e., What kind of innovation or business model can accelerate the diffusion of AVs? How do you envision the future of mobility evolving with AVs, especially in urban environments?).

7. Reflections on business model dynamics

   Additional reflections regarding the business model dynamics (i.e., What kind of niches should be involved at the beginning for the technology to be used and to benefit from the learning curve? How do you think consumer can be educated for using this technology?).

A full version of the interview guide is included in Appendix A: Complete version of the interview questionnaire. Prior to data collection, the interview protocol was reviewed by an external academic expert with extensive experience in mobility innovation research. Based on this feedback, several questions were reworded, re-sequenced, or removed to enhance relevance, avoid redundancy, and ensure alignment with the study's objectives.

We followed Braun and Clarke's six-step process for thematic analysis (Braun and Clarke, 2006). After transcription, the first author read through all interviews to become familiar with the content, manually created codes using Excel and notes, and then clustered these into themes. This hybrid process combined deductive coding based on our literature framework with openness to inductive insights emerging from the data (McInnes et al., 2023). A second researcher reviewed approximately 20 % of transcripts and the preliminary codebook to verify consistency. Discrepancies were discussed and resolved by consensus, enhancing the reliability and validity of our findings. No qualitative analysis software (e.g. NVivo, ATLAS.ti) was used. Instead, we used manual coding to maintain deep engagement with the data, consistent with recent high-impact studies using expert interviews (Chandrasekar et al., 2024; Manns et al., 2025; Peace et al., 2023). We tracked code definitions and theme evolution through spreadsheets and analytic memos, ensuring a transparent audit trail.

To support methodological rigor, we followed Lincoln and Guba's qualitative trustworthiness criteria: (1) credibility was ensured through triangulation between researchers and use of direct quotations; (2) dependability through detailed documentation of analysis steps; (3) confirmability through maintenance of an audit trail; and (4) transferability through detailed participant context and thick description (Lincoln and Guba, 1985).

Thematic saturation was reached after approximately 19 interviews, when new interviews yielded no substantial novel themes. Overall, our use of expert interviews combined with reflexive thematic analysis is consistent with accepted academic practice and provides a rich foundation for the empirical sections that follow.

The results of this methodology are reflected in the following sections, where we present the challenges identified, supported by both literature references and illustrative input from our expert interviewees. By using this dual-method approach, consisting in literature review and expert interviews, our study enhances validity through triangulation of sources and richness of insight. The literature provides breadth and established knowledge, while the expert interviews provide depth, real-world context, and up-to-date perspectives on how these challenges are evolving. This combined methodology is well-suited to address our research objective of understanding AV deployment barriers in Europe comprehensively, and it lays the groundwork for the subsequent discussion and conclusions drawn in the paper.

3. Key findings

Prior research on autonomous driving reveals a broad spectrum of challenges that must be overcome before self-driving vehicles can be fully realized on European roads. This section synthesizes the insights

Table 3
Profile of interview participants.

ID	Segment	Company size	Business area	Position
1	Service	SM	General Management	CEO
2	Service	LA	General Management	ADAS analyst/consultant
3	Product/service	LA	Research and Development	Head of the R&D group
4	Product/service	LA	Sales Management	Operations director
5	Product/service	LA	Technology department	Mobility researcher
6	Product	LA	Research and Development	Global head of innovation
7	Product/service	SM	General Management	Technical director
8	Product	LA	General Management	Head of the electronics engineering department
9	Service	SM	General Management	Automotive consultant
10	Product/service	LA	Research and Development	System engineer - Connected mobility team
11	Product	LA	Sales Management	Head of innovation
12	Product/service	LA	Innovation management	CEO
13	Service	LA	General Management	Managing director
14	Product	ME	Innovation management	Product developer - Connectivity team
15	Service	LA	Technology department	Sales director
16	Service	ME	Technology department	Go-To-Market manager
17	Service	SM	Technology department	CEO
18	Service	SM	General Management	CEO
19	Service	LA	General Management	Product/commercial developer - Insurtech captive
20	Service	SM	General Management	Mobility expert
21	Product	LA	General Management	ADAS consultant

Notes: SM… small enterprises < 50 employees, ME… medium-size enterprises < 250 employees, LA… large enterprises ≥ 250 employees.

Table 4
Summary of interviews conducted.

ID	Date of the interview	Duration of the interview	Language
1	01/11/2024	60 min	Italian
2	11/06/2024	60 min	Italian
3	09/05/2024	45 min	Italian
4	27/05/2024	60 min	Italian
5	25/06/2024	60 min	Italian
6	04/06/2024	60 min	English
7	21/05/2024	60 min	Italian
8	31/05/2024	60 min	English
9	16/05/2024	60 min	Italian
10	14/06/2024	60 min	English
11	02/10/2024	60 min	English
12	27/06/2024	50 min	Italian
13	14/06/2024	60 min	Italian
14	21/06/2024	60 min	Italian
15	20/05/2024	60 min	Italian
16	04/06/2024	60 min	Italian
17	27/08/2024	60 min	Italian
18	06/06/2024	45 min	Italian
19	21/06/2024	60 min	Italian
20	25/10/2024	60 min	English
21	02/07/2024	60 min	English

from both academic literature and expert interviews, organized into six recurring themes that reflect the most critical and frequently discussed challenges. By integrating scholarly findings with industry perspectives, the analysis provides an extensive understanding of the multi-layered obstacles that must be addressed to enable the transition toward autonomous mobility.

3.1. Regulatory and legislative challenges

One prominent barrier identified in the literature is the lack of a harmonized regulatory framework for autonomous vehicles across Europe. Researchers note that European Union member states have adopted varying laws and guidelines for AV testing and operation, resulting in fragmentation (Lee and Hess, 2020; Taeihagh and Lim, 2019). Some countries permit certain levels of vehicle automation on public roads, while others have more restrictive rules or no specific AV legislation at all (Taeihagh and Lim, 2019). This inconsistency creates uncertainty for developers and manufacturers because an automated driving feature that is legally approved in one country might be prohibited just across the border, complicating efforts to develop vehicles for an integrated European market (Lee and Hess, 2020). Multiple studies call for pan-European standardization of AV regulations, including unified safety certification procedures, licensing requirements for automated systems, and clarification of traffic laws as they apply to driverless cars (Fagnant and Kockelman, 2015). Without greater regulatory alignment, firms face higher compliance costs and delays, which ultimately slow down AV deployment on the continent (Brodsky, 2016).

And to increase the challenge, there is Europe's generally cautious regulatory stance toward emerging mobility technology (Mordue et al., 2020; Taeihagh and Lim, 2019). Safety is a major concern in European transport policy, which has led to deliberate, step-by-step progress in approving autonomous driving functionalities. While this careful approach prioritises risk mitigation, it may inadvertently hold back innovation compared to regions that offer more permissive sandboxes for AV experimentation. For instance, real-world pilots in Europe often operate under strict limitations in geo-fenced areas, with low speeds, mandated safety drivers, etc., while broader commercial use cases like robotaxis remain largely prohibited as of the mid-2020s. Some authors have pointed out that regulatory uncertainty, being unaware about when and how laws might evolve, tends to discourage investment, as companies cannot plan for large-scale deployment if the legal status of high-level automation remains confused (Brodsky, 2016; Mordue et al., 2020). The literature suggests that establishing a clear timeline and roadmap for AV legislation would help signalling to stakeholders that the pathway to deployment will be supported by consistent rules.

Another regulatory aspect frequently discussed is data privacy and security law. The European Union's stringent data protection regulations, notably the General Data Protection Regulation (GDPR), affect autonomous driving technologies because AVs rely on extensive data collection through sensor recordings, map data, telemetry, etc. and on data sharing through vehicle-to-cloud or vehicle-to-vehicle communications. Scholars highlight that while privacy regulations are crucial for user trust, they can limit certain data-driven innovations or create compliance burdens (Experts say privately held data available in the European Union should be used better and more | Shaping Europe's digital future, n.d.; Lee and Hess, 2020). Future laws like the proposed EU Data Act may further define how vehicle data is governed (Taeihagh and Lim, 2019). Researchers thus emphasize the need for regulatory frameworks that balance safety and innovation with privacy, allowing vital data (such as anonymized driving recordings) to be utilized for improving AV systems while upholding Europe's strong values on data protection (Fagnant and Kockelman, 2015; Lee and Hess, 2020). In brief, the current regulatory environment characterized by fragmentation, cautious policy evolution, and strict data laws is seen as one of the most significant barriers in the literature, necessitating proactive governance reforms to facilitate autonomous vehicles' adoption.

Our expert interviewees confirmed these academic concerns, highlighting regulation as one of the biggest roadblocks. Interviewee 13 remarked, *"local legislations, plural and fragmented across states, are the main barrier"*, emphasizing that each country's different rules complicate the efforts to introduce AVs across Europe. Another aspect the interviews particularly underline is the practical impact of regulatory fragmentation: an expert described a scenario of autonomous shuttles ready to operate in an Italian city but remaining idle awaiting a national ministry's special authorization (Interviewee 15), illustrating how bureaucratic inertia can stall deployments beyond what academic literature typically documents. Indeed, Interviewee 15 also observed that *"public authorities often lack the technical expertise to evaluate and approve AV pilots, resulting in delays"*, a point rarely addressed in academic papers, which tend to assume regulators will eventually adapt. On the positive side, both literature and interviews acknowledge recent progress. Several interviewees were aware of evolving European policies (for instance, the EU's 2019 regulation requiring advanced driver-assistance and data recorders in new cars) aimed at guiding higher automation. Yet, there is a cautious consensus that policy is not moving fast enough. A subtle difference in tone is that some industry experts exhibit impatience, whereas academic analyses usually take a longer historical view. For example, interviewee 2 argued that *"policymakers should be involved from the development phase onward to craft laws in parallel with technology"*, reflecting a desire for more agile governance.

3.2. Technological and safety challenges

Even with rapid advancements in sensors, artificial intelligence, and computing power, technological limitations remain a core challenge for autonomous vehicles (Eskandarian et al., 2021). A consistent theme in technical research is that AV systems have yet to demonstrate robust reliability across the full range of real-world driving conditions (Guo et al., 2020; Kalra and Paddock, 2016). Unlike human drivers, who possess general intelligence and adaptability, current AVs operate through predefined algorithms and learned patterns that can be brittle when encountering rare or unexpected situations (Eskandarian et al., 2021; Guo et al., 2020). Numerous studies underscore the difficulty of validating AV safety to a level that satisfies both regulators and the public (Kalra and Paddock, 2016), and statistical analyses have shown that to prove with high confidence that an AV is safer than a human, it would require hundreds of millions of test miles, an unfeasible target if relying solely on physical road testing (J. Wang et al., 2020). Therefore, researchers advocate for advanced validation techniques such as virtual simulation environments, scenario-based testing, and formal verification methods to complement on-road tests. These approaches can expose AV algorithms to thousands of hypothetical dangerous scenarios in a safe, controlled manner. Nevertheless, the literature acknowledges that no amount of pre-deployment testing can guarantee performance in every conceivable circumstance, which means some level of residual risk will always remain when AVs eventually mix with open traffic (Jin et al., 2022). This uncertainty feeds into regulatory caution and must be addressed by transparent safety assurances and continuous learning even after deployment.

Another critical technical challenge area is cybersecurity. As vehicles become highly connected, communicating with infrastructure, other vehicles, cloud services, and receiving over-the-air software updates, expose them to attacks from malicious actors (Petit and Shladover, 2015; Sheehan et al., 2019). Scholars have catalogued a range of potential cyberattacks on AVs, from sensor spoofing tricking cameras or LiDAR with false images, GPS signal jamming, and denial-of-service attacks on communication channels, to malware that could take control of the vehicle's driving software (Petit and Shladover, 2015; Sheehan et al., 2019). The literature highlights the difficulty of defending against such attacks because automotive systems traditionally lack real-time monitoring and patching infrastructure common in IT systems, and there is limited historical data on vehicle cyber incidents to inform risk model (Liu et al., 2020; Sheehan et al., 2019). Ensuring cybersecurity is not just a technical necessity but also a precondition for public trust. Highly publicized hacks or vulnerabilities could severely setback consumer willingness to ride in an autonomous car (Liu et al., 2020), so achieving a high level of software and network security in AVs is considered equally important as achieving functional safety of the driving system. This challenge is especially pronounced in Europe, where the UNECE WP.29 regulations (R155/R156) make robust cybersecurity compliance a legal prerequisite for AV type approval and market entry. In contrast to the U.S., where cybersecurity guidelines are mostly voluntary, these European requirements impose mandatory technical standards and certification processes, raising the compliance bar for manufacturers (Lukic, 2022). From a broader safety and testing perspective, Europe also presents unique regulatory hurdles that distinguish it from other Western markets. The European regulatory framework is more fragmented and cautious compared to that of the U.S., which allows certain states like California and Arizona to serve as permissive testing grounds. In fact, several German OEMs conduct AV tests in the U.S. precisely because European jurisdictions impose more stringent entry conditions (Beedham, 2025). In the EU, fully autonomous vehicle testing and commercialization often require multi-country approvals, and few countries currently allow extensive driverless on-road trials. Moreover, European standards mandate specific safety redundancies in vehicle systems (e.g., dual brake, steering, and sensor systems), making the technological compliance process more rigorous and costly than in other regions. These structural and legal complexities create a higher threshold for AV deployment in Europe.

