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Article

Barriers to Electrification: Analyzing Critical Delays and Pathways Forward

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Abstract: This paper extensively explores the intricate nuances surrounding the delayed transition to new business models for electric vehicles. While there is commendable clarity regarding stakeholders, model possibilities, emission-reduction strategies, state aid initiatives, and citywide prohibitions, the central challenge lies in the gradual pace of this transition. Notably, the persistent high costs of electric vehicles, primarily attributed to exorbitant battery prices and the raw materials involved, represent a formidable hurdle to widespread adoption. In this article, a comprehensive examination of the multifaceted aspects contributing to the delays in the shift towards electrified transport is proposed. By meticulously scrutinizing the intricacies of this delay, the aim is to provide valuable insights that can contribute to accelerating the adoption of electric vehicles. The exploration of these challenges is essential for fostering a nuanced understanding of the impediments hindering the transition and, subsequently, for devising effective strategies to overcome them. The analysis presented herein not only identifies the hurdles but also seeks to offer potential solutions and strategies that can drive the transformative change needed in the realm of electric transportation. Understanding and mitigating the barriers impeding the transition is crucial for fostering a rapid and successful shift towards electric mobility in Spain, ensuring a sustainable and efficient transportation landscape for the future.

Keywords: electric vehicles; business models; electric mobility

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1. Introduction

In the rapidly evolving landscape of modern transportation, the ongoing transition to electrified transportation is a profound and paradigm-shifting development. This transition holds the promise of not only achieving environmental sustainability but also reducing dependence on traditional fuel sources. As governments, industries, and consumers navigate this transformative journey, it becomes increasingly evident that relying solely on state aid programs and citywide restrictions is insufficient to propel such significant shifts. Despite numerous analyses [1–3] underscoring the urgency of this transition in mitigating climate change, the actual pace of the shift remains suboptimal. Consequently, a nuanced examination of the diverse elements influencing this transformation is imperative.

A substantial impediment to the widespread adoption of electric vehicles (EVs) lies in the persistent and elevated costs, primarily dictated by soaring battery prices [4] and the intricate matrix of raw materials entwined in their production [5]. Moreover, the significant rise in demand for critical minerals for EVs raises concerns about sustainable extraction and supply chain reliability, especially regarding nickel and lithium production [6] and the risk of raw-material shortages [7]. Despite considerable advancements in battery technology, the barrier of insufficient battery capacity remains in the mindset of citizens [8], even though EV users rarely undertake long trips [9]. This social positioning contrasts with the fact that sizing high-capacity EV batteries is a contradiction regarding the sustainability of EVs [10]. As battery capacity grows, the expansion of fast-charging infrastructure for extended journeys needs to increase. While commendable progress has been made, its deployment is still not covering peak demands [11], posing conceptual barriers to EV acquisition and driving planning needs, as well as a notable safety concern for users [8]. However, fast-charge infrastructure deployment has its own economic difficulties. According to Luiz Avelar [12], Senior Director of Strategy at Envision Digital, the charging infrastructure has high installation costs and logistical issues that limit the availability of charging stations, which will still be a problem, even with the expected cost parity with ICE vehicles by 2026, due to decreasing battery prices.

Additionally, the increased electricity demand from EVs poses a risk of grid overload [13], necessitating new investments in grid infrastructure and the improved management of intermittent energy supply. The high-carbon profile of current electricity grids undermines the environmental benefits of EVs [14], highlighting the need for grid decarbonization [15].

So many expectations lie in energy and mobility transition policies. "The Global EV Outlook" [16], supported by the EVI (the Electric Vehicles Initiative, a multi-governmental policy forum established in 2010), analyzes global electric mobility developments annually. The report explores EVs' impact on energy consumption and emissions to offer insights for policymakers. It includes tools like the Global EV Data Explorer and Policy Explorer for the interactive exploration of EV data and policies. The key findings highlight a sustained growth in EV sales, projecting an overall increase of 31.1%, with potential reductions if incentives, particularly in Europe, diminish. They advocate increasing charging points to one per twelve vehicles and emphasize lowering EV acquisition costs by reducing operating expenses to spur adoption. The report concludes by stressing the necessity of policies to enhance affordability, expand charging infrastructure, and ensure sustainability in transitioning to electric mobility.

