Autonomous Driving and Sustainable Mobility: A Shared Future and Technological Synergies Between Türkiye and Spain

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Abstract

The convergence of autonomous mobility and sustainability emerges as a transformative paradigm addressing contemporary challenges in transportation, road safety, and environmental preservation. This study explores the technological synergies and ethical and regulatory challenges tied to the integration of autonomous vehicles in Türkiye and Spain, two nations that have adopted distinct yet complementary approaches in their transition toward intelligent transport systems. Initiatives such as TOGG in Türkiye and AUTOCITS in Spain are analyzed as paradigmatic models of innovation, highlighting their contribution to designing a more efficient and resilient mobility ecosystem. Moreover, the implications of these technologies for achieving the Sustainable Development Goals are examined, emphasizing their potential to mitigate emissions, optimize resources, and redefine road safety by minimizing human error. Finally, international collaboration is proposed as a strategic axis to overcome regulatory and ethical challenges, thereby enhancing the capacity of both nations to lead a global transition toward more inclusive, autonomous, and sustainable mobility.

Keywords: Autonomous mobility, sustainability, technological innovation, regulation, Türkiye, Spain.

Introduction

Innovation and Sustainability in the Mobility of the Future

In the 21st century, society is in transition towards a more sustainable and technologically advanced future. Mobility is one of the sectors that have been most affected by this transformation, as the demand for transport is growing and environmental and road safety concerns are increasing. In this context, autonomous driving and sustainable mobility are presented as two key concepts to address these challenges and create a safer, more efficient and environmentally friendly future (Duboz et al., 2022).

On the one hand, autonomous driving, also known as “autonomous vehicles” or “driverless vehicles”, would be understood as the ability of vehicles to move independently without direct driver intervention. This is achieved through the implementation of advanced technologies such as image recognition, signal processing and satellite navigation. 1Autonomous driving would have great potential to significantly reduce road accidents, as it could minimise or eliminate the possibility of human error and improve traffic efficiency.

Sustainable mobility, on the other hand, refers to the ability to move people or goods in a way that does not harm the environment. This can be achieved through the use of electric vehicles, alternative fuels and more efficient travel routes. Sustainability in transport is essential to reduce greenhouse gas emissions and thus protect the planet. In this respect, it is worth mentioning that criminology in its road discipline also addresses this approach, but with a focus on “sustainable road safety”. This concept refers to the management and understanding of risks in different real traffic environments, fostering social responsibility and promoting a better quality of life. Recognising this holistic view of the road environment allows the design of policies that include both road users and vehicle manufacturers and the institutions involved, generating a joint and clearly defined action regarding the responsibilities of each actor within the road system (Monclús, 2007). Also, the interconnection of autonomous vehicles raises concerns about cybersecurity, affecting both users and manufacturers (Bekerman, 2021).

From the present and with an innovative and integrative future perspective, the combination of autonomous driving and sustainable mobility must be taken into consideration to achieve global goals, thus designing a truly transformative future. Autonomous vehicles can be designed to be more energy efficient, reduce gas emissions and thus improve road safety (adding that satellite navigation systems can also help to optimise travel routes and reduce waiting time or traffic congestion).

1 The human factor is responsible for 70-90% of accidents, while the rest are due to the vehicle (4-13%) and the road (10-35%). (Montoro, Lijarcio, Roca, & Puchaes, 2007, pp. 9-13)..

For the implementation of such autonomous and sustainable technologies, Türkiye and Spain are already leading projects in their road infrastructure. Both countries share common, albeit ambitious, objectives aimed at reducing pollutant emissions and improving road safety on their road network (Narayanan, Chaniotakis, & Antoniou, 2020). As innovative countries, they should continue to foster collaboration between the two for the sharing of knowledge, technologies and best practices that address sustainable mobility challenges in a comprehensive and transformative manner.

Türkiye and Spain as Examples of Technology Adoption in Different Contexts

In a globalised world where technology is evolving rapidly, it is essential to look at examples of countries that have adopted disruptive innovations to transform their infrastructure and services. Two countries that could and will stand out in this regard are Türkiye and Spain, whose national and regional initiatives are revolutionising the way traffic moves and interacts with technology.

