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Review

Progress, Challenges and Opportunities of Electromobility in Mexico

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Abstract: This paper highlights the attempts made by the government to integrate electromobility in Mexico, despite not having a well-defined National Electric Mobility Strategy, and compares the advances, challenges and future opportunities of electromobility with other countries with similar conditions in terms of the public policy, the evolution of the electric vehicles market, the charging infrastructure, incentives and legal framework, and diffusion channels. The results showed that Mexico has made partial advances in the infrastructure, production and exportation of electric vehicles, consumer incentives and project implementation. However, the country requires strengthening strategies on the economic incentives for the user and industry, homologation of chargers, training of personnel specialised in electric vehicles, handling and destination of batteries, and defining its National Electric Mobility Strategy. As a way forward, our study suggests comparing the electromobility strategies of other countries and understanding the key aspects that might enable the successful introduction of electric vehicles.

Keywords: charging infrastructure; electric vehicles; National Electric Mobility Strategy; electromobility in Mexico; lithium

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1. Introduction

The world's population continues to grow steadily, which is why its consumption needs are increasingly demanding; as a result, several environmental issues have emerged among those that highlight global warming and environmental degradation. The 2020 International Energy Agency (IEA) report found that the transport sector is responsible for 24% of direct CO_2 emissions from fuel combustion and greater energy consumption. It is estimated that by 2050 it will increase by 70%, generating more significant consequences regarding global warming and quality of life [1].

In Mexico, transport is one of the most significant emissions generators and has the highest energy consumption. According to the 2021 National Energy Balance [2], Mexico consumed 5402.34 petajoules (PJ) in 2021, of which 51.55% corresponds to transportation, 21.34% to the industrial sector, 17.42% to the residential sector, 3.31% to agriculture, 5.56% to losses and 0.83% to non-energy consumption, as shown in Figure 1. Motor transport was the most representative mode of transport, with 93.30% participation, followed by air and railway transport with 4.82% and 0.91% of the total, respectively. Finally, the lowest participation was in electric transportation, with 0.19%. Of the total energy consumed, 99.8% was supplied with petroleum derivatives (gasoline (66.93%), diesel (25.70%), kerosene (4.78%), liquid petroleum gas (LPG) (2.17%), fuel oil (0.14%) and dry gas (0.06%)) and the rest, barely 0.2%, with electricity [3].

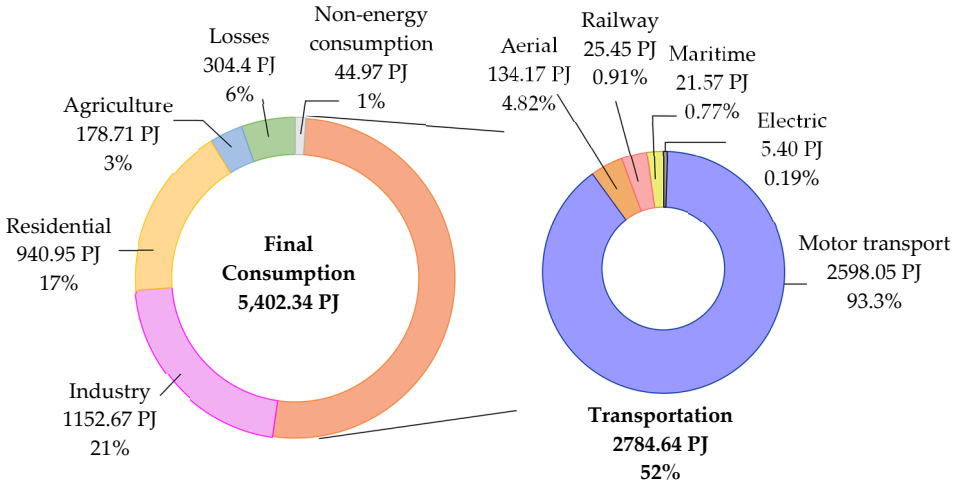

Figure 1. Total final energy consumption by sectors.

Since 2017, Mexico has stood out worldwide as one of the most competitive countries in the manufacturing of vehicles and auto parts, and it occupies seventh position worldwide in the manufacturing of cars and fifth position in the manufacturing of auto parts. In Latin America, Mexico maintains leadership in both manufacturing areas. Furthermore, this sector is a strategic component in the national economy because it generates approximately 3% of the national gross domestic product (GDP) and more than 20% of the manufacturing GDP and is also one of the industrial sectors that is more attractive in terms of foreign investment, and an essential generator of employment with high export dynamism [4,5].

As the transport of passengers and goods is essential to the development of a region, government organisations have developed several regulations on the maximum permitted emissions limits. Under this context, the United Nations Framework Convention on Climate Change (CMNUCC) and the United Nations Organization (UN), through the World Health Organization (WHO) and its different regional bodies, established guidelines to ensure air heat [6]. Examples of these guidelines are the Kyoto Protocol and the Paris Agreement, which aim to reduce the global warming caused by winter greenhouse gases. Mexico participated in the 2015 meeting of the Conference of the Parties (COP-21) held in Paris, with proposals including reducing winter greenhouse gas emissions (GEI) by 22%, representing 210 Mt for 2030. To achieve its objective, the Mexican government has promoted electromobility as a socially, economically and environmentally viable transport alternative [7,8].

Mexico's progress in adopting electric vehicles (EVs) trails behind other countries. In countries like Norway, EVs have achieved remarkable market penetration, with incentives like tax exemptions, toll-free roads and access to bus lanes driving widespread adoption [9]. As the world's largest EV market, China has implemented aggressive policies to promote EVs, including subsidies for manufacturers and consumers, resulting in a rapid increase in EV sales [10]. Similarly, in the United States, states like California have set ambitious goals for EV adoption, with initiatives such as zero-emission vehicle mandates and investment in charging infrastructure [11]. While Mexico has the potential to leverage its automotive manufacturing expertise and abundant renewable energy resources to become a regional leader in EV production and adoption, concerted efforts and policy support are needed to overcome existing barriers and accelerate the transition towards sustainable transportation.

In Mexico, there is a limited number of studies on electromobility. For example, Curiel-Ramirez et al. [12] discussed the central socio-technical systems of smart electromobility in emerging countries and reviewed some other efforts that have been occurring in Mexico. Sanchez et al. [13] reviewed the market's electrical transport, charging stations and types of connectors. Briseño et al. [14] presented a multivariate analysis considering economic and ecological factors associated with acquiring low-emission vehicles in Mexico. Maciel et al. [15] carried out a cost–environmental impact assessment of electric taxi in-

troduction in Mexico City using life-cycle cost (LCC) methodology and greenhouse gas (GHG) emissions assessment. Vallarta-Serrano et al. [16] identified challenges, strengths and drivers that condition the performance of electromobility, developed an updated business-as-usual emissions projection and compared it against the reduction targets. In addition, they described some of the incentives to purchase a vehicle with electrical technology. Álvarez-Medina et al. [17] explored the capacity for agency and legitimacy to influence the transition to electromobility in the City of Mexico. Using a diffusion model, Bonilla et al. [18] assessed the changes in privately owned vehicle fleets and tax losses associated with the deployment of electric vehicles (EVs). Tal et al. [19] showed the implications of Global Electric Vehicle Adoption Targets for the Light Duty Auto Industry in Mexico.

This paper was prepared in order to summarise the development of Mexican electromobility. The aim is to map electromobility's advances, challenges and opportunities in Mexico based on public policy and the legal framework, the charging infrastructure, the electric vehicle market, the economic cost and rates, incentives, education, standards and projects. The results obtained in this study represent an essential contribution to this topic, given the emphasis on mitigating polluting emissions and reducing the dependence on fossil fuels.

The paper is organised in the following manner. In Section 2, we describe the methodology used in this paper. In Section 3, the environmental goals set by Mexico, both international and national, are summarised. In Section 4, we show the results regarding the electric vehicle market, charging infrastructure, incentives, standards, promotion and education, and projects. In Section 5, we analyse the limitations and challenges. We also compare the results with those of other countries. Finally, Section 6 summarises the primary conclusions.

2. Methodology

This paper identifies the government's attempts to integrate electromobility in Mexico. It compares them with other countries with similar situations, considering the charging infrastructure, the evolution of the EV market, incentives, public policy, legal framework and education. Two research questions were formulated to discuss the aim of this article, as shown in Table 1.

Table 1. Research question and motivations.

	Research Questions	Motivation
1.	What is the current status of Mexican electromobility in light electric vehicles?	This research question focuses on understanding the current status of the evolution of the EV market in Mexico. It is essential to know the implementation and advancement of the strategies and projects, considering the topics of charging infrastructure, incentives, public policy, legal framework and diffusion channels.
2.	What are the strengths and weaknesses of electromobility in Mexico and other countries?	It will help to compare strategies of other countries with similar conditions and find future opportunities in electromobility.
3.	What are the challenges and opportunities of electromobility in Mexico?	To give suggestions for improvement in this aspect.