As observed globally, various authors underscore critical factors influencing the shift to electric mobility, such as infrastructure deficiencies, EV costs (especially batteries), state incentives, urban mobility policies proposed by local policymakers, sustainability concerns and raw-material shortages, and the various challenges associated with the electrical grid, as mentioned earlier.

Rogers' Diffusion of Innovations theory [17] provides a valuable framework for analyzing the adoption of EVs within societies. This theory outlines several stages of adoption: knowledge, persuasion, decision, implementation, and confirmation, which can be applied to understand how EVs gain traction among consumers. Research indicates that factors such as perceived benefits, social influence, and compatibility with existing values significantly impact the adoption rates of EVs [18,19]. Together, these factors underscore the multifaceted nature of progress across various fields, integrating technology, policy, sustainability, consumer insights, and collaboration.

This article, as part of a comprehensive analysis, unravels the intricate complexities contributing to the delay in transitioning to electrified transportation. By meticulously dissecting the multifaceted challenges impeding progress, the aim is to shed light on these obstacles but also to illuminate potential strategies that can be employed to overcome them. Through this exploration, the goal is to facilitate a more expeditious and effective integration of electrified vehicles into mainstream transportation systems, thereby contributing to a sustainable, eco-friendly, and forward-looking future.

2. Materials and Methods

This study employs a comprehensive and systematic approach to analyze the critical transition to electrified transportation. The methodology begins with an extensive examination of the landscape, including key stakeholders, recent emission-reduction targets, governmental proposals for state aid, and the increasing number of municipal bans on high-emission vehicles.

This analysis informs the development of a business model that accounts for the second life of batteries [20]. To address the slow integration of electrified transport, this study adopts a multifaceted approach, structured around the following key areas:

* Stakeholder Identification and Analysis: Key stakeholders are identified, with an exploration of their roles and vested interests in the transition to electrified transportation. The study also addresses the challenges in fostering collaboration among these stakeholders—a critical factor in the transition's success.
* Market and Business Model Analysis: Research into potential business models for EV, both in their primary and secondary life phases, is conducted [21]. This includes a detailed analysis of market trends [22], consumer preferences, and pricing dynamics within both primary and secondary markets. Additionally, the durability of batteries is scrutinized to challenge initially unfavorable estimates [23].
* Emission Reduction and Environmental Impact: The study extends its focus to emission-reduction targets, with a thorough assessment of the environmental benefits of electrified transport. A comparative analysis of emissions between traditional vehicles and electric cars is undertaken, supplemented by a review of the literature on the challenges of meeting these targets.
* Policy and Incentive Evaluation: The research also examines the impact of state aid, incentives, and municipal bans on reducing pollution and enhancing urban quality of life. This includes a critical evaluation of government initiatives and financial support programs, as well as an analysis of the effectiveness of municipal bans in curbing pollution [24–27].
* Battery Technology and Cost Analysis: The study delves into the technical aspects of battery technology, focusing on battery durability and associated costs. This section analyzes the role of battery costs in the overall pricing structure of EVs [28], identifying the factors contributing to high vehicle costs, and reviews studies on battery aging and longevity [29].

By integrating these components, this study provides a holistic perspective of the challenges and strategies involved in the transition to electrified transportation. Through this research, we aim to offer actionable insights into accelerating this critical shift, emphasizing how to overcome the barriers related to cost, stakeholder collaboration, and policy effectiveness.

3. Results

As previously mentioned, a pivotal aspect involves the identification of various stakeholders within the system, focusing specifically on the Spanish territory. As illustrated in Figure 1, the relevant administrations offering incentives or punishing strategies are identified as key stakeholders. Subsequently, there are companies either receiving or providing aid, as detailed in Table 1. Another category comprises entities installing facilities for end-users, enabling qualification for assistance. These installations encompass chargers or systems for renewable energy generation, which are pivotal stakeholders for the transition towards the electrification of energy and mobility. Moreover, companies responsible for managing the electricity grid—Transmission and Distribution System Operators (TSOs and DSOs, respectively)—have to incorporate and oversee these changes. Furthermore, EV manufacturers are included along with associated sales centers. Lastly, research centers and universities contribute with the dissemination and transfer of valuable knowledge and innovations to propel the transition towards green electrification, receiving aid for technological advancements, even if not directly related to incentives.