Our interviews strongly corroborated the technological hurdles identified in the literature, emphasizing the imperative of proven safety before widespread deployment. Interviewee 2 cautioned that *"the tech is advancing, but it must be proven safe and secure. We need laws to ensure it's validated before wide deployment"*, highlighting that rigorous testing and regulatory oversight must accompany technical progress. Similarly, Interviewee 12 warned that the technology, although *"quite mature"*, still *"lack[s] tons of testing... we simply haven't seen these systems perform in all circumstances"*, reflecting the literature's point that limited real-world exposure leaves significant uncertainty. However, not all experts agreed on the magnitude of technical barriers. For instance, Interviewee 13 argued that *"I don't see technology as a preponderant barrier anymore because the vehicle systems work; but it is the legal and economic conditions that lag"*, suggesting that non-technical issues have become more limiting. In contrast, Interviewee 6 insisted, *"The barrier is the technology, absolutely. It just doesn't work well enough yet"*, pointing out that early autonomous prototypes still struggle with complex traffic situations and that every high-profile AV accident undermines public trust. These differing emphases indicate a divergence, some industry stakeholders are more optimistic on the technology, whereas others remain cautious, very much in line with academic scepticism. The literature does recognize that there's no unanimous outlook on timing, having some papers which note optimistic scenarios while others predict decades of iterative improvements, and the interviews reflect this spectrum. Despite these differences, there was consensus that robust proof of safety is indispensable. A theme that emerged in multiple interviews was the effort to bridge the validation gap with new methods - Interviewee 12 mentioned the use of generative AI to create countless virtual test scenarios - which reflects innovative approaches in the research community. Talking about cybersecurity, practitioners were in full agreement with scholars that new cyber risks pose a critical challenge. Interviewee 5 stressed that *"the biggest challenge, apart from regulation, will be cybersecurity. It should be ensured the total security of the system"*, underscoring that any vulnerability could erode public confidence overnight. No interviewee downplayed this issue, reinforcing how vital it is to secure AV systems against attacks in order to maintain the trust required for adoption.

3.3. Infrastructure and connectivity requirements

Autonomous vehicles do not operate in a vacuum, but they are part of a broader transport ecosystem that includes physical infrastructure and digital communication networks. A recurring finding in European studies on autonomous vehicles is that existing road infrastructure may not be fully adequate to support widespread autonomous driving (Fraedrich et al., 2019; Tengilimoglu et al., 2023a). Some scholars, for instance, highlight long-standing infrastructure bottlenecks, such as inconsistent road markings and signage, that pose persistent challenges for AV systems across Europe (Fraedrich et al., 2019). More recently, other researchers, drawing from 168 expert responses across 29 countries, confirm that infrastructure limitations remain a key operating constraint for AV deployment, especially in varied or substandard roadway environments (Tengilimoglu et al., 2023a). Unlike a human driver, who can sometimes adapt to poor road conditions or missing signs using intuition and context, AVs rely heavily on consistent infrastructure signals (Tengilimoglu et al., 2024, 2023a). Well-maintained lane markings, clear road signage, and standardized traffic control devices are critical for machine vision systems to interpret the environment (Babić et al., 2020; Tengilimoglu et al., 2024). In Europe, the quality and "AV-friendliness" of infrastructure vary by region (Gandia et al., 2019), and this unevenness means that an AV capable of self-driving in one city or highway might perform poorly in another setting with inferior infrastructure, limiting the geographical transferability of the technology. Moreover, road quality and digital infrastructure readiness vary widely across member states, meaning that consistent AV performance across countries is difficult to guarantee without harmonization.

Beyond physical road conditions, digital infrastructure and connectivity are pivotal for advanced stages of vehicle automation. In fact, cooperative systems, in which vehicles exchange information with each other and with road infrastructure, can greatly enhance an AV's awareness beyond the line-of-sight of its own sensors. Europe has launched a variety of initiatives to strengthen such infrastructure. For instance, the European Commission provides a consolidated overview of EU-funded 5 G deployment projects along major transport corridors, many of which were last updated as recently as January 2024 (European Commission, 2022). These include the 5GNETC project, completed in April 2025, which deployed 5 G connectivity infrastructure in countries like Finland, Sweden, and Latvia. Several countries have begun rolling out 5 G networks (Katsaros et al., 2023; Pereira, 2021) and dedicated short-range communication (Wippelhauser et al., 2023) along key transport corridors to enable low-latency vehicle connectivity.

However, the deployment is still in progress and not uniform. The literature emphasizes a coordination problem: the benefits of Vehicle-to-Everything (V2X) communication increase with the number of equipped vehicles and infrastructure nodes (Tengilimoglu et al., 2024), yet the incentive for any single actor, a car manufacturer or a road operator, to invest is lower until others are on board (Feess and Muehlheusser, 2024). This can lead to a slow start or patchy implementation of connectivity technology. Europe, in particular, faces a coordination challenge across multiple countries and stakeholders. Unlike the U.S., where single firms or federal agencies may drive deployment, Europe's fragmented governance requires harmonization of standards and funding mechanisms among many players, which can delay rollout without strong public-sector leadership. To address this, policy analyses suggest the need for public-sector leadership or partnerships to ensure widespread deployment of V2I systems, creating a baseline infrastructure that all vehicles can utilize (Tengilimoglu et al., 2024, 2023a).

Another challenge is ensuring interoperability and standards for infrastructure. Different brands of vehicles and infrastructure equipment need to "speak" the same language. Efforts are underway in Europe to standardize protocols for vehicle communication and digital mapping, often through collaborations between industry consortia and European regulators. Nonetheless, some studies point out that without clear common standards, there is a risk of fragmented systems (Tengilimoglu et al., 2023a). Moreover, infrastructure upgrades can be costly, and questions arise about who will finance the modernization of roads and cities for AV readiness. Will it be governments, taxpayers, or private investors? If these upgrades lag, even technically capable AVs may be geofenced to only operate in limited areas that have the necessary supporting infrastructure.

In essence, the literature makes it clear that infrastructure readiness is the foundation for autonomous driving (Tengilimoglu et al., 2023b). To fully unlock AV capabilities, European roads need to evolve into smarter, well-maintained, sensor-equipped, and connected roads. EU initiatives like C-Roads and 5 G Corridors represent important steps, but disparities in infrastructure quality and connectivity across member states remain a bottleneck. Until that happens, infrastructure remains a significant external barrier, and close cooperation between the automotive industry, telecommunications providers, and public infrastructure agencies will be required to build an environment in which AVs can thrive.

Industry experts agreed with the literature that infrastructure readiness is a fundamental obstacle for AV deployment, while adding important practical clarifications. Interviewee 9 observed that *"the hardest thing will be upgrading infrastructure so these vehicles can circulate, especially in mixed traffic environments like cities where today's roads are not designed for AVs interacting with human drivers"*, reinforcing the scholarly concern that current road environments limit AV performance. Another expert highlighted a coordination gap between vehicle manufacturers and infrastructure operators: Interviewee 11 lamented that there is still *"too little synergy between car makers and road operators"*, noting that many new vehicles still lack the V2X receivers to communicate with even the upgraded smart roads. In her words, *"some highly connected cars still lack V2X, so they can't talk to the infrastructure… since it's not a mandatory feature, adoption is slow!"*. This practical disconnect is not heavily emphasized in literature, which often assumes that once technology is available it will be utilized. The interviewee's observation reveals a coordination problem, both vehicle manufacturers and infrastructure providers could be waiting for the other to move first. Literature calls for rapid expansion of V2I capabilities, and here we see why. Even where infrastructure is upgraded, it yields little benefit if vehicles aren't equipped to reciprocate. Additionally, experts stressed that deploying advanced infrastructures is only part of the challenge; maintaining them is equally critical. Interviewee 16 emphasized that *"connected infrastructure needs an extremely high level of maintenance to assure AVs that road signals and data are accurate"*, a point seldom explicit in academic studies. Overall, these practitioner insights underscore that beyond building smarter roads, ensuring cross-sector collaboration and ongoing reliability of infrastructure are vital, highlighting institutional and operational barriers intertwined with the technical ones.

3.4. Ethical and legal issues

The introduction of autonomous vehicles raises ethical questions and legal uncertainties that have been widely debated in the academic literature. While early ethical discussions often focused on highly symbolic dilemmas such as the AV version of the trolley problem - i.e., if an accident is unavoidable, how should an autonomous car be programmed to react, especially when any course of action could harm human life (Santoni De Sio, 2021)? - this debate is increasingly viewed as of limited practical relevance, particularly in managerial and regulatory contexts.

Several studies conducted landmark research on this topic, finding a paradox in public opinion because people generally agree that an autonomous vehicle should be programmed to minimize total casualties in an emergency, so following a utilitarian approach, but at the same time, individuals indicate they would prefer to ride in a vehicle that prioritizes their own life and that of their loved ones (Lucifora et al., 2020; Takaguchi et al., 2022; Zhu et al., 2022). But recent literature and European policy discourse have moved beyond hypothetical dilemmas, focusing instead on the more urgent ethical and legal questions surrounding accountability, fairness, and societal impact. For example, discussions today centre on how to ensure algorithmic transparency, how to protect vulnerable road users, and how to balance innovation with public trust (Poszler et al., 2023).

In fact, current European discourse has shifted toward real-world legal frameworks. EU is proactively establishing regulations to govern AV behaviour, liability, and data. Notably, the newly updated EU Product Liability Directive extends strict liability to software and AI components in vehicles, meaning manufacturers can be held liable for accidents caused by algorithm or cybersecurity failures in autonomous driving systems (European Parliament, 2024). Complementing this, the European Data Act will standardize rules for vehicle data sharing and user data rights, ensuring compliance with Europe's privacy standards (European Parliament, 2023). Additionally, regulators are working on harmonizing AV policies across EU member states, moving toward a single European framework that replaces the current patchwork of national rules. These legal initiatives reflect Europe's emphasis on safe, transparent, and accountable deployment of AV technology.

Manufacturers and regulators are thus in a quandary over how to encode ethical principles. No matter what is decided, a segment of the public may find the choices objectionable. The literature suggests that transparent dialogue and societal consensus-building are needed on issues like these, potentially leading to formal ethics councils or regulations that define acceptable algorithmic behaviours for AVs (Poszler et al., 2023; Santoni De Sio, 2021). Moreover, public concern about fairness (e.g., ensuring AVs are safe for children, elderly, and cyclists) has emerged as a more actionable ethical concern than theoretical emergency scenarios, shifting the focus toward inclusive algorithm design (Gless and Ligeti, 2024).

Closely related to ethics is the question of legal liability in the event of an accident involving an autonomous vehicle. Under traditional traffic laws, the human driver is always held responsible for the control of the vehicle (Nyholm and Smids, 2020). But with increasing automation, the "driver" might effectively be the car's software or an entire chain of entities including the vehicle owner, the car manufacturer, and the software developer (Vellinga, 2023). Scholars note that current legal systems in Europe and elsewhere are ill-prepared for this shift (Gless and Ligeti, 2024). A key concern is the gap in determining fault: if a self-driving car causes a collision while its human occupant was not actively driving, should liability rest on the owner (for deploying the AV), the manufacturer (for any design flaws), or perhaps a third-party service provider (e.g. the developer of the AI algorithm or the map data)? As of 2025, European countries are still in the process of updating legislation to address these questions. The EU has been examining issues of product liability and insurance for AVs, for example considering whether existing product liability directives suffice or need revision to cover advanced AI-driven products (Hacker, 2023). Insurance companies, on their part, are experimenting with policies that account for partial automation, but standard practices have yet to solidify (Kester, 2022).

The literature widely recognizes that unclear liability and insurance arrangements constitute a significant barrier to adoption (Naiseh et al., 2025). Consumers may be reluctant to use or ride AVs if they are unsure who is accountable in case of a malfunction or crash, and manufacturers are wary of undefined legal exposure that could lead to massive lawsuits. Thus, scholars call for establishing clear liability regimes, perhaps through new laws that assign responsibility in proportion to control or through no-fault compensation systems funded by industry (Li et al., 2019; Santoni De Sio, 2021). In fact, solving these ethical and legal issues is not just a theoretical exercise but a practical prerequisite for deployment. People need confidence that AVs will behave ethically, and all parties need to know the legal implications of using the technology. Ongoing interdisciplinary research involving ethicists, legal scholars, engineers, and policymakers is attempting to shape frameworks that address these concerns in parallel with the technological development of AVs.

Our interviews confirmed that the ethical dilemmas and legal uncertainties highlighted in the literature are not abstract worries but real impediments. Interviewee 16 vividly explained that with autonomous driving we are effectively shifting from split-second human reactions to premeditated machine decisions, calling it *"an enormous ethical issue since you replace an unconscious human reaction with an algorithmic decision"*, a transformation with huge legal ramifications. This perspective connects ethical and legal challenges as two sides of the same coin, manifesting what literature claims about the fact that societal acceptance of AVs will depend on both moral and liability assurances. Interviewee 18 suggested that an autonomous vehicle must provide *"many more safety guarantees than a human-driven vehicle"* for the public to accept it, implicitly because any accident by an AV is judged more harshly due to these ethical expectations. On the liability front, the experts conveyed palpable concern. Interviewee 12 noted that automakers are terrified by the unresolved liability question, conceding that *"even now, it's not clear who's at fault if a completely autonomous car crashes"*, referencing the famous Uber AV incident as a cautionary tale (Riess and Sottile, 2023). This validates legal scholars' warnings that without a clear framework, companies fear massive lawsuits and consumers lack confidence in the technology. Interviewee 21 pointed out that some European manufacturers have even pre-emptively pledged to assume liability for certain automated driving modes to reassure customers - a bold step, albeit not a substitute for formal law. The literature often calls for updated laws and insurance models to clarify these matters, and the interviews confirm that work is urgently needed. An insight from the experts is how regulatory changes in related domains can introduce new liabilities. For example, interviewee 12 referred to the new EU Data Act which will require carmakers to share vehicle data with users (Sharing vehicle data: let's not reinvent the wheel, 2024). He warned this could open *"a can of worms"* if terabytes of driving data from an AV's sensors become accessible, potentially sparking litigation after any incident. In sum, the expert perspectives both validate the critical importance of ethical and legal challenges identified by the literature and add a sense of urgency and detail, illustrating that these unsolved questions are already influencing corporate strategies and must be addressed to unlock broader AV deployment.