This article combined qualitative and quantitative analysis to examine this topic since 2016. The research process was completed in 4 stages:

Stage 1, the literature review, focused on collecting the current status of the Mexican electromobility in light electric vehicles. The literature search was carried out by searching for relevant articles published in Elsevier (www.sciencedirect.com, 24 May 2023), Google Scholar (scholar.google.com, 24 May 2023), official websites and social media discussions. Due to the difficulty in obtaining research papers regarding the development of electromobility in Mexico, much of the information used in this paper was obtained from secondary

sources, for example, official governmental online publications and Mexican journals, articles and reports of SENER, INEGI, SEMARNAT, CFE, SCT and others since 2016.

Stage 2 Search process: This combined the keywords with logical connectors "AND" and "OR". The keywords used were related to synonyms and their acronyms: electromobility, e-mobility, Mexico, Latino America, electric vehicles (EVs), barriers, infrastructure, incentives, public policy, legal framework and diffusion channels.

Stage 3 Inclusion criteria: Determining whether a study should be considered relevant was based on analysing the title, abstract and keywords from the electromobility topic in Mexico and Latin American countries. In some cases, it was necessary to read the entire document to determine its relevance. Only studies written in English and Spanish were included. The results from the search strings were downloaded as PDFs to be screened and assessed for eligibility by the authors.

Stage 4 Information extraction: We read the papers and reports, found them relevant and extracted qualitative and quantitative information to answer the research questions. The information was cross-checked with other papers or reports to check the consistency of data extraction. In this study stage, we obtained electromobility's main advances and challenges and compared them with other countries, such as Brazil, Costa Rica, Argentina, Colombia, etc. As a result of the studies and analyses that were conducted, conclusions were drawn and research opportunities for further studies were identified.

3. Environmental Goals Set by Mexico

3.1. International Goals

Mexico is one of the countries that, within the framework of the Paris Agreement of the United Nations (UN), have acquired specific commitments to stop global warming and climate change. Mexico's specific unconditional goals for 2030 are as follows [20]:

1. To reduce the volume of black carbon emissions by 51%.
2. To reduce its Greenhouse Gas (GHG) emissions by 22%.

The Nationally Determined Contributions (NDCs) by Mexico that are aligned with the objectives of the Paris Agreement contemplate as follows [21]:

- To generate 35% of clean energy in 2024 and 43% by 2030.
- To reduce methane leaks and venting and control burning by 25%.
- To control black soot particles in industrial equipment and facilities.
- To homologize in the Treaty between Mexico, the United States and Canada (USMCA) the environmental regulations for new and in-circulation vehicles and non-road vehicles, such as locomotives, ships, and mobile agricultural and construction machinery.
- To supply ultra-low sulphur gasoline and diesel.
- To increase the natural gas vehicle fleet and have clean fuels.
- To modernize the vehicle fleet and reduce the importation of used cars.
- To promote the construction of buildings and the transformation towards sustainable cities with energy efficiency and low carbon.
- To improve forest management and achieve zero deforestation rate by 2030.
- To promote sustainable modernisation of the countryside, promote biodigesters on agricultural farms and recover pastures.

Mexico has set several strategies to achieve these targets in three main areas, as described below [22].

Transportation Sector: This is one of the largest emitters of greenhouse gases in Mexico. The government has tried to strengthen the regulations applicable to vehicles; it has also promoted the use of alternative transportation systems, promoted clean transportation programs, and worked on the development and implementation of the National Electric Mobility Strategy and urban planning oriented to efficient public transportation systems.

Electricity generation: This is one of the sectors that generates the most emissions nationally and globally due to the consumption of fossil fuels to produce electrical energy. Some of the actions that have attempted to mitigate the environmental damage that this

activity generates are the increase in the participation of clean energies in the national electrical grid, the strengthening and optimization of electrical infrastructure and the promotion of innovative technologies in the areas of storage, and intelligent networks; the energy sector will be permanently innovating to achieve the mitigation levels established by the General Law on Climate Change (GLCC).

Oil and gas: This sector generates emissions from the production, transportation, distribution, processing and refining of hydrocarbons in the country. Actions have been identified to promote the optimization of the refining and processing systems and the implementation of the Methane Emissions Reduction Policy.

3.2. National Goals in the Transportation Sector

The National Electric Mobility Strategy (ENME) is part of the planning for developing low-carbon technologies and promoting public transportation and projects by the National Development Plan. The ENME establishes the bases and guidelines on the technical, financial, legal, institutional and administrative requirements and priorities and the incentive schemes, which allow electric mobility to be promoted and positioned nationally as a viable and sustainable mobility alternative. This strategy is in the development process under the responsibility of SEMARNAT [23]. The proposed plan has tentative goals for 2030, 2040 and 2050, designed based on studies and projections made by the INECC [24].

The goals for 2030 are as follows [25]:

(i) In total, 50% of sales of light and heavy vehicles will be electric and plug-in electric hybrids.
(ii) The introduction of at least 7 million light vehicles and 338,000 heavy load or passenger vehicles in 2022–2030.
(iii) The incorporation of EVs in the public transportation systems of the country's ten cities and urban areas with the highest emissions of GHG and short-lived climate pollutants (SLCPs).
(iv) The development of a public electric charging system, both in cities and on the main highways of Mexico.
(v) Promulgation of the regulations for the approval of electric chargers.

The goals for 2040 are as follows [25]:

(i) In total, 100% of light and heavy passenger vehicle sales will be electric vehicles and plug-in electric hybrids.
(ii) The introduction of at least 22 million light vehicles and 894,000 heavy load or passenger vehicles.
(iii) To have a system of open and homologated electric chargers for both light and heavy vehicles in the ten main cities of the country.
(iv) To have a system of open and homologated electric chargers, both for light and heavy vehicles, on all federal highways.

The goals for 2050 are as follows [25]:

(i) In total, 100% of the sales of light and heavy vehicles will be electric vehicles and plug-in electric hybrids.
(ii) The introduction of 31 million light vehicles and 987,000 heavy load or passenger vehicles.
(iii) To consolidate an electrical system for heavy electric vehicles on strategic highways in the country.

To achieve the fulfilment of the goals, lines of action established in eight axes will be executed. These axes are divided into two parts: four sectoral axes address the particularities by type of transport (public, cargo, light vehicles, motorcycles and non-motorised mobility), prioritising the development of public transport (Table 2), and four transversal axes that develop lines of action for all types of transport (Table 3). They are about the infrastructure, interinstitutional coordination, promotion of research and development of human capital, communication about and dissemination of technology [24,26].

Table 2. Sectoral axes.

	Short-Term Measures	Medium- and Long-Term Measures
Public Transport	-Safety standards and Comprehensive Waste Management Standards for batteries -Subnational–federal government collaboration -Low- or zero-emissions zones and corridors -Tax and non-tax incentives	-New scrapping schemes -Promote the purchase of buses or electric units -Quality public transportation
Freight transport	-Promote the formalisation of companies and access financial support -Accident care protocol -Promote professionalisation of the sector	-Promote the formalisation of companies and access financial support -Accident care protocol -Promote professionalisation of the sector -Electrification of trade routes
Light vehicles And motorcycles	-Standard for standardisation of chargers -Promote training of the civil protection body -Redesign of green license plates and benefits of EVs and Hybrid Electric Vehicles (HEVs)	-Update of NOM-194 security -Promote fast charging network -Preferential parking and public loading areas on roads and buildings
Alternative Mobility	-Promote business models and their intermodal integration -Promote its inclusion in urban development plans -Inclusive urban road design guide that provides safety and clear rules	-Promote the development of infrastructure for alternative mobility -Promote its use as an alternative in congestion areas

Table 3. Transverse axes.

Transverse Axes	Relevant Information
Infrastructure	-Promote the modernisation and development of road infrastructure -Development of a network of electric charging stations with fast chargers -Incorporate electric mobility into construction and fund and trust requirements -Waste standard for batteries -Develop interstate networks
Interinstitutional coordination	-Facilitate the coordination, monitoring and communication of the ministries involved -Define collaboration between local and federal authorities -Create alliances for its implementation
Promotion of research and valuable information and development of human capital	-Promote training programs for operators in alliance with universities, incorporating the best international practices -Development of a national digital platform that provides valuable and timely information -Implementation of pilot projects promoting technological exchange
Communication and dissemination	-Inform the population of the social, environmental and financial benefits of EVs and HVEs -Communication and dissemination -Promote and make the location of the electric stations generally known (integrate it into mobile apps) -Create forums and communication spaces

4. Results

4.1. Electric Vehicle Market

4.1.1. Sales of EV Vehicles

The evolution of the EV market has had a slow growth rate but is steady, as shown in Table 4. From January 2016 to June 2023, 202,562 EVs, Plug Hybrid Electric Vehicles (PHEVs) or HEVs were sold, representing 2.5% of the total sale of light vehicles. In 2017, sales increased by 27.7% compared to 2016, even though the general market presented a contraction of 8.63% in light vehicle sales. In 2018, sales increased again to 68.7% compared

to 2017. In 2019, a positive trend was maintained, registering 43.8% compared to 2018. Finally, with the sector's contraction due to the pandemic, the sales volume decreased by 21.4% in 2020. Although there was a reduction in sales, it was less than the total sale of vehicles, which registered a drop of 30.37% [27,28].

