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Article

Barriers and policy solutions for electric vehicle adoption in Spain: a multidimensional analysis

Bianca Cid,[1,*] María Teresa García-Álvarez,[1]

[1] Universidade da Coruña, Elviña, 15071 A Coruña, Spain
*_Correspondence_: bianca.cid@udc.es

Abstract. In Spain, the transport sector is one of the largest contributors to greenhouse gas (GHG) emissions, primarily due to the widespread use of fossil fuels. Electric vehicles (EVs) are a key component in transitioning towards sustainable mobility and transport decarbonization. The article presents novel insights into the interplay between economic, technical, regulatory, and social factors affecting EV uptake in Spain, distinguishing itself from previous studies, using a multidimensional approach. It not only identifies the main challenges but also proposes actionable solutions based on successful international case studies. These include enhancing financial incentives, expanding nationwide charging networks, ensuring consistent regulatory frameworks and promoting public awareness campaigns to dispel misconceptions about EVs, among others. By integrating these aspects, the research contributes significantly to the discourse on sustainable transport in Spain, aiming to provide a roadmap for policymakers and stakeholders in achieving national climate targets.

Keywords: electric vehicles; sustainable mobility; greenhouse gas emissions; charging infrastructure; energy transition.
JEL classification: L62, R48, Q42, Q48, Q54, O33, D12

1. Introduction

The transport sector in Spain has historically been dominated by petroleum-based fuels, particularly diesel and gasoline. This supremacy has contributed to the provision of cheap and reliable transport services. However, it has made transport the largest emitter of greenhouse gas (GHG), the main cause of climate change. In 2022, this sector accounted for an estimated 30.4% of emissions, followed by industrial activities (19.0%), electricity generation (15.2%), agriculture and livestock as a whole (11.0%), fuel consumption in the residential, commercial and institutional sectors (7.9%) and waste management (4.9%). In addition, most sectors experienced an increase compared to the previous year, in the case of transport it was 4.4% (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023a).

In Spain, the predominant mode of transport for passengers and freight is road, accounting for more than 90% of journeys (Ministerio de Transportes y Movilidad Sostenible, 2024). In 2022,

road transport alone accounted for an estimated 28.1% of total GHG emissions. As illustrated in Figure 1, the evolution of GHG emissions in the transport sector has been marked by a steady increase from 1900 until 2007, when emissions peaked.

Subsequently, there was a decrease, mainly due to the Spanish economic crisis. From 2013 onwards, there was again a sustained increase in emissions until 2020, when they fell by 17% due to the mobility restrictions imposed by the COVID-19 pandemic. However, in 2021, the previous upward trend returned, with a year-on-year increase of 15% and 2.9% in 2022 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023b).

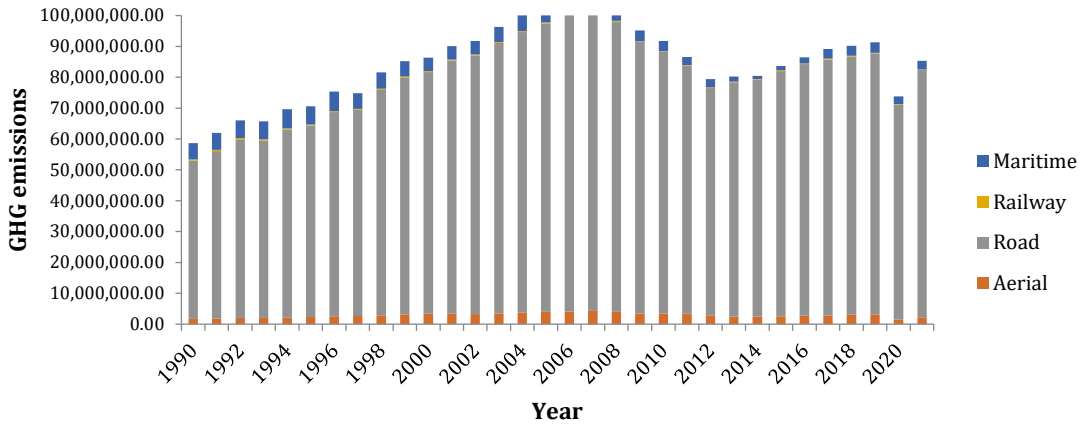

Figure 1. GHG emissions measured in tonnes of CO_2 equivalent in the transport sub-sector in Spain. Source: Own elaboration based on data from European Environment Agency (2024).

Spain ranks among the top five European Union Member States with the highest CO_2 emissions (see Figure 2) (European Parliament, 2023). This is due to a combination of structural, economic and energy factors that have shaped the country's emissions profile in recent decades.

Several elements explain why CO_2 emissions in Spain remain relatively high compared to other European countries. Firstly, Spain's economic structure has played an important role in shaping its CO_2 emissions. The Spanish economy has traditionally been dominated by sectors such as transport, construction, and industry, all of which are carbon-intensive. As highlighted above, the transport sector accounts for a significant proportion of CO_2 emissions in Spain, due to the fossil fuel-based model and the historical dependence on road transport. In addition, the extensive transport infrastructure network, including one of the largest road networks in Europe, has facilitated a steady growth in the use of private vehicles, which contributes to keeping emissions high (European Court of Auditors, 2020).

Another key factor is the energy matrix. Although in recent years there has been a significant increase in renewable energy production, particularly in the wind and solar sectors, the energy transition has progressed gradually. For much of the past decades, Spain relied heavily on fossil fuels such as coal, natural gas and oil for electricity generation. This dependence has resulted in persistently high CO_2 emissions, especially in comparison with European countries that have achieved a higher penetration of renewable energy and a more rapid reduction in the use of fossil fuels (Rosales-Asensio et al., 2024).

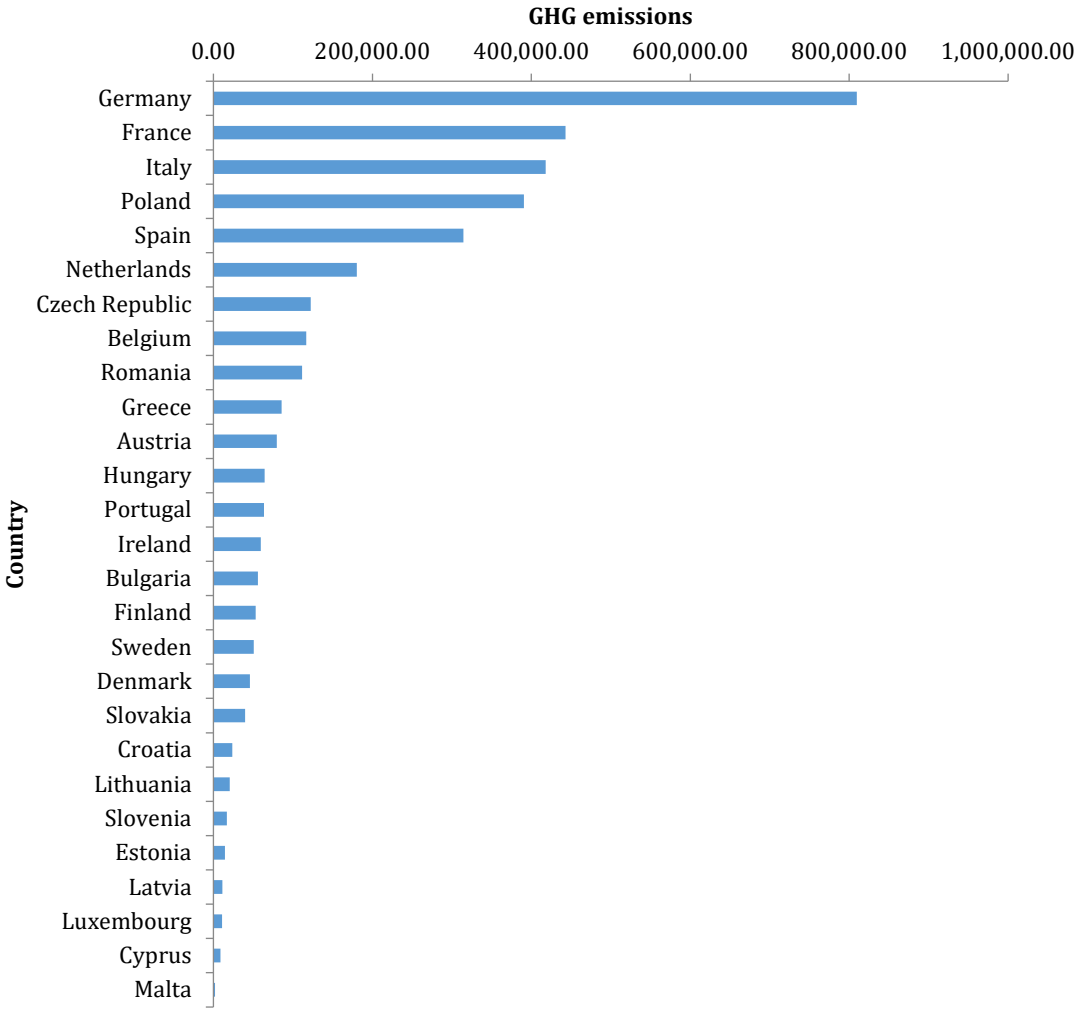

Figure 2. Total GHG emissions per European country in 2019 measured in kilotonnes of CO_2 equivalent. Source: Own elaboration based on data from European Parliament (2023).