3.5. Economic and market challenges

Beyond regulatory and technical domains, the adoption of autonomous vehicles in Europe faces economic and market hurdles. Developing and deploying AV technology is an expensive venture, and the immediate business case for fully autonomous cars remains uncertain. A number of economic analyses have questioned whether the substantial upfront costs of AVs can be justified in the consumer market, especially in the early stages of the technology (Nunes and Hernandez, 2020). Key cost drivers include the advanced sensor suite, onboard computing hardware, and the extensive software development and testing efforts, all of which can add tens of thousands of euros to the production cost of a single vehicle (Kaplan et al., 2019; Nunes and Hernandez, 2020). Until economies of scale are achieved, these costs are likely to be passed on to consumers, resulting in AVs that are significantly more expensive than their conventional counterparts (Kaplan et al., 2019; Wu et al., 2025). This has led some commentators to suggest that private ownership of fully autonomous cars might stay niche for a long period, and that shared mobility models like driverless taxis or shuttles may be the more viable way to introduce AVs commercially (Nazari et al., 2018; S. Wang et al., 2020).

Another economic challenge is the uncertain return on investment and timeline for profitability. Traditional automakers and tech companies are investing billions in research and development, with the expectation that autonomous mobility will eventually generate new revenue streams like autonomous ride-hailing services, logistics automation, data services (Alvarez León and Aoyama, 2022). However, it remains unclear when these ventures will break even (Fritschy and Spinler, 2019). Pessimistic projections suggest that a fully self-driving taxi service may not become profitable until it operates at large scale in dense areas, which itself requires overcoming the regulatory and public acceptance hurdles (Nordström and Engholm, 2021). This long-horizon payoff can be a tough sell to shareholders, particularly for incumbent car manufacturers that are concurrently facing financial pressures to electrify their fleets and meet environmental targets. In fact, the literature notes that the automotive industry in Europe is undergoing a dual transformation: electrification and automation, both of which are capital-intensive and fraught with uncertainty (Alvarez León and Aoyama, 2022; Fritschy and Spinler, 2019). As a result, some European automakers have scaled back or re-prioritized their autonomous driving programs in recent years, focusing on incremental driver-assistance improvements rather than full autonomy in the near term (Kaplan et al., 2019). Additionally, exogenous shocks have impacted the economic landscape. For example, the COVID-19 pandemic shifted consumer priorities and strained supply chains, leading companies to retrench and refocus on core business (Amis and Janz, 2020; Krammer, 2022), often at the expense of more speculative projects like AVs. Compared to other regions, Europe faces distinct market challenges. One key difference is investment levels: European AV ventures have attracted significantly less funding than their U.S. and Chinese counterparts. For example, companies like Waymo in the U.S. have raised over $10 billion in capital, while no European player has matched such figures (Huber et al., 2025). This lack of capital hampers the scalability and competitiveness of Europe's AV ecosystem. According to Juliussen, unless European stakeholders accelerate investments, the region risks falling irreparably behind global AV leaders (Juliussen, 2024). The investment environment and public funding also play roles. Europe's approach to AV development has included substantial public research funding and the formation of partnerships between private firms and public agencies for pilot projects. While this support has been valuable, some analysts argue that more coordinated investment is needed to reach deployment scale (Fritschy and Spinler, 2019; Kaplan et al., 2019). Without strategic public-private investment models, the burden of cost may be too high for industry alone to carry through the "valley of death" between prototype and mass product. Furthermore, market structure questions arise since new entrants like startups and tech giants are challenging traditional automakers, and it's not yet clear how value will be distributed in the AV ecosystem. Will car manufacturers also become service providers, or will tech companies dominate the ride-hailing AV fleets? These uncertainties make it hard for companies to formulate clear business models around AVs in Europe's highly regulated and competitive mobility market.

Another structural difference is the nature of demand. Europe's dense urban environments and extensive public transit systems reduce the immediate need for privately owned AVs or robotaxis. In contrast to the U.S., where personal car ownership is more dominant, European cities already offer viable mobility alternatives. As a result, the urgency and commercial viability of AV ride-hailing services may be lower in Europe. This has pushed the market toward different use-cases, such as autonomous shuttles, urban delivery robots, and freight. The region is already a leader in AV shuttle deployments, with companies like EasyMile (France) piloting services integrated with public transit systems.

In brief, the economics of autonomous vehicles present a chicken-and-egg problem. Costs will likely drop, and benefits result only after widespread adoption, but extensive adoption may not occur until costs drop and benefits are evident. The literature suggests phased or niche deployment as a potential solution, for example focusing on high-value use cases like autonomous trucks on highways where driver shortages and long-haul efficiency needs could justify the technology sooner (Fritschy and Spinler, 2019), or geo-fenced urban shuttles that serve as testbeds for gradually expanding service (Mahmoodi Nesheli et al., 2021). These limited deployments could generate success stories and technological refinements that, over time, improve the viability of broader consumer AV adoption. Until such models are proven, however, economic and market factors remain a significant barrier in Europe, tempering the initial enthusiasm with pragmatic caution in investment decisions.

The economic and market barriers identified in the literature were strongly echoed by our interviewees, who described a cautious industry climate due to high costs and uncertain returns on AV investments. Interviewee 3 observed that *"the primary barrier today is economic, driven by major uncertainties in the global landscape"*, noting that recent "black swan" disruptions (from supply-chain collapses to geopolitical crises) have made companies exceedingly careful about committing to long-term, capital-intensive projects. This directly ties into the literature's point about hesitation to invest without guaranteed payoff. He provided as an example that even a tech giant like Apple had to scale back its autonomous car ambitions after spending billions with little to show (Apple unplugs self-driving electric car project, reports say, 2024), and this is just an exemplary case illustrating that even abundant resources can be wasted in this domain. Several experts noted that firms are accordingly recalibrating their timelines and goals, often prioritizing incremental automation (Level 2–3 driver assistance features) that can be monetized sooner, rather than plunging immediately into Level 4–5 autonomy. As Interviewee 13 put it, *"apart from a few committed truck manufacturers, no one right now is thinking of jumping directly to Level 3″*, given the expense and risk involved. This statement reinforces literature's suggestion that freight and niche markets like automated trucking or low-speed shuttles may spearhead deployment due to clearer business cases. A striking addition from the interviews is the frank acknowledgement that viable business models for AV services remain elusive: Interviewee 10 stated plainly that *"we don't yet have a business model that guarantees a return on such high costs"*, underscoring the uncertainty in how companies will recoup their investments in lidar sensors and other components (that drive up vehicle cost). This admission aligns with academic and consulting reports which speculate on various models like ride-hailing, subscription and logistics, but acknowledge none is yet fully validated in the market. Both sources also note that public-sector support can influence economic feasibility. Interviewee 2 remarked that *"if not for public innovation funds, many LiDAR companies wouldn't exist"*, highlighting the role of European funding programs in sustaining innovation. Experts also emphasized that regulatory clarity is intertwined with financial calculus: as Interviewee 14 argued, the heavy cost of AV development means firms will only commit if they are confident the regulatory path is clear, since *"nobody wants to spend billions only to hit a legal roadblock"*. This interdependency might explain why some automakers pulled back from ambitious autonomy plans in recent years. Overall, there is strong agreement between academic and industry perspectives that the AV sector will remain in a cautious, high-investment holding pattern until costs come down or clear payoffs emerge. The interviews reinforce this view with an on-the-ground sense of heightened risk aversion (amplified by recent global events) and concur with the scholarly suggestion that autonomous driving may first need to prove itself in niche markets to build momentum toward broader viability.

Finally, surveys suggest that consumer attitudes in Europe toward AVs are more sceptical than in other regions. Recent data shows that only around 50 % of European drivers express trust in driverless vehicles, compared to nearly 80 % in China (Kumar et al., 2020). Furthermore, 84 % of Chinese respondents reported willingness to forgo private car ownership in favour of autonomous ride-hailing services, whereas such willingness is far lower among European consumers. This consumer caution adds another layer to Europe's unique market hurdles. In conclusion, what sets Europe apart are the lower capital flows, stronger public transport alternatives, more sceptical consumer attitudes, and a preference for AV applications integrated into existing urban mobility systems rather than private robotaxis. These differences mean that Europe's AV path may be slower and differently shaped compared to the U.S. and China, but also uniquely adapted to its context.

3.6. Societal acceptance and cultural barriers

Finally, and perhaps most importantly, the success of autonomous vehicles will depend on societal acceptance. No matter how advanced the technology or favourable the regulations, if people are unwilling to use AVs or share the road with them, adoption will stagnate. Research in Europe and globally has consistently found mixed public attitudes toward autonomous driving, with a sizeable proportion of individuals expressing distrust or outright discomfort with the idea of a self-driving car (Hohenberger et al., 2017). Trust is a central issue because potential users often question whether AVs can truly make safe decisions at highway speeds or in complex environments. Surveys indicate common fears such as the car's software might malfunction at a critical moment, or that an AV could be hacked to behave maliciously (Kaur and Rampersad, 2018). High-profile incidents have compounded these fears, for example the 2018 fatal accident in Arizona involving a self-driving test vehicle received global media attention and may have undermined public confidence in the technology's readiness (Uber self-driving crash "mostly caused by human error", 2019). In Europe, where consumer protection and safety standards are deeply valued, the public generally expects a high level of safety. Many people believe that autonomous cars must clearly prove they are safer than the average human driver before they can be trusted on the roads (Shariff et al., 2021).

Another dimension of acceptance is the loss of control. Driving has a deeply ingrained cultural significance in many European societies since it is associated with personal freedom, skill, and even enjoyment (Buckley et al., 2018). For some drivers, the idea of transferring all the control to a machine can evoke resistance or emotional reluctance. Qualitative studies have found that while younger generations who grew up with advanced technology and ride-sharing services tend to be more open to using autonomous mobility, older generations exhibit greater scepticism and attachment to the traditional driving experience (Buckley et al., 2018). Cultural differences between countries also emerge, having populations in tech-forward cities or countries that have embraced automation in other domains that are more receptive, whereas those with a strong car enthusiast culture or higher distrust of technology which might be slower to accept AVs (Hohenberger et al., 2017). Europe, being culturally diverse, will likely see varying rates of acceptance regionally unless concerted efforts are made to educate and build trust across the board.

Privacy and surveillance concern also play into societal acceptance in Europe. As mentioned earlier, AVs will collect vast amounts of data, including potentially tracking movements of individuals. Given Europe's focus on data privacy, some members of the public may worry about how AV data is used or shared. If not addressed, this could feed opposition to the technology on civil liberties grounds (Buckley et al., 2018; Kaur and Rampersad, 2018).

The literature suggests several strategies to improve public acceptance. One is exposure and education: the more people experience AV technology in a controlled, positive way, the more their comfort and trust can grow (Adnan et al., 2018; Xu et al., 2018). Pilot programs that give the public rides in autonomous shuttles, or demonstrations of AVs transparently explaining their decisions, have been shown to increase understanding and reduce mystique. Effective communication about safety records and advancements is also important (Shariff et al., 2021; Xu et al., 2018). For example, if data shows that an AV shuttle has been operating for months without incident, making such information public can slowly build confidence. Another strategy is involving the public in dialogue about ethical and deployment decisions. Finally, user-centric design of AV systems, ensuring that passengers feel safe and in control can help mitigate the psychological barrier of handing over control (Buckley et al., 2018; Hohenberger et al., 2017; Xu et al., 2018)l.

In conclusion, societal acceptance is an overarching challenge that intersects with all other aspects. If technology is safe but people perceive it as unsafe or undesirable, policy will reflect those public sentiments, and the market will respond cautiously. Therefore, achieving a positive public perception and comfort level is an essential part of the roadmap for autonomous vehicles. European literature on AVs frequently ends on this note: a call for trust-building measures, user engagement, and gradual introduction to ensure that society is ready to embrace autonomous mobility when the technology and regulations finally converge to make it available.

Our experts underscored, just as the literature does, that public trust and cultural acceptance are core issues. Interviewee 6 stated bluntly that *"the public isn't ready yet"*, arguing that people remain hesitant to "unleash" AVs broadly because they do not yet trust the technology. He linked this aspect to today's hyper-connected media environment which amplifies every autonomous vehicle accident, even speculating that if early 20th-century car inventors had faced modern social media, widespread automobile adoption might have been stunted by public outcry over accidents. This perspective supports academic insights that psychological and emotional reactions to AV incidents can significantly influence acceptance. Other interviewees described the public's wariness in vivid terms: Interviewee 5 remarked that *"AVs today are seen as a strange thing, even an enemy… something like a UFO that must be fought"*, highlighting how unfamiliar technology can trigger fear of the unknown. Consistent with these observations and with academic studies, many experts stressed the need for broad public education and awareness-raising campaigns to change public perceptions on AVs. They argued that Europe must proactively help people understand the benefits of this transition so that societal attitudes do not become an impediment on top of the technical and regulatory challenges. The interviews also enriched our understanding of demographic and cultural divides in acceptance. Interviewee 19 drew a generational comparison, noting that *"if you ask a 20-year-old boy and his 50-year-old mother whether they would blindly trust an autonomous vehicle, the young person might say yes but his mother would never - not in a million years!"*. This consideration illustrates the well-known trend that younger individuals tend to be more open to new mobility tech, whereas older adults are often more sceptical or reluctant to relinquish control. He further added a cross-cultural observation: *"In China, if they tell you to jump on one foot, you do it… Here in Europe, these changes clash with individual mindset"*, suggesting that more collectivist or tech-embracing cultures might adapt to AVs more readily than societies that prize individual autonomy (though this generalization would need careful validation). Such insights, rarely detailed in the literature, indicate that cultural context can influence how quickly AV adoption gains social acceptance. Interviewees even pointed out potential second-order social effects of AVs that researchers are only beginning to consider. For example, Interviewee 4 warned that if commuting becomes far easier and less stressful (since occupants can work or relax in a self-driving car), people might be willing to live much farther from city centres - raising the risk of expanded urban sprawl. This scenario of AVs potentially undermining sustainable urban planning goals is an emerging discussion point in literature, and our experts flagged it as a reminder that AV-related societal impacts must be managed thoughtfully. In the near term, however, building public trust is paramount. Across the board, our experts concurred with the academic consensus that visible safety assurances, transparency, and positive real-world demonstrations will be essential to win over a cautious public. Many interviewees advocated for pilot programs and gradual deployment to let people experience autonomous vehicles in a controlled, reassuring way. This pragmatic approach to fostering acceptance aligns directly with scholarly recommendations for phased introduction and stakeholder engagement to accompany technological advancements.