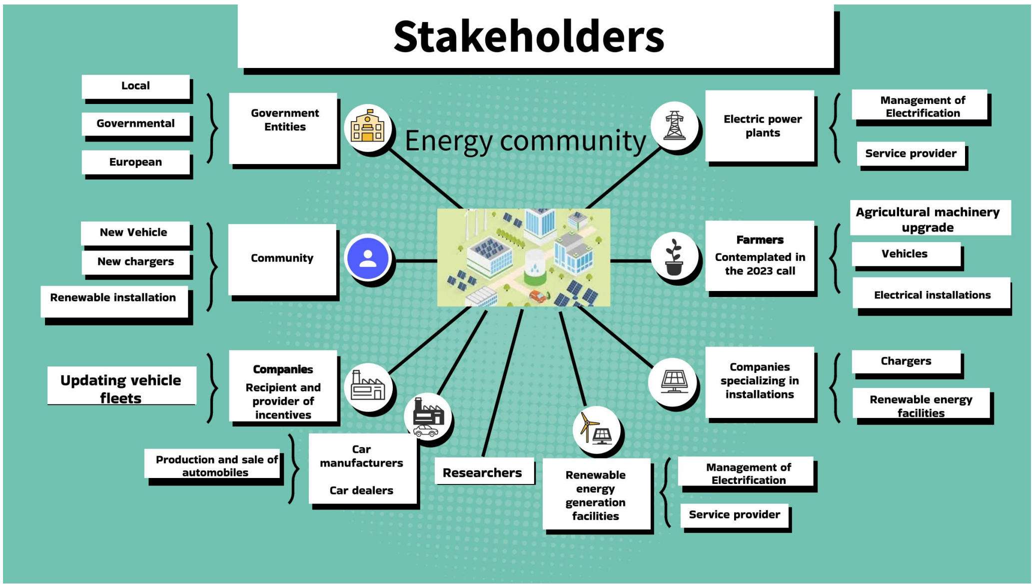

Figure 1. Identification of key stakeholders.

Table 1. Scrutinizing government initiatives and financial support.

Plan MOVES III (2022)	This program, promoted by the Spanish Government, offers aid for the purchase of electric vehicles, installation of charging points, and sustainable mobility projects.
Plan Renove (2024)	The Renove Plan incorporates incentives for acquiring fuel-efficient and environmentally sustainable vehicles, encompassing electric cars.
Local and regional support	Numerous cities and autonomous communities in Spain provide their own grants and discounts for the acquisition of electric vehicles. The availability and specifics of these programs may vary depending on the location.
Tax discounts	Some cities offer discounts on local taxes for electric vehicle owners.
Sustainable mobility programs in companies	Certain companies institute internal programs aimed at promoting the adoption of electric vehicles among their employees. These initiatives often involve offering financial incentives or establishing charging infrastructure within the workplace.

Regarding reward and/or punishment strategies, it is imperative to scrutinize the incentives predominantly provided by administrations, among other entities. While incentives at the European level are conceptualized, their execution and application fall under the purview of individual governments. As delineated in Table 1, various programs exist in Spain aiming to stimulate the acquisition of EVs and chargers. Noteworthy in this discussion are the farmers who, in recent years, underwent a fleet renewal, encompassing 1083 vehicles and machinery at a total cost of EUR 957,165. To gauge the efficacy of these incentives, four key indicators are proposed: the quantity of vehicles procured during the incentive period, the reduction in greenhouse gas emissions attributed to the transition to EVs, the utilization of charging infrastructure, and the return on investment. At a governmental level, this return could be measured by a reduction in overall environmental impact, calculated with CO_2 equivalent emissions, while, in terms of economic benefits, it could be quantified through a decrease in pollution-related taxes.