Table 4. Sales of HEVs, PHEVs and EVs [27].

Year	Vehicles Sold	HEVs	PHEVs	EVs	Total	% Total
2016	1,607,165	7490	521	254	8264	0.514
2017	1,534,827	9349	968	237	10,554	0.687
2018	1,426,926	16,022	1584	201	17,804	1.248
2019	1,317,727	23,964	1339	305	25,608	1.943
2020	949,353	22,139	1817	449	24,405	2.571
2021	850,215	42,447	3492	1140	47,079	5.537
2022	1,094,728	40,859	4375	5631	51,065	4.665
2023 *	633,087	13,127	1506	3150	17,783	2.809
Total	9,414,028	175,397	15,602	11,602	202,562	2.5

* Total sales until June 2023.

The sales of EVs represented 4.1% of the total sales of light vehicles, with hybrid electric cars having the most significant participation. In 2022, the vehicle fleet reported approximately 55,167,421 vehicles to be in circulation, divided into vehicles with legal registrations, regularised units and illegal units. Of the total vehicles, just over 50% were light vehicles, followed by 48.99% trucks, 0.74% tractors and 0.10% buses. Of the total light vehicles registered, only 2.5% of vehicles in Mexico were hybrid or electric (9,414,028 units). In this category, 1.8% were HEVs (175,397 units), 0.16% were PHEVs (15,602 units) and 0.12% were EVs (with 11,602 units) [14,29].

The state with the highest sales of EVs was Mexico City (29.2%), followed by the State of Mexico with 14.6%, Jalisco with 9.2%, Nuevo León with 8.2% and Puebla, Guanajuato and Michoacan with about 3% each [25], see Figure 2. The hybrid models that dominated the domestic market in sales were the Toyota Prius with 37,433 units, the Toyota Prius-C with 19,971 units, the KIA Niro with 4739 units, the Hyundai Ioniq with 3155 units and the Honda Insight hybrid with 1697 units. The models that dominated the sales of EVs in the country were the Nissan Leaf with 651 units, the BMW i3 with 469 units, the Renault Twizy with 209 units, the Audi e-tron with 125 units and the Renault Kangoo ZE with 95 units [30].

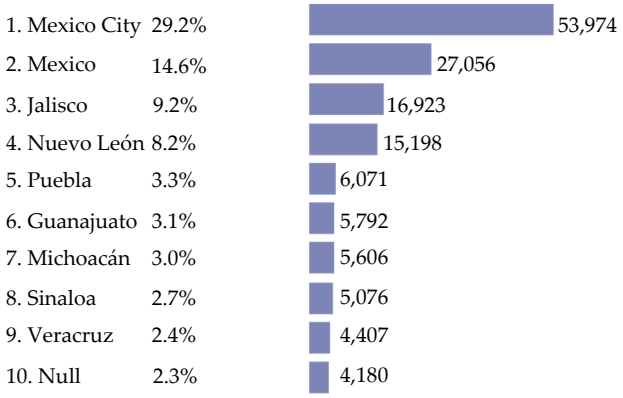

Figure 2. States with the highest sales of EVs.

4.1.2. EV Production

EV production in the country reports sustained growth. According to the Automotive Directory, in 2020, 6717 vehicles were produced, while in 2021, production increased by 89.7%, reaching 58,453 units. In 2022, an increase of 57.61% was reported compared to 2021. Similarly, in 2023, there was an increase in EV production of 36.3% compared to 2022, with

66,845 units (January–July 2023), making a total of 211,489 EV units produced [30]. The model that dominated the market was the hybrid Ford Fusion with 204,690 units, followed by the Ford Mustang Mach-E with 52,580 units, the Lincoln MKZ hybrid with 16,531 units, the Ford Maverick (2021) with 7034 units and the JAC Sei2 with 4600 units [30].

For the next few years, the vehicle fleet of EVs and HEVs can be expected to maintain its growing trend. According to the analysis of the Business Intelligence Area of Automotive Directory [31], the projected production will be around 221,970 EVs by the end of 2023, which would represent an increase of 179% compared to 2022, with models such as the Ford Mustang Mach-E, Chevrolet Blazer EV, Chevrolet Equinox EV and JAC E 10X. With regards to sales, JD Power estimates that approximately 255,900 hybrids and 59,100 electric vehicles will be purchased in the country in 2030, which will represent 17.3% of the total units.

Several initiatives are underway to develop or assemble electric vehicles in the country. For example, among the brands that are about to start production of electric vehicles this year and in the coming years, the Japanese Toyota stands out with an electrified version of its Tacoma model, as well as Tesla with the manufacture of the Cybertruck in Nuevo León and the Neue Klasse of BMW electric vehicles in San Luis Potosí towards 2027 [19,32].

4.2. Charging Infrastructure

Mexico is a pioneer country in terms of its charging infrastructure. In 2020, the IMT reported approximately 246 charging points with 2220 chargers for EVs [33]. These were installed in 2015 and were increased exponentially from 2015 to 2018, going from 156 chargers to 2013 chargers. From 2018 to 2020, the installation of charging stations presented stagnation due to the emergence of the COVID-19 pandemic. Figure 3 shows the evolution of chargers' installation in Mexico. The highest concentration of EV chargers is found in the country's central area, including Mexico City, the State of Mexico, the Bajío area and Jalisco, as well as in the metropolitan regions in Monterrey and Tijuana. The least developed part in terms of chargers is the Mexican southeast [34–36].

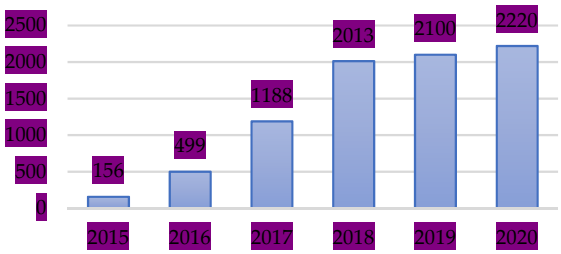

Figure 3. Number of chargers in Mexico [33].

The Electrolineras Program has implemented the start-up of two electric corridors for EVs: the Saltillo–Monterrey–McAllen corridor, which is being built and connects the states of Coahuila, Nuevo León, Tamaulipas and Texas in the United States, and the Puebla–Guadalajara corridor, which connects the metropolitan area of Mexico City with Puebla and Querétaro, as well as the metropolitan area of Guadalajara with Querétaro via Guanajuato [37], as shown in Figure 4.

In terms of the public charging stations, Mexico also has the fastest EV charging station in the world for electric and plug-in hybrid vehicles. This charging point is located in San Lorenzo Almecatla, Puebla. Its capacity of 1 MW allows it to recharge EV batteries up to 20 times faster than a traditional charger. The standby time can be from 7 to 25 min, depending on the type of battery. Different types of chargers are available, American, European and Asian, for different automotive brands. This service is offered by QiOn (a global electrical supply company) in collaboration with XC Power (a charger operator network company) [38,39].

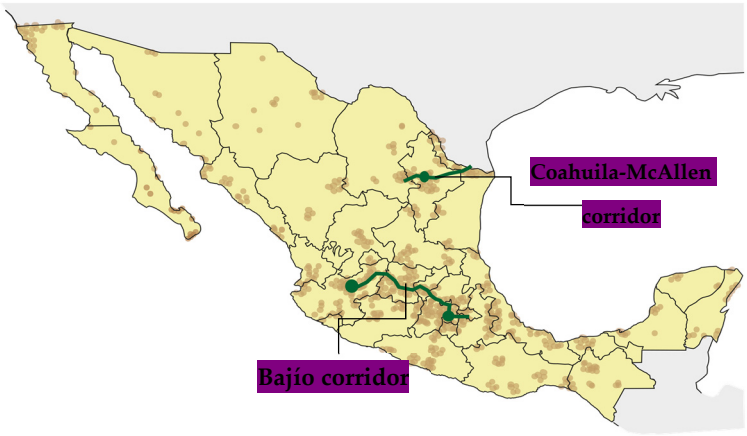

Figure 4. Coahuila–McAllen and Bajío corridor of charging stations [40].