In addition, Spain's demographic and urban growth, especially in the last decades of the 20th century and early 21st century, has contributed to the increase in CO_2 emissions. Urban sprawl, often uncontrolled and characterized by dispersed territorial development, has led to a rise in energy and transport demand, thus exacerbating emissions. Spatial and urban planning policies have not always favoured sustainable growth, resulting in carbon-intensive energy consumption patterns.

Finally, the implementation of climate and energy policies in Spain has had a significant impact on CO_2 emissions, but their effectiveness has been variable. While notable progress has been made in promoting renewable energies and improving energy efficiency, Spanish policy has at times been marked by a lack of continuity and abrupt changes in strategies, which has made it difficult to consolidate a sustained trajectory towards emissions reductions (González et al., 2024).

Given these circumstances and in line with the positions adopted by the European Commission and most member states, Spain has set itself the target of achieving GHG emission

neutrality by 2050 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2020).

To achieve this goal, a change in the transport sector is needed, as almost one out of every three tonnes of GHG emissions originates from this sector. This transformation necessitates replacing the current fossil fuel-based mobility model with an electric mobility framework. Thus, the key to this metamorphosis lies in the mass adoption of EVs (Usmani & Rösler, 2015).

EVs use one or more electric motors to generate the power needed for propulsion, unlike internal combustion engines that use fossil fuels. One of the primary advantages is that they do not emit exhaust gases at the point of operation (Adnan et al., 2016). Life cycle assessment is a tool that characterizes such impacts along the life cycle of vehicles. Recent life cycle assessment studies consistently demonstrate that EVs significantly reduce GHG emissions over their entire life cycle compared to conventional internal combustion engine vehicles powered by gasoline or diesel (Knobloch et al., 2020; Ajanovic & Haas, 2019; Moro & Lonza, 2018).

In addition to being the key player in transport decarbonization, EVs are an efficient alternative. Internal combustion vehicles have a modest thermodynamic efficiency of around 25% (Chernyshev et al., 2017). However, in the case of EVs, this figure rises to around 95% (Albatayneh et. al., 2020). At the same time, through new technologies such as vehicle-to-grid (V2G) and vehicle-to-home (V2H) chargers, EVs are a vector for energy storage (Izquierdo-Monge et al., 2024; Niu et al., 2024; Kamran, 2022).

In this context, this article aims to analyze the current situation of EVs in Spain, identifying the main barriers that hinder their mass adoption. This issue seems particularly interesting in this Member State, due to its peculiarities. Through a multidimensional approach, economic, infrastructural, regulatory and social factors that limit the growth of the EV market in Spain are examined. Furthermore, specific recommendations based on international experiences and case studies are proposed to improve public policies, encourage investment in charging infrastructure and foster greater public awareness of the environmental and economic benefits of this type of sustainable mobility.

This article makes a significant contribution to the field of sustainable transportation by providing a thorough examination of the EV landscape in Spain, a country that currently lags behind its European counterparts in EV adoption.

Unlike previous studies, this research uniquely integrates economic, regulatory, and social dimensions to provide a comprehensive understanding of the barriers to EV adoption in Spain. The findings reveal critical insights into the complex interplay of these factors, highlighting how they collectively impede the transition to electric mobility. Importantly, the article offers practical, evidence-based recommendations from successful international case studies, bridging the gap between theory and practice. By addressing the urgent need for cohesive public policies and targeted investment in charging infrastructure, the article positions itself as a vital resource for policymakers, industry stakeholders and researchers. Ultimately, this work lays the groundwork for future studies and actions aimed at accelerating Spain's transition to a more sustainable transport system, thereby contributing to broader European climate objectives.

This paper is structured in several parts. First, it describes the importance of electric mobility in Spain, highlighting its role and impact. Next, it analyses the obstacles to the mass adoption of this type of mobility, both at the micro and macro levels. It then reviews existing measures to

promote EV use and the targets set by the government for the coming years. Finally, a series of recommendations is provided to policymakers to overcome the barriers identified at the macro and micro levels to improve policy implementation and promote EV deployment.

2. Importance of electric mobility in Spain

The transport sector is the main cause of GHG emissions in Spain, making it the largest source of atmospheric pollution, contributing to climate change (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023). Thus, this is a critical time in which environmental awareness and the pursuit of sustainable solutions are imperative. In this context, electric mobility is a fundamental tool for addressing environmental challenges and transforming our relationship with transport. This shift towards EVs is not simply a trend, but an urgent necessity in building a more sustainable future.

One of the key pillars of electric mobility is its ability to reduce GHG emissions drastically. Traditional fossil fuel-based vehicles are responsible for much air pollution and climate change. In contrast, EVs run on electricity, meaning they do not directly emit pollutant gases during operation. However, it is important to emphasize that the environmental benefits of EVs depend heavily on the source of electricity used for charging. To maximize their potential for reducing emissions, it is crucial that this electricity comes from renewable sources, as relying on fossil fuels could undermine the sustainability goals of electric mobility (Maia et al., 2024; Sousa & Costa, 2022; Longo et al., 2019). The transition to a large EV fleet would significantly reduce our environmental footprint and contribute to climate change mitigation (Jeong et al., 2024).

Electric mobility not only contributes to environmental preservation but also reduces dependence on fossil fuels. In this respect, Spain experienced an extreme shift from near self-sufficiency to total dependence. In the 1940s, Spain imported only around 10% of the energy it consumed - taking into account the important role played at that time by traditional energy sources (biomass, human and animal) - a percentage that would increase to around 85% in 1975 and to an astonishing 90% at the beginning of the century (Muñoz Delgado & Rubio Vargas, 2015). This significant dependency remains unchanged, with only 25.65% of energy in 2022 sourced from domestic production (Statista, 2024).

Oil prices' volatility and concerns about energy security have underscored the necessity of diversifying energy sources in Spain. In this way, mass adoption of EVs can reduce dependence on oil imports, improving the trade balance and strengthening energy autonomy (Ross Morrow et al., 2010). EVs, powered by electricity generated from renewable sources, enable such diversification and the transition to a more sustainable and resilient energy system.

The transition to electric mobility also presents significant economic opportunities. The manufacture, sale and installation of EVs and their associated infrastructure generate employment and stimulate economic growth. Thus, in addition to car manufacturers, energy companies and service providers will benefit from this shift as new jobs will be created by developing modernized technologies in different sectors (Haddadian et al., 2015).

In this context, Spain has started to play a leading role, recognizing the importance of adopting EVs to drive a significant change in mobility and contribute to building a more environmentally friendly

society.

Like many other countries, Spain faces environmental challenges from rising GHG emissions and air pollution. The transport sector, responsible for the largest contribution of these emissions, is at the centre of attention to achieve a transition towards cleaner and more sustainable mobility. In this regard, electric mobility is the pillar of sustainable and energy-efficient modes of transport (Faria et al., 2014).

EVs offer several environmental, economic and social benefits. Firstly, EVs do not emit pollutant gases or CO_2 during operation, which contributes to reducing air pollution and carbon footprint. In addition, the electrification of transport can also help to reduce dependence on fossil fuels, promoting energy autonomy and generating new employment opportunities in the renewable energy sector (Will et al., 2024).

The analysis of EV development in Spain is relevant within the context of the European Union (EU) due to several interrelated reasons that underline both the importance of Spain as a key player in the European landscape and the particularities of its economic, industrial and geographical situation. Firstly, Spain is one of the largest and most populated countries in the EU (Eurostat, 2024), making its role in the transition to electric mobility crucial for the success of the European climate agenda (Ministerio para la Transición Ecológica y el Reto Demográfico, 2020).

Moreover, Spain holds a prominent position within the European automotive industry, being the second largest vehicle producer in the EU (International Organization of Motor Vehicle Manufacturers, 2024). The transformation of a traditional automotive industry towards the production and adoption of EVs is a complex process that involves adjustments in the supply chain, in the production infrastructure and the adoption of new technologies. In this context, a comprehensive analysis of how Spain is tackling this process would allow for a broader view of the challenges and opportunities facing the main industrial actors in Europe.

It is also essential to consider Spain´s capacity for renewable energy production, particularly in the wind and solar sectors, which has direct implications for the sustainability of EVs (Raluy et al., 2021). Integrating a growing EV fleet with an electricity grid dominated by renewable sources could maximize the environmental benefits of transport electrification, reducing dependence on fossil fuels (Bastida-Molina, 2020). Spain, thus, serves as a model of how the energy transition and transport electrification can progress in tandem, providing a blueprint that may be replicated or adapted by other EU countries.

Although the prevalence of EVs in Spain is experiencing a sustained increase (see Figure 3), its sales volume is still deficient. EV registrations grew by 38.6% in 2023 compared to the previous year. However, this growth is insufficient to meet the target set by the National Integrated Energy and Climate Plan, which aims for 5.5 million EVs in circulation by 2030. Currently, there are fewer than half a million EVs in circulation (AEDIVE, 2024; GANVAM, 2024).

