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Navigating the Technology Ahead: A Comprehensive Analysis Of European Union Autonomous Vehicle Regulations And Comparison with Regions Worldwide

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Abstract

This master's thesis comprehensively analyses the European Union's regulations on autonomous vehicles, comparing them to those in other regions worldwide (Singapore, United Kingdom, United States, Germany, Norway, Sweden, Australia, Japan and China). The study aims to understand the legal framework, policies, and guidelines governing autonomous vehicles within the EU and globally. The research employs a systematic search strategy using various related terminologies from databases, as well as official publications, reports, legislation, guidelines, and other authoritative sources related to autonomous vehicle regulations in the European Union and other countries. The results highlight the key components and provisions of the European Union's autonomous vehicle regulations, as well as the regulations in other regions worldwide. The study identifies similarities and differences between the European Union's regulations and those of other regions, discussing the implications of these differences for the future of autonomous vehicle technology. The findings suggest that international collaboration, standardization, continuous review of regulations, and stakeholder commitment are crucial for addressing the challenges posed by the variation in regulations across regions. This research contributes to the broader discussion of autonomous vehicle developments worldwide, providing valuable insights for policymakers, industries, and researchers involved in autonomous vehicle technologies.

1 Introduction

According to the World Health Organization (WHO), 1.3 million people die yearly in road accidents. Most road accidents happen due to human errors (Sun et al., 2016; WHO, 2018). In 2016, traffic accidents were the fifth cause of death in the EU, with roughly six people out of every 100,000 dying on the roads of the European Union (Statista Research Department, 2022). Around 20,600 people died in road traffic accidents on the European Union’s roads in 2022, according to the European Commission, which was a 4% increase compared to 2021 as traffic levels recovered after the pandemic (Directorate-General for Mobility and Transport, 2023a). Autonomous vehicles are a rapidly evolving technology that has the potential to revolutionize transportation (Parekh et al., 2022); they could help reduce road accidents often associated with human errors. Autonomous vehicles have the potential to increase mobility for people who cannot drive, such as older people, children, and people with disabilities(NHTSA, 2020).

The terms “autonomous vehicle”, “driverless vehicle”, “self-driving” or “automated vehicle” are often used interchangeably to describe a vehicle that can perform some or all driving tasks without human intervention”(Andraško et al., 2021). For reasons of simplicity, the terms “autonomous vehicles” will be used throughout the text. In the context of autonomous vehicles, a taxonomy has been established by SAE International (formerly the Society of Automotive Engineers) to categorize driving automation into six levels. These levels span from no driving automation at Level 0 to complete driving automation at Level 5. This classification system recognizes three key participants: the human user, the driving automation system, and other vehicle systems and components (Society for Automotive Engineers, 2021). The levels refer to driving automation features engaged during on-road operation, and the specific level exhibited depends on the features in use, with the term ‘autonomous vehicle (AV)’ usually associated with the automated vehicles in levels 4 and 5(J. Li et al., 2021).

The following table summarizes the Levels of driving automation according to the standard of SAE International

Table 1 Showing Levels of driving automation according to the standard of SAE International

SAE Level	Description
Level 0	**No Automation:** The driver is always fully in control of the vehicle.
Level 1	**Driver Assistance:** The vehicle has systems that can assist the driver with specific tasks, such as steering or acceleration, but the driver is still responsible for overall control.
Level 2	**Partial Automation:** the vehicle has systems that can assist with both steering and deceleration simultaneously, but the driver must remain engaged and monitor the driving environment
Level 3	**Conditional Automation:** The vehicle can take full control of the driving tasks under certain conditions, but the driver must be available to take over when requested by the system.
Level 4	**High Automation:** The vehicle can perform all driving tasks under certain conditions and environments without human intervention, but the driver may have the option to override the system manually.
Level 5	**Full Automation:** The vehicle can perform all driving tasks under all conditions and environments without human intervention. No driver is required.

Source: SAE International (2014)

The global autonomous vehicle market amounted to almost 17,000 units in 2022; It is projected that the market will grow and reach the size of some 127,000 units in 2030(Martin Placek, 2023). Several pilots are happening worldwide. For example, AV experiments(buses) have been conducted in Sweden, with the first pilot taking place in Stockholm(Hansson, 2020). Since December 2020, Cruise has been conducting autonomous vehicle tests in San Francisco, while Waymo, an Alphabet subsidiary, has been testing in Phoenix, Arizona since 2017(McCarroll & Cugurullo, 2022). The current autonomous models available on the market, such as Tesla's Autopilot, Audi's Traffic Jam Assist, and GM's Super Cruise, are primarily at level 2, requiring a human driver to be behind the steering wheel for safety reasons(Sever & Contissa, 2024). Mercedes-Benz introduced a level three Drive Pilot system approved for use in Germany, limited to speeds up to 70 km/h in dense traffic scenarios on German motorways(Sjoberg, 2023). Level 4 vehicles, like shuttle buses at airports and university campuses, exist and operate on specific predefined routes and specific conditions. Level five vehicles are not yet available for sale.

The introduction of autonomous vehicles has, however, led to several chaotic situations in various cities. In Arizona, a woman was struck by Uber’s autonomous vehicle in 2018(Wakabayashi, 2018). According to a study conducted between 2019 and 2021, there were 12 accidents involving Tesla’s self-driving cars in San Jose, resulting in two fatalities and 13 injuries(Seo, 2023). In San Francisco, self-driving cars have forced human drivers to use bike lanes, causing traffic disruptions (Medina, 2023). In October 2023, a crash involving a GM Cruise robotaxi Autonomous Vehicle (AV) and a pedestrian in San Francisco resulted in a severe injury, further highlighting the challenges associated with autonomous vehicles (Koopman, 2024). The potential for hackers to exploit vulnerabilities in connected cars and cause accidents or other disruptions has also been identified as a source of chaos associated with autonomous vehicles (Meyer et al., 2021).

The world needs appropriate regulations to be established by different government regulators. As the massive deployment of AVs becomes increasingly predictable (Martin Placek, 2021), it is crucial to understand and analyze the regulatory frameworks governing their operation to ensure safe and efficient integration into existing transportation systems. These regulations are necessary to control the tests performed on Autonomous Vehicles and ensure public safety regarding this promising technology. Furthermore, providing adequate regulations is key to reducing the potential legal and technological risks often associated with the technology. The risks encompass

various aspects, including legal liabilities in case of accidents or security breaches, and privacy concerns related to data collection and usage. Clear and comprehensive regulations can establish standards for safety requirements, data protection, privacy concerns, testing and certification procedures, and legal frameworks. Also, if the public sees possible threats or does not accept this emerging technology, it could stop the development of this technology and stop it from reaching the next stages of implementation (Bansal et al., 2016; Kalra, 2017); a clear legal framework would be the best way to overcome people's doubts. This would allow the benefits of Autonomous Vehicles to be explored at full potential without hindering innovation while avoiding the potential production of Autonomous vehicles representing a danger for public use.

The regulations related to autonomous vehicles (AV) vary across the globe (S. Li et al., 2019). Transport plays a very important role in the European Union's economy, allowing it to connect people and businesses across various EU regions and countries. The European Commission aims to make Europe a global leader in autonomous and connected systems, focusing on the integration of automation and connectivity in vehicles (European Commission, 2018). In the Commission's Sustainable and Smart Mobility Strategy, one of the significant stages specifies that by 2030 autonomous mobility will be deployed on a large scale across the EU as one of the strategies to address transport's negative impacts in terms of greenhouse gas emissions, environmental pollution, accidents, congestion and loss of biodiversity (Pape, 2021). Having identified potential benefits in the use of Autonomous Vehicles, the European Union is engaged in the development of a comprehensive framework. In line with the European Union's historical emphasis on consumer protection, which includes stringent product requirements and clear safety compliance accountabilities, the approach to autonomous vehicles is no exception, as it also underscores the necessity of robust regulatory frameworks(Sever & Contissa, 2024). Regulatory efforts have been made to govern autonomous vehicles. These include for example a call to revise the current legislative framework for liability rules and insurance by the Directorate-General for Parliamentary Research Services (EPRS) to support the legislative initiative report on civil law rules on robotics in 2018 (Evas T., 2018). The EU has established a comprehensive legal framework for AVs, which includes the General Data Protection Regulation (GDPR), the eCall system, and the Intelligent Transport Systems Directive. (Benyahya et al., 2023; Directorate-General for Mobility and Transport, 2023b; European Union, 2016). The General Data Protection Regulation (GDPR), safeguards the privacy and security of personal data collected by AVs. The

eCall system is another important aspect of the EU's regulations, requiring all new AVs to be equipped with an emergency call system that automatically contacts emergency services in the event of an accident. Furthermore, the Intelligent Transport Systems Directive focuses on promoting the deployment of intelligent transport systems, including AVs, to enhance road safety, traffic management, and sustainable mobility.

In April 2022, the European Union released a preliminary version of its legislation for vehicles equipped with autonomous driving systems (ADS). Since July 2022, the Regulation (EU) 2019/2144 of the European Parliament and of the Council on Motor Vehicle Type Approval Requirements (Vehicle General Safety Regulation) was implemented. The regulation sets out the rules for approving specific types of vehicles, particularly autonomous and fully autonomous vehicles(European Commission, 2022b). The different rules that govern the application of the (EU) 2019/2144 are formulated in the Commission Implementing Regulation (EU) 2022/1426 of 5 August 2022(European Commission, 2022a).

While the specifics of their regulatory frameworks differ, both the US and China have recognized the importance of policy and regulation in shaping the autonomous driving industry. In December 2023, China implemented its first regulation on the commercial operation of autonomous vehicles. This regulation sets ground rules for the commercial operation of autonomous vehicles, marking a significant step in the country's efforts to regulate autonomous vehicles. The United States is also one of the leading countries in autonomous vehicle development, with the ability to enact separate laws from the federal government, allowing states to try out different kinds of laws to regulate autonomous vehicle use (Punev, 2020).

In Canada, the provinces and territories are responsible for their legislation regarding autonomous vehicle testing and use, and there are no federal laws allowing for the operation of autonomous vehicles on public roads; AV test organizations must comply with all regulations set by the provincial and territorial governments based on their laws and regulations(Abu Bakar et al., 2022). Testing organizations should engage with municipal authorities to consider the local traffic conditions and infrastructure availability during testing activities. Testing organizations should submit and address the safety management plan as well as the test management plan.