Public charging points in Mexico can be used through membership and special identification cards. CFE, BMW Group, Nissan Mexico and private sector representatives have led the efforts to deploy electric vehicles and the associated charging infrastructure in this country [37].

4.3. Incentives

The promotion of electromobility requires fiscal and economic incentives to be promoted so that people opt for electric vehicles, in addition to supporting the development of infrastructure, as well as the promotion of research and battery technologies and electric mobility. In Mexico, the most important incentives are reflected, especially, in the income tax, the value-added tax law, the federal tax code and the new automobile tax law. Table 5 shows the incentives currently in force for this type of vehicle.

Table 5. Descriptions of incentives for EVs in Mexico [41].

Incentive	Description
ISAN exemption	EV does not pay the new car tax.
ISR reduction	A 50–70% reduction in EV value. Tax reduction of up to MXN 250,000 when buying an EV for legal entities.
Additional light meter	Installation of an independent meter by CFE to save 40% when billing electricity consumption at home.
Renewal of the taxi fleet	Scrap bond for each taxi delivered to be replaced by a new EV.
Exemption from the payment of tenure	Exemption from holding fee in most states. In the State of Mexico and Mexico City, tenure is not paid during the first five years, after which it is paid with a 50% discount.
Bonuses and credits	Bonds or credits accessible to individuals or legal entities that invest in fleets of hybrid or electric vehicles.
Car sticker	In the City and State of Mexico, a special sticker is assigned to identify EVs.
Environmental Verification Exemption	EVs are exempt from the vehicle verification program, which implies a semi-annual emissions review and the restriction of the “no circulation today” program.
Ecological car license plates	Identification of vehicles that have hybrid or electric technology.

Table 5. *Cont.*

Incentive	Description
ISR deductibility for the acquisition of charging points	In the General Economic Policy criteria for the Income Law Initiative and the Expenditure Budget Project of the Federation corresponding to the fiscal year 2017, a tax credit of 30% of the ISR is established to be deducted for recharging infrastructure of EVs of public access.
Elimination of tariffs	Eliminate tariffs for importing electric motor vehicles, including cars, vans and cargo trucks. As the Ministry of Economy proposed, this applies to companies that subscribe to the decree to support competitiveness.
ECOTAG	Discount on toll roads: Electric and hybrid cars receive a special 20% discount on TeleVía roads in Mexico City (North Urban Highway, West Urban Highway and South Urban Highway).
Discount tolls ECOTAG	A 20% discount on toll rates on certain urban highways in Mexico City.
Preferred parking	Preferential parking and charging stations in establishments in Mexico City and ChargeNow for hybrid and electric vehicles.
Assembly in Vehicles	Removal of VAT for EVs assembled in Mexico.

4.4. Standards

Concerning regulations, standardisations and certifications, Mexico has a general official regulatory framework regarding electrical/electronic appliances and devices in vehicles, but none on specific or oriented standards for electric vehicles. Thus far, the ANCE Standardization Committee (CONANCE) has developed some Mexican Standards for road vehicles, fully or partially powered by electricity from autonomous energy sources, including charging infrastructures for these vehicles [42]. The current Mexican Standards are summarised in Table 6.

Table 6. Description of Mexican Standards for EVs [42].

Standard	Description
NMX-J-668/1-ANCE-2013	Personal protection systems for power circuits—Part 1: General requirements
NMX-J-668/2-ANCE-2013	Personal protection systems for power circuits—Part 2: Particular requirements for protective devices for use in charging systems
NMX-J-677-ANCE-2020	Electrical power equipment
NMX-J-678-ANCE-2020	Plugs, receptacles and couplers
NMX-J-683/1-ANCE-2013	Plugs, Receptacles, Connectors and Flanged Plugs. Systems for non-inductive charging of EVs—Part 1: General requirements.
NMX-J-683/2-ANCE-2020	Plugs, Receptacles, Connectors and Flanged Plugs—Non-inductive charging of EVs—Part 2: Compatibility and dimensional interchangeability requirements for pin fittings and contact tubes in alternating current.
NMX-J-684/1-ANCE-2013	Systems for non-inductive charging of EVs—Part 1: General requirements.
NMX-J-684/21-ANCE-2014	Systems for non-inductive charging of EVs—Part 21: EV requirements for non-inductive connection to an alternating/direct current power network.
NMX-J-684/22-ANCE-2014	Systems for non-inductive charging of EVs—Part 22: AC charging station for EVs.
NMX-J-725-1-ANCE-2016	Induction charging systems—Part 1: General requirements

4.5. Promotion and Education

For the promotion of e-mobility, Mexico has a specialized group of automotive companies, researchers, academia and ministries, such as energy, finance, economy and urban development, as shown in Figure 5. This group is divided into five work subgroups. The first group deals with regulation, norms and standards. The second group is focused on research, technologies, infrastructure and energy. The third group deals with incentives,

business models and financing. The fourth group oversees demonstration projects, communication and dissemination. Finally, the fifth group has formed an Alliance of Cities for Electric Mobility to implement and replicate pilot projects in different regions. This group is led by two States, Puebla and Yucatán, and the UN Environment. Other cities that make up this alliance are Coahuila, Tlaxcala, Guanajuato, Chihuahua, Guerrero and Mexico City. The ENME doesn't designate any specific responsible entity or organization or outline consequences for failing to meet its goals [23].

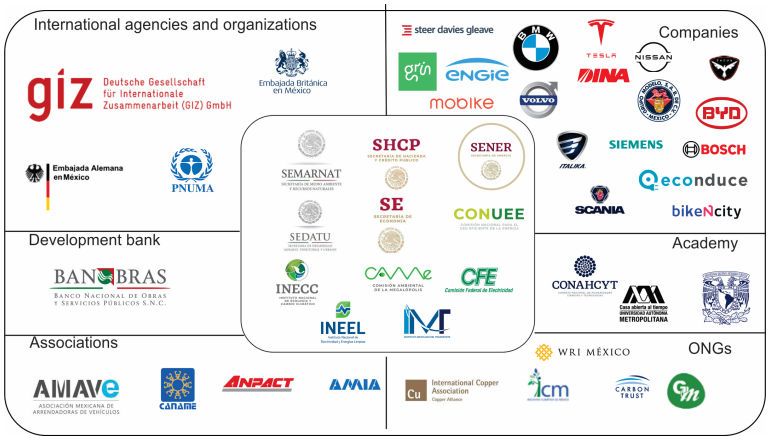

Figure 5. Specialised work groups in electromobility [23].

These groups have committed to (i) organise forums, conferences and seminars to disseminate concepts and best practices on electrified vehicles and sustainable mobility, (ii) carry out information campaigns on the benefits of electrified vehicles and schemes of incentives and financing, and (iii) develop educational programs to incorporate subjects on electrified technologies in the study plans of engineering careers at universities and technological schools [43].

In this last aspect, some universities have planned to incorporate professions related to handling and managing batteries and high-power density electronics, designing electric motor traction, programmers for autonomous vehicles, data network operators and communication with the infrastructure [41]. To date, Mexico has had a binational Mexico–United States collaboration through the University of California and the Ministry of Foreign Affairs called the Transportation Electrification Group in Mexico. This collaboration has two objectives: (i) to provide a diagnosis of the global and regional electric mobility transition, emphasising the opportunities for Mexico and the United States, and (ii) to reflect the recommendations of the analysis carried out in the first part, looking for opportunities for investment in industries and technological development infrastructure driven by nearshoring of supply chains [41,44].

There is also a project called "Contributing to decarbonise Mexican cities through an ecosystem of electric transport and sustainable mobility: Case studies in two polar cities (Cuernavaca, Morelos and Hermosillo, Sonora)". This project tries to show the challenges of changing transport towards electric mobility and the technological complexity involved in the transition. Institutions such as the Institute of Engineering of the Autonomous University of Mexico (UNAM), the Network of Experts in Automotive Innovation of the National Polytechnic Institute (IPN), the National Institute of Electricity and Clean Energy (INEEL) and the Popular University of the State of Puebla collaborated on this project. The Sonora College (COSON), in support of the CONAHCYT, is responsible for this project [45].

On the other hand, the Mexican Association of the Automotive Industry (AMIA) is working to disseminate information about vehicles with hybrid and electric technology. This is because most consumers still do not know the essential characteristics of these technologies. They consider that the more people who see the subject, the more they will choose to use an electric one [41].

4.6. E-Mobility Projects in Mexico

Public and private initiatives have sought to develop projects that contribute to the country's electromobility development. This is why several states have implemented their strategies to transition towards electric fleets, mainly oriented towards urban transport. This section shows the states that have given way to the renewal of transport means and the projects in operation and development from 2018 to today [46,47].