The Republic of Türkiye has thus proven to be a pioneer in the adoption of sustainable technologies, especially in the field of electric mobility. One of the most prominent initiatives is the TOGG (Turkish Automobile Manufacturer) project, which aims to create an all-Turkish electric vehicle. This project not only aims to reduce the country's dependence on fossil fuels (Celik & Özgür, 2020), but also to become a global benchmark in innovation and technology. The importance of TOGG lies in its ability to demonstrate that electric mobility can be a viable reality in any context, even in countries with limited infrastructure. The implementation of TOGG has had a significant impact on the Turkish automotive industry, boosting job creation and stimulating innovation. Furthermore, this project has laid the groundwork for Türkiye to become a centre of excellence in electric mobility technology, which could have important long-term implications both domestically and internationally.

While Türkiye focuses on electric mobility, Spain is leading projects more specifically related to autonomous driving; it has become one of the leaders in the research and development of autonomous driving technology. The adoption of European road safety regulations has allowed Spain to take advantage of its geographical location to lead projects that address the challenges of autonomous driving in both urban and rural contexts (Dirven & Candia, 2020). The fact that the European Union (EU) has established a regulatory framework for autonomous driving has allowed Spain to leverage its resources to develop innovative technologies and solutions. Some of the most prominent initiatives in this regard include the "Smart Mobility" project, which aims to create an autonomous and sustainable public transport system in Spanish cities (Balea, 2016). Arguably, one of Spain's strengths in the contribution of autonomous driving technologies is the ability to combine both innovation and the necessary and indispensable road safety. Moreover, by being aligned with the aforementioned European regulations, Spain can take advantage of its resources to develop solutions that are not only safe and efficient, but also sustainable in the long term (being able to share experiences that promote these technologies for the common good in other contexts).

Global Context: Autonomous Technologies and Sustainability

It is undeniable that we are at a turning point in terms of the revolution in the way we move, work and even interact with our environment brought about by a digital transformation. In the new global scenarios, it is appropriate to question whether these technologies, which are here to stay and continue to reshape our environment, will be sustainable in the long term. It is time to confront present trends and challenges in order to make informed decisions for the future.

In a recent short time, the advancement of both autonomous technology and artificial intelligence has driven new interactions and, therefore, new challenges. Among them, the challenge of sustainability is indispensable when considering the environmental impact of these innovations; for example, what amount of natural resources and energy they would generate, or even, in relation to artificial intelligence systems, what digital footprint they could cause (Parlak, 2023). This is not a local issue, but a global one, which is why international cooperation is essential to develop common standards and regulations that protect both safety and sustainability and reduce the long-term environmental impact of emerging technologies.

Not only the weaknesses generated by the implementation of the object of the present development should be considered, but it is fair to mention that the technological revolution has not only brought changes in our environment but has also promoted new economic opportunities, providing e.g. more efficient services, job creation and fostering economic growth, especially in related sectors such as logistics, transport and infrastructure. If, in addition, autonomous vehicles are powered by renewable energy sources and thus contribute to the reduction of fossil fuels, together with the creation of artificial intelligence systems that enable the optimisation of natural resources, they can contribute to a significant reduction in environmental impact. 2In addition, the combination of these two innovations not only reduces environmental impact, but also expands access to transport services in remote areas and encourages smarter interaction between vehicles and their environment, reducing the risk of accidents. In addition, these technologies drive the development of more economical transport systems capable of covering longer distances with less resource consumption.

Türkiye and Spain: Leaders in Technological Innovation and European Integration

It is clear that, in today's world, technological innovation is a key factor for economic growth and social progress. In this sense, Türkiye and Spain, each with their own strengths and contributions to the community, present themselves as active agents in the global contribution.