Finally, several countries have collaborated on international standards and regulations for the possible deployment of autonomous vehicles. For example, in 2019, the United Nations Economic

Commission for Europe adopted regulations on cybersecurity for connected and autonomous vehicles, establishing binding rules for securing vehicle software and hardware(Baldini, 2020).

The current literature on autonomous vehicles focuses primarily on the technological advancements and potential benefits of these vehicles. However, there is a significant gap in the existing research regarding the regulatory frameworks that govern their development and deployment (especially in the European Union with a simultaneous focus on the Safety, Liability and privacy aspects of the regulations). While some studies have investigated the legal framework, policies, and guidelines governing AVs, little research has analyzed and compared the regulatory approaches of the European Union with various countries or regions towards AVs.

The objective of this master's thesis is to conduct a comprehensive analysis of the European Union's regulations on autonomous vehicles. The study aims to understand the legal framework, policies, and guidelines governing autonomous vehicles within the EU. Additionally, it seeks to compare these regulations with those in other regions worldwide, identifying similarities, differences, and best practices. The goal is to provide valuable insights for policymakers, industries, and researchers involved in autonomous vehicle technologies. This research will ultimately analyze the pros and cons of the current regulations and provide insights for industries and relevant stakeholders, gaining a holistic understanding of the current landscape of the AV industry and contributing to the broader discussion of AV developments worldwide.

The aimed objective creates ample opportunity to gear up the following main research question: how do the European Union’s autonomous vehicle regulations compare to those of other regions worldwide, and what are the implications for the future of autonomous vehicle technology? The main research question is broken down as follows:

- What are the key components and provisions of the European Union's autonomous vehicle regulations?
- What are the autonomous vehicle regulations in other regions worldwide?
- What are the similarities and differences between the European Union's regulations and those of other regions worldwide?
- What are the implications of the differences in autonomous vehicle regulations for the future of autonomous vehicle technology?

This research is structured as follows: Section 2 presents the methodology, Section 3 presents the comparison and the analysis of the results, Section 4 presents the discussion, and Section 5 presents the major conclusions.

2 Methodology

To obtain a comprehensive overview of regulations for autonomous vehicles, a systematic search strategy using various related terminologies from databases was used. Then based on the relevance of papers, 30 papers published between 2017 and 2024 were selected. The next section below describes the methodology for the database search strategy in more detail. To have a better overview of the autonomous vehicle regulations in the European Union and the selected regions, official publications, reports, legislation, guidelines, and other authoritative sources related to autonomous vehicle regulations in the European Union and other countries were also consulted. These include documents from the European Commission, transport authorities, and regulatory bodies.

2.1 Search Strategy

This research uses the methodological framework by (J. Li et al., 2021) which combines the frameworks used by (Jalali & Wohlin, 2012; Mualla et al., 2019; Wee & Banister, 2016) for database searches. Web of Science (core collection) and ScienceDirect were selected as literature databases. “Automated” and “self-driving” were chosen as alternative words for “autonomous”. For “regulation(s)”, “policy” and “law(s)” were chosen. The following search query was then applied to the databases with Boolean operators: ((autonomous OR automated OR self-driving) AND (vehicles) AND (regulation(s) OR policy OR law(s))). As per the framework of (Mualla et al., 2019), a coarse inclusion was conducted by stopping article collection in the database after more than 10 articles did not match the topic. The remaining paper’s abstracts were then filtered after excluding duplicate results, followed by full-text screening (fine-grained inclusion) for inclusion. An article was included if (1) the entire manuscript was written in English (2) the article is related to government regulations on autonomous vehicles (3) the article was not published before 2017 (4) the article is related to regulations (5) the article is related to regions or countries with most of the AV-related developments. To ensure a comprehensive overview of regulations for autonomous vehicles, specifically regarding safety requirements, data protection, privacy concerns, testing and certification procedures, and legal frameworks, articles primarily focusing

on proposed policies or regulation models with limited insight into the actual regulations were excluded.

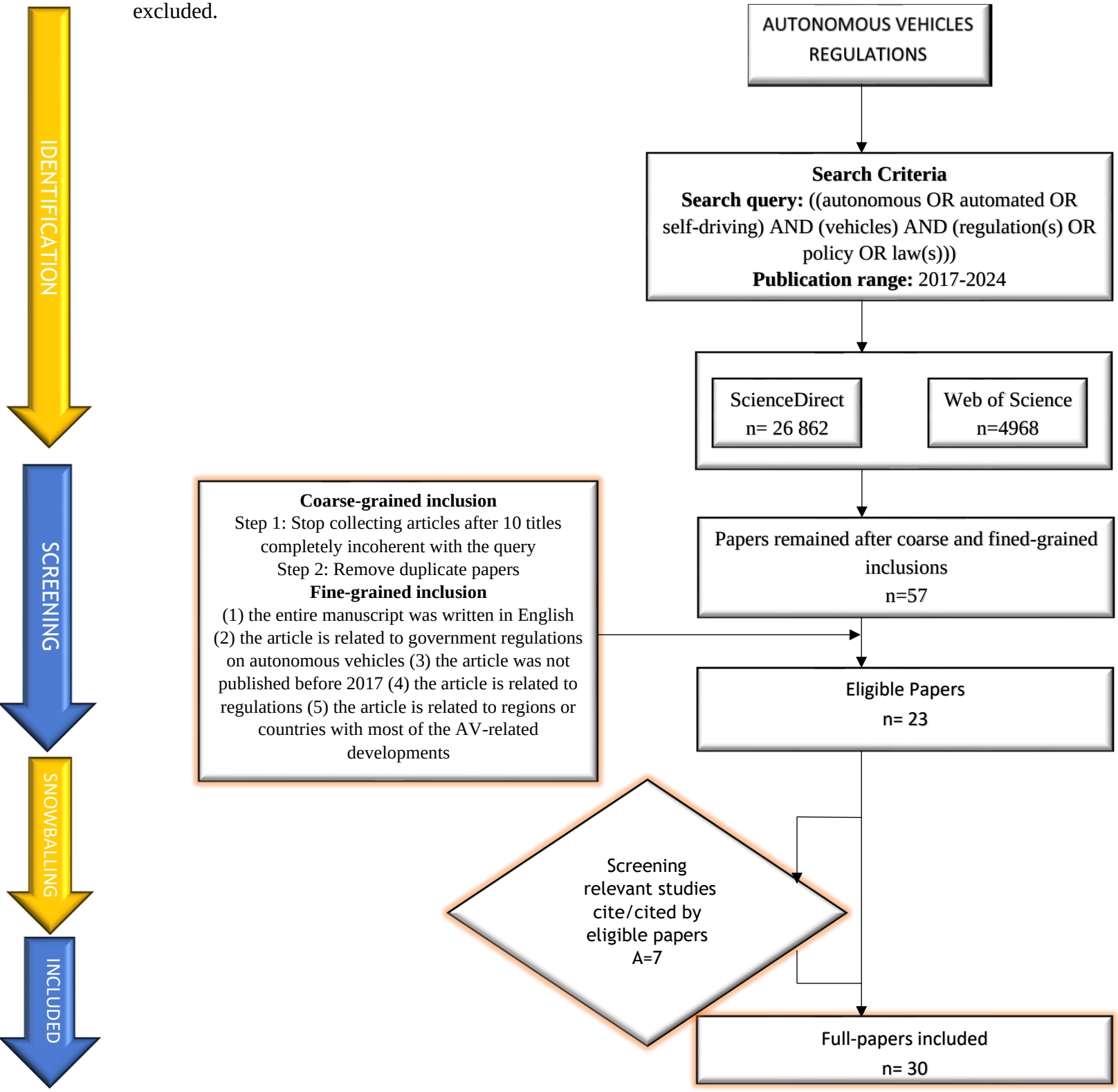

Figure 1. Showing search strategy

2.2 **Reviewed Results**

To compare Autonomous Vehicles regulations in the European Union to worldwide regulations, we apply an established theoretical framework by (Taeihagh & Lim, 2019) which has been applied in previous studies on the governance of disruptive technologies in the transport sector(Y. Li et al., 2018; Rosique et al., 2019; Tan & Taeihagh, 2021). The framework consists of defining and classifying Autonomous Vehicles associated risks and then analyzing the government responses to identified risks. The risks include safety, liability, privacy and cybersecurity (in the European Union only). We then analyzed the current regulations in the European Union and other regions worldwide. The regulations were first examined at the EU level. Germany and Sweden were analyzed as examples of governments's approach at country level. Germany was chosen since it was the first member state to adapt the regulations to AVs at EU level. Sweden was also chosen as country as they also had a unique interpretation of some EU regulations as it will be discussed in the following parts. The regulations of the European Union were compared to the regulations of the following countries in the analysis (this list includes some countries(regions) in the EU): Singapore, United Kingdom, United States, Germany, Norway, Sweden, Australia, Japan and China as most AV-related developments can be associated to those regions. Additionally, they score high on the Autonomous Vehicles Readiness Index (AVRI) top 30 in terms of policy and legislation: first, second, sixth, seventh, tenth, fifteenth, seventeenth, eighteenth and twenty-first positions respectively. The AVRI is a tool to measure how prepared different countries are for AVs(KPMG, 2020; Tan & Taeihagh, 2021).

3 Analysis of results

In this section, we systematically analyze AV regulations in the European Union and across other regions. Each subsection analyses the regulations in this order: the European Union, Germany, Sweden and Norway, Singapore, China, Japan, Australia, the United States and the United Kingdom. It is divided into three subsections. Subsection 3.1 examines testing and safety regulations, comparing countries and regions. Subsection 3.2 focuses on liability regulations in the European Union and selected countries. Subsection 3.3 compares privacy regulations in different countries and regions. Rounding out the section, subsection 3.4 discusses cybersecurity regulations specifically within the context of the European Union. The results are summarized in Appendix A, a comparative table between the different investigated countries and the European Union.

3.1 **Testing and Safety**

Safety and testing regulations refer to requirements and protocols established by governments and other bodies to ensure that autonomous vehicles are safe to operate and that they can be tested properly before they are introduced to the market or public roads. Safety and testing regulations are essential because they address certain risks associated with Autonomous Vehicles (AVs) as they can pose a challenge to public safety as in the previously cited examples.