4.6.1. México City

(i) Purchase and operation of 300 new generation trolleybuses, as well as the inauguration of the elevated trolleybus.
(ii) Leasing of 60 electric buses for Metrobús L3.
(iii) A total of 900 shared electric bikes.
(iv) Implementation of bicycle taxis with assisted pedalling in Tláhuac, Venustiano Carranza and Iztapalapa.
(v) A project for 400 electric taxis, supported by a new program between the KfW (Bank of Development of the State of the Federal Republic of Germany) and National Financiera (Nafin) for financing.
(vi) A total of 1500 electric motorcycles shared through Econduce.
(vii) Inauguration of two cable bus lines until August 2021 and the current construction of Line 3 and Line 4.
(viii) Construction of the Chalco–Santa Martha trolleybus.
(ix) Renovation of the light rail.
(x) Expansion of Metro Line 12, from Mixcoac to Observatorio.
(xi) Renewal of Line 1 of the Metro.

4.6.2. Jalisco

(i) It has the country's first 100% electric route, line 3, with 38 buses that travel from its capital, Guadalajara, to the Miguel Hidalgo y Costilla International Airport.
(ii) Construction of line 4, Tlajomulco.
(iii) A project for 50 to 80 electric wagons and trucks for Jalisco, supported by a new program between KfW and Nafin.
(iv) Electric buses are integrated into the Mi Macro Periférico system route.
(v) Development of electric bus and vehicle projects (in operation).
(vi) Purchase and operation of 38 8.5 m electric buses (in operation).

4.6.3. Monterrey

(i) A proposal for three electric corridors, with 110 12 m buses to connect with the new Line 3 of the Metrorrey System. The first pilot phase will be carried out with 12 units from the Hospital Metropolitano station of the Nuevo León subway station to the Airport Route.
(ii) Electric Bus Standard Project.

4.6.4. Hidalgo

(i) JAC produces and sells three EVs and two electric trucks (in operation).
(ii) Development of Regulation and Electric Taxis Program.

4.6.5. Puebla

(i) Plan for the Deployment of Electric Vehicle Chargers in the State of Puebla. It has developed and manufactured 43 electric chargers that facilitate recharging.

4.6.6. Mexico State

(i) Construction and sale of Mustang Match-E electric cars (in operation).
(ii) Piloting of two electric wagons (in operation).

(iii) Piloting 11.5 TON 100% electric delivery trucks (in operation).
(iv) Projection of a high-capacity bus, trolley type, in the Chalco area.
(v) The Teleférico is called Mexicable, with cabins that use solar and electrical energy.

4.6.7. Hermosillo

(i) Electrification of 24 km of the BRT line.

4.6.8. Mérida

(i) A total of 30 electric opportunity charging units by 2024.

4.6.9. Guanajuato

(i) León–Optibus: Analysing Electric Modernization project.

4.6.10. Sonora

The lithium reserve ensures a reliable and sustainable supply for the growing demand for batteries in the electrified transport industry. In this sense, Mexico is one of the countries with more lithium resources, as shown in Figure 6. According to the United States Geological Survey, the country has approximately 1.7 million tons of lithium to satisfy battery demands and other applications [48].

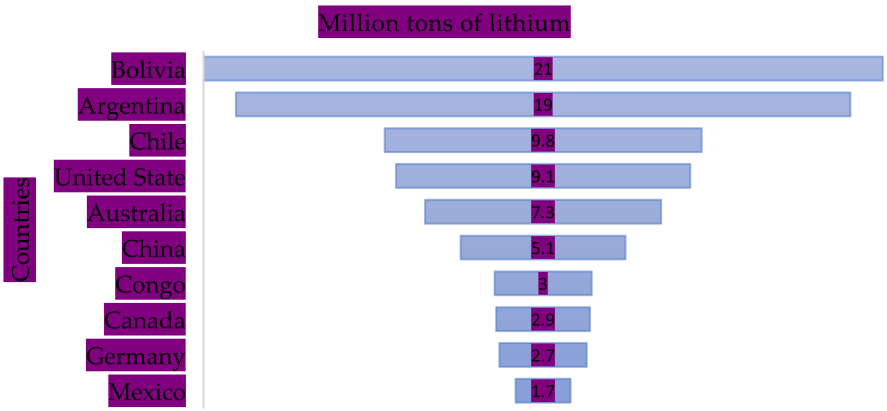

Figure 6. Lithium resources by country [48].

In Mexico, there are 18 states of the Republic where most of the lithium deposits are concentrated. On this list are Sonora with 13 sites, Puebla with 12, Oaxaca with nine and Nuevo León with eight. Durango has seven deposits; Chihuahua and Tamaulipas have five deposits; and in Coahuila, Guanajuato, Hidalgo, Jalisco, San Luis Potosí and Zacatecas, there are three deposits of this mineral, respectively, while, in Chiapas, Michoacán, Morelos, Sinaloa and Veracruz, there is only one [49].

Given that Sonora is the state of Mexico with the most lithium deposits, the Mexican government has proposed the Sonora Plan to exploit this mineral [50]. The plan contemplates the construction of five solar parks and the associated transmission lines to promote an energy transition in the country, as well as the exploitation of lithium, a mineral necessary in producing batteries for electric vehicles, the production of semiconductors and the development of clean energy plants.

The Mexican government has estimated that the lithium exploitation value chain has a potential of 12 billion pesos. Therefore, it has nationalised lithium and created a decentralised public body of the Federal Public Administration called LitioMx. This organisation aims to develop and execute engineering projects, research, geological activities and all those related to lithium exploration, benefits and use [48,51].

4.7. Other Projects

In 2017, Mexico City, Guadalajara and Monterrey developed an infrastructure program for plug-in hybrid and electric vehicles to cover the electrical needs of this sector. This program proposes installing level 2 and 3 charging points in interurban corridors. Additionally, Mexico City and Querétaro have a shared electric bicycle system and electric skateboard and motorcycle systems in operation. Micromobility has also been promoted in different states, such as Mexico City, the State of Mexico, Hidalgo, Morelos, Puebla, Querétaro and Tlaxcala [46,47].

On the other hand, the private sector has also begun to carbonise its vehicle fleets. Many companies in Mexico, mainly with international scope, have started to renew their vehicle fleets with electric vehicles, thus reducing their polluting gas emissions. The soft drink, beer, courier and bakery industries stand out [46,47].

5. Discussion

This paper aimed at better understanding the advances and challenges in Mexican electromobility based on public policy, the evolution of the EV market, the charging infrastructure, incentives, the legal framework, and promotion and education. The results showed that Mexico has great potential to encourage electromobility. However, it still faces difficulties in promoting and adopting EVs.

Regarding public policy, Mexico has partial goals that have allowed it to incorporate electromobility in slow steps. Therefore, the country requires that the National Electromobility Strategy be defined with goals that adjust to the economic, political and environmental conditions of the government. The lack of legislation could affect commercial opportunities linked to electromobility in Mexico. In this sense, the electromobility strategies of Colombia, Chile, Costa Rica and Panama could be used as a reference framework [37]. These countries have emphasised encouraging electric mobility and have made significant political, environmental and educational advances, among others.

With regards to the EV market, we find that Mexico is one of the leading manufacturers in the automotive industry worldwide. Its production and exports have experienced steady growth, positioning the country as the fourth largest in terms of turnover for this concept, trailing behind the United States and in competition with Japan, South Korea, Germany and Canada [52]. Although EV sales have increased in recent years, we find that the sales goals of the National Electric Mobility Strategy (ENME) for 2030 are unattainable. Setting goals such as 50% of total sales of plug-in hybrid or electric vehicles by 2030 implies selling approximately 7 million in the next six years. This would represent almost 100% of light vehicle sales in Mexico, whether plug-in hybrids or electric vehicles, which is not happening. Norway, for example, took 30 years to achieve 50% of annual vehicle sales being electric, boosting them through incentives and infrastructure development [9].

In sales of EVs, the Latin American market has presented a gradual increment since 2016, as can be seen in Figure 7. However, the electric or hybrid vehicles' segment continues to be a minority in the region. For example, in the Mexican and Chilean markets, these vehicles represent less than 10% of total private vehicle purchases. Some of the reasons for the low adoption of this new technology are related to the high prices of the models, mostly imported from high-income economies, and the developing level of the development of the charging infrastructure [9]. Therefore, it is necessary to develop a comprehensive action plan that incorporates measures in terms of production and marketing.

