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E-mobility: Current & Future Trends

Abstract

The aim of this analysis is to synthesize recent academic research, to explore the complex interplay between electromobility, urban planning, environmental impact, and pursuit of carbon neutrality. This work will provide a comprehensive and analytical framework for e-mobility, with a focus on what its current state is in some counties and what needs be done to establish the electric trend further. It will also describe the main challenges of electric vehicles' supply chain and propose solutions to unlock the industry's full potential. Forthwith, the study intends to make a comparative analysis of lifecycle emissions from EVs as against conventional vehicles (CVs) along with their significant environmental benefits and challenges. The research also delves into the implications of EVs for urban planning and infrastructure, specifically highlighting the need as well as the planning requirements for changing infrastructure developments and integrating them in city designs. It further delves into the wider goal of realizing true carbon neutrality by addressing strategies for technological advancements, policy frameworks, and socio-economic considerations. It pinpoints current limitations and proposes the necessity of interdisciplinary approaches and innovations to green technology and policy. The paper delivers an instructive review on the various aspects of sustainable transportation and urban development in relation to global climate change mitigation measures.

Keywords: Electromobility, Urban Planning, Carbon Neutrality, Electric Vehicles, Sustainable Transportation, EV Supply Chain

List of Abbreviations

1. BEV - Battery Electric Vehicle
2. BIM - Building Information Modeling
3. CO2 - Carbon Dioxide
4. CV - Conventional Vehicle
5. C2G - Cradle-to-Grave
6. EPR - Extended Producer Responsibility
7. EV - Electric Vehicle
8. FCEV - Fuel Cell Electric Vehicle
9. GHG - Greenhouse Gas
10. HEV - Hybrid Electric Vehicle
11. ICE - Internal Combustion Engine
12. ICEV - Internal Combustion Engine Vehicle
13. IPCC - Intergovernmental Panel on Climate Change
14. LCA - Life Cycle Analysis
15. LCA - Life Cycle Assessment
16. OC - Opportunity Charging
17. OECD - Organization for Economic Co-operation and Development
18. OEM – Original Equipment Manufacturer
19. PHEV - Plug-in Hybrid Electric Vehicle
20. V2G - Vehicle-to-Grid

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Chapter 1. Introduction

1.1 Background and Rationale

The 21st century has, in fact, started with increased environmental concerns and the realization of the lack of sustainability of modern means of conveyance. The transport sector, based almost wholly on internal combustion engine (ICE) vehicles running on fossil fuels, accounts for a critical share of global greenhouse gas emissions and local air pollution. In order to stay in tune with the Net Zero Emissions (NZE) by 2050 target, CO2 emissions from the transport sector must fall by more than 3% annually, for every year up until 2030. This calls for a re-look at modes of transportation and fuel sources, with electromobility being a silver lining amidst it all. Electromobility refers to the use of electric vehicles (EVs) as a cleaner and more efficient means of transport that includes all-electric (battery-operated) as well as plug-in hybrid vehicles.

The underlying rationale for the switch to electromobility is manifold, embracing environmental, economic, and technological dimensions. From the environmental viewpoint, the need for change is patently clear: stemming the tide on climate change and improving air quality in urban areas. EVs may potentially reduce emissions related to global warming, especially when supplemented with renewable energy electricity. Economically, more so the potential for job creation in new technology driven sectors as well as the oil price volatility provides the impetus needed for countries to develop and adopt EV technologies. Technologically, battery, the motor and charging infrastructure improvements in terms of their reach and accessibility makes EVs more viable than what they ever have been before.

Environment wise, around 14% of the world's total greenhouse gas emissions come from just the transportation sector itself with passengers' cars being a major contributor (IEA, 2020). The shift to EVs can substantially reduce these emissions. Well-to-wheel assessment, which is an analysis of the life cycle emissions from the production of the fuel to the operating phase of the vehicle, generally indicates that EVs have a lower carbon footprint than the gasoline powered ICE vehicles even after considering the electricity generation (Hawkins et al., 2013). Since the electricity grid becomes greener with more of its sources becoming renewable, benefiting from the environment through the EVs, hence, increases consecutively.