3.1.1 **European Union**

The United Nations (UN), the Geneva Convention, and the Vienna Convention have significantly influenced the regulation of autonomous vehicles in the European Union due to their role in setting international standards and guidelines for road safety and traffic management. Most of European Union countries are part of both the conventions. Established in 1949, the convention is an international agreement designed to promote the development and safety of international road traffic through the establishment of standardized regulations(United Nations, 1950). The convention defines a driver as any person who drives a vehicle guides animals, or is in actual physical control of the vehicle(Bartolini et al., 2017). This interpretation reflects the convention's emphasis on road safety and the need for human intervention and control in vehicle operations. While the Geneva Convention does not explicitly address autonomous vehicles, it requires a driver who can control the vehicle at all times(Bartolini et al., 2017; Hansson, 2020; Vellinga, 2017). The Vienna Convention of 1968 supersedes the Geneva Convention (as stated in Article 48) and is ratified by several countries, including Germany(United Nations, 2006). Both conventions include requirements regarding the driver's responsibilities and obligations(Vellinga, 2017).

The Vienna Convention on Road Traffic of 1968 is an international treaty designed to facilitate cooperation among nations concerning road traffic. Under the Vienna Convention on Road Traffic, every moving vehicle or combination of vehicles must have a driver who controls it(United Nations, 1969). The convention emphasizes the importance of having a driver fully in control of a vehicle on public roads. High-level autonomous systems were unknown in 1968 and therefore not regulated. Regulations at that time were based on a vehicle controlled by a human driver. In 2016 and July 2022, the Vienna Convention was amended, opening the Convention to the use of Level 3 autonomous driving. However, the requirement of having a driver who should always be ready to take control of the AVs for certain types of vehicles stood. Initially, in Europe, the testing of

autonomous vehicles was still predominantly confined to private streets, pre-defined routes, or restricted to very low speeds(Taeihagh & Lim, 2019). In 2022, there was a significant advancement in autonomous driving regulation within the European Union. Introduced in 2022, The EU New General Safety Regulation set a legal framework enabling the deployment of autonomous and fully autonomous vehicles on European roads(European Commission, 2022b). Technical rules were adopted alongside the regulation to ensure the safety and technological readiness of autonomous vehicles before their introduction into the market.

Regulation (EU) 2022/1426, effective from August 5th, 2022, establishes regulations for implementing Regulation (EU) 2019/2144 -which amends (EU) 2018/858- of the European Parliament and Council concerning standardized procedures and technical requirements for approving the autonomous driving system (ADS) of fully automated vehicles(European Commission, 2022a). This regulation outlines the criteria for approving three systems tailored to specific use cases:

- Fully autonomous vehicles for the transport of passengers/goods within a predefined area (e.g. robotaxis).
- "Hub to Hub": fully autonomous vehicles for the transport of passengers/goods in a predefined route.
- "Valet parking": fully autonomous mode for parking in predefined installations.

These regulations represent significant steps towards facilitating the deployment of Autonomous Driving Systems (ADS), establishing standards for safety and performance in different use cases and vehicle categories:

Table 2 Showing regulations that govern AVs in the European Union

Regulation	Scope
EU Regulation 2019/2144	Type-approval requirements for motor vehicles and their trailers, including general safety and protection of occupants and road users.
EU Regulation 2022/1426	Lays down rules for the application of Regulation 2019/2144 regarding uniform procedures and technical specifications for the type-approval of ADS in fully autonomous vehicles.
Annex I to Regulation 2019/2144	Lists UN Regulation 157 on autonomous lane-keeping systems as compulsory in the EU for automated vehicles.
Annex II, Part I, Appendix 1 of Regulation 2018/858	Requirements for whole-vehicle type approval of fully autonomous vehicles complemented with ADS type approval under Regulation 2022/1426.

Manufacturer Requirements	Manufacturers must provide information documents based on templates for type approval, demonstrate safety management systems, and validate ADS performance in relevant scenarios.
EU Type-Approval Certificate	Issued based on templates in Annex III to Implementing Regulation 2020/683, ensuring consistency in entries relevant for ADS type approval.
Regulation 2020/683	Administrative requirements for the approval and market surveillance of motor vehicles and their trailers, and of systems, components, and separate technical units intended for such vehicles

Source: Official Journal of the European Union, COMMISSION IMPLEMENTING REGULATION (EU) 2022/1426

Regulation (EU) 2022/2236, adopted in June 2022, focuses on technical requirements for vehicles produced in unlimited series, small series, and fully automated vehicles(European Commission, 2022b). It allows for the approval of fully autonomous vehicles, with or without a human driver's seat, in a limited series. This regulation introduces adapted technical requirements for systems beyond the autonomous driving system, including passive safety, emissions, and general safety. It considers three architectures of autonomous vehicles: dual-mode vehicles, fully autonomous vehicles without a driver seat but with occupants, and fully autonomous vehicles without a driver seat or occupants in certain categories.

The following table highlights the key characteristics of autonomous requirements according to the regulation:

Table 3 Showing key characteristics of autonomous requirements according to Regulation (EU) 2022/2236

Autonomous vehicles	Fully autonomous vehicles
• Driver present • Automated driving mode limited to motorways up to 60 km/h, up to 130km/h from January 2023 • No limitation to the size of the vehicle series • Cybersecurity measures • Capability to handle automated driving on motorways (lane keeping and lane change) • Monitoring safety in the field • Interaction with driver	• No driver present • Automated driving permitted in defined areas • Limit on size of vehicle series to max.1500 vehicles per model per year Review of limit by July 2024 • To be allowed from September 2022 • Capability to handle automated driving in defined areas • Advanced safety monitoring in the field • Interaction with passengers and road users • Remote intervention operator • New vehicle design possibility (no driver seat)

Source: European Commission, NEW RULES ON VEHICLE SAFETY AND AUTOMATED MOBILITY, 2022

While countries within the EU must adhere to these regulations - including the Geneva and Vienna conventions, they can have their interpretations and regulations for the use and operation of fully autonomous vehicles within their borders(Lee & Hess, 2020). These regulations may include additional testing and safety measures, operational restrictions, or specific requirements for the use of fully autonomous vehicles in certain areas or situations. However, these regulations must not conflict with the EU regulations and must ensure the safety and protection of vehicle occupants and other road users.

The following technical requirements ensure that the Autonomous Driving System of fully autonomous vehicles (ADS) meets stringent standards for safe and efficient operation in the EU:

Table 4 Showing ADS technical requirements in the EU

Requirement	Description
Operational Design Domain (ODD)/ operating conditions under which a given ADS is specifically designed to function	The ADS must perform the entire Dynamic Driving Task within its defined ODD
Basic Performance	Capabilities like object detection, event response, and planning functions must be demonstrated
ADS Functions	A detailed description of internal and external functions, including backend infrastructure requirements.
Components	Overview of major components such as control units, sensors, actuators, maps, and other hardware elements
Performance Requirements	Ability to operate within ODD, adapt to traffic conditions, and prioritize safety
Safety Concept	Manufacturer statement affirming the ADS is free from unreasonable risks for occupants and road users
Verification & Validation	Manufacturers must validate performance requirements, including operational design domain (ODD) adherence

Source: Official Journal of the European Union, COMMISSION IMPLEMENTING REGULATION (EU) 2022/1426

It is worth noting that the list of requirements is not exhaustive, as further details and specifications are included in the regulations.

3.1.2 **Germany**

Germany can be considered a legal pioneer in the EU as it was the first Member State to adapt the regulations to AVs(Sever & Contissa, 2024; Tran & Le, 2022).

Germany has a strong automotive industry and it makes it attractive for testing for autonomous vehicles(Akca et al., 2020; Lee & Hess, 2020). However, it is crucial to adhere to specific legal requirements. Vehicles need to be registered and operated following regulations. As previously mentioned, The Vienna Convention mandates that all vehicles must have drivers capable of intervening if necessary(Lee & Hess, 2020).

Germany has established a comprehensive regulatory framework for autonomous vehicles. The Federal Ministry for Digital Affairs and Transport (BMDV) is like the glue that keeps everything together and makes sure everyone is on the same page (Sever & Contissa, 2024; Tran & Le, 2022). They bring industry, research, associations, administration, and politics to the table to work together towards making sure that autonomous vehicles can be safely and smoothly integrated on public roads. The Road Traffic Authority (RTA) is responsible for overseeing and enforcing road traffic regulations.

Several laws and ordinances govern different aspects of autonomous vehicles. These include the Road Traffic Act (StVG), the Road Traffic Ordinance (StVO), the Road Traffic Licensing Regulations (StVZO), and the Driving License Regulation (FeV). These regulations cover penalties, fines, driving licenses, vehicle registration, traffic rules, and vehicle construction requirements(Sever & Contissa, 2024). The Federal Motor Transport Authority (KBA) serves as the type approval authority. It is responsible for ensuring that vehicles meet safety and environmental standards.

Germany allows autonomous driving at Levels 3 and 4. The Autonomous Driving Act, effective in July 2021, permits Level 4 autonomous driving within defined operating areas(Xu et al., 2023). This legislation regulates technical requirements and testing procedures. It also regulates the obligations of those involved in vehicle operation, data processing, and the activation of autonomous driving functions. In February 2022, an ordinance(“Autonomous Vehicle Approval and Operation Ordinance (AFGBV)”) was introduced to provide further specifications on technical requirements, procedures, operating permits, approval of operating ranges, and market

surveillance for vehicles with autonomous driving functions(Sever & Contissa, 2024; Tran & Le, 2022).

However, the Level 5 autonomy, which lacks the provision for human intervention is currently not permitted under German law(Tran & Le, 2022; Xu et al., 2023). The Road Traffic Act allows for the use of automated driving systems in specific situations where the driver can transfer control to the system. However, to allow Level 5 autonomy, further legislative steps are required.

Special permits, obtained from the responsible District Office under the German Road Traffic Act, are required for testing on public roads(Tran & Le, 2022). The approval process evaluates the safety and compliance of the vehicles and testing generally takes place on designated tracks. Comprehensive insurance coverage is recommended. Safety standards encompass functional safety and protection against cyber-attacks (with specific approvals and permits necessary for autonomous shuttles and taxi-like services.)

3.1.3 **Sweden and Norway**

Before the advances in the regulation of the AVs mentioned at the EU level, Norway and Sweden were already referring to the Vienna Convention and Geneva Convention when it comes to the rules concerning the driver. As pointed out above, these conventions allude to having a driver who has full control over the vehicle. However, the Swedish report's discussion concerning the Vienna Convention is more extensive than that of Norway(Hansson, 2020). Indeed, it points out that the Vienna Convention makes it "inappropriate to introduce national driver-specific rules". The report, however, notes that there would be no sanctions if Sweden were to read the convention in a different way than it was written.