4. Discussion

A critical comparison between academic literature and expert interviews reveals general agreement on the key challenges facing autonomous driving in Europe, while also highlighting some differences in emphasis and new perspectives. Both sources converge on the notion that deploying AVs is not just a technological endeavour, but more of a socio-technical transition filled with regulatory, technical, and societal hurdles. To further enrich this analysis, the discussion draws on a comparative lens by referencing recent studies and projects on AV adoption in the United States and China. While Europe remains the central focus of the paper, contrasting the European context with the policy frameworks, societal attitudes, and deployment strategies in completely different environments offers additional insight into how different governance models and cultural settings shape the diffusion of autonomous vehicles. These international benchmarks help underscore both shared challenges - such as public trust and liability - and region-specific differences in regulatory pace, infrastructure investment, and state-led innovation, which are discussed throughout the following thematic subsections.

4.1. Regulation and policy

As detailed in Section 3.1 Regulatory and legislative challenges, Europe's regulatory framework for AVs remains fragmented and overly cautious, a situation acknowledged by both academic studies and our industry experts. Without greater regulatory clarity (especially on issues like liability and operational permissions), companies will continue to hesitate in deploying self-driving vehicles across Europe.

This challenge is not unique to Europe. A comparative look at other major AV markets, like United States and China, provides additional context and highlights distinct governance models. If Europe's fragmented regulatory framework forces companies to navigate parallel approval pathways, delaying deployment and increasing compliance costs, by contrast the United States adopts a more permissive, decentralized model. In the absence of a unified federal AV law, regulation occurs at the state level (Hemphill, 2020). Some states, like Arizona and Texas, offer minimal restrictions on AV testing, while others, like California, impose detailed reporting and oversight requirements (Hampel, 2024). This fosters innovation but also creates its own form of fragmentation and legal uncertainty. In particular, accident liability is unresolved at the national level and may be determined on a case-by-case basis, which introduces risks for developers and consumers alike. Scholars warn that the U.S. "hands-off" approach could backfire if legal ambiguity erodes trust or deters insurers from underwriting AV use (Brodsky, 2016; Mardini, 2019). China, in contrast, offers a centrally coordinated model. The national government plays a guiding role by issuing policy frameworks, designating pilot zones, and integrating AV development into its broader smart mobility strategy (Li and Miao, 2023). In cities like Beijing and Shanghai, dedicated AV lanes, smart traffic systems, and favourable testing regimes are already operational (Rajpal, 2024). These top-down measures reduce regulatory inconsistency and encourage collaboration between public and private actors. However, China's legislative process is still catching up: while national guidelines promote AV adoption, formal laws on liability, insurance, and data use are still under development and have yet to significantly influence user behaviour (Xu et al., 2023). Surveys indicate that regulatory policy alone is not currently a key driver of adoption intention in China, while trust in safety and perceived usefulness remain more decisive factors (Zhang et al., 2020). Nonetheless, China's proactive governance approach may allow it to close these legal gaps more swiftly than jurisdictions with more distributed legislative authority. Policymakers in Europe might draw valuable lessons from the U.S.'s flexible sandbox approach and China's strategic coordination, while maintaining Europe's strong standards on safety and rights protection.

4.2. Technology readiness vs. real-world performance

As outlined in Section 3.2 Technological and safety challenges, both the literature and the expert interviews stress that AV technology - while rapidly advancing - is not yet foolproof and requires rigorous validation under real-world conditions. There is a subtle divergence in perspective: many practitioners, like academics, remain cautious about the technology's current limitations, though a few experts are more optimistic, believing the core systems are essentially ready and that other barriers (e.g. legal and economic) are now more pressing.

Comparative insights from Europe, United States and China show that despite differing AV development models, all three regions face strikingly similar technological and safety hurdles. In the United States, major AV developers like Waymo, Cruise, and Tesla have made notable advances, but real-world safety concerns persist (Tiwari, 2024). Even the most mature AV systems remain geofenced to limited, pre-mapped areas and struggle outside ideal conditions. The 2018 fatal Uber AV crash in Arizona triggered public backlash and cast doubt on the industry's readiness for unsupervised operation (Riess and Sottile, 2023). As a result, safety validation through extensive simulation and phased deployment is now standard. However, public trust remains fragile, and researchers point out that reaching high levels of automation (SAE Level 4 or 5) is not sufficient unless AVs can safely navigate edge cases (Moradloo et al., 2024). China presents another model of AV development. Backed by strong government support, firms like Baidu Apollo, AutoX, and Pony.ai are rapidly piloting AVs in urban environments (AutoX, n.d.; Pony.ai, n.d.; Etherington, 2017). However, the fundamental challenge of ensuring safe and consistent performance under real-world conditions remains. Chinese cities present highly complex traffic conditions (dense vehicle flows, vulnerable road users, and unpredictable behaviours) which stress AV perception and control systems (Jie and van Zuylen, 2014). Chinese experts similarly point to the need for enhanced reliability as a key prerequisite for consumer acceptance (Huang and Qian, 2021). One notable difference is that China is aggressively pursuing cooperative automation, embedding smart infrastructure such as roadside sensors, 5G-enabled intersections, and AV-dedicated lanes to support vehicle decision-making (Rao, 2023). This infrastructure-vehicle synergy could help mitigating technical limitations at the vehicle level but also shifts part of the technological burden to public investment in connected systems. Nonetheless, the bar for "functional safety in all conditions" is still unmet, and like in the West, remains a top-tier barrier to mass rollout. While each region differs in strategy, all grapple with the core technological challenge of achieving safe, cybersecure, and broadly deployable AV systems. These comparative experiences reinforce the view that technological maturity is not a binary milestone but a gradual, iterative process and a universally shared constraint.

4.3. Infrastructure and vehicle-to-infrastructure integration

Section 3.3 Infrastructure and connectivity requirements showed that inadequate infrastructure and connectivity are universally seen as major barriers, and our expert findings reinforced this consensus while adding that better coordination is urgently needed. Both literature and practitioners agree that significant upgrades to physical and digital infrastructure (from smarter roads to 5 G networks) are required, but the interviews emphasized a point less visible in scholarship: the current lack of synergy between automakers and road operators in implementing these upgrades. Achieving an effective vehicle–infrastructure ecosystem will therefore demand unprecedented collaboration across these sectors, alongside the investments and standards-development that researchers call for.

These infrastructure-related challenges are mirrored internationally, even if approached differently across regions. The U.S. faces its own infrastructure challenges because of its geography. The interstate highway network is generally well-marked and has been a focus for early AV applications (e.g., highway autopilot features, long-haul trucking pilots) (I-94 Connected and Automated Vehicle (CAV) Corridor Project, n.d.). However, infrastructure quality varies widely by locale. Urban centres have complex environments, while rural highways may lack updated signage or connectivity (Burghardt et al., 2022). Some U.S. cities are now considering dedicated AV lanes or smart traffic systems, but on the whole, the U.S. has not embarked on a nationwide smart infrastructure overhaul specifically for AVs. China arguably views infrastructure as a key lever for enabling AVs and has integrated it into its adoption strategy. The government and industry are investing in smart city infrastructure, such as roadside lidar/radar units and 5 G communication at intersections, to support autonomous vehicles (Patil and Gupta, 2025). These efforts could give China an advantage in addressing the infrastructure barrier, effectively upgrading the environment to meet the technology halfway. There is also the challenge of scaling infrastructure upgrades across hundreds of cities and thousands of kilometres of highways, but on the positive side, China's strong central planning and investment capacity have led to rapid progress in a few years (for instance, installing smart highway corridors) (Moustafa, 2025). In short, while infrastructure inadequacy is a barrier in China as elsewhere, the Country is actively mitigating it through policy-backed investments, aiming to create an ecosystem where vehicles and infrastructure jointly enable safe autonomous mobility. So, while all regions acknowledge infrastructure as a limiting factor, China's coordinated investment strategy stands in contrast to the more fragmented and reactive approaches observed in Europe and the United States. Nonetheless, all share the recognition that AVs cannot scale safely and efficiently without parallel upgrades to the roads they drive on.

4.4. Ethical dilemmas and liability: theory vs. practice

As discussed in Section 3.4 Ethical and legal issues, unresolved ethical questions and legal liability uncertainties form a critical barrier to AV adoption, a point on which both the academic literature and our interviewees agree. The need to assure the public that autonomous vehicles will make morally acceptable decisions, and that clear liability will be assigned in the event of a mishap, is paramount. The expert insights added concrete urgency to this issue, affirming that industry players are already uneasy about the blurry legal responsibilities and that they recognize a higher standard of "safety assurance" will be demanded of AVs by society.

This concern echoes global trends, though the way these challenges are confronted varies considerably by region. In the U.S., ethical and legal issues are similarly delineated, though the approach tends to be more reactive (through courts) than proactive regulation. Liability in AV crashes is largely unresolved at a federal level: when a driver is effectively a passenger, traditional notions of driver liability shift to manufacturers or even fleet operators (Beilman and Schoeb, 2025). A patchwork of state laws offers some clarity, but no universal rule exists. This creates legal uncertainty for companies and insurance providers. On the ethical front, the "moral algorithm" debate has been less central to U.S. policy, but it has appeared in public discourse and research. Americans generally expect AVs to be at least as safe as human drivers, if not more, and there is an implicit ethical standard that needs to be met. However, recent studies emphasize that trust in AV technology and its governance is still critical (Orth, 2025): if the public doesn't trust that AVs will behave safely and that companies will be held accountable for failures, adoption will stall. Thus, the U.S. must eventually resolve questions of liability and ensure transparent handling of ethical issues to foster public acceptance. China faces many of the same ethical and legal questions, but the context is distinct. The Chinese government has strong influence over regulatory direction, which means it can, in principle, address issues like liability through top-down legislation more swiftly (China, the Global Leader in Autonomous vehicles – how did that happen?, 2025). Indeed, Chinese authorities are studying new insurance models and laws to define liability for autonomous driving. One proposal is a special insurance regime where, for example, the manufacturer or operator is primarily liable to ensure victims are compensated without ambiguity (Mallesons, 2017). Culturally, there may be less public debate on abstract ethical scenarios in China, since the emphasis is more on pragmatic outcomes like avoiding accidents. Nonetheless, public trust in AVs will depend on seeing that the government has put stringent safety regulations in place (Glück and Wu, 2025). Ensuring that this regulatory evolution keeps pace with technology will be key to maintaining public confidence.

Together, these regional perspectives illustrate that while the content of ethical and legal barriers may be similar globally, the political, cultural, and institutional responses to them differ significantly, and these differences must be accounted for in AV deployment strategies and public communication.

4.5. Economic viability and investment risks

As detailed in Section 3.5 Economic and market challenges, economic and market factors present a substantial hurdle: the high costs of AV development and uncertain return on investment have made both companies and investors cautious. The academic narrative identifies these issues, and our experts' experiences strongly concurred, emphasizing how recent global shocks and the lack of proven business models have reinforced a risk-averse atmosphere in the AV sector. Importantly, both literature and practitioner perspectives suggest that breakthrough deployment is likely to occur first in specific commercial niches (where the cost/benefit equation is more favourable) unless and until broader conditions improve.

This risk-averse economic climate is mirrored globally, but different regions have developed distinct strategies for managing AV investment and deployment. The U.S. has seen both intense investment in AV startups and sobering economic realities. On one hand, tech companies and venture capital fuelled a rapid rise of the AV sector, often with bold promises (Alvarez León and Aoyama, 2022). Moreover, recently announced partnerships of Uber and Lyft with Waymo ensures interest in the economics of AVs (Lee, 2025). On the other, the past few years have also brought consolidation and retrenchment, for example with the shutdown of Argo AI in 2022 signalling a shift in priorities even among major automakers like Ford and Volkswagen (Ferris, 2023). Like Europe, a core economic barrier is uncertain monetization. Deploying autonomous fleets at scale, whether for ride-hailing or freight, has proven more expensive and complex than anticipated. U.S. households, especially low- and middle-income ones, are unlikely to afford AVs at current prices, and consumer willingness to pay remains tepid (Wexler and Fan, 2022). The American AV sector thus faces a classic innovation dilemma: high investment costs today, uncertain returns tomorrow. China's economic strategy around AVs differs substantially in its top-down design and massive scale. The government has identified AVs as a strategic industry and is investing heavily across the value chain, from core technology R&D and domestic firms to pilot zones and smart infrastructure (Kuang et al., 2018). State support, combined with a population of 1.4 billion and strong urbanization, provides a fertile environment for scaling. Even so, Chinese consumers remain cost-sensitive. Studies indicate that high prices are a major barrier to individual adoption, prompting the government to explore a mix of financial incentives (e.g. tax breaks, subsidies), traffic privileges, and awareness campaigns to bolster uptake (Li et al., 2024). Much like its approach to EVs, China is encouraging fleet-first adoption: robotaxis, logistics vehicles, and autonomous buses in megacities are being trialled as ways to operationalize AVs in profitable niches (Chen et al., 2025). These applications may deliver returns at scale, and some experts argue they are better aligned with China's infrastructure investment strategy than personal car ownership (Zhou and Xu, 2023). Nonetheless, even in China, profitability remains uncertain. AV features are often rolled out incrementally (e.g. driver-assist on highways), and market viability still hinges on cost reduction and demonstrated user value. Overall, all three regions are grappling with the same fundamental problem: how to transform vast R&D investments in AV technology into viable, scalable business models. Without profitable use cases or strong government incentives, the pace of rollout will likely remain cautious, particularly for privately owned AVs.