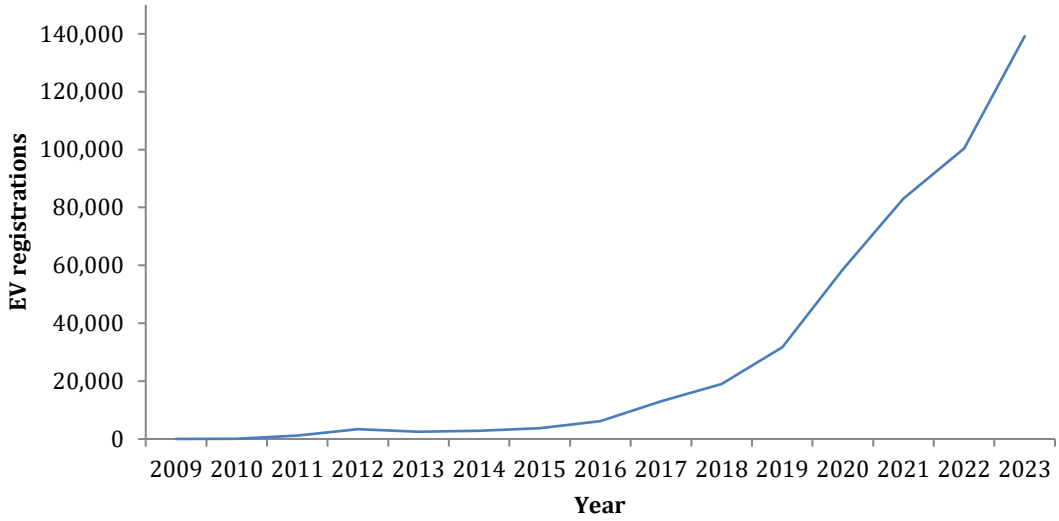

Figure 3. Evolution of EV registrations in Spain 2009-2023. Source: Own elaboration based on data from AEDIVE (2024) and GANVAM (2024)

Approximately one out of every 10 passenger cars registered in Spain in 2023 was an electrified model, an increase of almost two and a half percentage points compared to the previous year. However, this figure is below the European average - where two out of every 10 passenger cars registered were electric - and far behind countries such as Norway, Iceland and Sweden. In 2023, the Norwegian country remained supreme, with more than 90% of vehicle registrations being electrified models (European Automobile Manufacturers' Association, 2024).

As in most European countries, gasoline vehicles remain the dominant choice for consumers in Spain, accounting for a market share of 40.8% –35.70% in Europe–. Although diesel is losing the most presence -registrations in Spain fell by almost five percentage points in 2023 compared to the previous year and in Europe by nearly three percentage points- these two fuels still account for more than half of new registrations in Spain (European Automobile Manufacturers' Association, 2024).

In Europe, transport electrification is proceeding at very uneven rates. In 2022 and 2023, Spain ranked 17th in the share of EV registrations (see Figure 4).

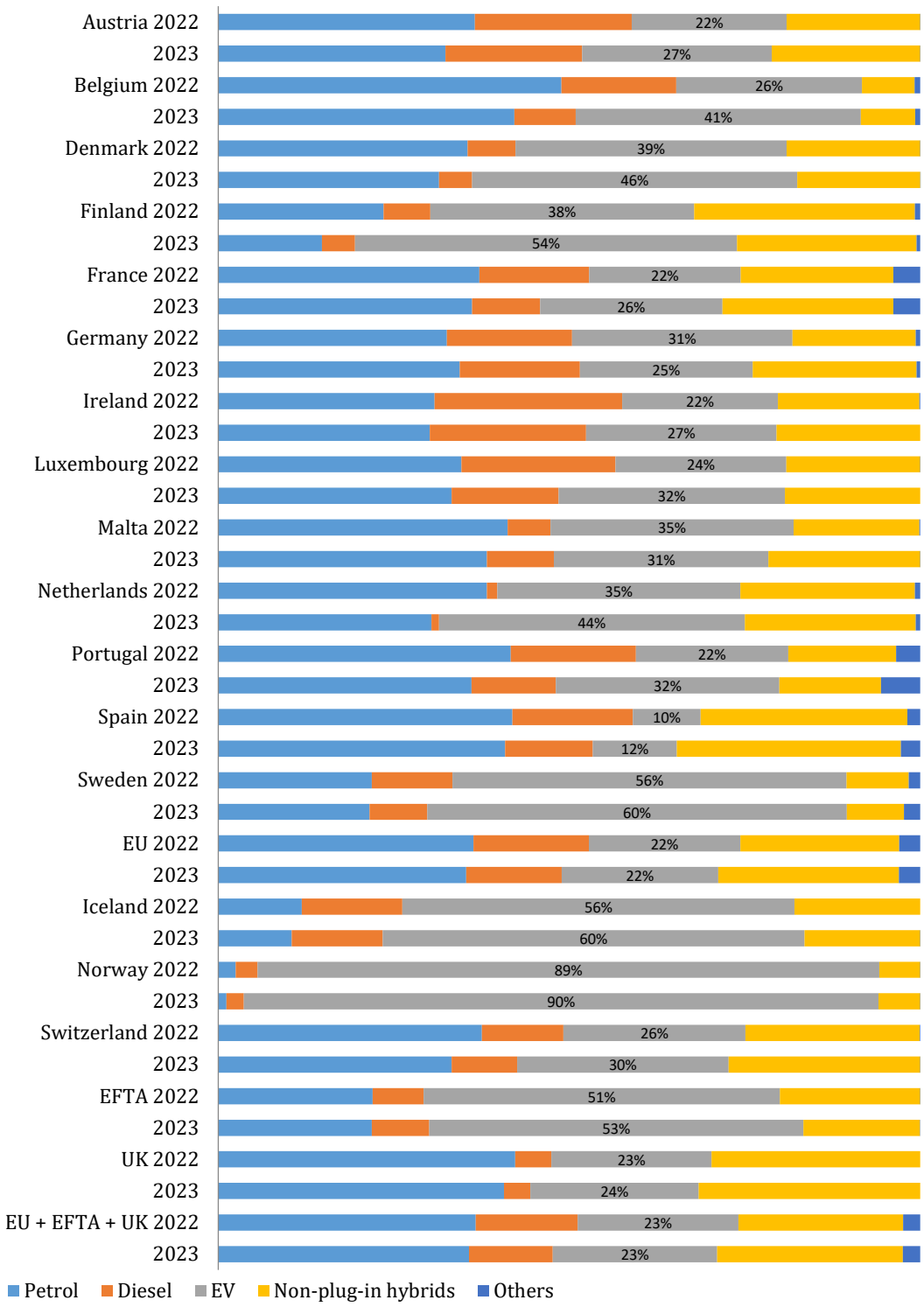

Figure 4. Registrations by energy source in Europe. Source: Own elaboration based on data from the European Automobile Manufacturers´ Association (2024)

3. Barriers to EV uptake in Spain

The transition to electric mobility represents a significant change in the transport industry, but the adoption of EVs in Spain faces several challenges at both the micro and macro levels.

Barriers at the micro level:

High initial cost. One of the main barriers to electric mobility is the high purchase price (Wood & Jain, 2020). Although battery cost –the most expensive component of the EV propulsion system– has dropped by nearly 90% (Berckmans et al., 2017), EVs still have a higher initial price than internal combustion vehicles. This represents a significant challenge for consumers who have to make a greater financial effort to purchase a car. Over 50% of respondents in various studies (Coffman et al., 2017; Carley et al., 2013) identified the high initial costs as the primary barrier to the intention to purchase EVs.

To analyse the price difference, some vehicle models with their electric and internal combustion versions have been selected (see Table 1).

Table 1. Retail prices of selected vehicle models in Spain.

	Internal combustion engine version	Electric version
Peugeot 208 Allure	20,950 €	35,000 €
Peugeot 2008 Style	24,989.99 €	36,490 €
Peugeot 308 Style	29,250 €	37,820 €
Peugeot Rifter Standard Allure	26,873.07 €	32,850 €
Renault Kangoo Furgon	18,182 €	28,952 €
Renault Master Furgon	28,505 €	49,528 €

Source: Own elaboration based on data from Peugeot and Renault (2024)

EVs are consistently higher priced across all models analysed –on average 40% more expensive–. Notably, Renault Master Furgon is 73.8% more expensive in its electric version than in its internal combustion version.

Limited range and range concerns. The limited range of some electric models and concerns about the distance they can travel on a single charge are determining factors for EV purchase (Chakraborty et al., 2022; Wicki et al., 2022; Wood & Jain, 2020; Canepa et al., 2019; Carley et al., 2013). Although batteries have improved considerably in capacity and efficiency, the range remains a concern for some drivers. The fear of running out of charge on long journeys becomes a deterrent for many drivers to initiate the transition to electric mobility. 56% of Spanish drivers would not buy an electric vehicle because they consider that the range is not sufficient (BNP Paribas, 2024).

Insufficient charging infrastructure. The lack of a well-developed and accessible charging infrastructure is one of the main challenges facing the mass adoption of EVs (Yang & Lin, 2024). The charging infrastructure in Spain is still insufficient compared to other European countries (International Energy Agency, 2024). Drivers need the assurance that they will be able to charge their vehicles properly.

Perceptions and lack of knowledge. User attitudes and perceptions are another barrier to adoption (Wicki et al., 2022; Singh et al., 2020; Adnan et al., 2017). Lack of awareness and understanding of the benefits and capabilities of EVs are major determinants to be taken into account, as many consumers are still unfamiliar with the technology, the options available and the

benefits they offer. In Spain, many consumers are still unaware of key attributes of EVs, such as long-term cost savings, environmental advantages and the availability of government incentives (Higueras-Castillo et al., 2020).