On the one hand, Türkiye has emerged as a leading country in technological innovation in the Mediterranean region. Its economic development strategy focuses on creating a knowledge-based economy, making it an attractive destination for investors and entrepreneurs. The city of Istanbul, in particular, has

2 Note to the reader on the use of "casualty" instead of "accident": Extensive research in this area shows that most road accidents involve causal factors rather than chance events. This implies that addressing and reducing these causes can significantly reduce the number of accidents and thus the associated casualties. For this reason, road incident victims' associations advocate replacing the term "accident" with "casualty", as the latter more accurately reflects the nature of these events. Pere Navarro, director of Spain's Directorate General of Traffic (DGT), argues in the foreword to the book El Atestado that: "We can no longer refer to traffic accidents as if they were unforeseeable events, the product of chance or fate. It is more appropriate to call them accidents and apply the corresponding legal qualification to those who cause them" (Marchal Escalona, Varela González, Yedra Rovira, Galiana Fernández, & Campón Domínguez, 2009, p. 22).

become an important technological landmark, with numerous innovative startups and companies developing disruptive solutions in areas such as artificial intelligence, the Internet of Things (IoT) and biotechnology. Türkiye ‘s position as an emerging country in technological innovation is largely due to the establishment of programmes and policies to support the growth of the technology sector. The National Innovation Plan 2023-2027 is an example of this strategy, which seeks to increase investment in research and development, improve the infrastructure of universities and research centres, and foster collaboration between the public and private sector Çelikok, K., & Talih, Ö. (2023).

As for Spain, it has established itself as a reference in the integration of European Union (EU) standards. Its geographical position in southern Europe and its membership in the EU have allowed it to develop a deep knowledge of European regulations and standards. This is reflected in its ability to adapt to regulatory and policy changes, making it a valuable partner for international companies and organisations. Spain’s experience in integrating European standards is particularly relevant in areas such as health, food safety and the environment. Its capacity to develop and implement effective policies and regulations has been recognised internationally, and its expertise is sought to be shared with other emerging countries. In addition, Spain has a network of institutions and organisations that support innovation and European integration. The State Research Agency (AEI) is an example of this infrastructure, which funds research and development projects in areas such as materials science, biotechnology and artificial intelligence.

Collaboration between Türkiye and Spain in technological innovation and European integration offers important opportunities for both countries. Shared experience in these areas can help strengthen bilateral relations and foster cooperation in areas such as research, the development of sustainable technologies and the promotion of international trade.

Autonomous Driving Regulations: Differences and Similarities Between Spain and Türkiye

Autonomous driving is a constantly evolving field, with technological innovations changing the way we move. However, behind these technological advances are rules and regulations that guide the development and use of autonomous vehicles (Bonnefon, Shariff, & Rahwan, 2016). The regulation of autonomous driving is a constant challenge, as technologies change rapidly. However, with a clear understanding of the regulations in different countries, developers and companies can navigate this complex regulatory environment and introduce their products in different markets.

The increasing adoption of these new driving models has led to a greater need for regulation and oversight. Governments and international bodies have established norms and standards to ensure the safety and effective operation of autonomous vehicles. However, these regulations vary from country to country, creating challenges for companies and developers seeking to introduce their products in different markets (Navarro Michel, 2020).

In Türkiye, there is currently no specific legislation that comprehensively regulates autonomous vehicles. However, general traffic regulations, aligned with international standards such as Regulation EU/2019/2144, provide a basis for defining technical and operational aspects of this technology. The country is developing specific strategies and regulations for the certification, type approval and testing of autonomous vehicles, although this framework is still evolving.

In Spain, autonomous driving is regulated in the context of tests and trials by Order TEC/1005/2016, which establishes the technical and safety conditions necessary to carry out these tests on public roads. However, regulations for the widespread use of autonomous vehicles are in the process of development, as a comprehensive framework for their full integration into the transport system has not yet been implemented.

Although both countries share the goal of fostering technological innovation in the field of autonomous vehicles, their approaches differ significantly. While Spain has focused its efforts on facilitating controlled testing through specific regulations, Türkiye is taking a more cautious approach, aligning itself with European regulations and prioritising the creation of technical standards to ensure interoperability and safety.