Economy wise, oil prices have been proven to be very volatile in relation to economic planning as well as security. Energy diversification, that would result in electromobility, could ensure minimal dependency since at the other end, the fundamental cost of energy would not vary largely. The growth in the EV market could further stimulate employment in new economic segments such as battery production, manufacturing of new electric vehicles as well as the development and production of charging stations. The resulting challenges are, among others, driving the investments by governments and the private sector towards electromobility (Sierzchula et al., 2014). In addition, there needs to be a lower dependency on critical raw materials both for the sake of supply chain sustainability, resilience, and security and also for the sake of new battery materials' developments that continually surface.

On the technological front, a major stride has been made over time. Critical components like fossil fuels for lithium-ion batteries of EVs have become dramatically cheaper, thus improving EVs' price competitiveness against ICE vehicles (Nykvist & Nilsson, 2015). Concerns regarding its use, such as battery autonomy as well as the small number of charging spots have been adequately addressed through battery energy density improvement as well as advancements to battery management systems. In addition, with the help of fast charging technology and the building of corresponding infrastructure for it, EVs have become more suitable for daily use (Hardman et al., 2018).

On the other hand, the implementation of electromobility is not a straightforward process. The up-front cost of ownership of an EV, while declining, remains more expensive than that of a similar ICE vehicle. The availability and convenience of charging infrastructure, while increasing, is not yet on par with traditional refueling stations. Equally important environmental and social challenges, regarding the establishment of electric vehicles, include the impact on the oil industry, changes to the automotive workforce, and the requirement for huge new infrastructure investments.

Regardless of the challenges, the electromobility trend rises every year. The various countries' governments are formulating policies to boost EVs' adoption, like subsidies, tax incentives, and reforms regarding gas emissions. Further improvements to battery technology are made by increasing its capacity, thus, considered more reliable.

Concluding the above, the transition from internal combustion engines to electric ones, could be considered a step forward the carbon neutral objective as long as economic opportunities and technological advancements converge for this cause. The supply chain, in general, its last mile in specific, are all directly influenced by the steps taken to adopt electromobility and help the trend penetrate the sector as much as possible. The transportation sector in total requires an immediate eco-friendly turn which can only be achieved via rigid policy making, innovative technology and societal acceptance.

1.2 Aims and Objectives

The main purpose of this thesis into the field of electromobility will be to document the depth and breadth of transition from traditional ICE (internal combustion engine) vehicles to the new landscape of electric vehicles (EVs), and its general impact on the society, economy, and environment. This research aims to present a well-rounded analysis that will evaluate the current state of electromobility, assess its actual economic and environmental impact and make projections of the future trends. It also aims to identify the critical factors that prohibit its evolution and analyze supply chain's role in this process. The objectives set for achieving this aim are presented in a multidimensional view so as to portray the complexity of the new sector of electric cars, vans, trucks and buses.

1. Evaluating the current state of electromobility: The first objective is to evaluate the current condition of the electric vehicle industry in the world. This includes looking at the share of the market for EVs, the range of models available, and regional adoption rates of consumers. Examining the current state of electromobility today allows us, in a sense, to set the benchmark in order to project future trends and identify the key indicators to help steer and redirect electromobility to an even more progressively upward path. Studies such as the ones drafted by the International Energy Agency (IEA) provide an important source of information that help draw insight on global EV market trends and to realize the objective behind the electric vehicles' scope (IEA, 2020).

2. Assessing Economic Viability of EVs: Evaluating the economic parameters pertaining to EVs with relation to the conventional ICE vehicles is one of the major purposes of this thesis. Such considerations include a study for the total cost-of-ownership analysis taking into consideration acquisition cost, fuel consumption costs, maintenance and possible resale value. On the same note, governmental incentives such as subsidies also make for

a major aspect of the cost of electric vehicles, with regards to the effects they may have on the consumers' decision to go electric or not. Nykvist and Nilsson (2015) studies on the rapidly declining costs of electric vehicle battery packs reveal key economic aspects of EV adoption. The cost of batteries is also directly related to the supply chain challenges of battery production. Therefore, addressing these issues will help lower the cost even more.