Uncertainty about batteries. Uncertainty about the durability and lifespan of EV batteries is yet another obstacle for consumers. There is concern about the gradual degradation of battery capacity over time and with use, since as batteries are repeatedly discharged and recharged, they may lose energy storage capacity, resulting in reduced range and reduced vehicle performance. Spain's warmer climate accelerates battery wear compared to countries with milder conditions, like Norway, making it a less favorable environment for battery longevity (Geotab, 2024).

Uncertainty about battery durability is also related to the cost and convenience of battery replacement. Consumers fear that battery replacement is costly and may be needed early, which would significantly increase the total cost of ownership of the EV. In addition, the rapid evolution of battery technology may also lead to uncertainty about durability and lifetime, as battery technology advances may result in more efficient and durable models in the future, which could make current EVs obsolete more quickly (Adu-Gyamfi et al., 2024).

Lack of model variety. The choice of EV models is minimal in size, style and functions compared to the wide range of internal combustion vehicle models, because this market is fully developed (International Energy Agency, 2023). It is estimated that in 2020 there were approximately 370 internal combustion vehicle models available on the global market, compared to approximately 140 EV models. This represents a ratio of roughly 1 EV model for every 2.6 internal combustion vehicle models (International Council on Clean Transportation, 2022). Although the supply of EVs is increasing rapidly, it remains significantly lower than that of internal combustion vehicles, which may limit the options for consumers interested in transitioning to cleaner technologies.

Resistance to change. Familiarity, resistance to change and fear of the unknown strongly influence transformation. Drivers are used to internal combustion vehicles and may initially be reluctant to switch to new technology (Krishna, 2021). 64% of Spanish consumers do not consider buying an electric vehicle when renewing their car (Alphabet, 2024).

Macro-level barriers

Changing policy incentives. Political support is a key determinant of EV adoption (Wood & Jain, 2020; Canepa et al., 2019; Hardman et al., 2017; Jenn et al., 2018). Changing decisions on tax incentives, subsidies and regulations can create uncertainty among consumers and manufacturers. According to the empirical results, democracy and the quality of the government have a significant role in the success of environmental policy. Implementing and enforcing environmental policies and ensuring they are based on community needs and objectives require democratic governance systems and effective government institutions (Dokuzoğlu & Güzel, 2024). Policy stability is needed to encourage investment and long-term planning in the EV sector.

Limited public charging infrastructure. Despite efforts to increase the number of charging stations, the current network may not be sufficient to support mass EV adoption. Significant expansion is needed to ensure that drivers have convenient access to charging in both urban and

rural settings (Bastida-Molina et al., 2022).

Electricity generation capacity. The increase in electricity demand associated with the mass adoption of EVs poses challenges regarding electricity generation capacity (Gilleran et al., 2021; Anastasiadis et al., 2019). For every million EVs, the impact on demand in the electricity system is estimated at 2,100 GWh (Red Eléctrica Española, 2018). Significant investments in electricity infrastructure are needed to ensure that it is robust and sustainable, especially considering the increasing focus on renewable energy sources (Fernández, 2021).

Waste battery management. As the number of EVs in circulation increases, the amount of discarded batteries is expected to increase considerably in the coming years. Once EV batteries are degraded to 70–80% of their initial capacity, EV owners must replace them as the residual capacity becomes insufficient for automotive use (Haram et al., 2021). However, there is a lack of infrastructure and capacity to recycle these batteries properly. Lithium-ion batteries often contain valuable materials such as lithium, cobalt, nickel and aluminium, but without an effective recycling system, these materials can be lost or end up in landfills, representing a significant waste and environmental risk. Toxic materials in batteries can leach into soil and water if not properly disposed of, which can have adverse effects on local ecosystems and human health. Therefore, efficient recycling policies and systems are needed to address this problem and ensure that the transition to EVs does not create new environmental problems (Feng et al., 2024).

Competition with the traditional automotive industry. The transition to EVs may face resistance from the traditional automotive industry, which has significant investments in producing internal combustion engine vehicles. EV manufacturing often requires different components and materials compared to conventional cars. Policies are needed to encourage research and development and the transition to EV manufacturing. Public policymakers can put entrepreneurs at the centre of their interests, but this may not be enough, as the entrepreneurial community is heterogeneous and has different interests (Sahiti, 2023).

Uncertainty about the availability of raw materials. EV battery manufacturing depends on raw materials such as lithium, cobalt and nickel. Dependence on these raw materials is a concern, as their supply may be limited, their extraction may have negative environmental impacts, and their price may be volatile due to increasing demand. Several studies have analyzed the effects of EV penetration on lithium demand and compared it with data on lithium reserves and resources. Some of these analyses also detected a potential premature depletion of current lithium reserves (Pehlken et al., 2017; Weil & Ziemann, 2014; Gruber et al., 2011; International Energy Agency, 2009). Thus, uncertainty about the availability and sustainability of these raw materials may affect the scalability of EV production.

4. Existing measures to promote the use of EVs in Spain and the targets set by the Government

Spain has implemented a series of measures to encourage the adoption of EVs and move towards cleaner and more efficient mobility. These initiatives reflect the country's commitment to transitioning to more sustainable transport and significantly reducing GHG emissions.

Financial assistance. One of the most important measures is implementing financial incentives to purchase EVs. These incentives take the form of direct subsidies that reduce the purchase cost, making this option more attractive to consumers. These incentives aim not only to boost demand for EVs but also to accelerate the transition to a more environmentally friendly vehicle fleet.

In addition to direct subsidies, Spain has implemented several tax benefits for EV owners. These include reductions in registration and circulation taxes, as well as tax exemptions in certain areas. These measures not only ease the financial burden for EV owners but also encourage the incorporation of clean technologies into the country's vehicle fleet.

For more than a decade, the Spanish government has been implementing a series of economic measures to encourage the adoption of EVs as part of its transition strategy towards more sustainable mobility.

In 2009, Spain launched the Movele Program as one of the first financial support programs for the purchase of EVs. This scheme offered direct subsidies to buyers of EVs to promote their market penetration and contribute to the reduction of dependence on fossil fuels. In 2012, the PIVE Program was implemented, which not only included incentives for the purchase of EVs but also for the renewal of the Spanish vehicle fleet, encouraging the retirement of old and polluting vehicles. Finally, the Moves I, Moves II and Moves III Programs are the most relevant in promoting electric mobility in Spain. These plans, in force from 2019 to 2024, have earmarked a considerable amount of economic resources to facilitate the acquisition of EVs, as well as the installation of charging points and other charging infrastructures. The most important features of these plans are detailed below.

The Movele Program had a budget of 8,000,000,000 € and was aimed at new passenger cars or commercial vehicles with a maximum authorized mass of less than 6,500 kg, motorbikes, heavy quadricycles and minibuses corresponding to EVs and plug-in hybrid cars and range-extended EVs with a range of more than 32 km. The amount of aid was determined as a percentage of the vehicle price with an absolute limit depending on the category concerned (see Table 2). The percentage corresponded to 15% or 20% of the price (before tax), depending on whether the vehicle's technical data were below or above, respectively, the average energy efficiency curve established in the program (Ministerio de Industria, Turismo y Comercio, 2009).

Table 2. Aid ceiling of the average energy efficiency curve for the different vehicle categories of the MOVELE Program

	Upper limit	**Lower limit**
Passenger Cars/Commercials	7,000 €	5,000 €
Motorbikes	1,200 €	750 €
Heavy quadricycles	3,500 €	2,000 €
Minibuses	20,000 €	15,000 €

Source: Own elaboration based on data from Ministerio de Industria, Turismo y Comercio (2009)

The PIVE Program had a budget of 75,000,000 €. It was aimed at new or used passenger cars and light commercial vehicles less than one year old since first registration and corresponding to conventional, hybrid, plug-in hybrid and extended-range electric cars (fully or partially powered by petrol or diesel internal combustion engines and electric), which were classified as class A or B in the

IDAE database for fuel consumption and CO_2 emissions in new cars; pure electric vehicles and those powered by internal combustion engines that can use alternative fossil fuels and that could be certified as having CO_2 emissions of no more than 160 g/km. The price of the vehicles could not exceed 25,000 €, before VAT, except in the case of pure electric, plug-in hybrid and extended-range cars, where this requirement did not apply. In addition, the vehicle to be scrapped had to have been permanently withdrawn from circulation, which had to be at least 12 years old in the case of passenger cars, and at least 10 years old in the case of light commercial vehicles. The total discount to be included in the purchase invoice under the program was at least 2,000 € (Ministerio de Industria, Energía y Turismo, 2012).

The latest version of the MOVES Program (MOVES III), which runs until 31 July 2024, was approved in 2021 with an initial budget of 400,000,000,000 € and was subsequently increased to 1,200,000,000,000 €. The vehicles eligible for incentives are passenger cars, vans, motorbikes and electric quadricycles.

The program is managed by the autonomous communities and the amount of aid can be up to 7,000 € (9,000 € with scrapping) for commercial vehicles up to 3,500 kg and up to 4,500 € (7,000 € with scrapping) for passenger cars. These amounts can be increased by 10% if the recipient is a disabled individual with reduced mobility, is registered in a municipality of fewer than 5,000 inhabitants or is a self-employed person using the vehicle for taxi or chauffeur-driven transport services (Instituto para la Diversificación y Ahorro de la Energía, 2024).