In another sense, while the regulations in Türkiye and Spain have important differences, they also share key similarities in their approach to autonomous driving. Both jurisdictions seek to ensure the safety and performance of autonomous vehicles by implementing specific requirements for their testing and certification. [3]In Spain, this is embodied in Order TEC/1005/2016 , which regulates the technical and safety conditions for testing on public roads.[4] Türkiye, although it does not have a specific regulation, is aligning with international standards such as Regulation EU/2019/2144, which establishes technical criteria to ensure the interoperability and safety of autonomous vehicles. In both cases, developers must provide detailed information on the performance and safety features of their products to facilitate their evaluation and eventual integration into transport systems.

The comparison between regulations in Türkiye and Spain offers valuable lessons for other countries seeking to regulate autonomous driving. First, it is important to establish a clear and consistent regulatory framework to ensure the safety and effective operation of autonomous vehicles. Second, regulations must be flexible and adapt to the changing needs of the market.

Spanish Approach: Integrating Autonomous Driving with Sustainability - the Autocits Initiative

As mentioned above, Spain has become a benchmark in the regulation of autonomous driving by adapting European directives for this purpose and promoting sustainability. The European Union has established a series of regulations to ensure the safety and efficiency of autonomous vehicles, and Spain has made efforts to integrate these regulations into its legal framework. Sustainability is a crucial aspect in the regulation of autonomous driving in Spain in particular and should be a crucial aspect globally in general. Autonomous vehicles can help reduce pollutant emissions and improve air quality in cities, which is fundamental to achieving the sustainability targets set by the European Union. This adaptation has required close collaboration between public authorities and the private sector. The General State Administration, through the Secretary of State for Mobility, has worked closely with regional and local governments to develop a coherent regulatory framework. In addition, Spain has established an action plan for autonomous driving, which includes objectives and strategies to promote its development. The plan seeks to foster research and development of technologies related to autonomous driving, as well as to incentivise the adoption of autonomous vehicles in different sectors. The integration of autonomous vehicles on Spanish roads also requires the implementation of adequate infrastructures. The General State Administration is working to develop an infrastructure network to enable communication between autonomous vehicles and traffic authorities.

3 Order TEC/1005/2016. Ministry of Industry, Energy and Tourism (2016). Order TEC/1005/2016. Official State Gazette. Retrieved from https://www.boe.es/diario_boe/

4 Regulation EU/2019/2144. European Union (2019). Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019. Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/

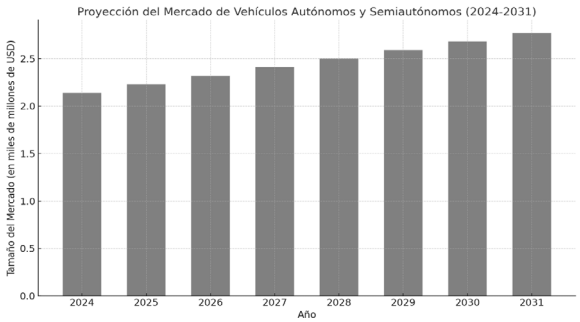
The AUTOCITS (Automóviles Autónomos e Inteligentes: Tecnología, Seguridad y Conducir) initiative is an outstanding example of how Spain is approaching autonomous driving. This project seeks to integrate autonomous vehicles in selected road corridors, with the aim of reducing traffic congestion and improving energy efficiency. This initiative (AUTOCITS) is supported by various stakeholders, including technology companies, vehicle manufacturers and public authorities. Together, they are working to develop a favourable regulatory environment to enable the integration of autonomous vehicles on Spanish roads (Naranjo, Jiménez, Castiñeira, Gil, & Gómez, 2018).5 In Spain, collaboration with the European Union (EU) has also been fundamental for the development of projects such as SEAT Urban Mobility . The electric BRT project in Santander also stands out for its focus on reducing emissions and promoting urban sustainability (Eraña Martínez, 2023).