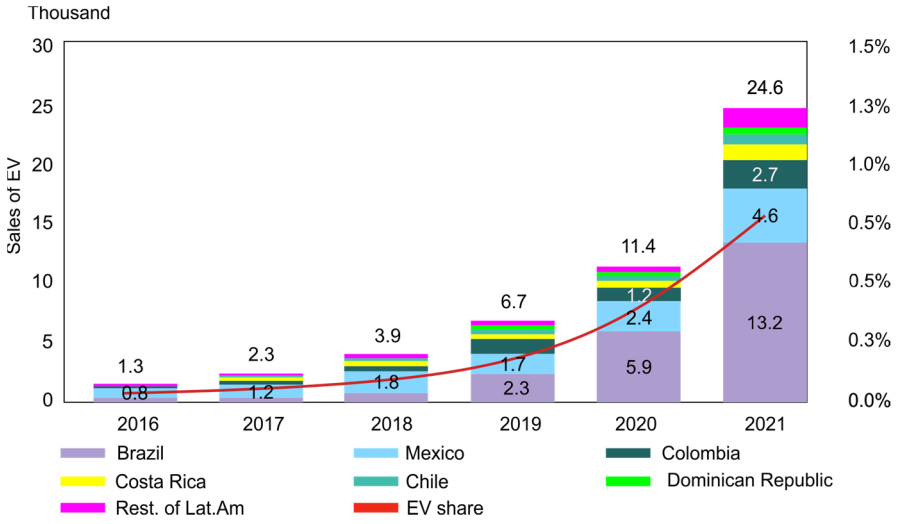

Figure 7. Sales of EVs in the American market [53].

In terms of infrastructure, we find an essential advance in electromobility in the installation of charging points, making Mexico one of the countries with the highest number of charging stations in Latin America, without considering the United States. They were followed by Chile with 316 charging points, Costa Rica with 267 charging points and Colombia with 191 charging stations [54], as shown in Figure 8. This type of network makes it possible to enable the management of and billing systems for charging services. The advantage that Mexico has over these countries is that it has the world's fastest EV charging station, which recharges the battery as quickly as possible and thus avoids traffic congestion.

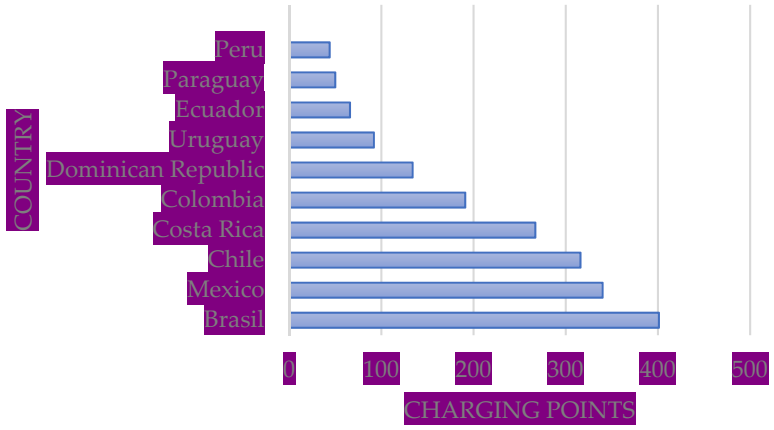

Figure 8. Top ten of charging points in Latin America 2023 [54].

Although Mexico has increased its charging points, they are insufficient. According to the company XC Power analysis, more than 15,400 charging points are needed in the Mexican territory to meet the users' needs [55]. Currently, the country has less than one-third of the necessary charging points. Considering the increase in demand for EVs in recent years, about 38,000 charging stations will be required to cover the needs of 700,000 electric vehicles, which are projected to be in circulation in 2041 [40,56]. This means that 40,000 charging stations will be necessary to satisfy the energy demand, equivalent to installing 2000 charging stations per year. In this context, the AMIA has sought to negotiate with the Congress of the Union modifications to the Electric Industry Law to accelerate the construction of electrical corridors, as well as federal and state incentives that promote facilities to add more clients to the purchase of these vehicles.

In terms of incentives, Mexican electromobility has focused on the new vehicle tax law. Among the EV purchase incentives, the Mexican federal government eliminated the new car tax (ISAN) for hybrid and electric vehicles in 2012, and this measure has also been applied in Argentina, Brazil, Chile and Panamá. In Colombia, this rate must not surpass 1% of the new vehicle's commercial value. In addition, Mexico has Free Trade Agreements with around 40 countries, with the majority of imported vehicles not paying the 16 percent tariff that is paid when the car comes from a country without a free trade agreement. Similarly, Colombia, Brazil and Costa Rica have omitted the import tax on EVs. This allows the industry to have the opportunity to compete against foreign markets, especially the Chinese market. In terms of use and circulation incentives, Ecuador allows EV users to travel freely without movement restrictions. Meanwhile, Mexican users of EVs are subject to the regulations of each state. Colombia has exempted users from paying for parking meters. However, Mexico and Costa Rica have applied this to some specific locations. Finally, Mexico has other incentives such as the acquisition of charging infrastructure, ecological plates, Ecotag and installation incentives for additional meters through the CFE; however, there is a lack of economic support for the purchase and sale of EVs and support for EV manufacturers [57,58]. Table 7 shows a comparison of incentives in Latin America.

Table 7. Incentives in Latin America [58].

Category	Incentive	Argentina	Brazil	Chile	Colombia	Costa Rica	Ecuador	Mexico	Panama
Purchase incentive	Value-added tax				✓	✓	✓		
	Import tax	✓	✓		✓	✓		✓	
	Others	✓	✓		✓		✓	✓	✓
Use and circulation tax	Property/ circulation tax					✓		✓	
	Exception for parking, tolls, etc.				✓	✓		✓	
	Others					✓		✓	

✓ Instrument in design/partial phase. ✓ Instrument approved and running.

Concerning standardisation and certification regulations, Mexico has a gap in development opportunities in this area. Although there are some norms or standards in the country on the subject of electromobility, these focus primarily on electric vehicles and the charging infrastructure and are voluntary. Unfortunately, none of them apply specifically to the implementation, handling and destination of the batteries, the security systems present in the vehicle, or its interaction with the infrastructure. In addition, there is a lack of regulations for the standardisation of charging points, the type of connectors, communication protocols, battery performance and certifying bodies that can endorse and regulate the different devices on board electric vehicles. Mexico could take the regulations of Brazil, Chile, Costa Rica or Argentina as a reference. In the case of Brazil, this country has regulations on the procedures and conditions for EV charging by dealers and electrical distribution companies. This resolution requires that public charging stations be compatible with open communication, supervision and remote-control protocols. Similarly, Chile has regulations for the commissioning of EV charging infrastructure, which establishes the characteristics and safety and protection requirements for public, private and home charging points, as well as their approval and the standards to be considered in new buildings. At the same time, Costa Rica and Argentina have established standards for charging stations [59,60].

In the aspect of promotion, Latin American countries have formed associations or specialised groups for the promotion of electromobility. For example, in Mexico, the National Association of Electric and Sustainable Vehicles (ANVES) and the Alliance for electromobility; Argentina has the Argentine Association of Electric and Alternative Vehicles

(AAVEA); Brazil has two associations: the Brazilian Association of Owners of Innovative Electric Vehicles (ABRAVEI) and the Brazilian Association of Electric Vehicles (ABVE); Chile has the Electric Vehicle Association of Chile (AVEC) and the Electric Car Club for the promotion of electromobility; and in Ecuador, the Automobile Club of Ecuador (ANETA) and the Association of Automotive Companies of Ecuador (AEDADE) have taken the role of promoters of electromobility in the country. All these associations organise events to promote electromobility at the national level, and at local, and state levels [61–63].

In the educational aspect, Mexico is working on educational and training programs for technical, undergraduate and graduate careers, while Argentina, Chile and Ecuador have technical schools throughout the country to train human capital in the area of alternative and non-polluting transportation, as well as to design, produce and test these new technologies. Brazil only has some vocational schools partnered with private companies for training [37].

Finally, in terms of projects, the country has shown advances; for example, Guadalajara and Mexico City have respective trolleybus systems. The Mexico City system added 63 new units in 2019, expecting to reach up to 500 new vehicles by the end of the current legislative period. In addition, there are modes of mass rail transportation (metro, suburban trains and light rail). Currently, Mexico lacks battery electric buses in the public transportation service. However, at the state and city levels, various initiatives analyse or prepare tenders for introducing electric buses. Such is the case of the Government of the State of Jalisco, which plans to electrify some routes of the Mi Macro Periférico system, a 41 km trunk corridor and feeder routes. Similarly, the states of Monterrey and Hermosillo plan to electrify public transportation routes. The nationalised lithium and its industry have been a critical element in attracting investment from more electric car plants, which need this mineral to make their batteries.

In summary, the gaps and advances in electromobility in Mexico are generally described in Table 8.

Table 8. Gaps and advances of electromobility in Mexico.