3. Assessing Environmental Impacts and Benefits: One of the key objectives is assessing the environmental implications resulting in the need for a shift to electromobility. This includes an extensive analysis about the gases and the air pollution deriving from EVs during their production, their operation, and eventually their disposing of in the life-cycle of the products. There is, therefore, potential reduction in greenhouse gas emissions plus local air pollutants as an incentive for EV adoption. Comparative life cycle assessment of the environment, such as that performed by Hawkins et al. (2013), give a framework for considering the environmental tradeoffs of EVs use, relative to that of ICE vehicles.

4. Understanding Policy Frameworks and Regulatory Environments: Yet another critical objective is to be able to understand how the policy has played a major role either in fostering or hampering the adoption of EVs. This will entail understanding famous incentives, regulations, and policies that have been put to effect by the governments across the globe so as to encourage the use of EVs. It also has to be linked with its effectiveness in different socio-economic contexts.

5. Consider Infrastructure Development and Advancements in Technology: This would be one of the primary objectives, which is to consider the present as well as the future infrastructural requirements that have become critical elements toward successful establishment of EVs, especially the charging infrastructure involved. In addition, the research will delve into the progressively sustained developments in battery technology, electric drivetrains, and vehicle design. In this regard, it will be carried out with an objective to establish the technological challenges, as well as breakthroughs that could prove influential over the path in which electromobility evolves.

6. Future Trends Projection: This, further with the understanding obtained from the above objectives, aims at projecting the future trends of electromobility. This

encompasses designing several related scenarios with regards to various assumptions about progress of technology, development of policies, dynamics in markets, and behavior of consumers. In this backdrop, scenarios' analysis portrays the possible pathways towards an efficient transition to electromobility by concentrating on the factors that are likely to affect the pathways chosen.

Summarizing, these aims and objectives were outlined in order to provide full insight into the process of transition to electromobility, its current condition, and the future perspectives. With this analysis of the economic, environmental, technological, and policy dimensions of the EV transition, this work aims to generate some useful insights for community, policymakers, industry stakeholders, and the consumers. The ultimate goal is contributing to a deeper understanding of electromobility, the issue to regard strategy and decision for inspiring the future of transportation. After breaking down the current state of electric cars' sales, we will be able to see whether its penetration rate is satisfactory, whether battery electric vehicles as well as plug-in hybrid electric vehicles are here to stay, how we can improve their life cycle environmental impact and how can the industry's supply chain help towards this direction.

Automakers are surely directed to electromobility. Based on their own announcements, BMW Group estimates that, by 2030, 50% of its fleet sold will be electric, Volkswagen anticipates having 70% of its fleet sold in Europe by 2030 to be electric, and Volvo plans to sell solely electric cars within the same time frame. We will see whether these targets along with governmental policies can help electromobility progress even further, and what could be done to further support global decarbonization efforts.

1.3 Scope and Limitations

Defining the dimensions of the scope of such research and pointing out its limitations is fundamentally important in order to analyze the transition to electromobility.

The geographical coverage of the study will, by consequence, be formed by the global landscape of electromobility with particular regard to the leading regions in EV adoption which are Europe, North America, and parts of Asia, notably China. Despite the global perspective for this thesis, in-depth analysis should focus on specific countries or regions which are pioneers in the electromobility transition. Passenger vehicles represent the focus of electric transportation transitions as major contributors to the global vehicle markets. Though electric buses, trucks, and two-wheelers are mentioned, thorough analysis is reserved to passenger cars inclusive of all-electrics, battery and plug-in hybrid electric vehicles.

The market and economic analysis of EVs form the core research that includes their adoption rates, consumer behavior, as well as the economic viability of electric transportation. The evaluation would also stream down to the costs that customers would have to bear while owning the vehicles as well as the incentives put to force by governments. Part of the costs of electric vehicles are the complicated supply chains behind the production of batteries, an issue that is very present among automakers around the world. In addition, there is the objective of assessing the environmental impacts of EV adoption which are crucial to the shift towards electric, mainly focusing on greenhouse gas emissions and possible abatement of air pollution through a lifecycle assessment of EVs versus ICE vehicles. Therefore, it becomes important to gain understanding of the role of policy in driving electromobility; hence, with assessments and evaluations, the research will explore different government initiatives, regulations, and incentives made to promote EV adoption and develop the relative infrastructure. This work further touches on recent developments in EV technology - particularly batteries' systems, electric drivetrains and charging stations.