Turkish Approach: Fostering Innovation and Sustainability - the TOGG Initiative

Türkiye does not currently have a comprehensive regulation that allows testing of autonomous vehicles without a special licence. However, developing initiatives indicate a focus on facilitating experimentation, especially in controlled urban settings (Himmetoglu, Zengin, & Özkök, 2022). It is also investing in infrastructure and collaborating with academic institutions to promote the development of autonomous technologies but is still working on a more defined legal framework (Koruyan & Bedir, 2019). In addition, the Turkish transport administration has established an action plan to promote autonomous technology research and development in the country. By encouraging innovation and experimentation in this field, Türkiye is positioning itself as a leader in the autonomous driving industry.

Figure 1

Data Bridge Market Research (2023). “Global Semi-Autonomous and Autonomous Vehicle Market – Industry Trends and Forecast to 2031



In the global context, the market for autonomous and semi-autonomous vehicles is projected to experience significant growth. Figure 1 illustrates these projections, highlighting economic opportunities for emerging countries such as Türkiye , which is leveraging initiatives like TOGG to position itself strategically. Figure 1 shows the expected growth of the global autonomous and semi-autonomous vehicle market from 2024 to 2031, based on estimates by Data Bridge Market Research (2023). This market is anticipated to grow steadily, reaching $2.88 billion USD by 2031.

The use of autonomous electric vehicles such as the TOGG allows Turkish companies to assess their ability to navigate urban environments without emissions and pollution (Durmuş Şenyapar & Rida Tur, 2023). This not only reduces the costs associated with experimentation, but also contributes to sustainability and environmental well-being. Turkish expertise in autonomous vehicles is based on close collaboration between automotive companies, government and academic institutions. The TOGG initiative is an outstanding example of how public-private cooperation can foster innovation and technological development.

5 This project aims to create connected autonomous systems that allow vehicles to travel the streets safely and efficiently. Undoubtedly, innovative technologies that are changing the way people move around cities.

The TOGG (Türkiye Otomobil Grubu) initiative, a consortium of leading Turkish automotive companies, has developed an autonomous electric vehicle for experimentation in urban environments. The aim is to evaluate the vehicle's ability to navigate congested streets and avoid obstacles in heavy traffic conditions. In cities such as Istanbul, the city administration is working on initiatives to integrate autonomous technologies into smart grids. This includes the implementation of autonomous navigation systems that allow vehicles to navigate the streets safely and efficiently. The city has become a living laboratory where new technologies are tested and developed to improve urban mobility. The promotion of autonomous technologies is aligned with the strategic autonomy goals in Türkiye 's foreign policy (Fouskas, 2022).

Türkiye has made significant progress in establishing a sustainable automotive and technological ecosystem, spearheaded by initiatives such as TOGG (Türkiye Otomobil Grubu). This consortium of Turkish automotive companies not only manufactures electric vehicles but also drives the development of autonomous technologies for integration into both urban and rural environments. In collaboration with universities and research centers, TOGG has developed prototypes equipped with advanced real-time navigation and detection systems designed to enhance road safety and optimize traffic flow.

The Turkish government has also invested in smart infrastructure, including electric charging networks and sensors for real-time road monitoring. These efforts aim not only to promote the adoption of electric and autonomous vehicles but also to position Türkiye as a leader in automotive innovation within the Mediterranean region. A crucial aspect of Türkiye's strategy is its alignment with international standards, such as EU Regulation 2019/2144, which sets technical criteria to ensure the interoperability and safety of autonomous vehicles. Although Türkiye is not a member of the European Union, it has adopted a progressive approach by integrating elements of these regulations to facilitate the export of its technologies and products to the European market. This demonstrates Türkiye's adaptability in a highly regulated global context.

In comparison, Spain, with projects like AUTOCITS, benefits from established infrastructure and direct support from the European Union. Türkiye, however, faces the challenge of building an ecosystem from the ground up. Yet, this situation also creates opportunities to develop innovative solutions tailored to local needs, fostering public-private collaboration and positioning Türkiye as a replicable model for other emerging nations.