4.6. Societal acceptance and cultural factors

Section 3.6 Societal acceptance and cultural barriers highlighted that public acceptance is a make-or-break factor for autonomous vehicles, and this is fully supported by our interview findings. Both academic studies and experts agree that without public trust and willingness to use AVs, even the most advanced technology will fail to achieve widespread adoption. Thus, researchers and practitioners alike advocate for proactive measures - from transparency in safety performance to public education and pilot programs - to improve comfort levels and build confidence in AV technology.

Region-specific acceptance dynamics add important nuance to this global picture. Societal acceptance in the U.S. is somewhat mixed and in flux. On one hand, Americans generally have a history of embracing new car technologies (from automobiles themselves a century ago to modern ride-sharing apps). On the other hand, polls in recent years (e.g., by AAA) indicate a majority of Americans are nervous about fully self-driving cars (Moye, 2025). Safety remains the public's chief concern; many feel the technology is intriguing but don't want to be unwitting early adopters. Some U.S. scholars underscore that perceived usefulness and expected benefits greatly shape intentions to adopt AVs (Xiao and Goulias, 2022). In other words, if people see real advantages, they are more willing to try AVs; but if those benefits don't clearly outweigh their fears, they hesitate. As in Europe, a generational gap is evident: younger, tech-savvy individuals, especially those using EVs or ride-hailing apps, tend to view AVs more positively, while older or less digitally immersed groups remain cautious (Xiao et al., 2024). The polarized U.S. media environment, where tech optimism competes with frequent headlines about crashes, adds confusion. To improve acceptance, U.S. experts suggest emphasizing tangible benefits (e.g., testimonials from AV pilots helping seniors, or statistics showing fewer crashes), and ensuring transparency about incidents and safety performance (Townsend et al., 2021). Making clear that AVs won't be broadly deployed until they're proven safe can also help assuage public concerns. In China, societal acceptance of AVs may ultimately be high, but it is contingent on building trust in both the technology and the government's handling of it. Chinese consumers are generally enthusiastic about tech innovation - ride-hailing, EVs, and high-speed rail have all seen rapid uptake (Kash, 2010) - yet they still need to be convinced that AVs are safe (Wu et al., 2020). Interestingly, Chinese respondents also report high importance for "perceived enjoyment," reflecting a cultural openness to novelty and convenience that may exceed that in Western markets (Wu et al., 2020). Culturally, there is a widespread assumption that if the government supports and regulates a new technology, it is likely safe and worthwhile (Băzăvan, 2019; Tang et al., 2025). This top-down trust can expedite acceptance. The government has taken a proactive role by launching public awareness campaigns and organizing AV demonstrations in cities like Shenzhen, where residents can ride robotaxis under controlled conditions (Cheng, 2025). These initiatives help familiarize people with the experience and reportedly improve comfort levels. Overall, China's societal acceptance barrier appears lower in relative terms, but it is not absent. A single high-profile accident or scandal could still undermine trust. Thus, as elsewhere, sustained public education, transparency, and clear communication of AV benefits will be crucial for turning curiosity into long-term user confidence. In sum, cultivating societal acceptance is essential in all regions. Europe and the U.S. must overcome wariness and build trust through transparency and positive pilot demonstrations, while China leverages a more optimistic public mindset but still invests in public education to ensure continued support for autonomous mobility. Public attitudes do not just respond to the technology, but they actively shape its trajectory.

These cross-regional insights underscore that while certain challenges are shared, the paths to overcoming them are deeply shaped by institutional and cultural environments. Thus, Europe's response must be both technically informed and contextually tailored.

Synthesizing the interviews with the literature, a few novel perspectives come to light, as it is highlighted in Table 5. One is the importance of inter-stakeholder collaboration: multiple experts highlighted that stronger cooperation between car manufacturers, tech developers, infrastructure operators, and regulators is needed. This is sometimes implied in literature but was voiced explicitly and frequently by interviewees (e.g. on V2I integration and on regulators working alongside engineers), suggesting that breaking silos could accelerate solutions to many barriers. Another insight is the dynamic nature of challenges, as one issue gets resolved, another may emerge (e.g. if robust safety is achieved, data governance might become the next big hurdle, as per the Data Act example). Practitioners seem keenly aware of this moving target, and this forward-looking mindset is something policymakers might need to adopt, ensuring that legislation and investment not only address today's issues but anticipate tomorrow's ones. Finally, the interviews convey a sense of gradualism that complements the academic perspective. Rather than a sudden AV revolution, what is happening in Europe is a stepwise evolution. This manifests as emphasis on interim solutions and hybrid strategies as the way forward. The literature likewise has trended away from the most optimistic, disruptive predictions toward more incremental forecasts. The convergence of opinions here reinforces the need for flexible strategies and continuous dialogue between all stakeholders.

5. Conclusions

Autonomous driving in Europe faces a multifaceted array of challenges, but our review indicates that these challenges are well-understood and, with concerted effort, can be addressed. The implications of these findings are significant. In the short term, the persistence of regulatory uncertainty, technical limitations, and public scepticism means that fully self-driving vehicles will likely roll out slower in Europe than the most bullish predictions once suggested. Stakeholders must navigate a delicate balance between innovation and caution, since premature deployment could erode trust if incidents occur, whereas excessive delay could cause Europe to fall behind in a transformative industry. In the long term, overcoming these barriers is crucial because the potential benefits of AVs - from dramatically reduced traffic accidents and enhanced mobility for the elderly or disabled, to more efficient logistics and reduced congestion - are substantial. Failure to resolve the impediments could mean foregone benefits in safety and economic efficiency, not to mention Europe's competitiveness in the global automotive arena.

Based on the key findings, we propose several recommendations for policymakers, industry players, and researchers. For policymakers, the priority should be to create an enabling yet responsible regulatory environment. This involves accelerating the harmonization of AV regulations across Europe, developing EU-wide standards for what constitutes safe autonomous operation, and clarifying liability regimes through legislation or directives. Regulatory sandboxes and pilot zones could be expanded, allowing AV testing under real conditions with a temporary relaxed regulatory framework to gather data and experience safely. Policymakers should also invest in infrastructure, considering that a clear plan for upgrading road networks with V2I communication capability is needed. This might imply substantial public investment or incentives for private investments in smart infrastructure. In addition, governments and the EU should continue funding research and innovation initiatives to support technology validation, creating shared simulation environments, data exchanges, or certification labs for AV safety. Crafting flexible data governance regimes will be important too: regulators must ensure privacy and security without unintentionally blocking the data sharing that could enhance AV systems, allowing anonymized sharing of driving scenarios to improve algorithms, for example.

In operational terms, this can be achieved through:

Table 5
Synthesis of the barriers related to AVs adoption and main supporting quotes from the expert interviews.

Barrier	Description (Literature review)	Supporting quotes from interviews
Fragmented regulatory frameworks	Divergent and fragmented laws across European countries create a patchwork of AV regulations, causing uncertainty for manufacturers and slowing deployment.	**Interviewee 13:** "Local legislations, plural and fragmented across states, are the main barrier". **Interviewee 15:** "Public authorities often lack the technical expertise to evaluate and approve AV pilots, resulting in delays".
Technological limitations and cybersecurity	Current AV systems are not yet foolproof, struggling to guarantee safety in all scenarios, and new cybersecurity risks (e.g. hacking) raise serious concerns.	**Interviewee 2:** "The tech is advancing, but it must be proven safe and secure. We need laws to ensure it's validated before wide deployment". **Interviewee 12:** The technology is "quite mature, but we still lack tons of testing. We simply haven't seen these systems perform in all circumstances…". **Interviewee 6:** "The barrier is the technology, absolutely. It just doesn't work well enough yet".
Inadequate infrastructure and V2X integration	Many roads lack the necessary infrastructure (e.g. vehicle-to-infrastructure communication, consistent lane markings, …) to support AVs, limiting their operability and transferability.	**Interviewee 9:** "The hardest thing will be upgrading infrastructure so these vehicles can circulate, especially in mixed traffic environments like cities where today's roads are not designed for AVs…". **Interviewee 11:** There is still "too little synergy between car makers and road operators" in integrating vehicles with smart infrastructure. **Interviewee 16:** Even connected infrastructure needs an "extremely high level of maintenance" to remain reliable for AV use.
Unresolved ethical and legal liabilities	Open ethical dilemmas (e.g. how an AV should make moral decisions in a crash) and unclear legal liability (who is at fault in an AV-involved accident) remain unsolved, undermining trust and accountability.	**Interviewee 16:** With autonomous driving, we are shifting from split-second human reactions to premeditated algorithmic decisions, and it's "an enormous ethical issue since you replace an unconscious human reaction with an algorithmic decision, and this has huge legal repercussions". **Interviewee 18:** An autonomous vehicle must provide "many more safety guarantees than a human-driven vehicle" for the public to accept it. **Interviewee 12:** Automakers are terrified by the unresolved liability question, noting that "even now, it's not clear who's at fault if a completely autonomous car crashes".
Uncertain economic models	The high cost of AV technology and unclear business models for recouping investments make economic viability uncertain, especially amid market fluctuations and concurrent investments.	**Interviewee 3:** "The primary barrier now is economic, driven by major uncertainties in the global landscape". In recent years a series of black swans (e.g. supply chain collapses, geopolitical crises) have made companies extremely cautious about long-term, capital-intensive AV projects. **Interviewee 13:** Apart from a few committed truck manufacturers, "no one right now is thinking of jumping directly to level 3″ automation, given the expense and risk. Most are holding off on high autonomy until the business case improves. **Interviewee 10:** "We don't yet have a business model that guarantees a return on such high costs," he noted, referring to the huge investments (e.g. costly LiDAR sensors) that currently lack a clear path to profitability.
Low societal trust and cultural readiness	Public ambivalence and scepticism toward self-driving cars, driven by safety, privacy and trust concerns, reflect European society, which is not yet culturally ready to embrace AVs, impeding their widespread adoption.	**Interviewee 6:** "The public isn't ready yet". People are hesitant to "unleash" AVs broadly because they do not yet trust the technology. He noted that every time an AV is involved in a bad accident, the news goes global, and fear is amplified, which would have made it hard for even early automobiles to gain acceptance in today's media climate. **Interviewee 5:** "AVs today are seen as a strange thing, even an enemy…something like an UFO that must be fought", highlighting the fear of the unknown. He stressed the need for outreach to change perceptions, arguing that Europe must "make people understand the importance of this transition". **Interviewee 19:** When it comes to trusting AVs, generational and cultural divides are evident. A young person might be willing to try it, but, as one interviewee quipped, "my wife, for example, would never – not in a million years!". This underscores how deeply entrenched attitudes and scepticism, especially among older adults in Western cultures, could slow acceptance of self-driving cars.

- Short term (1–2 years): establishing EU-level coordination bodies under the European Commission to harmonize national AV testing frameworks and create an EU-wide database of pilot results.
- Medium term (3–5 years): expanding regulatory sandboxes and cross-border test corridors co-funded by the EU Innovation Fund to gather safety and performance evidence.

- Long term (> 5 years): adopting a European AV Regulation defining common certification, liability, and data-sharing standards. Infrastructure investments could be operationalized through Cohesion Funds and public–private partnerships, prioritizing high-traffic corridors for early V2I upgrades. Policymakers should also establish a European AV Observatory to continuously evaluate pilot outcomes and update policies dynamically.

For the automotive and tech industry, a key recommendation is to deepen collaboration and transparency. Automakers, technology companies, and infrastructure operators should establish partnerships to ensure that vehicles and infrastructure evolve in lockstep rather than in isolation. Sharing pre-competitive data on safety performance and incident lessons will help the industry collectively. The industry should also proactively engage with regulators and contribute technical expertise to the lawmaking process; this way, forthcoming regulations will be grounded in realistic understanding of the technology. Furthermore, industry should invest in public education and user experience design, making AV interfaces that keep riders comfortable and informed, and launch outreach campaigns to let people see the technology in action.

Implementation should focus on:

- Creating pre-competitive consortia (e.g., through CEN/CENELEC or UNECE) to standardize safety validation tools and cybersecurity protocols.
- Launching joint demonstration projects between automakers, telecom operators, and municipalities to test interoperability of V2X systems.
- Establishing public awareness programs (supported by industry associations such as ACEA or ERTICO) that allow citizens to experience AV shuttles and understand their safety logic.
- Developing sectoral investment alliances to co-fund simulation platforms and certification labs in partnership with national innovation agencies.

For researchers and academics, there are clear avenues to support this transition. Research should continue to tackle the open technical challenges by developing more sophisticated validation techniques. Interdisciplinary research is especially valuable, and collaborations between engineers, ethicists, and legal scholars can help formulate algorithmic decision policies that are ethically sound and legally compliant, providing a blueprint for manufacturers and regulators to follow. Human factors research will also be crucial, understanding how occupants and other road users interact with autonomous systems psychologically and behaviourally will inform designs that encourage safe and predictable interactions. We also recommend further socio-economic research into autonomous vehicle deployment, which will guide proactive policy measures to mitigate negative impacts like potential job losses or urban sprawl and amplify positive ones like improved accessibility. Lastly, longitudinal studies of the ongoing pilots in Europe will yield real-world insights, and researchers should work together on those pilot programs to evaluate outcomes and iterate on solutions in real time.