In terms of safety and testing regulations for autonomous vehicles, both countries have implemented regulations for autonomous vehicles. Some regulations allow experiments with AVs on public roads(Hansson, 2020). In Sweden, an ordinance was passed to allow such experiments with a driver physically present. In Norway on the other hand, a new legislation was passed that allows for experiments with AVs on public roads without a driver physically in or outside the vehicle. In both countries, it is imperative for the applicant that they meet several safety and technical requirements to obtain a permit(Hansson, 2020). These include vehicle control and emergency procedures.

3.1.4 **Singapore**

Singapore is one of the world's leaders in creating a regulatory framework for autonomous vehicles (AVs)(Tran & Le, 2022). In 2017, they amended the Road Traffic Act to allow the trialling and usage of equivalent Level 3, 4, and 5 AVs on Singaporean roads, recognizing AVs as a type of motor vehicle(Law et al., 2015; Tan & Taeihagh, 2021). The Land Transport Authority (LTA) has also set up the Committee on Autonomous Road Transport for Singapore (CARTS) to facilitate the deployment of AVs and transform the land transport system. To ensure safety, all AVs in Singapore must undergo testing in a controlled environment and comply with safety requirements outlined in the Technical Reference (TR) 68(Tran & Le, 2022). TR 68 provides a safety case methodology for AVs, including systematic hazard identification (HAZID), hazard analysis, and assessment of safety risks. These risks must be mitigated through measures such as safe system design, functional safety, and software safety management. The safety assessment process and associated measures must be documented in a Safety Case Report, which requires approval from the LTA before an AV can operate on public roads(Tran & Le, 2022). Additionally, Singapore mandates specific authorizations from the LTA for the trial and usage of AVs, which may include conditions such as a designated geographical area for the approved trial.

3.1.5 **China**

China is very involved in the autonomous vehicle industry. For example, the market size of Chinese autonomous driving platforms reached 81.12 million in 2022(Xu et al., 2023). Thus, to support AVs, China has introduced different regulations and plans at both national and local levels. These initiatives include, for example, "the provision of Pudong New Area of Shanghai Municipality on Promoting the Innovative Application of Driverless Intelligent Connected Vehicles"(Standing Committee of Shanghai Municipal People’s Congress, 2022; Xu et al., 2023). Companies testing autonomous vehicles in this area are required to obtain an authorized confirmation of self-safety declaration for their vehicles. In addition, it is also indicated that vehicles must comply with the prescribed technical standards. They must also pass road tests without traffic offences or safety accidents. Another initiative is the amendment, by the Minister of Public Safety of China in 2021, thus publishing "draft proposed amendments of the Road Traffic safety law(Chancellor et al., 2021; Xu et al., 2023). The document clarifies certain points in particular on road testing and access by vehicles equipped with autonomous driving functions. The draft proposed in particular that AVs be tested at specific times and in specific places. It also

proposed that vehicles pass tests on closed lanes beforehand. Also, those needing access to the road should always apply for motor vehicle number plates.

However, although regulatory initiatives were mainly local, at the end of 2023, China published a set of national safety guidelines for the use of AVs. It prescribes that buses and trams are only allowed in certain specific contexts, namely, on certain physically closed routes with basic road conditions. In addition, the presence of a human safety operator in buses, subways, and cargo ships. In addition, there is a ban on the transport of dangerous products by AVs. In addition, fully autonomous(L5) taxis can be monitored remotely but lower levels of autonomous vehicles require a safety operator.

3.1.6 **Japan**

In terms of safety regulations for AVs in Japan, the Road Transport Vehicle Act and the Road Traffic Act (RTA) are mandatory(Imai, 2019). These regulations have been amended. The amendments were to accommodate Level 3 AVs and above with safety standards (while also considering the specific requirements for Level 4 AVS)(Imai, 2019). This means that these vehicles are not allowed to operate unless they meet applicable standards. In line with those acts, the operational design domain (ODD) was reviewed for AVs. It determines the scope within which the safety of an AV system is tested from a technical perspective(Imai, 2019). This includes factors such as road conditions and geographic conditions. The revised Vehicle Act determines what is required as maintenance for AV driving.

In Japan, the current RTA permits level 3 driving. However, there were some changes to the Road Traffic Act in 2022(Umeda, 2022). The new amendment made it easier for people to ride electric kick scooters, and it also introduced a new rule for level 4 AVs. Service providers must obtain permission to operate (under remote monitoring) from the relevant public safety commissions in depopulated areas. This is done under strict rules, including specific times, areas and some speed limits.

3.1.7 **Australia**

The National Transport Commission is responsible for the development of the regulatory framework for AVs in Australia(Thiele-Evans et al., 2021). In addition, other legislative authorities such as the different states and road regulators must implement the road rules and safety requirements that apply to AVs(Kaye et al., 2019; Lee & Hess, 2020; Thiele-Evans et al., 2021).

In Australia, autonomous vehicles can be tested but this requires a permit issued by a relevant state/territory. Some, such as Queensland and Victoria, are renowned for the regulation of autonomous vehicles(Kaye et al., 2019; Thiele-Evans et al., 2021). For example, Queensland introduced the Motor Accident Insurance and Other Legislation Amendment Act 2019. This includes provisions regarding the testing of autonomous vehicles and insurance requirements. Victoria, on the other hand, passed the Road Safety Amendment (Automated Vehicles) Act 2018, which enables the operation of autonomous vehicles on its roads.

In 2016, the NTC was tasked with analyzing how to implement certain legislative reforms. This was in particular to overcome obstacles to the development of autonomous vehicles(Abu Bakar et al., 2022; Lee & Hess, 2020). Thus, in 2017, the NTC published guidelines for the testing of autonomous vehicles in Australia. The first concern was safety(Abu Bakar et al., 2022). The guidelines suggested carrying out preliminary tests in closed test facilities. This was accompanied by an obligation to have a human safety driver during road tests unless he is exempt. Testing organizations are encouraged to report serious incidents and take into account the impact on vulnerable road users.

3.1.8 **United States**

In the United States, the testing and deployment of AVs are regulated at the state level(Aoyama & Alvarez Leon, 2021; Ilkova & Ilka, 2017). However, there is, at the federal level, the National Highway Traffic Safety Administration which indicates the guidelines for autonomous driving systems(Taeihagh & Lim, 2019). Some states adopted early legal frameworks to regulate the testing and deployment of AVs. For example, Nevada was the first state to pass the first legislation allowing AV testing on public roads in 2011. California is one of the top states for autonomous vehicle testing on public roads(Shladover & Nowakowski, 2019). As of 2017, 42 manufacturers were authorized to produce AVs in the state(Hess, 2020; Shladover & Nowakowski, 2019). The California Department of Motor Vehicles published revised regulations in February 2018 that permitted remote supervisors for vehicles equipped with advanced autonomous vehicles (AV) technology, changing the initial policy of requiring human driver-supervisors to be behind the wheel for all AV testing(Hess, 2020; Shladover & Nowakowski, 2019). In 2022, the NHTSA established an order(amended in April 2023) for manufacturers and operators to record accidents for autonomous vehicles of levels L3 to L5(NHTSA, 2021). This involves all crashes in a vehicle

equipped with the specified systems that result in injury or property damage. The different levels of autonomous vehicles (L0 to Level 5) are allowed in the USA but this varies from one state to another. Indeed, depending on the level of autonomy(automation) and the state in charge, certain conditions apply to the regulation of AVs. The following table (with specific remarks below the table) from the Insurance Institute for Highway Safety summarizes the specific requirements according to the states.

Table 5 Showing the Insurance Institute for Highway Safety summarizes the specific requirements according to the states in the US

		DOES THE DRIVING AUTOMATION LAW/PROVISION…		
State	**What type of driving automation on public roads does the law/ provision permit?**	**Require an operator to be licensed?**	**Require an operator to be in the vehicle?**	**Require liability insurance?**
Alabama	Deployment-commercial vehicles only	Not addressed	no	Yes; $2,000,000
Arizona	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	yes
Arkansas	Deployment-commercial vehicles only	yes	Depends on level of vehicle automation	Yes
California	deployment	Depends on vehicle	no	Yes; $5,000,000
Colorado	deployment	no	Not addressed	no
Connecticut	testing	yes	yes	Yes; $5,000,000
District of Columbia	testing	Yes	no	Yes; $5,000,000
Florida	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	yes
Georgia	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	Yes
Hawaii	testing	Not addressed	yes	Not addressed
Illinois	testing	yes	yes	yes
Iowa	deployment	yes	Depends on level of vehicle automation	yes
Kansas	deployment	Depends on level of vehicle automation	No	yes
Louisiana	Deployment-commercial vehicles only	Depends on vehicle	no	Yes; $2,000,000
Maine	testing	Not addressed	no	Yes; $5,000,000
Massachusetts	testing	yes	yes	Yes
Michigan	Depends on vehicle	yes	no	yes
Mississippi	deployment	Not addressed	no	Yes
Nebraska	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	
Nevada	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	Yes
New Hampshire	deployment	Depends on vehicle	Depends on level of vehicle automation	Yes
New Mexico	testing	Depends on vehicle	Depends on level of vehicle automation	Yes; $5,000,000
New York	testing	yes	yes	Yes; $5,000,000
North Carolina	deployment	Depends on level of vehicle automation	no	yes
North Dakota	deployment	Depends on level of vehicle automation	Depends on level of vehicle automation	yes
Ohio	testing	yes	no	yes
Oklahoma	deployment	Not addressed	no	Yes; $1,000,000
Pennsylvania	deployment	yes	no	Yes; $1,000,000
South Dakota	Deployment (effective 07/01/24)	Yes (effective 07/01/24)	No (effective 07/01/24)	Yes (effective 07/01/24)
Tennessee	deployment	no	no	Yes; $5,000,000
Texas	deployment	no	no	Yes; $5,000,000
Utah	deployment	Depends on level of vehicle automation	no	yes
Vermont	testing	yes	yes	Yes; $5,000,000
Virginia	testing	Not addressed	Not addressed	no
Washington	testing	Depends on whether operator present in vehicle	no	Yes; $5,000,000
West Virginia	deployment	Depends on level of vehicle automation	no	Yes

Source:(Sever & Contissa, 2024); Insurance Institute for Highway Safety, Highway Loss Data Institute, updated May 2024(The Insurance Institute for Highway Safety (IIHS), 2024)

"A vehicle that requires a human to take over driving (Level 3 of the SAE Levels of Driving Automation) requires a licensed human driver".

"A vehicle that does not require a human to take over driving (Level 4 or Level 5 of the SAE Levels of Driving Automation) does not require a human to be in the vehicle."