The key differences between the TOGG and AUTOCITS initiatives are summarized in Table 1, which compares aspects such as primary objectives, public-private collaboration, and the expected impact of each initiative.

Table 1

Comparative Table: TOGG vs. AUTOCITS Initiatives

ASPECT	**TOGG (TÜRKİYE)**	**AUTOCITS (SPAIN)**
Primary Objective	Manufacturing electric and autonomous vehicles	Integrating autonomous vehicles in specific road corridors
Public-Private Collaboration	High, involving local companies and universities	High, supported by the EU and local stakeholders
Expected Impact	Reducing fossil fuel dependency and improving traffic safety	Optimizing traffic and reducing emissions

Impact on Road Safety and the Environment

Road safety[6] is one of the issues of greatest incidence and concern worldwide, with road accidents being one of the main causes of fatalities (globally), and it is estimated that, in this global context, 90% of incidents are attributed to human error (such as distractions, incorrect decisions or negligent behaviour (Bonnefon, Shariff, & Rahwan, 2016).7Therefore, autonomous vehicles are presented as a solution that would promise to minimise the incidence of road accidents (and road crime) (Bekerman, 2021).

The human factor is and has been identified as the main cause of road crashes, ranging from poor decisions to inattention. These failures can stem from factors such as fatigue, substance abuse or simple negligence. According to information published by the Directorate General of Traffic (DGT) in 2017, around 30% of traffic fatalities, approximately 500 people, were linked to reckless behaviour. Among these behaviours, the use of mobile phones is considered particularly dangerous, an opinion shared by 94% of drivers. However, 42% acknowledged that they use their mobile phone while driving, according to a 2016 study by the RACC. For its part, the American Automobile Association (AAA) warns that using a mobile phone while driving generates three types of distractions: visual, cognitive and manual, which increases the probability of having an accident by 23%. To illustrate this risk, the DGT highlighted in 2017 that, when dialling a phone number while driving at 120 km/h, 429 metres are travelled without observing the road, which is equivalent to the length of four football pitches. In the case of composing a message, this distance rises to 660 metres. This behaviour, which has spread considerably throughout Spain, reflects a change in road risk patterns generated by technological advances and their integration into everyday life. It has therefore become essential to study this phenomenon, which did not exist until a few years ago, and to design preventive strategies focused on reducing its impact on road safety.

Autonomous vehicles, by operating with advanced algorithms and artificial intelligence systems, eliminate these vulnerabilities, offering more predictable and safer driving (Bustamante Donas, 2022). Cutting-edge technologies, such as advanced sensors, high-resolution cameras and LIDAR (Light Detection and Ranging) systems, enable an accurate understanding of the environment in real time. The integration of these systems ensures early detection of potential hazards and immediate response, even in adverse conditions (Rickert, Pulgar Vielma, & Gutiérrez, 2019). Furthermore, machine learning technologies allow these vehicles to adapt and improve their performance as they accumulate more data on different driving scenarios.

This would therefore not only reduce the frequency or number of crashes, but also have a direct impact on their severity. Studies led by the United States already estimate a 90% reduction in accidents with a full implementation of autonomous vehicles (Navarro Michel, 2020). Needless to say, this impact would not only improve life and road safety, but would also have an impact on costs related to health intervention, insurance and property damage (Othman, 2021).

There are already countries, such as Sweden and Singapore, that have demonstrated the aforementioned reduction in crash rates (during controlled trials), reinforcing the viability of the technology and therefore the reliability and acceptance by society (Sanchez Mateo, 2023).

As with any challenge and substantial change of such magnitude, the irremediable legal regulation must not be left aside, clearly defining frameworks that determine responsibilities in alleged failures or generation of accidents (Mesa Rosas, 2022), without forgetting

6 The DGT (2015) defines road safety as: "The achievement of a driver with sufficient knowledge and skills who, in an adequate physical and mental state, drives a properly designed and maintained vehicle along properly planned, maintained and signposted routes in a social environment that is aware of the problem and cooperates in finding appropriate solutions". In view of the content of this definition, the DGT adds to the three classic factors involved in an accident (human, vehicle and road), the characteristics and conditioning factors of society according to the time and place where the road system operates.