The global trajectory of EV purchases is evident [30]. Focusing specifically on Spain [31], there has been a notable surge in EV acquisitions in recent years, as validated by [32]. In 2023, a significant purchase of 120,000 units was recorded, representing a 26% increase in contrast to the previous year and an impressive 84% growth when compared to 2020. A paper from the Banco de España [33] showcases the increase in vehicle purchases following incentive plans, which effectively play an important and useful role in the transition of vehicle fleets to cleaner mobility. Before any plan was in place, the share of EV sales in Spain was about 1%; just after the MOVES I program, it grew up to 3% on average per month during the 8-month duration of the plan; with the MOVES II program, it increased up to 5% in 5 months; and the last MOVES III topped the share up to 8%.

Innovative policy measures have also been used to accelerate the adoption of EVs worldwide. Zero-emission vehicle (ZEV) mandates, for example, require automakers to produce a certain percentage of EVs, pushing the industry toward cleaner transportation options [34]. Urban low-emission zones (LEZs) are another effective strategy, restricting the access of high-emission vehicles to certain areas, thereby encouraging the use of EVs. In Spain, large cities, such as Barcelona, have implemented these so-called low-emission policies that have driven the purchase of electric, hybrid, and even gas-powered vehicles by both individuals and companies operating in urban areas. These policies have proven effective in reducing emissions, although user acceptance remains limited [35].

Additionally, measures to enhance urban mobility have been introduced, including the increase in the percentage of EVs used in procurement processes for both small-scale mobility and public transportation. These subsidies, along with the incentives outlined in Table 1, represent the strategies that have been successful in Spain in recent years.

Concerning the charging infrastructure, a discernible deficit in the number of charging points has been observed. However, metropolises such as Madrid, Barcelona, and those along the Mediterranean coast are demonstrating readiness for the transition. On a global scale, a pressing need for a 30% increase in the number of charging points has been identified. These figures could be affected by an additional issue identified during the summer period: the queuing time at charging stations. The user-to-charger ratio ranged from six to eight, leading to waiting times of over two hours in addition to the approximately 20 min required for the actual charging process. In this sense, public–private partnerships have proven useful in developing the necessary infrastructure for EVs, such as expanding charging networks and offering incentives for businesses to install charging stations, even though it might not be the best option from a societal perspective. These policies promote EV adoption as they raise awareness of the commitment of both the public and private sector to electric mobility [36].

Shifting the focus to CO_2 emissions data, the transport sector stands out as a major contributor to greenhouse gas (GHG) emissions, which have experienced a consistent rise since 1990. The sector currently contributes nearly 20% of the total GHG emissions of the EU. In 2021, CO_2 emissions in Spain reached 19,447 megatons, reflecting a notable 9.15% increase compared to those in 2020.

Overall, C_2 emissions in Spain amounted to 272,244.4 Mt CO_2 Eq. in 2021, positioning the country in the 159th position among 184 countries in a global ranking by CO_2 emissions, arranged from least to most polluting. The subsequent reduction in emissions observed in 2023 (271,629.5 MtCO_2Eq) stands in stark contrast to the prevailing global trend of escalating C_2 emissions. This notable reduction in Spain is attributed largely to the increasing prominence of renewable energies within the energy mix. As elucidated by OTEA [37], the ascendance of solar energy in Spain has witnessed a more than fivefold increase since 2018, while wind energy has doubled during the same period.

Examining the evolution of CO_2 emissions per USD 1000 of GDP, which gauges the "environmental efficiency" of a country's production over time, Spain emitted 0.13 kilos per USD 1000 of GDP in the previous period. Although this is higher than the 2020 figures, the reduction observed in 2023 indicates an encouraging improvement in these environmental efficiency metrics.