This research is also faced with a number of limitations. Lack of data availability is a major setback in electromobility research. The electric market is still young, only running in a few, mostly developed, countries and the real data available is limited. Market data, consumer tastes and relevant cost break-ups may not only be readily available for all areas but could also be outdated. Projections of future trends are somewhat uncertain and subject to each country’s government policies, grid infrastructure and other dynamic factors. An environmental lifecycle assessment is incomplete because it requires data on many levels of EV operation. While this study will try to provide a generalized assessment, the outcome varies widely due to the underlying suppositions and methodologies. Providing a detailed analysis for each region or country is beyond the scope of this research.

Moreover, the governments, their policies and rules may change due to political, social or economic reasons. While outlining the policy context, this study neither categorically expects or predicts future changes in the policy landscape that may affect electromobility. While accepting such limitations, the search develops a realistic approach and creates an opportunity for future studies to add information. Taking all difficulties into account, the thesis tries to shed light on transition to electromobility itself, its state, and perspectives of the future. Its ultimate goal, however, is to inform about the strategies and decisions that will shape the transportation of the future – and also about the economic, environmental, and technological nuances entailing the shift.

Chapter 2. Electromobility: An Overview

2.1 Definition and Types of Electric Vehicles (EVs)

2.1.1 Battery Electric Vehicles (BEVs)

Electromobility represents a meaningful shift in the transportation sector, moving from fossil fuels to more sustainable and creative mobility. There are, currently, three main types of electricity-powered vehicles, the hybrid electric (HEVs), the plug-in hybrid electric (PHEVs) and the pure electric or battery electric cars (BEVs), which have emerged as the cornerstone of the transportation electrification. BEVs are characterized by the complete reliance on electric power as the only mode of propulsion, compared to the other EV types that may use a combination of electric and traditional fuel sources (Sierzchula et al., 2014).

BEVs function by utilizing electricity drawn from high-capacity batteries, which power the electric motor as well as the other in car electronics. In short, there is no internal combustion, and this is part of the solution to significantly lower vehicle emissions and guide long-term sustainability. Electricity is typically generated by an on-board rechargeable battery pack. Charging the battery is made either at home, in standard electricity outlets or in outdoors' charging ports. Pure Electric Vehicles provide the opportunity to significantly decrease the harmful greenhouse gas emissions. Apart from this, however, battery electric cars also exhibit certain advantages in their performance, compared to gasoline vehicles. Due to their built-in high power battery packs that can drive electric motors with higher torque in lower vehicle speeds, the battery electric cars can be much quicker and accelerate a lot faster than the conventional internal combustion engine cars, without using transmission or clutch systems. Indeed, BEV energy efficiencies are far better than conventional vehicles since electric motors are capable of using over 75% of the battery's chemical energy to actual wheelwork unlike gasoline-powered engines that average an efficiency rate of only about 20% in their utilization of fuel (Ehsani et al., 2018).

Battery technology has come a long way. The new lithium-ion battery technology provides higher energy capacity, superior safety performance, and significantly longer lifespan compared to their former nickel-based battery, which had been problematic from the start (Nykvist & Nilsson, 2015). Despite these advancements, the driving range of BEVs is one of the most question-arising aspects. Whereas earlier versions had less range, recent technological developments have seen BEVs like the Tesla Model S and Chevrolet Bolt offering ranges well over 300miles with one single charge, hence making them increasingly preferable to an even broader range of consumers (Knupfer et al., 2020).

The environmental benefits are massive, firstly because BEVs do not produce any tailpipe emissions. However, the overall environmental impact is dependent on the electricity being used in charging the batteries. Comparatively, BEVs reduce greenhouse gas emissions considerably, especially in regions where electricity production is mainly from sustainable sources. Conversely, the environmental benefit associated with BEVs is marginalized in areas dominated by high coal or other fossil fuel use for power generation (Hawkins et al., 2013). While, however, the global energy mix gradually shifts towards renewables, BEVs too bear great potential to lead the route towards the minimization of transport emissions.