Aspect	Condition
-National Electric Mobility Strategy	In Review
-Environmental goals or objective	With advance
-Projects for the implementation of electromobility	With advance
-Regulatory provision of recharge management	Lack
-Chargers' standardisation	Lack
-Distribution and planning strategy for the diversity of chargers	Lack
-Creation of certifying associations regarding electromobility	Lack
-Certifications and trade regulations for EV and charger emissions standards	Lack
-Installation of public charging stations	With advance
-Creation of an official registry of the location and characteristics of public charging stations	With advance
-Production and export of EVs	With advance
-Energy distribution for the supply of charging stations (regulatory and non-regulatory markets)	Lack
-Technical training, job adaptation	Lack
-Dissemination of information on the benefits of EVs	With advance
-Charging infrastructure operation, installation and maintenance programs	Lack
-Granting incentives for the acquisition of electric vehicles	With advance
-Reduction in tariff taxes	With advance
-Reduction in the domestic energy consumption rate with the installation of a second meter	With advance
-Financing strategies for the construction of public and private stations	Lack
-EV sales	With advance

6. Improvement Opportunities for the Electromobility in Mexico

Mexico, committed to decarbonization, faces a complex challenge in the adoption of sustainable mobility, given the country's vast territorial expanse and the multitude of cities that need attention. However, in order to capitalize on the opportunity to transition towards electromobility, it is imperative to address various aspect

First of all, it is crucial to define a national electromobility strategy that establishes objectives and goals in accordance with the economic, political and social situation in which the country is immersed. This strategy should not be limited only to reducing greenhouse gas emissions, but also to positioning Mexico as a global leader in the manufacturing of electric and hybrid vehicles. While the Mexican government has made progress in terms of the market, infrastructure, incentives and regulations, there remains a critical need for detailed reports on the progress, challenges and results of the strategy at the state level. To fully realize the potential of electromobility, it is crucial that there is a coordinated body that has the authority to carry out regular monitoring and evaluation, ensuring that the strategy stays on track and continues to drive positive changes in the transport landscape [41].

Secondly, the supply and demand of electric vehicles remain very limited, due to three issues: First, there are few vehicle models; second, electric and hybrid vehicles are substantially more expensive than those that use fossil fuels; and third, there is no adequate network of charging stations that guarantee the autonomy of said vehicles to travel throughout the country [64].

In Mexico, 13 main companies offer electric vehicles: Audi, BMW, BYD, Ford, Hyundai, JAC, Mercedes Benz, Nissan, Mitsubishi, Mini, Renault, Toyota and Volvo. With that amount, it is in the regional average, with Colombia being the country with the most brands at present (21), followed by Costa Rica (19), Panama (15), Uruguay (14), Argentina and Paraguay (6), Ecuador (5) and Guatemala (3) [65]. One approach to addressing the first challenge could be to manufacture more models of electric cars at low costs within the country by creating regulations that encourage investment in new production plants in this sector since, currently, the legal framework presents different levels of progress and the rules of operation and regulations are not completely defined, which generates uncertainty among both national and foreign investors—this lack of clarity limits plans and projects related to electromobility [66].

In the second situation, sales of electric and hybrid vehicles, stagnation has been observed in recent years due to the shortage of semiconductors, the decline in automobile production, the recent regulation of imported used cars and the price volatility of components such as steel and aluminium [67,68]. All of this has significantly increased the initial cost of this technology, so the Mexican government could take advantage of the opportunity to integrate its automotive industry with the North American industry and create a cluster for the regional supply of auto parts, semiconductors and batteries to reduce costs. of this technology. In this context, the lithium industry will play a leading role in the success of the integration of the automotive industry in the region, as is the case of Tesla, a company that has expressed its interest in investing in lithium mines in Mexico to supply its growing electric vehicle market and the construction of an industrial plant near Felipe Ángeles International Airport [69].

Regarding charging points, Mexico is one of the countries with the largest number of charging points in Latin America; however, there is a need to increase the number of public and private charging stations. It is essential to maintain the current support schemes for the installation of chargers, as well as the regularization procedures to adapt charging points to new constructions and existing homes. For example, in the aspect of electrical installation, most houses do not have the CFE regulations required. If the age of the inhabited private dwelling in the country is taken into account, it can be found that 28.7% were between 11 and 20 years old, 24.6% were 31 or more years old, and 22.5% were of recent construction—10 years or less of these, 3,180,346 (9.0% of the total) were five years old or less, so are considered new homes. The federal entity with the highest percentage of new homes built was Baja California Sur, with 21.1%, followed by Quintana Roo, with 16.5%. The entity with the lowest percentage of new home construction was Mexico City, with 3.4%. Regarding the state of the dwelling, the ENVI 2020 reported that 44.2% of the homes had humidity/water infiltration difficulties, followed by cracks/crevices, with 40.8% [70], as shown in Figure 9. In this regard, it can be seen that most users would be forced to modify their dwellings

to install a charging point, which would incur additional costs for its adaptation and to ensure that the modifications adapt to the CFE regulatory framework.

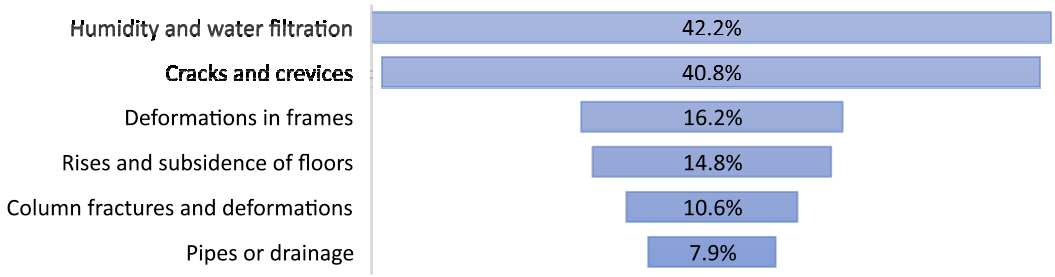

Figure 9. Structural problems in private inhabited households 2020 [70].

Additionally, it is necessary to conduct a thorough analysis of market growth patterns, evaluate available communication options and determine the power grid's ability to cope with growing demand. Given this need, it is crucial to focus on improving the capacity of the electrical grid to meet growing demand. Currently, most stations rely on energy derived from fossil fuels, highlighting the imperative to transition towards sustainable energy sources in line with international commitments on climate change. To achieve this, it is imperative to synchronize the PRODESEN with the National Development Plan 2019–2024. The restructuring of the electricity grid should prioritize both the generation of renewable energy and the improvement of the transmission and distribution infrastructure. According to CENACE projections, 10,926 GW will be needed to satisfy the increase in demand for electrical energy destined for electric mobility in 2035, which would represent 2.3% of the total consumption of the National Electrical System [71]. This amount of energy could aggravate existing problems in the electrical grid, such as increased harmonics and the risk of a collapse. The main challenge that the country must overcome is to have a sufficient renewable energy supply to attract large global companies to invest and establish their factories in Mexico. The current situation is that 52% of the energy generated in Mexico is through a combined cycle, while another 11% comes from coal, which, in sum, are large sources of greenhouse gases [72]. The national government has foreseen this situation in the Sonora Plan since, through it, it is expected that there will be five photovoltaic plants for energy generation, of 1 GW each, and it is expected to extend production until reaching 8 GW [73].

The opportunities for expanding the charging point coverage for electric vehicles in Mexico are promising, with various initiatives and investments aimed at bolstering the charging infrastructure across the country. According to recent reports, Mexico has seen a notable increase in the installation of charging stations, particularly in urban centres and along major highways, facilitated by both public and private sector efforts. Collaborations between government entities, utility companies and EV manufacturers have been instrumental in accelerating the deployment of charging infrastructure, with incentives and subsidies further incentivizing the expansion of charging networks. As Mexico continues to prioritize sustainability and reduce carbon emissions, the charging points should have updated mobile applications that offer information about the location and characteristics of charging stations, in order to continue planning the expansion of electrical networks, and establish a business scheme based on location and current regulations. While there are currently six mobile applications available for locating charging points, namely ElectroMaps, Google Maps, Charge Maps, PlugShare, Open Charge Map and Tesla, there remains a notable absence of an official, publicly accessible registry detailing all charging point locations and their respective specifications across Mexico, encompassing both public and private installations [74].

Incentives and financing for EVs remain limited. As the penetration of EVs continues to rise, there is a pressing need to enhance existing incentive programs, particularly by bolstering financing options for vehicle purchases, as well as supporting the manufacturing

and export of EVs. Additionally, developing comprehensive financial and technical assistance plans tailored to the phased replacement of aging vehicle fleets could significantly accelerate the transition towards electrification [64]. However, challenges persist, including the need to establish localized measures that simultaneously incentivize electrification while disincentivizing the maintenance of combustion fleets. For instance, implementing access policies such as Low-Emission Zones or time restrictions for accessing city centres could encourage EV adoption while discouraging reliance on traditional combustion vehicles. Moreover, initiatives like providing exclusive loading and unloading areas or offering special parking permits for EVs could further incentivize their usage, contributing to a more sustainable transportation ecosystem in Mexico.