Focusing on future trends for EVs, sales are increasing, but several issues still affect consumer decisions. Major concerns include battery costs and capacity [5], as well as recharging infrastructure. To mitigate these issues, fiscal aid strategies have been implemented to reduce the impact of battery costs. Additionally, promoting the reuse and revaluation of batteries aims to lessen their environmental and economic impact during their first life. Ref. [27] evaluates the cost and carbon footprint associated with the second-life use of EV batteries in both residential and utility-level applications. The study highlights that repurposing EV batteries can significantly reduce waste and lower carbon emissions compared to traditional disposal methods. By extending the life cycle of these batteries, municipalities can postpone pollution and enhance sustainability efforts. The findings suggest that municipal bans on the disposal of EV batteries could further amplify these benefits by promoting recycling and reuse, thereby decreasing the overall environmental impact. However, the study also notes potential challenges, such as the economic feasibility of second-life applications and the need for a robust infrastructure to support battery repurposing [28]. These factors must be considered when analyzing the effectiveness of municipal bans in reducing pollution and fostering a circular economy in battery management.

However, as the number of EVs and second-life batteries increases, the stationary market may become saturated. To address this, utilizing battery capacity while still in the car is suggested through Vehicle-to-Grid (V2G) strategies. Current car batteries often exceed daily needs, allowing part of this capacity to be used in the energy market throughout the day, thus providing additional user benefits and reducing vehicle costs [10].

Another approach involves producing vehicles with smaller batteries that meet daily needs [21], although manufacturers are hesitant due to consumer concerns about insufficient capacity. Moreover, the development of small mobility solutions for urban areas will become increasingly important.

From the perspective of the electrical network, technological advancements can mitigate challenges in EV adoption by enhancing intelligent and cleaner charging infrastructure, ensuring a steady and stable power supply, and reducing electricity costs. Smart and flexible charging technologies enable EVs to distribute the charge over time and to supply unused power to the grid during peak demand and recharge during off-peak hours. This reduces both grid congestion and consumer costs [38]. Additionally, smart energy management systems integrate renewable energy sources and demand assets, optimizing load management and providing grid stability. AI-enabled battery monitoring and analytics support predictive maintenance, extend battery life, and improve recycling processes, thereby reducing the demand for new batteries and alleviating supply chain pressures.

As the transition to electric mobility accelerates, AIoT-assisted technology, smart charging, energy management, and advanced battery solutions address infrastructure, grid management, and mineral supply challenges [39]. These innovations support global efforts to reduce emissions and positively position the EV environment, especially considering the potential bans on combustion-engine vehicles by 2030 in some countries.

The reduction in emissions resulting from the incorporation of EVs is dependent on the energy mix of each country. Consequently, the benefits of adopting EVs may be limited in countries with an energy mix that relies heavily on non-renewable energy sources.

In this sense, from the various stakeholders described in Table 1, governmental entities are responsible for providing funding and implementing policies that support and promote this shift. Researchers are dedicated to advancing technological improvements and studying the impacts and effects of the different alternatives, whether in terms of charging systems, energy storage solutions, battery recycling, or overall energy optimization. However, considerable progress is still required in these areas, particularly in reducing the reliance on scarce materials and developing more-efficient recycling systems with lower energy consumption.

As the EV fleet expands, the electrical grid will need to be thoroughly reviewed and upgraded, and a comprehensive optimization of charging points, based on the projected global fleet, will be essential. This process involves both utility companies and installation firms. In this identification, the agricultural sector has also been included, as significant efforts have been made in Spain to update the machinery used, as previously discussed. Moreover, there is a need for greater awareness among consumers and society as a whole.

Thus, current efforts have not yet met expectations; consequently, continuing the same policies, albeit with greater stringency, is essential to accelerate the process of change. This should be accompanied by incentives, whether for renewable energy installations, charging infrastructure, or the renewal of vehicle fleets.

When focusing on the costs associated with EVs, it becomes evident that these expenses can be attributed to several interconnected factors. Primarily, the production costs of EVs are heavily influenced by the prices of battery components, which represent a significant portion of the total vehicle cost. The dependence on rare materials, such as lithium and cobalt, intensifies these costs due to volatile market prices and vulnerabilities in the supply chain [40]. Moreover, research indicates that economies of scale have not yet been fully achieved in the EV market, resulting in higher per-unit costs compared to conventional vehicles. The initial investment required for EV infrastructure, including charging stations, further compounds the financial burden on both consumers and manufacturers. Additionally, consumer perceptions and the limited availability of affordable models deter potential buyers, despite the long-term savings associated with fuel and maintenance. Addressing these challenges is essential for improving the affordability and adoption of EVs.