"Arkansas does not require a steering wheel in a "fully automated vehicle," which must be "capable of achieving a minimal risk condition" in the event of a failure".

"Arkansas requires an "automated vehicle program" to comply with "the minimum liability insurance coverage requirements" under 49C.F.R. § 387.9 as that section existed on January 1, 2021."

"As of November 1, 2023, California has issued Autonomous Vehicle Testing Permits with a driver to a limited number of entities. 6 entities are allowed to perform driverless testing on defined areas, in certain weather and visibility conditions, time of the day and with specific speed limitations. As of January 11, 2024, California has authorized the deployment of autonomous vehicles to 3 different entities on defined areas, in certain weather and visibility conditions, time of the day and with specific speed limitations (California, 2024)."

"The District requires a "test operator" or "remote operator," who must successfully complete a training program.

"A vehicle that does not require a human to take over driving (Level 4 or Level 5 of the SAE Levels of Driving Automation) does not require a licensed human driver."

"Georgia requires a "fully automated vehicle" operating "without a human driver" to have liability insurance equivalent to the minimum required under existing insurance law."

"Although Kansas requires a driver to be physically present in a "driverless-capable vehicle" for the first 12 consecutive months it is in service, this provision does not apply if the vehicle is not intended to carry human occupants or if the vehicle lacks manual controls for driver operation."

"If a vehicle uses a remote driver, that driver must be licensed."

"Massachusetts requires applicants who seek to test to maintain a variety of insurance coverages, including commercial general liability, automobile, and workers compensation insurance."

"Michigan authorizes testing of any "automated motor vehicle" and deployment of "on-demand automated motor vehicle networks."

"The "automated driving system" is considered to be licensed to operate the vehicle."

3.1.9 **UK**

In the United Kingdom, testing and various trials of autonomous vehicles are allowed. The government has put in place a code of Practice: automated vehicle trialling (Abu Bakar et al., 2022; Vellinga, 2017). It was published jointly by CCAV(The Centre for Connected and Autonomous Vehicles), the Department of Transport, and the Department for Business, Energy and Industrial Strategy. Interested parties can conduct AV technology testing on any UK road without a specific permit in advance. But this does not exclude that certain legal requirements must be respected.

First, the AVs used must be roadworthy. They must also comply with the in-service requirements specified in the Road Vehicles (Construction and Use) Regulations 1986.

Secondly, when you do vehicle trials on public roads, it is mandatory to have a licensed and trained safety driver or operator who must be present all the time(Vellinga, 2017). The driver has the role of supervising the vehicle(Abu Bakar et al., 2022). This is to ensure that the vehicle complies with traffic laws. The driver must also be ready to override autonomous operations if necessary. The

safety driver or operator can be outside the vehicle, as long as he can switch and resume manual control when needed.

In the event of a trial of AVs conducted remotely, it is necessary to set up appropriate redundancies to manage and handle failures(Abu Bakar et al., 2022). This includes warning systems and the ability for the driver to take control of the vehicle at any time. When it comes to a trial of AVs driven remotely on public roads or other public places, the system must provide an equivalent level of safety to having a driver inside the vehicle.

Under the new Autonomous Vehicles (AV) Act which became law in May 2024, any AVs allowed on UK roads must first complete a safety test to ensure that it is equally capable as human drivers(UK Government, 2024). An independent incident investigation function will be implemented to support the approval process of AVs

3.2 **Liability**

Liability regulations are rules and protocols set up by governments to determine who should be held accountable in the event of an accident involving an autonomous vehicle. As mentioned by(Bartolini et al., 2017), liability can be analyzed from two aspects: civil liability and criminal liability. Civil liability refers to situations where harm takes place. On the other end, criminal liability addresses situations where harm is intended. In this context of AVs, we can say that civil liability means that compensation for damages caused by an AV would be provided by the vehicle's insurer(Bartolini et al., 2017; Punev, 2020). Usually, the vehicle owner and driver are liable for damages that are linked to maintenance effects. The vehicle manufacturer can be held liable for damages linked to vehicle defects. The existing laws did not envisage any liability of non-human actors like those which operate fully autonomous vehicles.

3.2.1 **European Union**

Before the recent changes (especially in 2022 as previously mentioned) in the regulation of AVs in the European Union, the existing 1985 Product Liability Directive (PLD) was in effect(Ng, 2024; Punev, 2020). Initially, the PLD did not take into account all the risks posed by the AVs(Patti, 2019). Indeed, under this directive, manufacturers were not liable for defects caused by software updates. Yet it could make them defective after leaving the factory(EPRS, 2023; Ng, 2024). Also, they were not liable if at the time of initial production, scientific and technical knowledge couldn't have identified the defect. Because of these gaps in liability, the PLD was

recently updated to reflect all the risks associated with AVs. The updated directive changed the product definition to include electricity, digital manufacturing files, and software(EPRS, 2023; Ng, 2024). This is for increasing the producer's liability for AVs. In addition, the update includes two new legal rights to ease the burden of bringing a claim: the "right of access to evidence" and the "presumption of causality"(EPRS, 2023). The first allows a claimant injured by a defective AV product to obtain evidence more easily from defendants when the claimant has presented facts to support the plausibility of their claim. The second shifts the burden of proof to manufactures if a plaintiff can provide some evidence that their product contributed to the damage.

3.2.2 **Germany**

In Germany, the regulation of AVs in terms of liability is defined in the Road Traffic Act and the Autonomous Driving Act(Tran & Le, 2022). The liability regulations vary according to the level of autonomy of the vehicle. Indeed, for AVs from levels L0 to L3, the driver can be considered liable for an accident according to the Road Traffic Act (presumed fault rule)(Patti, 2019; Tran & Le, 2022). This is because, at these levels, the human driver is involved in the driving process.

Concerning AVs from levels L4 to L5, a technical supervisor must take on the responsibility. This since there is no human actively controlling the vehicle. Here the technical supervisor is considered a person who can deactivate the vehicle during the autonomous operation(Tran & Le, 2022). The liability of the technical supervisor is regulated by the German Civil Code. In these cases, the injured party must prove the fault of the technical supervisor to hold them liable. From these elements, we can see that Germany has a legal framework that differentiates well from autonomy levels and assigns liability accordingly.

3.2.3 **Sweden and Norway**

The liability regulations for autonomous vehicles are not yet at a very developed stage in Sweden and Norway. This is justified by the fact that new regulatory standards are being developed for AVs. Sweden has proposed a liability regime quite similar to those in rigour in Germany and the UK(Lundahl, 2022). In this regime, a new drive role - "förare i beredskap" (driver on standby) - is introduced. In this new role, some other tasks are assigned to the driver. The driver on standby is not responsible for how the Autonomous Driving System (ADS) operates the dynamic driving task(Lundahl, 2022). However, the driver is responsible for taking control if the ADS so requests. If the driver is unable to do so, it can lead to criminal liability. The owner of the vehicle also has

his responsibilities. Indeed, he is responsible for the insurance of the vehicle and for ensuring that the traffic rules are followed. In the event of traffic offences, the owner receives a penalty fee. The owner does not receive this fee if the offence is due to a malfunction of the driving system that goes beyond his control(Lundahl, 2022). In addition, manufacturers, system developers, etc. are responsible for product safety. They are also responsible for damage caused by a defective product.

3.2.4 **Singapore**

In Singapore, the liability regulations that have been put in place require participating AV trials to purchase an AV insurance policy(Tan & Taeihagh, 2021; Tran & Le, 2022). This covers injury to persons, death, and property damage. However, claims for damages against the AV manufacturers cannot be facilitated based on product liability. Damages can be covered by insurance. It is worth noting that the liability regulations for AVS in Singapore raise issues as the technology becomes more complex over time(Tan & Taeihagh, 2021). Indeed, for the moment it is unclear as to which party bears the responsibility for damages or accidents that arise from AV deployment. In addition, insurance companies are unable to quantify the risks of AVs in real financial terms. Also, some manufacturing defects or designs of AVs can only show up after the trial period. AVs also have deep-learning capabilities, they could potentially alter their behaviours in unpredictable ways. That would create challenges to attribute full responsibility to the manufacturers or developers.

3.2.5 **China**

First, China is facing difficulties in determining the liability for accidents involving AVs. This is due to the absence of comprehensive regulations in that Area(Xu et al., 2023). Secondly, during the phase of fully autonomous driving, responsibility for accident prevention is transferred to the AV system. The legislation must clarify the relationship between the different actors, namely, AVs, drivers, producers and developers(Xu et al., 2023). Lastly, If Road traffic violations or accidents occur, both the driver and the autonomous driving system development unit will be held liable according to the law. The compensation is determined by relevant regulations(Xu et al., 2023).

3.2.6 **Japan**

The problem of who is liable for an accident is not solved in Japan(Imai, 2019). The concept of a driver and the ODD previously mentioned concerning AVs are always under review to find out who is liable between the vehicle and the driver.

3.2.7 **Australia**

In Australia, when a crash occurs that involves an AV, The Australian Consumer Law (ACL) provides for certain obligations for manufacturers to follow the standards in terms of safety and quality(NTC, 2021). Moreover, each state or territory has its Civil Liability Act for personal injuries caused by motor vehicle accidents. However, there are problems concerning compensation concerning liability. Indeed, for high levels of AVs, it is difficult to determine who to be held liable for harm. But, under ACL, manufacturers and suppliers may be held liable(NTC, 2021). The discussion paper was released in 2017 by the NTC (changing driving laws to support autonomous vehicles)(Lee & Hess, 2020; NTC, 2017). Autonomous vehicles are discussed in depth, and it says that ADS represent a system and not a person. As a result, they cannot be held responsible for his actions. It would be preferable for a certain entity to take care of the Shares of the ADS to ensure that they work safely. Later in 2019, the NTC confirmed that it wanted to take data from insurers to assess liability concerning road traffic breaches(Lee & Hess, 2020; NTC, 2019). The NTC had also stressed the need to provide access to compensation for injuries caused by AVs and keep the responsible parties liable.

3.2.8 **United States**

As introduced above, there are no comprehensive federal regulations for AVs in the US. Therefore, states have diverse AV testing, deployment, and liability regulations. This complicates the task of stakeholders to comply with those regulations or to prepare to deal with liability risks associated with different state laws(Sever & Contissa, 2024). For example, as seen in the previous table, the requirement of liability insurance is not addressed in some states (but it is in many)(The Insurance Institute for Highway Safety (IIHS), 2024). Also, the amount varies from state to state. Several states impose a duty on the vehicle operator, the AV, or the testing company to remain at the crash scene or to report the accident.