Eligible recharging infrastructure can be of any power and be intended for private use in the residential sector, including single-family homes; public use in the non-residential sector (public car parks, hotels, shopping centres, universities, hospitals, industrial estates, sports centres, etc.); private use in parking areas of private and public companies, to provide service to their fleet; public use in parking areas of private and public companies, to provide service to their employees and customers; public use on public roads, urban and interurban roads and public use on the road network, with a special interest in recharging infrastructure at service stations and petrol stations (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021; Ministerio para la Transición Ecológica y el Reto Demográfico, 2023c).

In addition to the MOVES III program, other government initiatives are also being carried out. In June 2023, the Ministry of Transport, Mobility and the Urban Agenda awarded 500,000,000 € of European Next Generation recovery funds to 120 municipalities to decarbonize their urban centres and promote sustainable mobility. 20% of the funds are earmarked to encourage bus zero-emission fleets and waste collection vehicles, as well as the charging infrastructure for their operation. This second call of the aid program to municipalities to implement low-emission zones complements the one awarded in 2022, which amounted to 1,000,000,000 € (Ministerio de Transportes y Movilidad Sostenible, 2023).

Two new deductions were also approved in June 2023 to promote the purchase of EVs by individuals. In this sense, taxpayers can deduct 15% of the purchase value of the new EV and the amounts paid for installing EV battery charging systems in a property they own until 31 December 2024 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023c).

The main characteristics of the initiatives carried out by the Spanish government to encourage the adoption of EVs are summarised in Table 3.

Table 3. Summary table: main contributions of the key regulations and programs promoting EV adoption in Spain.

Regulation/Program	Year	Main contribution
Movele Program	2009	Provided direct subsidies for EV purchases, focusing on passenger cars, motorbikes, and minibuses to promote initial market penetration.
PIVE Program	2012	Offered incentives for purchasing energy-efficient vehicles and retiring old, polluting vehicles, boosting fleet renewal.
MOVES I, II, III Program	2019-2024	Allocated significant financial resources to subsidize EV purchases and develop charging infrastructure. MOVES III expanded its budget and increased incentives for rural areas and low-income groups.
Low-Emission Zones	2022	Used European Next Generation recovery funds to promote zero-emission bus fleets and urban decarbonization, focusing on municipal sustainable mobility projects.
Tax deductions	2023	Allowed taxpayers to deduct part of the costs, including the installation of domestic charging points.

Source: Own elaboration from Ministerio de Industria, Turismo y Comercio (2009), Ministerio de Industria, Energía y Turismo (2012), Ministerio para la Transición Ecológica y el Reto Demográfico (2021), Ministerio de Transportes y Movilidad Sostenible (2023), Ministerio para la Transición Ecológica y el Reto Demográfico (2023c) and Instituto para la Diversificación y Ahorro de la Energía (2024).

Norway's tax strategy has proven to be the most effective incentive policy in Europe, driving the country to lead the world in EV market share (European Automobile Manufacturers' Association, 2024). Unlike Spain's direct subsidies, Norway focused on tax exemptions starting in the early 2000s, including a 100% exemption from VAT and registration tax for EVs, alongside free tolls, reduced parking fees, and access to bus lanes (Mauritzen, 2024; Rietmann & Lieven, 2019).

Expansion of recharging points. Deploying an efficient charging infrastructure is essential to drive the mass adoption of EVs. Recharging stations have been installed across urban areas and major roads in Spain, facilitating convenient and rapid vehicle recharging (see Figure 5). These infrastructure investments not only benefit EV owners but also contribute to economic growth and job creation in the sector (Bastida-Molina et al., 2022).

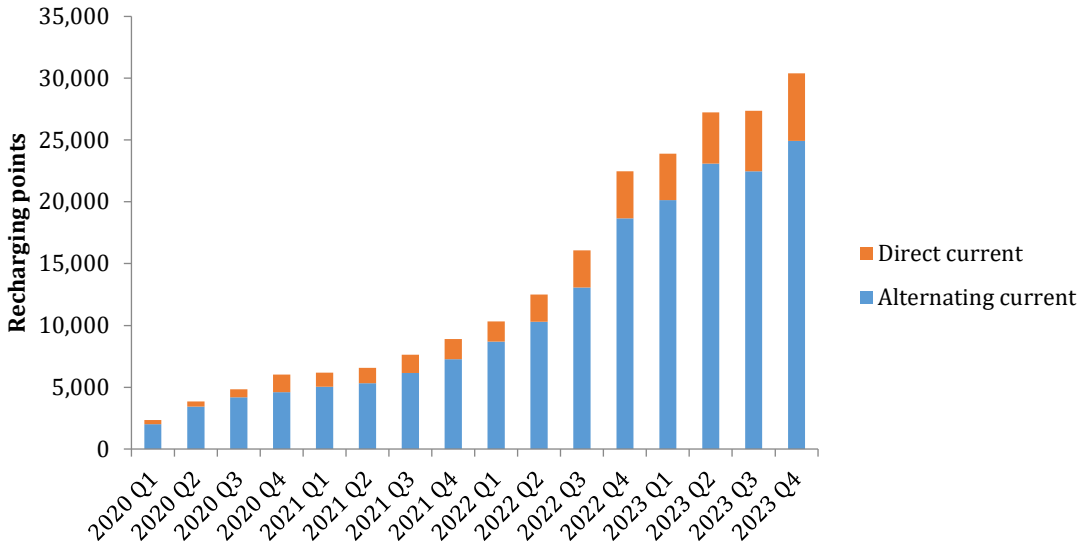

Figure 5. Recharging points in Spain. Source: Own elaboration based on data from the European Alternative Fuels Observatory (2024)

In Spain, at the beginning of 2020, there was one charging point for every 213 km². By 31 December 2023, one for every 16.54 km².

The number of recharging points has risen substantially in recent years, positioning Spain among the leading European countries. However, it still lags behind nations such as the Netherlands, Germany or France (see Figure 6).

The following is an analysis of the factors determining the number of recharging points in Spain and Europe. Only 14.29% of the variation in the number of recharging points can be explained by the surface area of European countries (see Figure 7). This low coefficient of determination suggests a weak relationship between the geographic size of a country and the extent of its charging infrastructure. Larger countries do not necessarily have more recharging points.

Surface area alone is insufficient to predict recharging point distribution in European countries. Therefore, geographic considerations should be viewed as secondary.

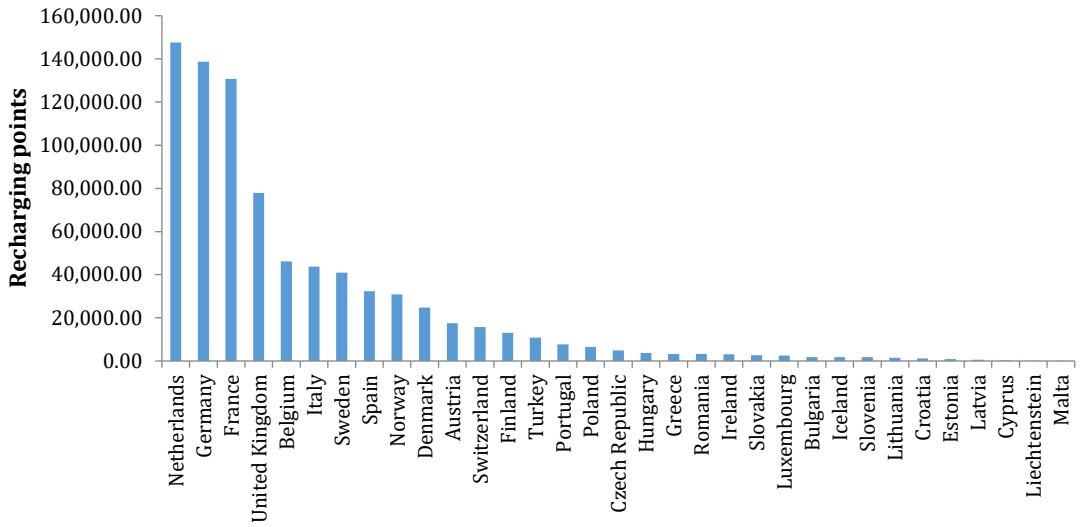

Figure 6. Recharging points per country. *Source*: Own elaboration based on data from the European Alternative Fuels Observatory (2024).