Recent advancements in battery technologies highlight the growing interest in lithium–sulfur (Li–S) batteries, which utilize sulfur as a cathode material. Li–S batteries are noted for their high theoretical capacity (1675 mAh/g) and energy density (2600 Wh/kg), making them a promising alternative to conventional lithium-ion batteries (LiBs) that face limitations in energy density and resource availability [27]. Note that sulfur is abundant and low-cost compared to cobalt in LiBs. However, Li–S batteries face challenges such as the shuttle effect, poor conductivity, and volume expansion during cycling, which hinder their practical application [20]. Recent trends also indicate a focus on sustainability and environmental impact in battery production, as seen in the EU's proposed regulations. Table 2 summarizes the current load capacity and development status of various battery technologies.

Table 2. Summary of the current load capacity and development status of battery technologies.

Battery Type	Load Capacity (mAh/g)	Development Status
Lithium-Ion (LiB)	150–250	90%
Lithium–Sulfur (Li–S)	1675	60%
Metal–Sulfur	Varies (up to 1000)	50%

These emerging technologies also are playing a crucial role in overcoming the current barriers to the widespread adoption of EVs. Advancements in battery technology, such as solid-state batteries, are not only significantly enhancing energy density but are also reducing charging times and improving overall vehicle range. Meanwhile, the integration of smart grids is facilitating more-efficient energy distribution and management [23], enabling EVs to interact dynamically with the power grid, which helps in load balancing and reduces charging costs [22]. Additionally, the development of wireless charging infrastructure is poised to make electric vehicle ownership more convenient by allowing vehicles to charge seamlessly without needing physical plugs. These innovations collectively contribute to a more accessible future for electric mobility.

4. Conclusions

The ongoing transition towards the electrification of transportation in Spain marks a promising trajectory, supported by strategic government incentives. Despite the positive momentum, challenges persist. While commendable reductions in emissions and improvements in environmental efficiency have been achieved, the scale and efficiency of the charging network emerge as pivotal determinants for the sustained and widespread adoption of EVs.

The success of the electrification movement hinges on the seamless availability and accessibility of charging points throughout the country. A comprehensive expansion of the charging infrastructure is not just a logistical necessity but a strategic imperative to alleviate range anxiety among potential EV adopters, even though they would rarely undertake these trips. It also plays a crucial role in facilitating long-distance travel and supporting the integration of EVs into diverse urban and rural landscapes.

A well-developed infrastructure network can significantly contribute to reducing the required capacity of batteries, thereby optimizing the use of rare materials and improving efficient resource management.

Until such a reduction in capacity is achieved, the proposal includes utilizing batteries (inside the cars in their first life) as a primary support for grid stability.

Furthermore, there should be a concerted effort to enhance the development and implementation of small-scale mobility solutions within urban centers. This initiative aims to reduce emissions, alleviate traffic congestion that impedes smooth circulation, and mitigate associated stress for users.

Moreover, the emphasis on renewable energy sources, particularly the noteworthy surge in solar- and wind-energy contributions, underscores a commendable commitment to a sustainable and eco-friendly energy matrix. This transition not only aligns with global environmental goals but also positions Spain as a proactive player in the broader context of mitigating climate change.

In conclusion, while Spain has made commendable strides in the electrification of transport, the journey ahead necessitates a comprehensive and collaborative approach. Strengthening the charging infrastructure, coupled with sustained government support and technological innovations, will be instrumental in solidifying Spain's position at the forefront of sustainable and electrified mobility.

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Abbreviations

The following abbreviations are used in this manuscript:

EV	Electric vehicle
GHG	Greenhouse gas
MDPI	Multidisciplinary Digital Publishing Institute
V2G	Vehicle-to-Grid

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