3.2.9 **UK**

In the UK, through the Automated and Electric Vehicles Act (AEVA) introduced in 2018, the insurer is liable for damages suffered by a person(Punev, 2020; UK parliament, 2018a). This includes death, personal injury and property. It is indeed an insurance regime for AVs in case of an accident. When it happens that there is no insurance, the owner of the vehicle is automatically taken liable for the damage(Rosemadi et al., 2022; UK parliament, 2018a). The AEVA prohibits

insurers from excluding or limiting coverage except in two cases. The first case implies that the accident is caused by changes (alteration) of software by the insured person. The second case implies that the insured person fails to install necessary software updates. In both cases, the insurer can recover the amount paid. The UK government's Autonomous Vehicles (AV) Act, which came into law in May 2024 clarifies certain liability concerns. The AV Act stipulates that automotive manufacturers and software developers will assume legal responsibility for any crashes or accidents that occur while autonomous systems are in use(UK Government, 2024).

3.3 **Privacy**

Privacy regulations refer to policies and laws that seek to protect personal information that autonomous vehicles collect, store, and share. These regulations are necessary to ensure that personal data collected by autonomous vehicles are not misused by third parties. That is because AVs collect vast amounts of sensitive data,

3.3.1 **European Union**

In the European Union, AVs are regulated by the GDPR (General Data Protection Regulation) in terms of privacy. This implies that for any data collected by the vehicle, there are rules to follow. These data include location or biometric data(Begishev et al., 2022; Mulder & Vellinga, 2021). Indeed, it is imperative to obtain user consent for data collection and as well as provide transparency in data use(Akca et al., 2020). The GDPR introduces two important concepts in terms of documentation that companies must follow when managing customer data(Andraško et al., 2021; Mulder & Vellinga, 2021). The first refers to the directory of processing activities, including all the steps to be followed by the company to process customer information. This ensures that companies comply with GDPR. The second refers to the documentation of processing security, which requires companies to have measures to secure sensitive customer and user data.

3.3.2 **Germany**

Being a member of the EU, Germany considers data collected by autonomous vehicles as personal data. This includes data rental and sensor data. This is also defined in the Data Protection Act (BDSG)(Federal Ministry of Justice, 2021). These regulations imply that the types of data mentioned can be traced back to the owner, the driver or the passenger. This information can be identified as information about the actual circumstances of a person. If justified, collect, store and use personal data under the data protection law.

Companies must be able to judge what data is necessary and proportional to collect(Federal Ministry of Justice, 2021). This applies in scenarios such as company sales, asset deals, order processing, data transfers to third countries and address trading. Customers have the right to their information as the right to request data copies, have data deleted under certain circumstances, and restrict further data processing.

3.3.3 **Sweden and Norway**

Sweden has implemented the GDPR in its national legislation through the Swedish Data Protection Act(The Swedish Parliament, 2018). The Swedish Data Protection Authority ensures that the GDPR is respected. It can give sanctions for non-compliance. However, there is a difference between the GDPR and the Swedish Data Protection Act for certain elements(The Swedish Parliament, 2018). For example, in Sweden, it is imperative to have only explicit consent concerning data processing. In the GDPR, on the other hand, it is rather requested that consent be given freely, specific, unambiguous and informed. Also, the Swedish Data Protection Act concerns all businesses operating in Sweden but the GDPR extends to all members of the European Union.

For its part, although it is not a member of the European Union, Norway follows the GDPR. This is the result of its participation in the European Economic Area (EEA)(Opdahl et al., 2023). The regulations regarding the privacy of AVs are governed by the Personal Data Act of June 2018. The Act implements the GDPR.

3.3.4 **Singapore**

Based on(Tan & Taeihagh, 2021), the privacy guidelines that are specific to AVs, in particular concerning the protection of data collected by AVs, have not been formulated to date. The Personal Data Protection Act (PDPA) serves as a guide for AV implementation in Singapore(Lim & Taeihagh, 2018). This is an act enacted in Parliament in October 2012 and effective since 2014. However, it is not specific to AVs. It covers all non-government entities and private sectors. In addition, the Personal Data Protection Commission (PDPC) published a discussion paper in June 2018(Lim & Taeihagh, 2018; Tan & Taeihagh, 2021). The paper explained best-practice guidelines for personal data protection in artificial intelligence systems. It is therefore imperative that there be other regulations to prevent the misuse of personal information by developers.

3.3.5 **China**

China has several laws for the protection of personal data (information and data). This includes the Requirements on Personal Information Protection for Users of Vehicle Network Information Service, the Personal Information Protection Law of the People's Republic of China (PIPL), and the Cybersecurity Law of the People's Republic of China. The PIPL, which is surely the most important in terms of privacy, requires that the processing of personal information be lawful and justified(Government of the People's Republic of China, 2021). Also, the collection of this data must be limited to the minimum scope required for the intended purpose of processing. There are also restrictions in terms of transfer outside China. However, according to (Xu et al., 2023), these laws provide only general legal principles for the privacy and security information of AVs. This is because these laws were not specifically enacted for AVs. (Xu et al., 2023) therefore suggest that the regulations must strike a balance between the collection and the use of data necessary for the safe operation of AVs. This is by ensuring the protection of this information. Indeed, given the huge amount of data collected, it is imperative to clearly define the reason for data collection and ideally reduce the collection of unnecessary data. This is with transparency and the customer's agreement regarding the use of data.

3.3.6 **Japan**

As for privacy regulations in Japan, the Road Traffic Act requires drivers to record and store the necessary information to confirm the proper functioning of the AV driving system(Imai, 2019). The requirement is to analyze and clarify problems in the system that could potentially lead to accidents or problems that would have caused an accident. However, the data that is recorded is protected by the privacy provisions of the Traffic Act.

3.3.7 **Australia**

In Australia, personal data (access, storage, management) are governed by two regulations. This is the Privacy Act 1988 and the Australian Privacy Principles (APPs)(Khan et al., 2023; Lim & Taeihagh, 2018). This also extends to data collected by AVs. There is a possibility that AVs collect personal information such as facial recognition, location, and user preferences (NTC, 2021). All this must imperatively follow the Privacy Act requirements. Personal data can only be stored and transmitted if it is necessary for the operation of the vehicle(NTC, 2021). The user's consent is required and the user must be notified of the collection and use of his data. This must match the

intended purpose. The data must also be protected and the user has the right to alter and correct their information. Organizations must ensure that no one accesses (or alters) this data without authorization according to the privacy act(NTC, 2021).

3.3.8 **US**

In the United States, the Spy Car Act was introduced to protect the privacy of driving data collected in vehicles sold in the United States(Aoyama & Alvarez Leon, 2021; Taeihagh & Lim, 2019). According to the act, the NHTSA previously cited has the authority to regulate access to and use of this data. All vehicle owners (and lessees) must have some control over the collection of their driving data. This is except for data required for safety and post-incident investigations. Beyond that, manufacturers have certain restrictions. They may not use the collected data for advertising or marketing purposes without the prior consent of the vehicle owner or lessees. This allows the protection of their data.

3.3.9 **UK**

AVs need a lot of data to function (rental, driver/passenger information, etc.). This data is personal and protected by the Data Protection Act 2018, the UK GDPR(UK Parliament, 2018b). This data is also protected by the Privacy and Electronic Communications (EC Directive) Regulations 2003. Although these laws were not specifically written for AVs, these vehicles must follow all data protection laws that apply. The developers should be mindful of data privacy issues from the outset of the design process(UK Parliament, 2018b). They must also choose parameters that reduce the amount of personal data collected to protect privacy. Data subjects must be able to access, modify or delete their data easily(Taeihagh & Lim, 2019). In addition, any personal data must be locally processed or made anonymous. A data protection impact assessment of the vehicle is also required to minimize any risk involved.

3.4 **Cybersecurity regulations in the European Union**

Cybersecurity regulations refer to policies that seek to ensure that autonomous vehicles' communication networks are secure from malicious attacks that would undermine cyber and physical security.

In the European Union, AVs are regulated in terms of cybersecurity through different regulations and standards. The first important regulation is the UNECE R155(Benyahya et al., 2023). This regulation makes the Cybersecurity Management System (CSMS) certification mandatory for the

vehicle type approval stage. The CSMS certification makes it possible to prove that there is an efficient threat governance. This is risk monitoring, assessment, and mitigation. A second important regulation is the UNECE R156, which makes it mandatory to assess by the approval authorities(Benyahya et al., 2023). The assessment results in the issuance of a Software Update Management System (SUMS) certification upon the conformity of software update processes.

In addition to these regulations, the GDPR as mentioned above provides a framework for the protection of Personal Data. ISO/SAE 21434 is a standard that describes cybersecurity engineering processes for road vehicles(Benyahya et al., 2023). Through this standard, there is a provision of a framework for the integration of cybersecurity activities into the engineering processes of road vehicles(Khan et al., 2023). This is an approach to cybersecurity that includes its management, design, implementation, verification and validation.

ISO/PAS 5112 is a guide for cybersecurity engineering audits.(Benyahya et al., 2023) It allows you to have a series of guidelines for uniformly auditing cybersecurity engineering. This standard describes the audit team's composition and the scope of the audit. It also describes how to plan and conduct the audit, and how to report the results.

Despite all these regulations, it is important to note the existence of several challenges facing the deployment of AVs. Protecting AVs from cyber-attacks and data breaches remains precarious(Benyahya et al., 2023). Indeed, as mentioned by (Benyahya et al., 2023) and (Khan et al., 2023), AVs represent a complex interconnected system. It is made of sensors, Artificial Intelligence (AI) processors and external units to ensure autonomous driving without human interaction. All these factors make AVs vulnerable to cyber assaults. It also entangles security audits and certification procedures. Given that complexity, further efforts are needed to ensure that these regulations and standards keep pace with the cybersecurity security risks which are rapidly evolving.

4 Discussion

Our study aimed to conduct a comprehensive analysis of the European Union’s regulations on autonomous vehicles and compare these regulations with those in other regions worldwide.

4.1 Key Components and Provisions of the EU's AV Regulations

Our research has identified that the regulation of autonomous vehicles is consistent with the historical emphasis of The European Union on historical consumer protection. This implies having stringent product requirements and clear safety compliance accountabilities. We can say that aligns with what the EU consumer protection protection policy says. It says "The aim of European consumer policy is to make the European Union (EU) a tangible reality for 500 million citizens by guaranteeing their rights as consumers. That means protecting consumers from serious risks and threats that they are unable to tackle as individuals; empowering them to make choices based on accurate, clear and consistent information; enhancing their welfare and effectively protecting their safety as well as their economic interests. That is to be achieved by aligning consumer rights and policies to changes in society and economy"(Valant, 2015, p.3.). For example, as we have previously seen, the EU imposes rigorous technical requirements for the autonomous driving system of fully autonomous vehicles. That is done to ensure their safe and efficient operation in the EU.