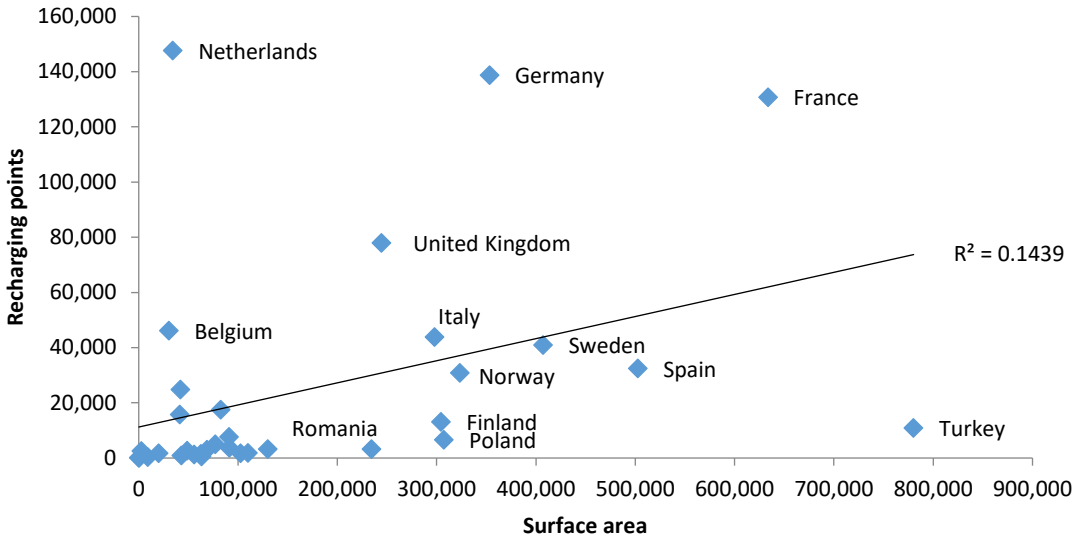

Figure 7. Ratio between recharging points and surface area (Km²) of European countries. Source: Own elaboration based on data from the European Alternative Fuels Observatory (2024) and Eurostat (2024)

64.87% of the variability in the number of recharging points across European countries is explained by GDP per capita (Figure 8). This reflects a moderately strong relationship between economic wealth and investment in EV infrastructure, where wealthier countries are better positioned to allocate resources for expanding charging networks. This makes sense since higher GDP per capita typically correlates with greater fiscal capacity to subsidize green technologies, incentivize infrastructure development, and support EV adoption.

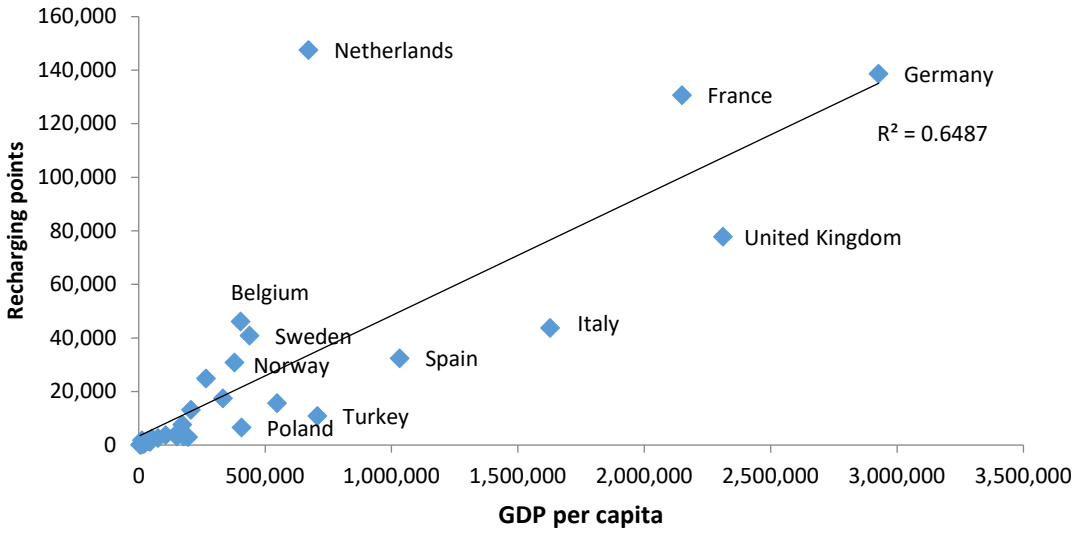

Figure 8. Ratio between recharging points and GDP per capita (current prices, billions of euros) of European countries. *Source*: Own elaboration based on data from the European Alternative Fuels Observatory (2024) and Eurostat (2024).

75.66% of the variability in the number of recharging points is explained by the number of electric vehicles in circulation (see Figure 9). This very high R^2 suggests a strong direct correlation between the growth of EVs and the expansion of charging infrastructure. It is logical that as EV adoption increases, the demand for charging infrastructure rises, compelling both public and private sectors to invest in expanding the network of recharging points.

A strong R^2 like this one indicates that EV demand is the primary driver of infrastructure development. This highlights the interdependency between vehicle adoption and charging facilities, where supply (charging infrastructure) closely follows demand (EV uptake).

In conclusion, the number of electric vehicles is the strongest predictor of charging infrastructure among the variables considered. Policymakers should thus prioritize boosting EV adoption through incentives and awareness campaigns to simultaneously accelerate infrastructure growth.

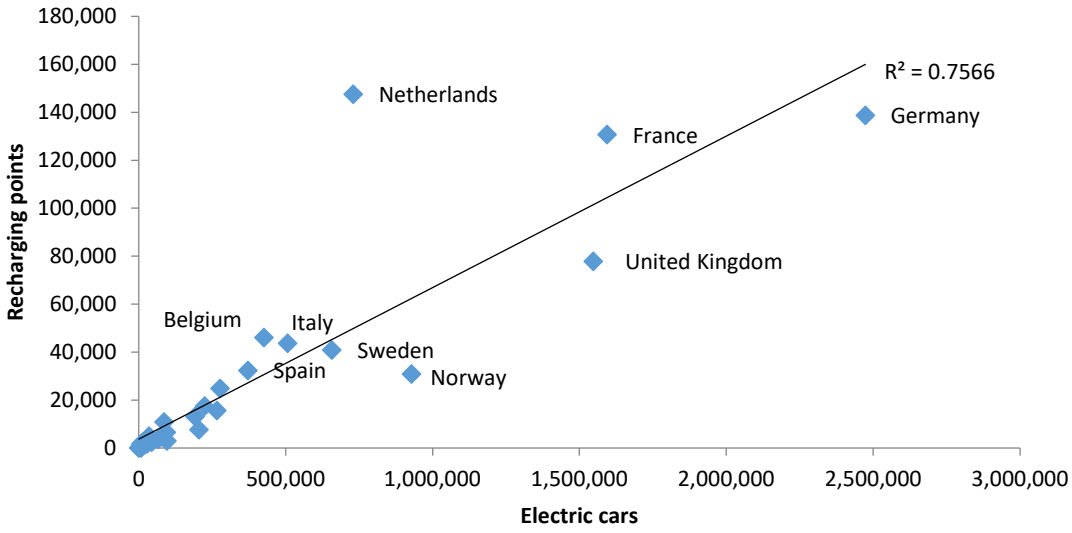

Figure 9. Ratio between recharging points and electric cars of European countries. *Source*: Own elaboration based on data from the European Alternative Fuels Observatory (2024) and the European Automobile Manufacturers´ Association (2024).

Only 14.27% of the variability in recharging points across Spain's autonomous communities is explained by surface area (see Figure 10). This low R^2 mirrors the result found in European countries, indicating that geographic size is not a significant factor in predicting the number of charging stations. In Spain, smaller but highly urbanized regions (like Madrid or Catalunya) may have far more recharging points than larger, more rural regions.

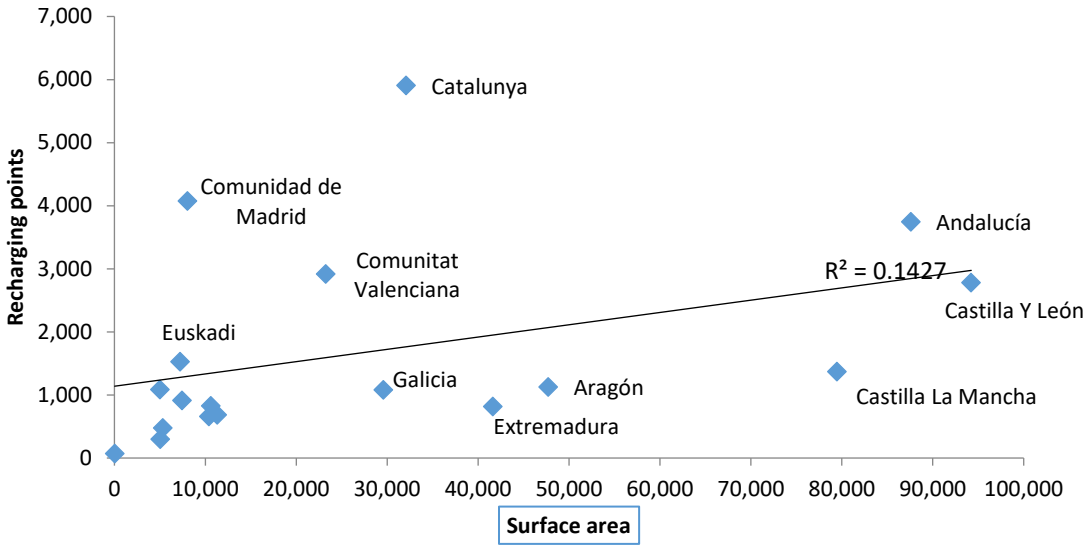

Figure 10. Ratio between recharging points and surface area (km²) of Spanish autonomous communities. *Source*: Own elaboration based on data from AEDIVE (2024) and Instituto Geográfico Nacional (2024).

Only 10.04% of the variability in recharging points in Spain's autonomous communities is explained by GDP per capita (see Figure 11). This is a surprisingly weak correlation, especially when compared to the European level (see Figure 8). It suggests that regional economic wealth is not a strong determinant of charging infrastructure, perhaps due to Spain's centralized approach to EV policy or disparities in how regions allocate resources to EV infrastructure.

Unlike the European context, GDP per capita is not a strong predictor of EV infrastructure in Spain. This points to the importance of local policies and government initiatives over economic factors in driving the growth of recharging points.