For researchers and academics, translation to practice requires targeted collaborations. In general:

- Short term: forming interdisciplinary research clusters that integrate engineering, ethics, and law, with funding under Horizon Europe.
- Medium term: embedding evaluation protocols within ongoing AV pilots to generate real-world evidence supporting regulation.
- Long term: contributing to international benchmarking initiatives for safety metrics and socio-economic impact assessment. Universities can also act as neutral hubs for data-sharing and public dialogue on AV ethics, bridging the gap between science, society, and governance.

Effective realization of these measures will depend on multi-level coordination across EU, national, and local authorities, supported by public–private partnerships and targeted funding mechanisms. A phased approach is advisable: initial pilots and sandboxes (short term) should generate empirical evidence; institutional harmonization and standardization (medium term) should follow; and large-scale infrastructure integration (long term) will complete the transition. Embedding continuous evaluation and adaptive regulation throughout this process will ensure that policies evolve alongside technological and societal developments.

Future research should also address several identified gaps and emerging questions. One area is the development of international frameworks for AV safety assurance, in order to have metrics or thresholds that could be accepted globally to certify an AV as road safe. This would greatly assist regulators and build public trust. Another interesting field involves exploring the integration of autonomous vehicles with other evolving technologies to understand how AVs can work in tandem with smart city systems or with public transport - connected or not - to create a holistic mobility ecosystem. Additionally, continued work on cybersecurity frameworks specific to vehicles is necessary, as this remains something of an arms race between defenders and potential attackers, and methods like resilience engineering and quantum-resistant encryption for V2X communications could be fruitful topics.

In conclusion, the transition to autonomous vehicles in Europe is a complex journey with numerous obstacles, but it is not an insurmountable one. The key challenges are increasingly better understood by all stakeholders. Our study draws on insights from both the literature and expert practitioners to outline a clear roadmap for action. Addressing them will require a coordinated effort, with the policymakers providing clear rules of the road and supportive infrastructure, the industries sharing knowledge and aligning their innovations with societal needs, and the researchers breaking new ground while informing policy and practice. By heeding these evidence-based lessons, Europe can overcome the present barriers and unlock the full potential of autonomous driving, making transport safer, more accessible, and more efficient for decades to come.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to improve the clarity, coherence, and readability of the manuscript by refining sentence structures, correcting grammar, and ensuring consistency in terminology. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Giuseppe de Leo: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Giovanni Miragliotta:** Writing – review & editing, Visualization, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Appendix A. Complete version of the interview questionnaire

1. **Introduction and Warm-Up Questions**

- Can you briefly introduce yourself and your role within your society?

- How long you have been working in your company? What was your position in the past?
- What is the size of your company? What is the context in which you operate?

2. **Automotive in general**

- (What about the general landscape of the automotive industry at the moment?)
- How would you describe the technological advancement at the moment in the automotive industry?
- What are the important transformations in the automotive industry right now?

3. **Exploring Perspectives on ADVs**

- How would you define Autonomous Driving Vehicles (ADVs)?
- Do you perceive ADVs as standalone entities or as integral components of a broader mobility ecosystem? Why?
- How would ADVs will change the automotive value chain? (Are there new actors coming in/out? How would the current actors change their way of doing business?)
- How do you think that your role as a company will change in the automotive value chain?
- What will be the role of mobility service providers (e.g., car-sharing companies, ride-hailing platforms) evolving with the advent of ADVs?
- Do you envision some changes in the roles of the suppliers? Of the manufacturers? Etc.
- To what extent will the products and services change?
- How to monetize these products and services?
- What is the most important challenge(s) in facing this transformation?

4. **Policy and Regulatory Considerations**

- What will be the role of policymakers to enable this transformation?
- How might regulatory frameworks need to adapt to accommodate the deployment of ADVs, particularly in terms of safety and liability?

5. **Environment/society/safety**

- Do you think that ADVs can support the environmental objectives? Why?
- From a society perspective, what kind of impacts will ADVs have? Why?
- For what concern the theme of safety, which will be the impacts of ADVs? Why?

6. **Industry Vision and Innovation**

- What kind of innovation or BM can accelerate the diffusion of ADVs?
- How do you envision the future of mobility evolving with ADVs, especially in urban environments?

7. **Reflections on Business Model Dynamics**

- What kind of niches should be involved at the beginning for the technology to be used and to benefit from the learning curve? (The technology should start to be diffused, …)
- How do you think consumer can be educated for using this technology? (Which are the steps to take customers on board)

8. **Closing Thoughts and Recommendations**

- Are there any questions that you expected from me that I didn't ask?
- Could you recommend me any interview partners that can be helpful for my work?

References

2024 sees 3% drop in EU road fatalities, yet progress remains slow [WWW Document], n. d. . European Commission - European Commission. URL https://ec.europa.eu/commission/presscorner/detail/en/ip_25_789 (accessed 5.21.25).

Abboud, K., Omar, H. A., & Zhuang, W. (2016). Interworking of DSRC and Cellular Network Technologies for V2X Communications: A Survey. *IEEE Transactions on Vehicular Technology, 65*, 9457–9470. https://doi.org/10.1109/TVT.2016.2591558

Adnan, N., Md Nordin, S., Bin Bahruddin, M. A., & Ali, M. (2018). How trust can drive forward the user acceptance to the technology? In-vehicle technology for autonomous vehicle. *Transportation Research Part A: Policy and Practice, 118*, 819–836. https://doi.org/10.1016/j.tra.2018.10.019

Ahmad, M., & Wilkins, S. (2024). Purposive sampling in qualitative research: A framework for the entire journey. *Quality & quantity*. https://doi.org/10.1007/s11135-024-02022-5

Alvarez León, L. F., & Aoyama, Y. (2022). Industry emergence and market capture: The rise of autonomous vehicles. *Technological Forecasting and Social Change, 180*, Article 121661. https://doi.org/10.1016/j.techfore.2022.121661

Amis, J. M., & Janz, B. D. (2020). Leading change in response to COVID-19. *The Journal of Applied Behavioral Science, 56*, 272–278. https://doi.org/10.1177/0021886320936703

Andersson, P., & Ivehammar, P. (2019). Benefits and costs of autonomous trucks and cars. *JTTs, 09*, 121–145. https://doi.org/10.4236/jtts.2019.92008

Apple unplugs self-driving electric car project, reports say, 2024.

AutoX [WWW Document], n.d. URL https://www.autox.ai/en/index.html (accessed 7.20.25).

Babić, Dario, Fiolić, M., Babić, Darko, & Gates, T. (2020). Road markings and their impact on driver behaviour and Road safety: A systematic review of current findings. *Journal of Advanced Transportation, 2020*, Article 7843743. https://doi.org/10.1155/2020/7843743

Bagloee, S. A., Tavana, M., Asadi, M., & Oliver, T. (2016). Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies. *Journal of Modern Transportation, 24*, 284–303. https://doi.org/10.1007/s40534-016-0117-3

Bajpai, J. N. (2016). Emerging vehicle technologies & the search for urban mobility solutions. *Urban, Planning and Transport Research, 4*, 83–100. https://doi.org/10.1080/21650020.2016.1185964

Bardt, H. (2017). Autonomous driving — A challenge for the automotive industry. *Intereconomics, 52*, 171–177. https://doi.org/10.1007/s10272-017-0668-5

Baumeister, R. F., & Leary, M. R. (1997). Writing narrative literature reviews. *Review of General Psychology, 1*, 311–320. https://doi.org/10.1037/1089-2680.1.3.311

Băzăvan, A. (2019). Chinese government's shifting role in the national innovation system. *Technological Forecasting and Social Change, 148*, Article 119738. https://doi.org/10.1016/j.techfore.2019.119738

Beedham, M., 2025. Risk and ADAS regulation, U.S. and Europe| TomTom Newsroom [WWW Document]. TomTom. URL https://www.tomtom.com/newsroom/explainers-and-insights/risk-tolerance-and-adas-regulation-eu-and-usa/(accessed 12.27.25).

Beilman, V.P., Schoeb, R.D., 2025. Navigating liability in the age of autonomous vehicles [WWW Document]. URL https://www.wshblaw.com/publication-navigating-liability-in-the-age-of-autonomous-vehicles (accessed 11.15.25).

Bezai, N. E., Medjdoub, B., Al-Habaibeh, A., Chalal, M. L., & Fadli, F. (2021). Future cities and autonomous vehicles: Analysis of the barriers to full adoption. *Energy and Built Environment, 2*, 65–81. https://doi.org/10.1016/j.enbenv.2020.05.002

Bösch, P. M., Becker, F., Becker, H., & Axhausen, K. W. (2018). Cost-based analysis of autonomous mobility services. *Transport Policy, 64*, 76–91. https://doi.org/10.1016/j.tranpol.2017.09.005

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101. https://doi.org/10.1191/1478088706qp063oa

Brodsky, J. S. (2016). Autonomous vehicle regulation: How an uncertain legal landscape may hit the brakes on self-driving cars. *Berkeley Tech. L.J.*. https://doi.org/10.15779/Z38JC5S

Buckley, L., Kaye, S.-A., & Pradhan, A. K. (2018). A qualitative examination of drivers' responses to partially automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour, 56*, 167–175. https://doi.org/10.1016/j.trf.2018.04.012

Burghardt, K., Uhl, J. H., Lerman, K., & Leyk, S. (2022). Road network evolution in the urban and rural United States since 1900. *Computers, Environment and Urban Systems, 95*, Article 101803. https://doi.org/10.1016/j.compenvurbsys.2022.101803

Chandrasekar, A., Clark, S. E., Martin, S., Vanderslott, S., Flores, E. C., Aceituno, D., Barnett, P., Vindrola-Padros, C., & Vera San Juan, N. (2024). Making the most of big qualitative datasets: a living systematic review of analysis methods. *Front Big Data, 7*, Article 1455399. https://doi.org/10.3389/fdata.2024.1455399

Chen, O., Richichi, M., Lu, D., S, H., 2025. Robotaxis and robobuses accelerate autonomous driving growth [WWW Document]. S&P Automotive Insights. URL https://www.spglobal.com/automotive-insights/en/blogs/2025/09/autonomous-driving-expands-to-europe-and-middle-east (accessed 11.15.25).

Cheng, E., 2025. Pony.Ai becomes first to win citywide robotaxi permit in China's Silicon Valley [WWW Document]. CNBC. URL https://www.cnbc.com/2025/10/31/chinas-ponyai-gets-the-first-permit-for-robotaxis-in-all-of-shenzhen.html (accessed 11.15.25).

China, the Global Leader in Autonomous vehicles – how did that happen? [WWW Document], 2025. URL https://www.intertraffic.com/news/autonomous-driving/china-the-global-leader-in-autonomous-vehicles (accessed 11.15.25).

de Leo, G., & Miragliotta, G. (2025). Sustainability of autonomous cars: Environmental, social, and economic insights from a systematic review. *Sustainable Production and Consumption, 60*, 159–175. https://doi.org/10.1016/j.spc.2025.09.013

Donovan, T., Carter, H.E., McPhail, S.M., Abell, B., 2024. A qualitative interview study to explore costing of implementation strategies to support digital health adoption "it's the difference between success and failure." https://doi.org/10.21203/rs.3.rs-3828958/v1.

Duarte, F., & Ratti, C. (2018). The impact of autonomous vehicles on cities: A review. *Journal of Urban Technology, 25*, 3–18. https://doi.org/10.1080/10630732.2018.1493883

Eskandarian, A., Wu, C., & Sun, C. (2021). Research advances and challenges of autonomous and connected ground vehicles. *IEEE Transactions on Intelligent Transportation Systems, 22*, 683–711. https://doi.org/10.1109/TITS.2019.2958352

Etherington, D., 2017. Baidu's Apollo platform becomes the "Android of the autonomous driving industry." TechCrunch. URL https://techcrunch.com/2017/07/05/baidus-apollo-platform-becomes-the-android-of-the-autonomous-driving-industry.