7 Part of the accident rate is directly related to road crime, understood as an element of study of criminology as a science that analyses unlawful conduct related to non-compliance (intentional or reckless) with traffic regulations, which generate or could generate significant risks to the life, physical integrity and safety of people on public roads. These road network behaviours transcend administrative offences and are considered criminal offences due to their seriousness and potentially devastating consequences, such as serious, very serious injuries or fatalities, ultimately (Gómez García, 2019).

the ethical dilemmas that can be generated in decision-making regarding situations of imminent danger (Bonnefon, Shariff, & Rahwan, 2016). Of course, international, public-private and public-private cooperation are indispensable for overcoming all the challenges brought about by the implementation of new forms of mobility. In addition to the impact on road safety, as mentioned above, autonomous vehicles can also contribute to a significant reduction in energy consumption and pollutant emissions; by optimising traffic and reducing downtime, these vehicles can save up to 20% fuel, resulting in a considerable reduction.

In this regard, it is imperative to mention the 2030 Agenda for Sustainable Development, adopted by the United Nations. Among its 17 global goals are those aimed at protecting the planet and ensuring prosperity. 8Thus, it could be considered that autonomous vehicles would have an excellent potential to contribute directly to several of the Sustainable Development Goals (hereinafter SDGs), specifically in relation to environmental sustainability and road safety :

SDG 3: Ensure healthy lives and promote well-being for all. This would be linked to road safety and a significant reduction in road traffic deaths and injuries. By eliminating human error (the main cause of accidents), safer mobility could be achieved and thus contribute to well-being (target 3.6).

SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all. Autonomous vehicles enable the optimisation of energy consumption, reducing the use of fossil fuels and promoting transport efficiency, thus impacting on the target linked to improving global energy efficiency (target 7.3).

SDG 9: Industry, innovation and infrastructure. There would also be a breakthrough in transport infrastructure and technology that becomes sustainable, necessitating the promotion of innovation in smart systems and leading to more efficient cities (target 9.4).

SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable. Optimising traffic, reducing congestion and congestion times are other improvements of autonomous vehicles allowing an improvement in the air quality of urban settings, adding efforts to the target on reducing negative environmental impacts specifically with air quality (target 11.6).

SDG 13: Take urgent action to combat climate change and its impacts. Reducing fuel consumption and greenhouse gas emissions contributes directly to global efforts to mitigate climate change (target 13.2). The projected 20% decrease in pollutant emissions from such vehicles would support climate action targets.

Autonomous vehicles: cybersecurity risks and ethical dilemmas

All efforts within the automotive sector are currently focused on eliminating human intervention, not only partially but entirely. It is crucial to reference the existence of five levels of autonomy in this context. At level 1, the driver receives only partial assistance and remains fully responsible for the vehicle. At level 2, the vehicle can automatically manage distances and lane positioning, with all maneuvers supervised by the driver, who can release the pedals but must remain in control of the steering. At level 3, the driver can delegate driving tasks to the vehicle under specific circumstances, temporarily letting go of the steering wheel. In level 4, the driver is no longer required to oversee any aspect of the driving process, although they can take control if needed, while the vehicle handles the entire journey autonomously. Finally, level 5 represents vehicles that operate entirely on their own, with no driver involved, transporting passengers along pre-set routes.ACISSI, Bancal, Ebel, Vicogne, Fortunato, and collaborators (2022) state that currently, most connected vehicles exhibit levels 1, 2, and 3 of autonomy. The automotive sector predicts that by 2035, 75% of vehicles on the road will be autonomous, although the specific level of autonomy is not specified.