We also observe that by introducing regulations that cover a broad range of aspects(from data protection to technical and operational standards), the EU wants to mandate uniform regulation of AVs across member states. However, it can be observed that certain states in the EU have made it a priority to regulate AVs in the shortest time possible to allow the integration of AVs. We can see this in the examples of the interpretation of the EU regulations in their way by Sweden and the early adoption of the Autonomous Driving Act by Germany to allow L3 and L4 AV driving. However, the big question here is whether the rules that the European Union has put in place for Autonomous Vehicles will limit innovation and keep AV technology from reaching its full potential in transportation. We could argue that despite the efforts of the EU in the regulations of AVs (like the recent progress in 2022), their complexity could delay progress and prevent innovation from coming out as fast as it would be in other parts. Indeed, the regulations keep on changing (however, not as fast as AV technology) which can make it complicated to follow or keep up with the regulations for policymakers, developers and industry stakeholders.

We can also argue that one of the key implications of the European Union's regulations is that they could limit innovation and competition in the autonomous vehicle industry. Indeed, by imposing strict safety requirements and regulations on companies, there is a risk. Smaller businesses or start-

ups may struggle to comply and develop their AVs(high levels). As a result, we may see established companies holding greater power and influence in this market. We can also say however that there is a flip side to this. The fact that the EU impose strict regulations and places greater emphasis on safety standards and accountability measures could be an advantage. Consumers may be more trusting and willing to invest in these vehicles. That could pave the way to safer roads with reduced accidents caused by human errors

Additionally, it is now important to have clear liability rules for AVs for different situations. A clear distinction should be evident in terms of who is liable when an accident occurs, the driver (whether remote or physical), the system or the manufacturers. If the system is also considered as having some driving responsibility, the part of liability should be clear (this is also a problem in other regions as we will discuss later).

4.2 Comparison between the EU's Regulations and those of Other Regions Worldwide

When we contrast the approach of AV regulation in the European Union to other regions, differences and similarities arise, with some unique approaches like Norway's legislation that allows experiments with AVs without drivers on some roads. In some countries, the emphasis is on safety, and in others, the focus is shifting towards creating an environment where AVs can be tested and developed more efficiently (for example, in the EU, safety is the top priority whereas in Singapore, the focus is on rigorous testing procedures that ensure the safe and efficient operation of AVs). However, we can say that the major similarity among regions is the recognition of the potential benefits of Autonomous Vehicles. This is demonstrated by the development of regulations to accommodate AVs in different countries.

We observe that the US has taken a more decentralized approach to AV regulations. The regulation is mostly at the state level, allowing individual states to develop their regulations. This has resulted in many companies testing their AVs on public roads in various states since the US is involved in AV technology. This approach can foster innovation and accelerate the deployment of AVs in specific states. However, as we have seen, this approach has a problem, it leads to regulatory fragmentation and inconsistency across different states.

On the other hand, China has taken a more top-down approach to AV regulation, with the government playing a significant role in shaping and directing the development of AVs (Xu et al.,

2023)however suggests that the is a lack of comprehensive regulations. We see that this approach has resulted in significant investment by the government in AV technology and infrastructure to promote the development and the development of AVs.

We can say that the approach of Singapore to regulating AVs makes it stand out, especially the fact that the country considers AVs as a type of motor vehicle as previously mentioned. Additionally, having a comprehensive regulatory framework that allows trials of AVs up to L5 places them in a good position in terms of possible deployment of AV technology. Even if Singapore does not produce AVs(Tran & Le, 2022), its approach by the clarity it brought by accepting AVs as a type of motor vehicle to develop a comprehensive regulatory framework is a good example for other countries.

We observe the approach of the UK is different from other countries such as China and the US, where specific regulations and rules are discussing AV testing and commercial operation. As mentioned, the UK government put in place the Code of Practice which allows interested parties to conduct AV technology testing on any UK road without a specific permit in advance (there are still some requirements previously mentioned). However, there is a similarity in some aspects with the US. As highlighted by (Taeihagh & Lim, 2019), this is because the strategy of both the UK and the US is not to impose too stringent regulations, or to have a more permissive approach toward AV safety. This is to give room for innovation.

The approach of Australia to the regulation of AVs is to emphasize regulatory frameworks at the state level(Schepis et al., 2023). As highlighted previously, The Australian government's role is primarily centred on providing guidelines to ensure the safety of AVs in the country(Schepis et al., 2023). On the other hand, the state governments are responsible for the on-road operations of AVs(like Victoria and Queensland as we saw).

We also observe that Japan is active in innovation and the regulation of AVs with the amendments mentioned to allow high levels of AVs. But a great emphasis is put on safety as with see with the strict regulations on L4 AVs.

A recurring problem that seems to be common to all countries in terms of regulating autonomous vehicles is the driver concept. Indeed, the purpose of high-level autonomous vehicles (L4-L5) is to have a vehicle that can assume the functions of the driver without human intervention. However,

we can see that in most regions, it is required to have a human driver (physical or remote) to have the possibility to intervene and resume the system at any time for security reasons. This can be justified by the fact that AVs could fail at some point. However, in a way, it goes against the great benefit of solving accidents due to human error. Indeed, if the human driver can take back the system, there is a possibility that he will make a mistake that could result in an accident if he has made a bad judgement.

The driver problem also leads to another problem discussed earlier, liability. It can be observed that for the moment most countries struggle to have clear liability regulations. As mentioned by (Sever & Contissa, 2024), the theory of liability in traffic accidents examines the conflict between manufacturers' liability and driver's liability concerning AVs. Supporters of manufacturers' liability argue that manufacturers should be held liable for accidents because AVs are primarily operated by the system. For them, this relieves users from negligence liability while using the vehicle. On the other hand, the supporters of driver liability argue that assigning all the blame to vehicles would evade human liability. They propose that users should assume the wrong liability (the liability of AV operators and owners for any accidents or injuries resulting from the use of AVs).

At this point, it is therefore important to adapt the regulation of AVs to challenge as the deployment of L5 vehicles is possible. Here we reiterate that the regulators must look at the issue and decide who they define as a driver. By this, it is imperative to have regulations that take into account all the realities of AVs and detail who is liable in the event of an accident that is liable (and in which specific cases).

From our study, it can be observed that countries around the world put a great emphasis on personal data protection for autonomous vehicles. Personal data protection is very important for AVs to protect users’s personal information from any unauthorized or malicious use by third parties or other entities. As highlighted previously, in the EU the GDPR provides personal data protection for AVs. In China, the PIPL and other mentioned regulations provide similar protection. This is extended to Australia and the US with the APPs and the Spy Car Act respectively. These are just a few examples of the regulations put in place to protect personal data used in AVs. The amount of data that can be shared and analyzed by AVs will eventually increase. It is therefore very important that the trend of protecting user’s data continues.

4.3 Implications of the Differences in AV Regulations for the Future of AV Technology

Based on our analysis we can say that the implications for the future of autonomous vehicles are numerous because of the variation of regulations depending on the region. First, the difference between regulations can cause market fragmentation. This would be a problem for manufacturers that intend to operate in several jurisdictions at the same time. However, this fragmentation could also have another outcome to some extent, in the sense that it could stimulate innovation and competition. Indeed, companies would have to adapt to different regulatory environments to gain a competitive advantage. In addition, this difference in the regulation of AVs by region can cause problems concerning interoperability, particularly in safety certification and data sharing. As a consequence, this could complicate the continuous integration of autonomous vehicles.

4.4 The way forward for AV technology regulation

To tackle the problem of regulation in the future of AV technology, our study proposes different solutions. First, international collaboration is crucial. This collaboration should involve governments, regulatory bodies and industry stakeholders. It is possible to harmonize standards provided that best practices, research findings and regulatory experiences have been shared.

Secondly, an effort must be made in terms of standardization. If we have international standards and guidelines for AVs, this could allow the harmonization of safety certifications and data-sharing protocols. This would also facilitate global market expansion and travel between different countries.

Third, regulations must be continuously reviewed and adapted to keep pace with technological advancements. Regular updates will address emerging risks and incorporate new features. That will also ensure regulations remain relevant and effective in promoting safety and responsible innovation.

Finally, the commitment of stakeholders is important. Collaboration and dialogue with industry stakeholders, academic institutions, and civil society will ensure that we have inclusive and informed decision-making in the regulation of AVs.

5 Conclusion

Our study aimed to make a comprehensive analysis of the regulations that are in force within the European Union in terms of Autonomous Vehicles. With that objective, our study compared EU regulations with those of other countries or regions to deduce the implications of differences for AV technology. The countries include Singapore, the United Kingdom, the United States, Germany, Norway, Sweden, Australia, Japan, and China. Our research questions were: What are the key components and provisions of the European Union's autonomous vehicle regulations? What are the autonomous vehicle regulations in other regions worldwide? What are the similarities and differences between the European Union's regulations and those of other regions worldwide? What are the implications of the differences in autonomous vehicle regulations for the future of autonomous vehicle technology?

The study employed a systematic search strategy and reviewed other official publications, reports (or legislation). The findings of our study reveal that the EU has implemented comprehensive regulations for autonomous vehicles (covering various aspects such as testing and safety, liability, privacy, and cybersecurity). The regulation of AVs in the European Union is based on robust safety standards and approval procedures. The study reveals that it can be a double-edged sword (certainly it is important to ensure public safety and consumers may be more trusting, but it could pose challenges for rapid advancement and innovation. In addition, smaller and emerging companies may struggle to navigate the requirements).

Different approaches to the regulation of Autonomous Vehicles have been found. Some regions such as the EU prefer robust laws to ensure safety, others advocate a more permissive approach to stimulate innovation (like the UK and the US), others prefer regulation at the level of each state(like Australia and the US), and others prefer a top-down approach with heavy investment by the government (like China). However, these regions have in common the fact of seeing the potential of AV technology; but most of them need more to work on the definition of the driver and clear liability rules in case of accidents.