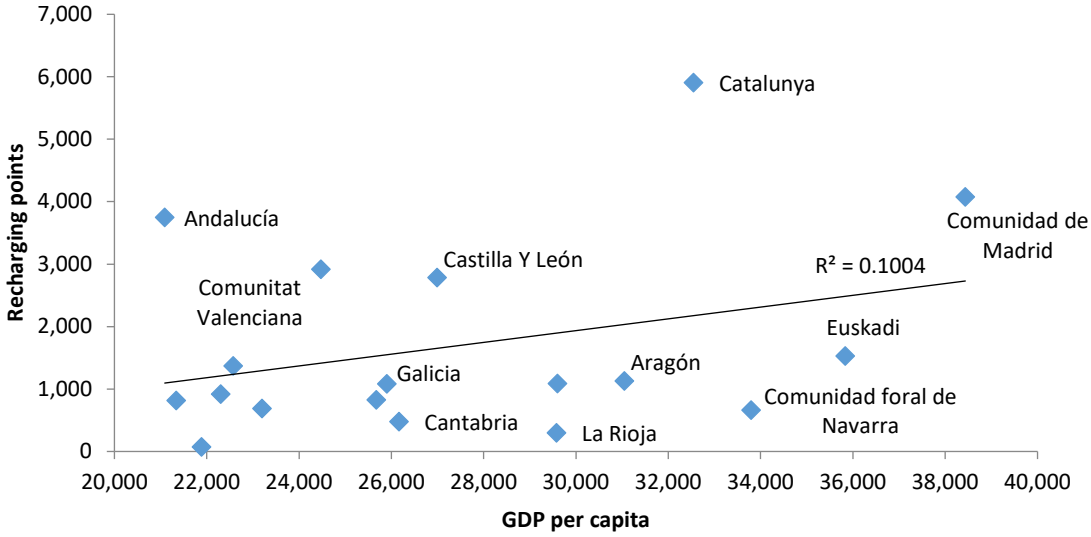

Figure 11. Ratio between recharging points and GDP per capita (euros) of Spanish autonomous communities. *Source*: Own elaboration based on data from AEDIVE (2024) and Instituto Nacional de Estadística (2024).

48.1% of the variability in recharging points is explained by the number of electric vehicles in circulation (see Figure 12). While this is a strong relationship, it is noticeably lower than the European level (see Figure 9). This suggests that while EV adoption is still a significant driver of infrastructure, other factors such as regional policies, government support, or even geographical characteristics could also be at play.

The number of electric vehicles remains an important predictor of charging infrastructure at the regional level in Spain, but other factors, such as regional policies and public investment strategies, also play a significant role. Boosting EV numbers would still help accelerate infrastructure expansion, but supplementary policies are also necessary to address the unexplained variability.

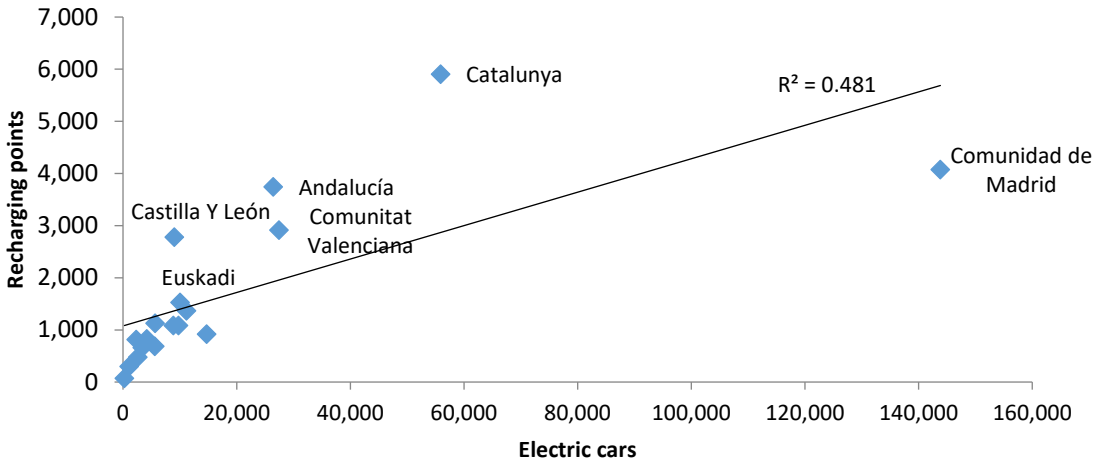

Figure 12. Ratio between recharging points and electric cars in Spanish autonomous communities. *Source*: Own elaboration based on data from AEDIVE (2024) and Ministerio de Transportes y Movilidad Sostenible (2024).

It should be noted that for the European countries and the Spanish autonomous communities, the variable analyzed that explains a higher percentage of the variability in the number of recharging points is the number of electric cars in circulation.

Thus, the result of the analysis shows that there is a significant relationship between the number of electric cars in a country and the number of available recharging points. This underscores the importance of strategic planning for EV charging infrastructure. As the EV fleet expands, it is essential to ensure a sufficient number of strategically distributed recharging points to enhance the convenience and accessibility of charging for users.

For the EV market to develop, investment in charging infrastructure by governments, businesses and other stakeholders is paramount. The availability of adequate charging infrastructure can, in turn, influence the continued adoption of EVs by reducing range anxiety and improving the convenience of charging.

Table 4. Ratio between recharging points, surface area, population density and electric cars of European countries.

	Recharging points/ 1,000 km²	Recharging points/ 10,000 inhabitants	Recharging points/ 100 electric cars
Austria	212.51	19.26	7.80
Belgium	1,515.80	39.27	10.82
Bulgaria	16.83	2.87	23.50
Croatia	21.74	3.16	14.24
Cyprus	36.69	3.67	13.66
Czech Republic	64.08	4.57	14.21
Denmark	591.54	41.86	8.98
Estonia	21.32	6.73	15.99
Finland	43.12	23.59	6.82
France	206.21	19.20	8.20
Germany	392.60	16.44	5.61
Greece	24.98	3.12	9.52
Hungary	40.53	3.85	5.56
Iceland	17.29	48.13	6.16
Ireland	44.32	5.86	3.15
Italy	146.98	7.44	8.64
Latvia	9.64	3.24	9.99
Liechtenstein	793.75	32.52	20.13
Lithuania	22.88	5.02	7.37
Luxembourg	959.01	37.53	5.62
Malta	322.68	1.86	1.33
Netherlands	4,317.68	82.88	20.23
Norway	95.39	57.22	3.32
Poland	21.45	1.79	7.00
Portugal	84.20	7.32	3.73
Romania	13.71	1.69	6.56
Slovakia	54.29	4.87	17.10
Slovenia	86.67	8.25	12.13
Spain	64.48	6.74	8.72
Sweden	100.43	38.88	6.22
Switzerland	381.26	18.16	5.91
Turkey	13.91	1.30	12.53
United Kingdom	318.79	11.62	5.03

Source: Own elaboration based on data from the European Alternative Fuels Observatory (2024), Eurostat (2024) and the European Commission Mobility and Transport (2024).

European countries are at different stages in the transition to electric mobility (see Table 4). In the first category, which corresponds to an already developed state, are countries where EVs have established a strong presence or have favourable conditions for their adoption shortly. This category includes Austria, Belgium, Denmark, Finland, France, Germany, Luxembourg, the Netherlands, Norway, Sweden and the United Kingdom. In the second category are countries with concrete interest in electrification, but where the transition is expected to take longer. This includes Greece, Hungary, Ireland, Italy, Portugal, Switzerland and Spain. Finally, the emerging category includes

countries where affordability and availability barriers are difficult to overcome. In the latter category are Bulgaria, Croatia, Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia and Turkey.

5. Recommendations to policymakers to overcome the identified barriers

Based on the results obtained, a series of strategies are proposed that policymakers could follow to overcome the obstacles detected, both at the micro and macro levels.

Financial incentives and subsidies. Implement stable government policies that offer financial incentives and subsidies for the purchase of EVs to reduce the high initial cost barrier. This would be based on approving a new MOVES Plan that would speed up and simplify its processing, advance the amounts to drivers, and establish criteria to favour the most disadvantaged groups so that individuals with lower incomes obtain higher amounts of aid. At the same time, a system of tax deductions could be established, such as reduced VAT, which would be applied directly to the purchase price.

Expand freight infrastructure. Make significant investments in expanding and improving public and private charging infrastructure to ensure an efficient and accessible nationwide network. As the demand for electric mobility increases, it is critical to have an extensive and accessible network of recharging points that meet users' needs and eliminate concerns about vehicle range. To achieve this goal, several comprehensive strategies need to be implemented:

— Prioritise installing recharging points in strategic locations, such as public car parks, commercial areas, service stations and densely populated residential areas. These public recharging points should offer various charging options, including fast charging and slow charging, to meet the different needs of users.

— Encourage public-private partnerships to accelerate the expansion of charging infrastructure. This may include incentives for private companies to invest in the installation of recharging points, as well as the simplification of administrative and regulatory procedures related to their installation and operation.

— Integrating charging infrastructure into urban planning is essential to ensure accessibility and convenience. Local governments should consider including charging requirements in building codes and urban planning, as well as reserving space for installing recharging points in new construction and retrofitting.

— Encourage the installation of recharging points in homes and residential communities.

This can be achieved through tax incentives or subsidies for the installation of residential recharging points, as well as the implementation of policies that facilitate their installation in residential buildings and community garages.