8 United Nations (2015). Sustainable Development Goals. Retrieved from: https://www.un.org/sustainabledevelopment/es/sustainable-development-goals/

This connectivity introduces various attack scenarios for both connected and autonomous vehicles at levels 1 and 2. Examples include activation or alteration of vehicle options, modifying ECU parameters to enhance performance, or incentivizing vehicle theft by bypassing locking systems, disabling ignition systems, or tampering with tracking systems. Other potential attacks involve forcing the driver to stop by simulating malfunctions or injecting false diagnostics. A critical consideration for automakers and governments, as level 4 and level 5 autonomous vehicles are developed and deployed, is the possibility of remotely taking control of these vehicles without the owner's consent. In this regard, researchers such as Charlie Miller and Chris Valasek have already demonstrated remote control vulnerabilities in a Jeep Cherokee (ACISSI et al., 2022).

Regarding ethical dilemmas, it is essential to note that autonomous vehicles rely on advanced communication systems, such as V2X (Vehicle-to-Everything), making them vulnerable to cybersecurity threats. A recent study emphasized that successful attacks could disable critical systems, endangering passenger safety (Hakak et al., 2022). Furthermore, there are concerns about the manipulation of sensitive data collected by sensors and navigation systems, raising significant privacy issues. From an ethical perspective, autonomous vehicles face complex decision-making challenges during emergencies. Their systems must prioritize minimizing harm to passengers, third parties, or the environment, posing dilemmas akin to the "trolley problem" scenarios (Himmelreich, 2018). These challenges highlight the urgent need for global standards in ethical design, robust security protocols, and fostering international collaborations to ensure transparency and accountability.

Conclusions: A Shared Future Autonomous and Sustainable Mobility

Technological cooperation between Türkiye and Spain offers great potential for the development of autonomous and sustainable vehicles. Through bilateral collaboration, significant innovations can be generated that can improve efficiency and safety on transport routes. However, the challenges (technical and ethical) and challenges associated with cooperation need to be overcome to fully realise this potential (Hussain & Zeadally, 2019). Both countries can together lead the transition towards safe, autonomous and sustainable mobility, jointly building a shared future on strengths and experiences, presenting themselves as a role model for other countries to follow. The sharing of knowledge, resources and expertise will not only benefit businesses and citizens as well as enable a reduction in costs (Durmuş Şenyapar, Akil, & Dokur, 2023) and an acceleration in the development of these innovative technologies, and of course citizens, but will also be a hopeful bet for generations to come.

Table 2

Comparative analysis of regulatory frameworks

Country	Key Initiative	Regulatory Strengths	Challenges
Türkiye	TOGG	Emerging national strategy; flexible	Lack of comprehensive regulatory framework
Spain	AUTOCITS	EU-driven standards; established framework	Need for cross-border alignment

The differing regulatory approaches, while presenting challenges, also provide opportunities for innovative solutions. Among the challenges generated is the need for clear regulations (Biresselioglu et al., 2021). In this sense, the integration of European regulations will be key to ensure a smooth, optimal and efficient transition (Bonnefon, Shariff, & Rahwan, 2016). In this process, both Türkiye and Spain may be able to contribute to a speedier process, both adapting quickly to the appropriate regulations, which may have an impact on the creation of a single European market for autonomous and sustainable vehicles.

Among the challenges generated is the need for clear regulations (Biresselioglu et al., 2021). In this sense, the integration of European regulations will be key to ensure a smooth, optimal and efficient transition (Bonnefon, Shariff, & Rahwan, 2016). In this process, both Türkiye and Spain may be able to contribute to a speedier process, both adapting quickly to the appropriate regulations, which may have an impact on the creation of a single European market for autonomous and sustainable vehicles. TOGG (Türkiye's Otomobil Girişimi) is an inspiring example of how one company can lead innovation in autonomous and sustainable mobility. With its commitment to creating electric and autonomous vehicles, TOGG is setting a new standard for the automotive industry in Türkiye . The cooperation between TOGG and Spanish companies can be a good start. Countries that succeed in developing a safer, autonomous and sustainable public transport system will have access to more abundant financial and technological resources. Sustainability is therefore fundamental to improving and designing the transport of the future (safer, more autonomous and sustainable). The integration of technological advances with European regulations can help to create vehicles that are more efficient in the use of natural resources. All this in the interest of contributing to a better quality of life for citizens, a common global objective.

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