The environmental toll for using BEVs also has to do with the sustainability concerns regarding the batteries' supply chain. The EV supply chain is different than that of conventional vehicles in the sense that these cars are mechanically simpler with much fewer parts. An electric vehicle's most costly component is its battery, which requires key raw materials for its production. Upon their mining, the raw materials, primarily lithium, nickel and cobalt, are shipped to China, South Korea or Japan for refining, processing and finally their production. The mining practices of existing raw materials make the EV supply chain quite complicated, vulnerable, and costly. Nowadays, an electric vehicle's battery represents approximately 40% of the car's cost.

Regarding economic implications, much just like any other disruptive innovation, BEVs pose challenges as well as potential. A lot more so in the past, BEVs especially cost more than a comparable vehicle working on internal combustion engine, mainly because of the battery packs that were then quite expensive. This cost difference, nevertheless, is in decline due to the fact that technology improves and that economies of scale bring down battery prices even more (Nykvist & Nilsson, 2015).

The range of EVs has improved significantly in the past years. For example, the Nissan Leaf, a car that debuted on the roads 13 years ago, offered a mere third of the range that most electric vehicles offer now. To allow for this significant improvement in range, the average capacity of battery packs has increased dramatically. Moreover, the costs associated with driving a BEV are usually lower specifically regarding their fewer mechanical parts as well as inexpensive electricity relative to gasoline, a factor that often offsets the differences in purchase cost over the life of a vehicle (Breetz & Salon, 2018).

Governments around the world have realized the potential of BEVs in helping them meet their environmental and energy security goals and hence put in place several policy incentives to speed up the electrification of the car market. These include direct subsidies, tax exemptions as well as the development of energy grid infrastructure (Hardman et al., 2018). In fact, such policies have been key to growing the market penetration of BEVs, especially in countries such as Norway, China, and the USA where BEV sales have increased particularly due to incentives for electric vehicles among other similar measures (Mersky et al., 2016).

In conclusion, Pure Electric Vehicles form a critical part within the greater electromobility frame. Advancement in battery technologies, cultivating environmental consciousness, and facilitating governmental policies are driving the further advancement and adoption of these vehicles. However, while issues related to driving range, up-front costs and charging infrastructure remain, the path BEVs are on today points towards an ever-growing role in the push to make transportation environmentally friendly and efficient.

2.1.2 Plug-in Hybrid Electric Vehicles (PHEVs)

Plug-in Hybrid Electric Vehicles (PHEVs) are an indispensable transitional technology enroute towards a greater version of vehicle electrification and mitigation of the reliance on fossil fuels. Plug-In Hybrid vehicles are able to run on fossil fuels, on battery or on a combination of both. This bipolarity gives them small dependence on oil, increased fuel economy, thus, low greenhouse gas emissions, as well as better power efficiency and vehicle-to-grid (V2G) technology. PHEVs combine an internal combustion engine (ICE) with an electric motor, powered by a battery that can be recharged through an external source of electric power being plugged in at the charging point. This dual powertrain of a PHEV ,thus, makes it possible to operate either in electric mode, gasoline mode or a combination of the two for the greatest performance and efficiency through minimum modification of driving conditions and battery charge level (Ehsani et al., 2018).

The key distinction between PHEVs and their counterparts, the traditional hybrid electric vehicles (HEVs), is in the fact that PHEVs can actually recharge their battery banks from the grid. It would increase the electric-only driving range of PHEVs substantially, typically to between 20 to 50 miles depending on model and battery capacity. After its battery is depleted of charge, PHEVs operate similar to HEVs by drawing upon the internal combustion engine to power the vehicle and at the same time, recharge the battery hence eliminating range anxiety that characterizes pure electric vehicles (BEVs) (Axsen et al., 2015).

Compared to HEVs, plug-in hybrids may offer 35-65% reduction on greenhouse gases and 40-80% reduction on gasoline consumption (A. Poullikkas, 2014). Especially with regards to greenhouse gas emissions, plug-in hybrids biggest advantage is that, in case the electricity used to power the car comes from renewable energy sources, such as wind, solar or hydropower, then the vehicle’s emissions could be close to zero.