Up-to-date information on recharging infrastructure. A continuously updated publication of publicly available recharging points should be created. This can be done by creating centralized online platforms, such as mobile applications and websites, that provide detailed and up-to-date information on the location, availability, connector type, tariffs, and operating hours of EV recharging points across the country. These platforms can be managed by governmental entities, private

companies, or non-profit organizations and should be easily accessible to users.

Collaborative mechanisms must be established between government entities, utilities, EV manufacturers, recharging point operators, and other relevant actors to collect and share up-to-date data on charging infrastructure. This could include creating shared databases and implementing information exchange standards.

Processes and procedures should be implemented to ensure continuous updating of data on the charging infrastructure, including regular verification of the availability and operational conditions of recharging points, as well as the addition of new recharging points as they are installed. User feedback on the charging infrastructure should also be facilitated through online platforms, allowing users to report on the availability, operational status and quality of charging services. This feedback can help identify problems and areas for improvement in the recharging infrastructure. In this regard, it is essential to implement notification and alert systems to inform users about changes in the availability or conditions of recharging points, as well as to provide real-time updates on events such as temporary closures or scheduled maintenance.

Awareness and education campaigns. Launch campaigns to raise awareness and educate about the benefits of EVs, addressing common concerns, and providing accurate and objective information. Although EV technology has advanced significantly recently, a lack of public knowledge and understanding hinders its acceptance and adoption. Therefore, it is essential to implement effective education and awareness strategies to inform citizens about the benefits of electric mobility and dispel common myths and concerns. To this end, awareness campaigns should be conducted at the national and local levels to highlight the environmental, economic and social benefits of EVs. These campaigns can include media advertisements, community events, educational seminars, and collaboration with opinion leaders and celebrities to amplify the message. It is essential to provide clear, accessible and transparent information about EVs, including their operation, costs, benefits and availability. This can be done through government websites, information brochures, outreach events and briefings at car dealerships. Also, organizing EV testing and demonstration programs allows consumers to experience the technology and understand its benefits directly. These programs can include test-driving events, demonstrations at trade fairs and exhibitions, and collaborations with car rental companies to offer EV rental options. It is also important to provide education and training to automotive industry professionals, such as salespeople, mechanics, and technicians so that they are better prepared to respond to customer questions and needs regarding EVs. This can include certification programs, training courses and hands-on workshops.

Improving battery technology. Continue to invest in research and development to improve battery technology, increase range and reduce long-term costs. Increasing the range of EVs is essential to eliminate concerns about "range anxiety" and increase consumer acceptance. Continued research and development are required to improve battery energy density and extend charge life, allowing EVs to travel longer distances on a single charge. This includes exploring new materials for electrodes and electrolytes, as well as designing more efficient batteries. It is also important to establish efficient battery recycling systems to reduce waste and promote the reuse of materials to mitigate the environmental impacts associated with battery production and disposal while ensuring the availability of key materials to manufacture new batteries. Thus, research incentives are essential, implementing tax incentives and funding programs for companies and institutions

conducting research and development in battery technologies. This could include tax credits, grants for research and development projects, and the creation of centres of excellence in the battery field.

Develop innovative business models. Explore new ways to offer and monetize services related to electric mobility, such as creating EV-sharing platforms that allow users to rent EVs for short periods and facilitating flexible and sustainable mobility in urban environments. Another alternative would be to introduce subscription and pay-as-you-go models for EVs, where users pay a fixed monthly fee or for the actual use of the vehicle, rather than having to purchase the car traditionally. This can make EV adoption more accessible and affordable for many users.

Variety of models and options. Stimulate the variety of EV models available by providing consumers with more options to suit their needs and preferences. This can be done by implementing fiscal and financial incentives for EV manufacturers and technology providers, such as tax credits, research and development subsidies, and preferential financing for the production of EVs and related components, as well as by simplifying and streamlining the approval and certification processes for EVs, which would facilitate the introduction of new models to the market and reduce the associated costs for manufacturers.

Development of electricity generation capacity. Invest in electricity generation capacity to meet the growing demand associated with electric mobility, prioritizing renewable energy sources to ensure sustainability. The electricity grid needs to be modernized and strengthened to ensure its capacity to support the additional load from EVs. This would include upgrading the transmission and distribution infrastructure, installing advanced monitoring and control equipment, and integrating smart load management technologies. It is also important to develop a smart charging infrastructure that enables efficient electricity demand management, especially during peak load periods when higher energy demand is expected due to EV charging. This would require implementing scheduled charging systems, dynamic tariffs and energy storage technologies.

Unified legislation and international collaboration. Actively engage in global collaboration and initiatives that promote common standards, share best practices and facilitate technology transfer. Set clear and ambitious targets for EV market penetration, as well as regulations that encourage the manufacture and marketing of EVs, such as stricter emission standards and severe restrictions on internal combustion vehicles in urban areas. It is also necessary to work on harmonising EV-related regulations and standards at the international level, which would facilitate the manufacturing, approval and marketing of EVs in different markets, reducing the complexity and associated costs for manufacturers and consumers. Finally, it is essential to facilitate the exchange of practices and experiences with countries leading the way in EV adoption, such as Norway, Iceland and Sweden. This may include the organization of conferences, seminars and workshops, as well as establishing networks and collaboration platforms.

6. Conclusions

Spain faces significant environmental challenges, from rising temperatures to biodiversity loss. These problems are exacerbated by GHG emissions, mostly from the transport sector. Electric mobility emerges as a key solution, as EVs contribute to directly reducing pollutant emissions and

improving air quality in cities. Electric mobility goes beyond reducing emissions. In addition, EVs provide higher energy efficiency, reduced noise pollution and lower maintenance costs. Moreover, by relying on electricity, they open up opportunities to harness renewable energy sources, such as solar and wind, thus strengthening the country's energy resilience.

The transition to EVs takes place in the context of a transport system in Spain that has historically been dominated by fossil fuels, mainly petrol and diesel. These have fuelled the majority of vehicles, which has led to the transport sector being the main GHG emitter in the country. The sustained growth of GHG emissions has put transport at the centre of the climate debate, making evident the need for structural change to decarbonize the sector.

Electric mobility appears to be one of the most promising solutions to reduce emissions, not only because of EVs' energy efficiency but also because of their ability to operate without directly emitting polluting gases. However, the contextual analysis reveals that Spain lags behind other European countries in EV adoption, with penetration levels below the European average and far behind leaders such as Norway and the Netherlands.

The main objective of this paper is to analyze, from a multidimensional approach, the barriers that hinder the mass adoption of EVs in Spain. Furthermore, it has been proposed that a diagnosis of existing policies and measures be carried out to promote the use of EVs, as well as to offer specific recommendations based on international experiences and case studies. The final objective is to identify best practices to guide policymakers and private sector agents in implementing solutions to facilitate the transition towards electric mobility.

This article presents a novel perspective on the adoption of EVs in Spain by offering a comprehensive analysis that integrates multiple dimensions of the challenges faced in this transition. Unlike previous studies that may focus predominantly on singular aspects of EV adoption, this research uniquely identifies the interconnected barriers that impede progress. Additionally, it introduces innovative, evidence-based solutions drawn from successful international case studies, emphasizing the need for cohesive public policies tailored to the Spanish context. By addressing these dimensions holistically, this article not only contributes to the existing body of knowledge but also provides a roadmap for stakeholders and policymakers to accelerate the transition towards sustainable mobility in Spain, thus filling a critical gap in the literature.

The analysis results confirm that, although EV registrations have shown steady growth in recent years, this pace is insufficient to meet the ambitious targets of the National Integrated Energy and Climate Plan.

The adoption of EVs faces several common challenges globally, such as limited driving range, public scepticism toward EV technology and high initial costs. The latter remains one of the most important problems. The elevated upfront cost of EVs, despite the decline in battery prices, continues to be a concern for consumers, particularly when compared to internal combustion vehicles, which are more cost-effective in the short term.

However, the Spanish case presents unique specificities that set it apart from the general landscape of EV adoption. One of the factors behind this gap is the lack of adequate infrastructure. Although the number of charging points has increased significantly, Spain still lags behind other European countries in terms of the availability and accessibility of charging stations. This infrastructure deficit is of particular concern in rural and some urban areas, where range anxiety

remains a major barrier for potential EV users. Policy inconsistency further complicates Spain's transition to electric mobility. Unlike countries such as Norway, which have implemented stable, long-term incentive strategies, Spain has experienced frequent shifts in its subsidy programs and regulatory frameworks. These abrupt changes create uncertainty for consumers and investors, hindering the sustained growth of EV adoption.

Based on the findings, recommendations are made for policymakers and key stakeholders, focusing on improving financial incentives, developing a robust charging infrastructure, awareness-raising and education campaigns, research and development in battery technology, regulatory stability, and international collaboration.

Thus, the transition to EVs in Spain presents several significant challenges that require coordinated action by all actors involved: governments, the automotive industry, energy companies and citizens. The potential of electric mobility to reduce GHG emissions, diversify energy sources and stimulate economic growth is extraordinary. However, for Spain to achieve its climate and sustainability goals, it is crucial that ambitious and coherent policies are implemented, and that adequate infrastructure is fostered to remove barriers to mass EV adoption. With the right measures, the country can position itself as a leader in the transition to sustainable mobility and set an example for other developing markets.

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