European Commission, 2022. 5G coverage along transport corridors: first wave of projects selected for co-funding 5G corridor infrastructures | shaping Europe's digital future [WWW Document]. URL https://digital-strategy.ec.europa.eu/en/news/5g-coverage-along-transport-corridors-first-wave-projects-selected-co-funding-5g-corridor (accessed 12.2.25).
European Parliament, 2024. Directive (EU) 2024/2853 of the European Parliament and of the Council of 23 October 2024 on liability for defective products and repealing Council Directive 85/374/EEC (Text with EEA relevance).
European Parliament, 2023. Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data and amending Regulation (EU) 2017/2394 and Directive (EU) 2020/1828 (Data Act) (Text with EEA relevance).
Experts say privately held data available in the European Union should be used better and more | shaping Europe's digital future [WWW Document], n.d. URL https://digital-strategy.ec.europa.eu/en/news/experts-say-privately-held-data-available-european-union-should-be-used-better-and-more (accessed 5.21.25).
Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77*, 167–181. https://doi.org/10.1016/j.tra.2015.04.003
Feess, E., & Muehlheusser, G. (2024). Autonomous vehicles: Moral dilemmas and adoption incentives. *Transportation Research Part B: Methodological, 181*, Article 102894. https://doi.org/10.1016/j.trb.2024.102894
Ferris, R., 2023. Why Ford and VW shut down their multi-billion dollar self-driving project [WWW Document]. CNBC. URL https://www.cnbc.com/video/2023/03/22/why-ford-and-vw-shut-down-their-multi-billion-dollar-self-driving-project.html (accessed 11.15.25).
Fraedrich, E., Heinrichs, D., Bahamonde-Birke, F. J., & Cyganski, R. (2019). Autonomous driving, the built environment and policy implications. *Transportation Research Part A: Policy and Practice, 122*, 162–172. https://doi.org/10.1016/j.tra.2018.02.018
Fritschy, C., & Spinler, S. (2019). The impact of autonomous trucks on business models in the automotive and logistics industry–a Delphi-based scenario study. *Technological Forecasting and Social Change, 148*, Article 119736. https://doi.org/10.1016/j.techfore.2019.119736
Galvin, R. (2015). How many interviews are enough? Do qualitative interviews in building energy consumption research produce reliable knowledge? *Journal of Building Engineering, 1*, 2–12. https://doi.org/10.1016/j.jobe.2014.12.001
Gandia, R. M., Antonialli, F., Cavazza, B. H., Neto, A. M., Lima, D. A. D., Sugano, J. Y., Nicolai, I., & Zambalde, A. L. (2019). Autonomous vehicles: Scientometric and bibliometric review. *Transport Reviews, 39*, 9–28. https://doi.org/10.1080/01441647.2018.1518937
Gless, S., & Ligeti, K. (2024). Regulating driving automation in the European Union – criminal liability on the road ahead? *New Journal of European Criminal Law, 15*, 33–57. https://doi.org/10.1177/20322844231213336
Glück, U., Wu, S., 2025. Autonomous vehicles law and regulation in China [WWW Document]. URL https://cms.law/en/int/expert-guides/cms-expert-guide-to-autonomous-vehicles-avs/china (accessed 11.15.25).
Gruyer, D., Orfila, O., Glaser, S., Hedhli, A., Hautière, N., & Rakotonirainy, A. (2021). Are connected and automated vehicles the silver bullet for future transportation challenges? Benefits and weaknesses on safety, consumption, and traffic congestion. *Frontiers in Sustainable Cities, 2*, Article 607054. https://doi.org/10.3389/frsc.2020.607054
Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough?: An experiment with data saturation and variability. *Field Methods, 18*, 59–82. https://doi.org/10.1177/1525822X05279903
Guo, J., Kurup, U., & Shah, M. (2020). Is it safe to drive? An overview of factors, metrics, and datasets for driveability assessment in autonomous driving. *IIEEE Transactions on Intelligent Transportation Systems, 21*, 3135–3151. https://doi.org/10.1109/TITS.2019.2926042
Hacker, P. (2023). The european AI liability directives – Critique of a half-hearted approach and lessons for the future. *Computer Law & Security Review, 51*, Article 105871. https://doi.org/10.1016/j.clsr.2023.105871
Hampel, S., 2024. Navigating the road ahead: Exploring the regulatory framework for autonomous vehicles in the United States [WWW Document]. URL https://www.volvoautonomoussolutions.com/en-en/news-and-insights/insights/articles/2024/apr/navigating-the-road-ahead-exploring-the-legal-framework-for-aut.html (accessed 11.15.25).
Hemphill, T. A. (2020). Autonomous vehicles: U.S. regulatory policy challenges. *Technology in Society, 61*, Article 101232. https://doi.org/10.1016/j.techsoc.2020.101232
Hohenberger, C., Spörrle, M., & Welpe, I. M. (2017). Not fearless, but self-enhanced: The effects of anxiety on the willingness to use autonomous cars depend on individual levels of self-enhancement. *Technological Forecasting and Social Change, 116*, 40–52. https://doi.org/10.1016/j.techfore.2016.11.011
Huang, K., Kockelman, Kara, & Gurumurthy, K. M. (2023). Innovations impacting the future of transportation: an overview of connected, automated, shared, and electric technologies. *Transportation Letters, 15*, 490–509. https://doi.org/10.1080/19427867.2022.2070091
Huang, Y., & Qian, L. (2021). Understanding the potential adoption of autonomous vehicles in China: the perspective of behavioral reasoning theory. *Psychology & Marketing, 38*, 669–690. https://doi.org/10.1002/mar.21465
Huber, A., Heineke, K., Kellner, M., Möller, T., 2025. The future of autonomous vehicles in Europe | McKinsey [WWW Document]. URL https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/autonomous-vehicles-the-future-of-european-transport (accessed 12.27.25).
I-94 Connected and Automated Vehicle (CAV) Corridor Project [WWW Document], n.d. URL https://www.michigan.gov/mdot/projects-studies/i-94-cav-corridor-project (accessed 11.15.25).
Jie, L., & van Zuylen, H. J. (2014). Road traffic in China. Procedia - social and behavioral sciences. *Transportation: Can we do More with Less Resources? –16th Meeting of the Euro Working Group on Transportation – Porto, 2013*(111), 107–116. https://doi.org/10.1016/j.sbspro.2014.01.043
Jin, W., Islam, M., & Chowdhury, M. (2022). Risk-based merging decisions for autonomous vehicles. *Journal of Safety Research, 83*, 45–56. https://doi.org/10.1016/j.jsr.2022.08.003
Juliussen, E. (2024). AV status: U.S. vs. China vs. Europe. *EE Times*. URL https://www.eetimes.com/av-status-u-s-vs-china-vs-europe/ (accessed 12.27.25).
Kalra, N., & Paddock, S. M. (2016). Driving to safety: how many miles of driving would it take to demonstrate autonomous vehicle reliability? *Transportation Research Part A: Policy and Practice, 94*, 182–193. https://doi.org/10.1016/j.tra.2016.09.010
Kaplan, S., Gordon, B., El Zarwi, F., Walker, J. L., & Zilberman, D. (2019). The future of autonomous vehicles: Lessons from the literature on technology adoption. *Applied Eco Perspectives Pol, 41*, 583–597. https://doi.org/10.1093/aepp/ppz005
Kash, D. E. (2010). Technological innovation and culture: research needed for China and other countries. *Journal of Science and Technology Policy in China, 1*, 100–115. https://doi.org/10.1108/17585521011059857
Katsaros, K. V., Amditis, A. J., Trichias, K., Shagdar, O., Soua, A., Requena, J. C., Santa, J., Kakes, G., Almeida, J., Sousa, E., Cruz, N., Velez, G., Sari, T., Cortizo, D. J., Correia, F., Kountche, D. A., Rommel, S., Nikolitsa, E., & Demestichas, P. (2023). Connected and automated mobility services in 5G Cross-border environments: challenges and prospects. *IEEE Intelligent Transportation Systems Magazine, 15*, 145–157. https://doi.org/10.1109/MITS.2023.3237271
Kaur, K., & Rampersad, G. (2018). Trust in driverless cars: investigating key factors influencing the adoption of driverless cars. *Journal of Engineering and Technology Management, 48*, 87–96. https://doi.org/10.1016/j.jengtecman.2018.04.006
Kester, J. (2022). Insuring future automobility: A qualitative discussion of British and Dutch car insurer's responses to connected and automated vehicles. *Research in Transportation Business & Management, 45*, Article 100903. https://doi.org/10.1016/j.rtbm.2022.100903
Krammer, S. M. S. (2022). Navigating the New normal: which firms have adapted better to the COVID-19 disruption? *Technovation, 110*, Article 102368. https://doi.org/10.1016/j.technovation.2021.102368
Kuang, X., Zhao, F., Hao, H., & Liu, Z. (2018). Intelligent connected vehicles: the industrial practices and impacts on automotive value-chains in China. *Asia Pacific Business Review, 24*, 1–21. https://doi.org/10.1080/13602381.2017.1340178
Kumar, A., Delaunay, F., Medury, A., 2020. Alixpartners' GLOBAL survey shows limited willingness to pay for autonomous vehicles.
Lachonius, M., Wallström, S., Odell, A., Pétursson, P., Jeppsson, A., Skoglund, K., & Nielsen, S. J. (2023). Patients' motivation to undergo transcatheter aortic valve replacement. A phenomenological hermeneutic study. *International journal of older people nursing, 18*, Article e12521. https://doi.org/10.1111/opn.12521
Lee, D., & Hess, D. J. (2020). Regulations for on-road testing of connected and automated vehicles: assessing the potential for global safety harmonization. *Transportation Research Part A: Policy and Practice, 136*, 85–98. https://doi.org/10.1016/j.tra.2020.03.026
Lee, L., 2025. Uber and Lyft see more demand with robotaxis. Here's what their CEOs say on a driverless future. [WWW Document]. Business Insider. URL https://www.businessinsider.com/uber-lyft-robotaxi-autonomous-vehicles-expansion-plans-2025-11 (accessed 11.15.25).
Li, S., Sui, P.-C., Xiao, J., & Chahine, R. (2019). Policy formulation for highly automated vehicles: emerging importance, research frontiers and insights. *Transportation Research Part A: Policy and Practice, 124*, 573–586. https://doi.org/10.1016/j.tra.2018.05.010
Li, X., Zou, J., Agrawal, S., Guo, Y., Tang, T., & Feng, X. (2024). Role of policy and consumer attitudes in people's intention to use autonomous vehicles: a comparative study in China and the USA. *Transportation*. https://doi.org/10.1007/s11116-024-10508-2
Li, X.-W., & Miao, H.-Z. (2023). How to incorporate autonomous vehicles into the carbon neutrality framework of China: Legal and policy perspectives. *Sustainability, 15*, 5671. https://doi.org/10.3390/su15075671
Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry [WWW Document]*. SAGE Publications Ltd. URL https://uk.sagepub.com/en-gb/eur/naturalistic-inquiry/book842 (accessed 12.27.25).
Litman, T., 2020. Autonomous vehicle implementation predictions: Implications for transport planning.
Liu, N., Nikitas, A., & Parkinson, S. (2020). Exploring expert perceptions about the cyber security and privacy of connected and autonomous vehicles: A thematic analysis approach. *Transportation Research Part F: Traffic Psychology and Behaviour, 75*, 66–86. https://doi.org/10.1016/j.trf.2020.09.019
Liu, Y., Tight, M., Sun, Q., & Kang, R. (2019). A systematic review: road infrastructure requirement for connected and autonomous vehicles (CAVs). *Journal of Physics: Conference Series., 1187*, Article 042073. https://doi.org/10.1088/1742-6596/1187/4/042073
Lucifora, C., Grasso, G. M., Perconti, P., & Plebe, A. (2020). Moral dilemmas in self-driving cars. *Rivista internazionale di Filosofia e Psicologia*, 238–250. https://doi.org/10.4453/rifp.2020.0015
Lukic, D., 2022. U.S. Lagging European Union in vehicle cybersecurity | WardsAuto [WWW Document]. URL https://www.wardsauto.com/news/archive-wards-u-s-lagging-european-union-in-vehicle-cybersecurity/796310/(accessed 12.27.25).
Mahdavian, A., Shojaei, A., Mccormick, S., Papandreou, T., Eluru, N., & Oloufa, A. A. (2021). Drivers and barriers to implementation of connected, automated, shared,

and electric vehicles: An agenda for future research. *IEEE Access : Practical Innovations, Open Solutions, 9*, 22195–22213. https://doi.org/10.1109/ACCESS.2021.3056025

Mahmoodi Nesheli, M., Li, L., Palm, M., & Shalaby, A. (2021). Driverless shuttle pilots: Lessons for automated transit technology deployment. *Case Studies on Transport Policy, 9*, 723–742. https://doi.org/10.1016/j.cstp.2021.03.010

Mallesons, K.& W., 2017. Self-driving cars:China and beyond- who will be liable∞. China law insight. URL https://www.chinalawinsight.com/2017/08/articles/corporate-ma/self-driving-cars:china-and-beyond-who-will-be-liable∞/(accessed 11.15.25).

Manns, A., Pezziardi, T., Kadlub, N., Burgun, A., Destrez, A., & Tsopra, R. (2025). Enhancing security in patient medical information exchange: A qualitative study. *International Journal of Medical Informatics, 197*, Article 105841. https://doi.org/10.1016/j.ijmedinf.2025.105841

Mardini, R. M. (2019). The quantification of remedying change: How the proliferation of autonomous vehicles will transform Michigan's insurance regime. *W. Mich. U. Cooley Law Review, 35*, 193.

Martínez-Díaz, M., & Soriguera, F. (2018). Autonomous vehicles: Theoretical and practical challenges. *Transportation Research Procedia, 33*, 275–282. https://doi.org/10.1016/j.trpro.2018.10.103

Martinho, A., Herber, N., Kroesen, M., & Chorus, C. (2021). Ethical issues in focus by the autonomous vehicles industry. *Transport Reviews, 41*, 556–577. https://doi.org/10.1080/01441647.2020.1862355

McInnes, C., Carstairs, S. A., & Cecil, J. E. (2023). A qualitative study of young peoples' thoughts and attitudes to follow a more plant-based diet. *Frontiers in Psychology., 14*. https://doi.org/10.3389/fpsyg.2023.1196142

Moradloo, N., Mahdinia, I., & Khattak, A. J. (2024). Safety in higher level automated vehicles: investigating edge cases in crashes of vehicles equipped with automated driving systems. *Accident Analysis & Prevention, 203*, Article 107607. https://doi.org/10.1016/j.aap.2024.107607

Mordue, G., Yeung, A., & Wu, F. (2020). The looming challenges of regulating high level autonomous vehicles. *Transportation Research Part A: Policy and Practice, 132*, 174–187. https://doi.org/10.1016/j.tra.2019.11.007

Moustafa, A., 2025. China's institutional advantages and how they help the five-year plans - Global Times [WWW Document]. URL https://www.globaltimes.cn/page/202510/1346581.shtml (accessed 11.15.25).

Moye, B., 2025. AAA: fear in self-driving vehicles persists. AAA newsroom. URL https://newsroom.aaa.com/2025/02/aaa-fear-in-self-driving-vehicles-persists/.