PHEVs provide a flexible solution to both consumers and policy makers who strive for reduced greenhouse gas emission and lowered consumption of fossil fuels. Outwardly, a PHEV can reduce the gasoline consumed and emissions produced by giving assistance to the average commuter vehicle through electricity from the grid for primarily the shorter trips that make up nearly all daily driving patterns. Moreover, where driving environments necessitate higher total distances altogether beyond the electric range, then the ICE ensures that PHEVs offer same convenience and range as conventional vehicles (Hardman et al., 2017).

From an economical aspect, PHEVs make a promising proposition. Rather more expensive than the conventional cars, however, if one takes into account government incentives, tax rebates as well as all the savings in operating costs, it can compensate the initial high price of the vehicle. These benefits may even be greater once taking into account the cost of electricity, a cost that is lower per mile than that of gasoline as well as the reduced maintenance costs of electric driving (Breetz & Salon, 2018).

However, PHEVs suffer some limitations and criticisms. The overall difference in the environmental advantage of PHEVs depends greatly on the source of electricity. In specific, if the car's battery uses fossil fuel electricity to re-charge, then the actual reduction of carbon emissions is not all that smaller. Additionally, due to the consumers' driving habits, real-world fuel economy and emissions that come from PHEVs can vary greatly, and those who drive frequently beyond the electric range may not fully feel all the benefits from this technology (Gnann et al., 2018).

Moreover, the future of PHEVs in the fast-paced automotive market is set to be under debate. The evolution of battery technology and the respective drop of acquisition cost improves the range and affordability of Battery Electric Vehicles. This increase in BEV sales could eat away from the share of Plug-In Hybrids. However, PHEVs are likely to remain aligned with the electrified future, especially in regions where the electric grid is not so developed or where the consumers need freedom and distance that comes with PHEVs (Sierzchula et al., 2014).

Summing up, Plug-in Hybrid Electric Vehicles represent a pragmatically flexible approach to the on-going concern of reducing emissions of the transport sector and dependence on fossil fuels. They offer a technological bridge that has the advantages of electric driving combined with the regular and comfortable driving range of gasoline and diesel vehicles. As the global community charts its course for a future with more sustainable transportation, PHEVs seem likely to remain a part of a much broader conversation – balancing high aspirations for the environment with the practical needs of consumers.

Ultimately, the role PHEVs play in the long-term transportation landscape will depend on a variety of factors such as the advent of technological advances to battery technologies, changes in consumer preferences, as well as the scale and approach of charge infrastructure buildout.

2.2 The Evolution of Electromobility

Electromobility, including all vehicles employing electric power for propulsion, has evolved almost entirely to its most advanced stage today in response to technological advancement and environmental consciousness.

Electric vehicles (EVs) have a history that dates back to the 19th century, but it was only from the late 1800s and early 1900s that the electric cars gained a relative popularity, mostly in the United States. At one point, they accounted for a third of all vehicles on the road. Early electric cars were valued for their quietness as well as for the fact that they didn't emit any form of gases. The discovery of large oil reserves, however, along with the advancement of internal combustion engine (ICE) vehicle technology all led to their mass production through Henry Ford who made gasoline cars less expensive and resulted in huge demand causing, thus, the decline of electric vehicles (Wakefield, 2018).

The oil crisis of the 1970s, however, provided an impetus for a shift of interest to the electric mobility with regards to independence from fossil fuels. However, by then, electric vehicles faced massive challenges. Among them were the low battery life, the inadequacies in power, as well as the insufficient infrastructure that hindered its scale within a large population (Mom, 2004). Despite those limitations, this was one important period in establishing foundations that would facilitate possible advancements surrounding electric vehicle technology.

One moment that marked the dynamic change in electromobility was the release of Toyota Prius back in 1997. The vehicle was known as one of the first hybrids available on mass markets, blending ICE to an electric motor. As such, it delivered hedge fuel economy and reduced harmful emissions within a comparison to traditional vehicles. Its success showed to other manufacturers that consumers are concerned with more sustainable options for their commute, prompting further investments by other manufacturers in electric vehicle technology (Sovacool & Hirsh, 2009).

In the advent of the 21st century, new and heightened concerns on climate change brought about bright new developments in battery technology especially with lithium-ion batteries that led the way for a new genre of fully electric vehicles. In 2008, Tesla Motors announced the production of the first electric vehicle to use lithium-ion battery cells and the first one to travel more than 200 miles per charge. This milestone became a clear indication of the change of public perception on electric vehicles (Schmuch et al., 2018).