In the context of the legal framework, one of the main opportunities lies in enacting laws and regulations that encourage investment in electric charging infrastructure, thus facilitating the expansion of the charging point network and promoting comfort and convenience for users of electric vehicles. In addition, establishing fiscal and financial incentives, such as tax exemptions or subsidies for the purchase of electric vehicles, can stimulate demand and make these vehicles more accessible to a more significant part of the population. Likewise, strengthening regulations that promote local manufacturing of components and electric vehicles can generate opportunities for the growth of the automotive industry and job creation in the country. The regulation of battery recycling offers an opportunity to establish environmental processes and standards that guarantee the proper management of these components, thus promoting sustainability and the reduction in polluting waste. Establishing comprehensive regulations for the environmentally responsible handling of EV batteries is imperative to mitigate potential environmental risks and ensure sustainable end-of-life management practices. This aspect also poses challenges regarding the infrastructure and technology necessary for the treatment and reuse of materials and the effective implementation of collection and recycling policies. Regarding the approval of charging chargers, there is an opportunity to establish precise and uniform regulations that ensure the interoperability and safety of the equipment, facilitating the expansion of the charging infrastructure and giving users confidence in the compatibility of the chargers with their electric vehicles [64,65]. However, this process also faces challenges related to the standardization of technologies and coordination between different regulatory entities. Ideally, Mexico would align with North America, due to its geography, to define the type of connector applicable to the region. Furthermore, regarding emissions' regulation, Mexico can draw ideas from global precedents such as Regulation (EU) 2019/631 of the European Union, which establishes CO_2 performance standards for new heavy vehicles and requires emission reduction trajectories [75]. Similarly, tools like California's Advanced Clean Trucks regulation underscore the importance of ambitious goals for adopting zero-emission vehicles [76], providing a roadmap for Mexico to follow suit and drive the transition towards cleaner transportation solutions. Adopting such regulatory frameworks can not only accelerate the deployment of energy-efficient technologies but also position Mexico as a proactive player in the global shift towards sustainable mobility.

Finally, in the field of education, Mexico has outstanding potential to develop specialized programs that meet the growing demand for trained professionals in the emerging electric vehicle industry. Implementing curricula focused on areas such as the design, engineering, maintenance and management of electric vehicles can be key to forming a highly qualified workforce, ready to address the demands of the electromobility market [64,65,77]. Likewise, collaboration between research and industry can foster the development of innovative solutions in the field, positioning Mexico as a leader in the sector worldwide. However, these advances face important challenges, such as the need to have adequate educational infrastructure and sufficient resources for the implementation of specialized programs. Furthermore, keeping study plans updated to keep pace with technological advances and market trends represents a constant challenge to guarantee the relevance and effectiveness of electromobility education in Mexico. Likewise, the specialization of personnel in battery recycling constitutes another important area of opportunity since the

proper management and disposal of electric vehicle batteries at the end of their useful life is essential to mitigate negative environmental impacts. In this sense, the implementation of training and certification programs in battery recycling could contribute to strengthening the electromobility value chain in Mexico, promoting sustainable and responsible practices throughout the industry.

In conclusion, Mexico stands at a critical juncture in its commitment to decarbonization and the adoption of sustainable mobility practices. The vast territorial expanse and diverse urban landscapes present complex challenges but also immense opportunities for the transition towards electromobility. To fully capitalize on these opportunities, it is imperative for Mexico to establish a comprehensive national electromobility strategy that aligns with its economic, political and social context. This strategy should not only focus on reducing greenhouse gas emissions but also position Mexico as a global leader in the manufacturing of electric and hybrid vehicles. While significant progress has been made in terms of market development, infrastructure expansion and regulatory frameworks, there remains a crucial need for enhanced transparency and accountability in monitoring and evaluating the strategy's implementation at the state level. Moreover, addressing the current limitations in the supply and demand of electric vehicles, including the scarcity of vehicle models, high upfront costs and inadequate charging infrastructure, requires concerted efforts from both the public and private sectors. Collaborative initiatives to incentivize local manufacturing, promote financial assistance for vehicle purchases and expand the charging network are essential to drive the widespread adoption of electric vehicles across the country. Additionally, Mexico must prioritize the development of renewable energy sources to meet the growing demand for electricity in the transportation sector while also ensuring the responsible handling and recycling of batteries to minimize environmental impacts. In parallel, education and training programs tailored to the needs of the electromobility industry can play a pivotal role in nurturing a skilled workforce and fostering innovation in Mexico's automotive sector. By addressing these challenges and seizing the opportunities presented by electromobility, Mexico can pave the way towards a more sustainable and resilient transportation system, contributing to the country's long-term economic prosperity and environmental well-being.

7. Conclusions

This study identified that Mexico still does not have a well-defined National Electric Mobility Strategy due to it being under review. Therefore, there is a considerable lag compared to the main electromobility markets. Notwithstanding this, Mexico shows partial progress in the production and export of EVs, installation of charging points, incentives, tariff reduction and implementation of electromobility projects. The evidence from this study indicates that there is a lack of strategies for approving chargers, training and training staff specialising in EVs, handling and destination of batteries, and strengthening of the strategies of the incentives for both the industry and the user, as well as a lack of the creation of a legal framework for the use, maintenance, installation and planning of charging points. The study is limited by the lack of information on electromobility in Mexico; notwithstanding these limitations, the study suggests comparing the electromobility strategies of other countries and understanding the key aspects that might enable the successful introduction of electric vehicles.

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Abbreviations

In this section, we show the acronyms used in the paper.

AAVEA	Argentine Association of Electric and Alternative Vehicles
ABRAVEI	Brazilian Association of Owners of Innovative Electric Vehicles
ABVE	Brazilian Association of Electric Vehicles
AEDADE	Association of Automotive Companies of Ecuador
AMAVe	Mexican Association of Vehicle Rental Companies
AMIA	Mexican Association of the Automotive Industry
ANCE	Association for Standardization and Certification
ANETA	Automobile Club of Ecuador
ANPACT	National Association of Bus, Truck and Tractor Producers
ANVES	National Association of Electric and Sustainable Vehicles
AVEC	Electric Vehicle Association of Chile
BANOBRAS	National Bank of Public Works and Services
BRT	Bus rapid transit
CAME	Megapolis Environmental Commission
CANAME	National Chamber of Electrical Manufacturing
CFE	Federal Electricity Commission
CMNUCC	United Nations Framework Convention on Climate Change
CONAHCYT	National Council of Humanities, Sciences and Technologies
CONANCE	ANCE Standardization Committee
CONUEE	National Commission for the Efficient Use of Energy
COP-21	21st Conference of the Parties
COSON	Sonora College
DAC	High consumption domestic rate
ENME	National Electric Mobility Strategy
ENVY	National Housing Survey
EV	Electric Vehicle
GDP	Gross Domestic Product
GEI	Greenhouse Gas Emissions
GHG	Greenhouse Gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLCC	General Law on Climate Change
HEV	Hybrid Electric Vehicle
ICA	International Copper Association
IVA	Value-Added Tax
IEA	International Energy Agency
IMT	Mexican Institute of Transportation
INECC	National Institute of Ecology and Climate Change
INEEL	National Institute of Electricity and Clean Energy
INEGI	National Institute of Statistic and Geography
IPN	National Polytechnic Institute
ISAN	New car tax
ISR	Income tax
KfW	Bank of Development of the State of the Federal Republic of Germany
LCC	Life-cycle cost
LPG	Liquid petroleum gas
Nafin	National Financial
NDCs	Nationally Determined Contributions
NOM	The Official Mexican Standard (Norma Oficial Mexicana)
ONG	Non-Governmental Organization.
PEII	Promotion of Electromobility through Investment in Recharging Infrastructure
PENUMA	United Nations Environment Program
PHEV	Plug Hybrid Electric Vehicle

PJ	Petajoules
RAIAVL	Administrative Registry of the Automotive Industry of Light Vehicles
SCT	Ministry of Communications and Transportation
SE	Ministry of Economy
SEMARNAT	Ministry of the Environment and Natural Resources
SENER	Ministry of Energy
SHCP	Ministry of Finance and Public Credit
SLCPs	Short-Lived Climate Pollutants
UN	United Nations Organization
UNAM	Autonomous University of Mexico
USMCA	United States–Mexico–Canada Agreement
WHO	World Health Organization
WRI	World Resources Institute

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