Naiseh, M., Clark, J., Akarsu, T., Hanoch, Y., Brito, M., Wald, M., Webster, T., & Shukla, P. (2025). Trust, risk perception, and intention to use autonomous vehicles: An interdisciplinary bibliometric review. *AI & Soc, 40*, 1091–1111. https://doi.org/10.1007/s00146-024-01895-2

Nazari, F., Noruzoliaee, M., & Mohammadian, A.(Kouros) (2018). Shared versus private mobility: Modeling public interest in autonomous vehicles accounting for latent attitudes. *Transportation Research Part C: Emerging Technologies, 97*, 456–477. https://doi.org/10.1016/j.trc.2018.11.005

Nordström, M., & Engholm, A. (2021). The complexity of value of travel time for self-driving vehicles – a morphological analysis. *Transportation Planning and Technology, 44*, 400–417. https://doi.org/10.1080/03081060.2021.1919349

Nunes, A., & Hernandez, K. D. (2020). Autonomous taxis & public health: High cost or high opportunity cost? *Transportation Research Part A: Policy and Practice, 138*, 28–36. https://doi.org/10.1016/j.tra.2020.05.011

Nyholm, S., & Smids, J. (2020). Automated cars meet human drivers: Responsible human-robot coordination and the ethics of mixed traffic. *Ethics and Information Technology, 22*, 335–344. https://doi.org/10.1007/s10676-018-9445-9

Orth, T., 2025. Americans warm to driverless cars, though skepticism remains | YouGov [WWW Document]. URL https://today.yougov.com/technology/articles/51199-americans-warm-to-driverless-cars-though-skepticism-remains (accessed 11.15.25).

Othman, K. (2021). Public acceptance and perception of autonomous vehicles: A comprehensive review. *AI Ethics, 1*, 355–387. https://doi.org/10.1007/s43681-021-00041-8

Patil, S., Gupta, P., 2025. The Digital Silk Road and Smart City Networks in the Indo-Pacific: A primer [WWW Document]. Orfonline.Org. URL https://www.orfonline.org/research/the-digital-silk-road-and-smart-city-networks-in-the-indo-pacific-a-primer (accessed 11.15.25).

Peace, J., Sweet, M., & Scott, D. M. (2023). Why do planners do what they do? And what are the implications? Guidance from on-demand ride-hailing policy in Toronto and Vancouver, Canada. *Transport Policy, 143*, 72–82. https://doi.org/10.1016/j.tranpol.2023.09.012

Pereira, J. M. (2021). 5G for connected and automated mobility (CAM) in Europe: Targeting Cross-border corridors. *IEEE Network, 35*, 6–9. https://doi.org/10.1109/MNET.2021.9454557

Petit, J., & Shladover, S. E. (2015). Potential cyberattacks on automated vehicles. *IEEE Trans. Intell. Transport. Syst.*, 1–11. https://doi.org/10.1109/TITS.2014.2342271

Pony.ai [WWW Document], n.d. URL https://www.pony.ai/(accessed 7.20.25).

Poszler, F., Geisslinger, M., Betz, J., & Lütge, C. (2023). Applying ethical theories to the decision-making of self-driving vehicles: A systematic review and integration of the literature. *Technology in Society, 75*, Article 102350. https://doi.org/10.1016/j.techsoc.2023.102350

Prioleau, D., Dames, P., Alikhademi, K., Gilbert, J.E., 2020. Barriers to the adoption of autonomous vehicles in rural communities, in: 2020 IEEE International Symposium on Technology and Society (ISTAS). Presented at the 2020 IEEE International Symposium on Technology and Society (ISTAS), pp. 91–98. https://doi.org/10.1109/ISTAS50296.2020.9462192.

Rahaman, Md.S., 2023. Australian Business Deans Council 2022 journal Quality List review final report about the Australian Business Deans Council.

Rahman, Md. M., & Thill, J.-C. (2023). Impacts of connected and autonomous vehicles on urban transportation and environment: A comprehensive review. *Sustainable Cities and Society, 96*, Article 104649. https://doi.org/10.1016/j.scs.2023.104649

Raj, A., Kumar, J. A., & Bansal, P. (2020). A multicriteria decision making approach to study barriers to the adoption of autonomous vehicles. *Transportation Research Part A: Policy and Practice, 133*, 122–137. https://doi.org/10.1016/j.tra.2020.01.013

Rajpal, S., 2024. Mainland China autonomous vehicle development on a different track [WWW Document]. S&P Automotive Insights. URL https://www.spglobal.com/automotive-insights/en/blogs/2024/10/mainland-china-autonomous-vehicle-development-on-a-different-track (accessed 11.15.25).

Rana, Md. M., & Hossain, K. (2023). Connected and autonomous Vehicles and Infrastructures: A literature review. *Int. J. Pavement Res. Technol., 16*, 264–284. https://doi.org/10.1007/s42947-021-00130-1

Rao, Y. (2023). Discourse as infrastructure: How "New Infrastructure" policies re-infrastructure China. *Global Media and China, 8*, 254–270. https://doi.org/10.1177/20594364231198605

Rezaei, A., & Caulfield, B. (2020). Examining public acceptance of autonomous mobility. *Travel Behaviour and Society, 21*, 235–246. https://doi.org/10.1016/j.tbs.2020.07.002

Riess, R., Sottile, Z., 2023. Uber self-driving car test driver pleads guilty to endangerment in pedestrian death case | CNN Business [WWW Document]. CNN. URL https://www.cnn.com/2023/07/29/business/uber-self-driving-car-death-guilty (accessed 5.21.25).

Santoni De Sio, F. (2021). The European Commission report on ethics of connected and automated vehicles and the future of ethics of transportation. *Ethics and information technology, 23*, 713–726. https://doi.org/10.1007/s10676-021-09609-8

Shahedi, A., Dadashpour, I., & Rezaei, M. (2023). Barriers to the sustainable adoption of autonomous vehicles in developing countries: A multi-criteria decision-making approach. *Heliyon, 9*, Article e15975. https://doi.org/10.1016/j.heliyon.2023.e15975

Shariff, A., Bonnefon, J.-F., & Rahwan, I. (2021). How safe is safe enough? Psychological mechanisms underlying extreme safety demands for self-driving cars. *Transportation Research Part C: Emerging Technologies, 126*, Article 103069. https://doi.org/10.1016/j.trc.2021.103069

Sharing vehicle data: let's not reinvent the wheel, 2024. . ACEA - European Automobile Manufacturers' Association. URL https://www.acea.auto/news/sharing-vehicle-data-lets-not-reinvent-the-wheel/(accessed 5.21.25).

Sheehan, B., Murphy, F., Mullins, M., & Ryan, C. (2019). Connected and autonomous vehicles: A cyber-risk classification framework. *Transportation Research Part A: Policy and Practice, 124*, 523–536. https://doi.org/10.1016/j.tra.2018.06.033

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Taeihagh, A., & Lim, H. S. M. (2019). Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. *Transport Reviews, 39*, 103–128. https://doi.org/10.1080/01441647.2018.1494640

Takaguchi, K., Kappes, A., Yearsley, J. M., Sawai, T., Wilkinson, D. J. C., & Savulescu, J. (2022). Personal ethical settings for driverless cars and the utility paradox: An ethical analysis of public attitudes in UK and Japan. *PLoS One, 17*, Article e0275812. https://doi.org/10.1371/journal.pone.0275812

Talebpour, A., & Mahmassani, H. S. (2016). Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transportation Research Part C: Emerging Technologies, 71*, 143–163. https://doi.org/10.1016/j.trc.2016.07.007

Tang, T., Guo, Y., Souders, D. J., Li, X., Yang, M., Xu, X., & Qian, X. (2025). Moderating effects of policy measures on intention to adopt autonomous vehicles: Evidence from China. *Travel Behaviour and Society, 38*, Article 100921. https://doi.org/10.1016/j.tbs.2024.100921

Tengilimoglu, O., Carsten, O., & Wadud, Z. (2024). The effects of infrastructure quality on the usefulness of automated vehicles: A case study for Leeds, UK. *Journal of Transport Geography, 121*, Article 104042. https://doi.org/10.1016/j.jtrangeo.2024.104042

Tengilimoglu, O., Carsten, O., & Wadud, Z. (2023a). Infrastructure requirements for the safe operation of automated vehicles: Opinions from experts and stakeholders. *Transport Policy, 133*, 209–222. https://doi.org/10.1016/j.tranpol.2023.02.001

Tengilimoglu, O., Carsten, O., & Wadud, Z. (2023b). Implications of automated vehicles for physical road environment: A comprehensive review. *Transportation Research Part E: Logistics and Transportation Review, 169*, Article 102989. https://doi.org/10.1016/j.tre.2022.102989

Tiwari, V. (2024). Navigating the autonomous era: A detailed survey of driverless cars. *Journal of Engineering Research and Sciences, 3*, 21–36. https://doi.org/10.55708/js0310003

Townsend, R. M., Atkinson-Palombo, C., Terbeck, F., & Garrick, N. (2021). Hopes and fears about autonomous vehicles. *Case Studies on Transport Policy, 9*, 1933–1942. https://doi.org/10.1016/j.cstp.2021.11.001

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British J of Management, 14*, 207–222. https://doi.org/10.1111/1467-8551.00375

Uber self-driving crash "mostly caused by human error," 2019.

Ullah, I., Zheng, J., Severino, A., & Jamal, A. (2025). Assessing the barriers and implications of autonomous vehicles: Implementation in sustainable cities. *Sustainable Futures, 9*, Article 100564. https://doi.org/10.1016/j.sftr.2025.100564

Vellinga, N.E., 2023. Cyber security in (automated) vehicles and liability: the EU legal framework and (a lack of) compensation. Transportation Research Procedia, TRA Lisbon 2022 Conference Proceedings Transport Research Arena (TRA Lisbon 2022),14th-17th November 2022, Lisboa, Portugal 72, 132–138. https://doi.org/10.1016/j.trpro.2023.11.386.

Wang, J., Zhang, L., Huang, Y., Zhao, J., & Bella, F. (2020a). Safety of autonomous vehicles. *Journal of Advanced Transportation, 2020*, 1–13. https://doi.org/10.1155/2020/8867757
Wang, S., Jiang, Z., Noland, R. B., & Mondschein, A. S. (2020b). Attitudes towards privately-owned and shared autonomous vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour, 72*, 297–306. https://doi.org/10.1016/j.trf.2020.05.014
Wexler, N., & Fan, Y. (2022). Gauging public attitudes and preferences toward a hypothetical future Public shared automated vehicle system: examining the roles of gender, race, income, and health. *Transportation Research Record, 2676*, 588–600. https://doi.org/10.1177/03611981221090512
Wippelhauser, A., Tomaschek, T. A., Verdes, M., & Bokor, L. (2023). Real-life traffic data based ITS-G5 channel load simulations of a major Hungarian C-ITS deployment site. *Applied Sciences, 13*, 8419. https://doi.org/10.3390/app13148419
Wishart, D., Weaver, S., & Apuli, A. (2023). Autonomous vehicles: What are your intentions? *Transportation Research Part F: Traffic Psychology and Behaviour, 99*, 450–459. https://doi.org/10.1016/j.trf.2023.08.011
Wu, J., Liao, H., & Wang, J. W. (2020). Analysis of consumer attitudes towards autonomous, connected, and electric vehicles: A survey in China. *Research in Transportation Economics, 80*, Article 100828. https://doi.org/10.1016/j.retrec.2020.100828
Wu, S., Yu, B., Liu, S., & Zhu, Y. (2025). Autonomy 2.0: The quest for economies of scale. *Communication ACM, 68*, 28–32. https://doi.org/10.1145/3708012
Wu, S. S. (2020). Autonomous vehicles, trolley problems, and the law. *Ethics and Information Technology, 22*, 1–13. https://doi.org/10.1007/s10676-019-09506-1
Xiao, J., & Goulias, K. G. (2022). Perceived usefulness and intentions to adopt autonomous vehicles. *Transportation Research Part A: Policy and Practice, 161*, 170–185. https://doi.org/10.1016/j.tra.2022.05.007
Xiao, J., Goulias, K. G., Ravulaparthy, S., Sharda, S., Jin, L., & Spurlock, C. A. (2024). Evaluating the impacts of autonomous electric vehicles adoption on vehicle miles traveled and CO2 emissions. *Energies, 17*, 6127. https://doi.org/10.3390/en17236127
Xu, L., He, B., Zhou, H., & He, J. (2023). Impact and revolution on law on road traffic safety by autonomous driving technology in China. *Computer Law & Security Review, 51*, Article 105906. https://doi.org/10.1016/j.clsr.2023.105906
Xu, Z., Zhang, K., Min, H., Wang, Z., Zhao, X., & Liu, P. (2018). What drives people to accept automated vehicles? Findings from a field experiment. *Transportation Research Part C: Emerging Technologies, 95*, 320–334. https://doi.org/10.1016/j.trc.2018.07.024
Yigitcanlar, T., Wilson, M., & Kamruzzaman, M. (2019). Disruptive impacts of automated driving systems on the built environment and land use: An urban planner's perspective. *Journal of Open Innovation: Technology, Market, and Complexity, 5*, 24. https://doi.org/10.3390/joitmc5020024
Zhang, T., Tao, D., Qu, X., Zhang, X., Zeng, J., Zhu, Haoyu, & Zhu, Han (2020). Automated vehicle acceptance in China: Social influence and initial trust are key determinants. *Transportation Research Part C: Emerging Technologies, 112*, 220–233. https://doi.org/10.1016/j.trc.2020.01.027
Zhou, Y., & Xu, M. (2023). Robotaxi service: The transition and governance investigation in China. *Research in Transportation Economics, 100*, Article 101326. https://doi.org/10.1016/j.retrec.2023.101326
Zhu, A., Yang, S., Chen, Y., & Xing, C. (2022). A moral decision-making study of autonomous vehicles: Expertise predicts a preference for algorithms in dilemmas. *Personality and Individual Differences, 186*, Article 111356. https://doi.org/10.1016/j.paid.2021.111356
Ziegler, D., & Abdelkafi, N. (2023). Exploring the automotive transition: A technological and business model perspective. *Journal of Cleaner Production, 421*, Article 138562. https://doi.org/10.1016/j.jclepro.2023.138562