After our study, several avenues for future research emerge. First, there is a need for an in-depth study on the implementation and enforcement of the AV regulations analysed above for the different regions. Indeed, it is imperative to analyse how effective they are and what would prevent their implementation (or what does not work). Secondly, autonomous vehicle technology is

evolving every day. It is therefore important that there is continuous research to always adapt the regulations to the latest updates. It would also be an opportunity to address certain emerging issues like ethical considerations and societal impacts. Additionally, studies focusing on the economic impact of AV regulations would provide valuable insights for policymakers and stakeholders. These could include effects on industries, job markets or transportation systems.

In conclusion, this thesis has given a comprehensive analysis of autonomous vehicle regulations in the EU, identifying essential components and comparing them with regulations worldwide. Therefore, the study contributes to the understanding of autonomous vehicle governance by answering research questions and formulating answers based on the findings. In the future, it is vital to promote international cooperation, strive towards harmonisation, and continue research efforts to responsibly and effectively integrate autonomous vehicles into our transportation systems.

6 Appendices

Appendix A: Comparative table between the different investigated countries and the European Union

Table 6 Showing the summary of regulations of AVs in the selected countries

Country/Region	Testing and Safety	Liability	Privacy	Autonomy Level
European Union	Stringent product requirements and clear safety compliance accountabilities (that account for the levels of autonomy in vehicles). General Safety Regulation set a legal framework enabling the deployment of autonomous and fully autonomous vehicles on European roads (specific technical standards to be followed and approval process regulations specific according to the level of autonomy and the type of vehicle)	Regulated by Product Liability Directive (PLD). claimant injured by a defective AV product to obtain evidence more easily from defendants when the claimant has presented facts to support the plausibility of their claim. The burden shifted to the manufacturer if there is evidence that their product contributed to the damage	AVs in the EU are regulated by the General Data Protection Regulation (GDPR). Companies must obtain user consent for data collection and ensure transparency in data use	The General Safety Regulation of 2022 accommodates the deployment of autonomous and fully autonomous vehicles on European roads but the level of autonomy accepted is still country-specific.
Germany	Germany has legislation for on and off-road autonomous vehicle operations, focusing on safety requirements. Testing is restricted to certain areas, and special licenses are required before testing.	For AVs from levels L0 to L3, the driver can be considered liable for an accident AVs at levels L4 to L5 require a technical supervisor who assumes liability. The German Civil Code regulates the liability of the technical supervisor.	Personal data collected by AVs must adhere to the data protection law, and individuals have the right to access and restrict further data processing. GDPR	AVs are allowed to operate at levels 3 and 4, and in July 2021, the Autonomous Driving Act was passed, permitting Level 4 autonomous driving within defined operating areas

Sweden	experiments with AVs on public roads (ordinance passed to allow such experiments with a driver physically present)	The driver is responsible for taking control if the ADS so requests. If the driver is unable to do so, it can lead to criminal liability. The owner is responsible for the insurance of the vehicle and for ensuring that the traffic rules are followed.	follow the GDPR but have additional requirements for explicit consent concerning data processing.	Sweden changed its road traffic regulations allowing AV tests on public roads without a safety driver being present in the vehicle (high level of autonomy)
Norway	experiments with AVs on public roads without a driver physically in or outside the vehicle (several safety and technical requirements to obtain a permit like emergency procedures and vehicle control)	The liability regulations for AVs are not yet at a very developed stage in Sweden and Norway. This is justified by the fact that new regulatory standards are being developed for AVs.	follow the GDPR but have additional requirements for explicit consent concerning data processing.	All levels with specific requirements
Singapore	Trials and usage of AVs allowed on Singaporean roads, AVs recognized as a type of motor vehicle (all AVs must undergo testing in a controlled environment and comply with safety requirements)	While AV trials are required to have insurance policies (injury to persons, death, and property damage), responsibility for damages or accidents arising from AV deployment is unclear. Guidelines and regulations for AV liabilities are yet to be formulated.	No specific guidelines for privacy regulations have been formulated yet. AV implementation in Singapore follows the Personal Data Protection Act (PDPA).	AVs are allowed to operate at levels 3, 4, and 5, and in 2017, the Road Traffic Act was amended to allow the trialling and usage of equivalent Level 3, 4, and 5 AVs on Singaporean roads
China	Various regulations and initiatives at both national and local levels. AVs are to be tested at specific times and in specific places. buses and trams are only allowed on certain physically closed routes with basic road conditions, L5 taxis can be monitored remotely but lower levels of AVs require a safety operator	Secondly, during the phase of fully autonomous driving, responsibility for accident prevention is transferred to the AV system. The legislation must clarify the relationship between the different actors, namely, AVs, drivers, producers and developers. If Road traffic violations or accidents occur, both the driver and the autonomous driving system development unit will be held liable according to the law	Privacy regulations for AVs are covered by the Personal Information Protection Law (PIPL) and the Cybersecurity Law. Consent is required for processing personal information, limited to the minimum necessary extent.	Testing of AVs allowed up to L5 with various requirements (technical standards)
Japan	AVs can be tested with safety standards (this includes factors such as road conditions and geographic conditions). For high levels of autonomy(L4), Service providers must obtain permission to operate (under remote monitoring) from the relevant public safety commissions in depopulated areas. This is done under strict rules, including specific times, areas and some speed limits.	Specific liability regulations for AVs are not yet formulated. Safety guidelines focus on ensuring AVs are safe and reliable to reduce traffic accidents.	The Road Traffic Act requires recording necessary information for AV driving systems, with privacy provisions protecting the recorded data	Level 3 driving permitted. A new rule for level 4 AVs was introduced.
Australia	AVs can be tested but this requires a permit issued by a relevant state/territory. Guidelines recommend conducting preliminary tests in closed test facilities with a mandatory human safety driver during road tests, except when exempt.	The Australian Consumer Law (ACL) sets obligations for AV manufacturers to ensure safety and quality standards are met, with liability provisions in each	Personal data, including data collected by AVs, is governed by the Privacy Act 1988 and the Australian	Level 3 autonomy permitted. Ongoing development of regulations to accommodate higher levels

		state's Civil Liability Act. However, determining liability for harm caused by highly autonomous AVs is challenging, and manufacturers and suppliers may be held liable under ACL	Privacy Principles (APPs).	
United States	The testing and deployment of AVs are regulated at the state level (AVs are allowed in the USA but this varies from one state to another); Order at the federal level for manufacturers and operators to record accidents for AVs of levels L3 to L5	There are no comprehensive federal regulations for AVs, resulting in diverse state-level liability regulations. The concept of "driver" may need to be reconsidered to assign liability in AV-related accidents	AV companies must have a privacy policy detailing data collection, usage, storage, and sharing. State-level regulation.	All levels of autonomy are allowed depending on the regulation of the state.
United Kingdom	Testing and various trials of AVs are allowed. AV technology testing on any UK road without a specific permit in advance (certain legal requirements must be respected). Mandatory to have a licensed and trained safety driver or operator who must be present all the time (the safety driver or operator can be outside the vehicle). For remote testing, the system must provide an equivalent level of safety to having a driver inside the vehicle. any AVs allowed on UK roads must first complete a safety test to ensure that it is equally capable as human drivers	Automotive manufacturers and software developers will assume legal responsibility for any crashes or accidents that occur while autonomous systems are in use.	Data is personal and protected by the Data Protection Act 2018. The developers should be mindful of data privacy issues from the outset of the design process.	As of May 2024, any level of autonomy can be tested if it passes the safety test to ensure it is as proficient as a human driver

Appendix B: Overview of main articles reviewed (Core) for the study

Table 7 Showing an Overview of the main articles reviewed for the study

(Abu Bakar et al., 2022)	Synthesis of Autonomous Vehicle Guideline for Public Road-Testing Sustainability
(Andraško et al., 2021)	Sustainable Data Governance for Cooperative, Connected and Automated Mobility in the European Union
(Xu et al., 2023)	Impact and revolution on law on road traffic safety by autonomous driving technology in China
(Vellinga, 2017)	From the testing to the deployment of self-driving cars: Legal challenges to policymakers on the road ahead
(Tran & Le, 2022)	Developing a Regulatory Framework for Autonomous Vehicles: A Proximal Analysis of European Approach and Its Application to ASEAN Countries
(Thiele-Evans et al., 2021)	Regulatory approaches to managing artificial intelligence systems in autonomous vehicles in Australia

(Tan & Taeihagh, 2021)	Adaptive governance of autonomous vehicles: Accelerating the adoption of disruptive technologies in Singapore
(Taeihagh & Lim, 2019)	Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks
(Shladover & Nowakowski, 2019)	Regulatory challenges for road vehicle automation: Lessons from the California experience
(Sever & Contissa, 2024)	Automated driving regulations – where are we now?
(Mulder & Vellinga, 2021)	Exploring data protection challenges of automated driving.
(Lee & Hess, 2020)	Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization
(Khan et al., 2023)	Cybersecurity regulatory challenges for connected and automated vehicles – State-of-the-art and future directions
(Kaye et al., 2019)	An adaptive approach for trialling fully automated vehicles in Queensland Australia: A brief report
(Imai, 2019)	Legal regulation of autonomous driving technology: Current conditions and issues in Japan
(Ilkova & Ilka, 2017)	Legal aspects of autonomous vehicles-An overview
(Hess, 2020)	Incumbent-led transitions and civil society: Autonomous vehicle policy and consumer organizations in the United States
(Hansson, 2020)	Regulatory governance in emerging technologies: The case of autonomous vehicles in Sweden and Norway
(Begishev et al., 2022)	Problems of legal regulation of unmanned vehicles
(Benyahya et al., 2023)	Analyses on standards and regulations for connected and automated vehicles: Identifying the certifications roadmap

Table 7 (continued)

(Bartolini et al., 2017)	Critical features of autonomous road transport from the perspective of technological regulation and law
(Aoyama & Alvarez Leon, 2021)	Urban governance and autonomous vehicles
(Rosemadi et al., 2022)	Civil liability of autonomous vehicles: a review of literature
(dos Santos et al., 2022)	An acceptance divergence? Media, citizens and policy perspectives on autonomous cars in the European Union
(Lee & Hess, 2020)	Regulations for on-road testing of connected and automated vehicles: Assessing the potential for global safety harmonization
(Lim & Taeihagh, 2018)	Autonomous Vehicles for Smart and Sustainable Cities: An In-Depth Exploration of Privacy and Cybersecurity Implications
(Akca et al., 2020)	Privacy, Security and Legal Aspects of Autonomous Vehicles
(Punev, 2020)	Autonomous vehicles: The need for a separate European legal framework
(Patti, 2019)	The European Road to Autonomous Vehicles
(Schepis et al., 2023)	How governments influence autonomous vehicle (AV) innovation

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