In the following years, consumer interest and investments in electromobility grew bigger. Governments of various countries of the world realized and believed that electric vehicles offer a great means to reduce greenhouse gas emissions as well as to improve cities' air quality. Many countries introduced incentives, subsidies, and established electric vehicle regulations so as to help accelerate the adoption of electric vehicles. For example, in their summarizing of legislation and initiatives for reducing emissions from road transport, the European Union set ambitious policy goals for the reduction of vehicle gas emissions and countries such as Norway adopted aggressive strategies to promote electric vehicle penetration. This resulted in an increase in EV market share to up to 17% of new car sales (Figenbaum & Kolbenstvedt, 2016).

The evolution of electromobility does not end in passenger cars alone. Buses, trucks, bikes, scooters are targeted for electrification with a comprehensive approach on sustainable transportation. The development of quick charging stations and wireless charging technology makes it practical even for long-duration trips (Nykvist & Nilsson, 2015), will all but remove the range anxiety.

Even with this bright future, there are still impediments facing the electric vehicle industry. The potential environmental impacts of electric vehicles depend on the methods used for the generation of electricity, and remaining concerns are in relation to battery production and disposal. There are ongoing researches on battery technology and recycling with alternatives on clean energy sources that serve to improve the sustainability profile of electric vehicles (Hawkins et al., 2013).

Electromobility has been a complex process that is yet far from having reached an end or conclusion. Indeed, from some of the first electric carriages to luxury sporty, high-performance electric cars on our roads today, this path has been paved by technological innovations, environmental concerns, and a great deal of policy decisions. As we look ahead, the continued development in electromobility will play a key role in ushering in our future for transportation that is more sustainable and efficient.

Table 1: Evolution of Electromobility

Year	Milestone	Vehicle/Event	Significance
Early 1900s	Emergence of Electric Vehicles	Detroit Electric, Baker Electric	Representing some of the first widely used EVs, showcasing the early potential of electric mobility.
1970s	Oil Crisis	-	Highlighted the vulnerability of over-reliance on fossil fuels, renewing interest in alternative energy sources including electric vehicles.
1997	Introduction of the Toyota Prius	Toyota Prius	The world's first mass-produced hybrid vehicle, blending an ICE with an electric motor and battery.
2008	Modern Era of EVs Begins	Tesla Roadster	The first highway-legal electric vehicle to use lithium-ion battery cells and the first to travel more than 200 miles per charge, changing perceptions of EVs' performance and range.
Present Day	Diverse EV Market and Infrastructure	Various modern EVs, charging stations	A wide range of electric vehicles are available, with significant advancements in technology and a growing charging infrastructure.
Future Concept	Speculative Advances	Concept Art of Future EVs	Envisions the future of EVs with advanced technology like improved batteries, autonomous features, or innovative designs.

2.3 Key Drivers of Electromobility Adoption

The adoption of electromobility is a multi-dimensional project. The adoption of electromobility is the result of technological advancements, economic motivations, environmental concerns, and policy frameworks. The following discussion explores the drivers that shape consumers' behavior with regards to electromobility. In addition, they have influence over society of which the consumers are part.

Technological Advancements: The rapid progression of technology is a primary driver of electromobility. This includes battery technology improvements, where an increase in energy density, reduction of charging time, and extended lifetime of the batteries directly addressed the initial electric vehicle limitations under range anxiety and performance (Nykvist & Nilsson, 2015). Moreover, advancements in electric motors and power electronics have improved the efficiency and reliability of EVs. Besides, the incorporation of information technology to speak with all the features and its autonomous driving also adds to the appeal for EVs as a comfortable and sophisticated vehicle (Hardman et al., 2018).

Economic Factors: The economic factors tend to leave a greater impact on what consumers choose related to EV adoption. The overall total cost of ownership (TCO) for EVs will decrease due to falling battery prices and the inherent efficiency of electric powertrains. The higher upfront costs of EVs compared to other conventional vehicles keep reducing, thus, making the overall economic competitiveness of these vehicles increase, especially with respect to their lower operating and maintenance costs (Breetz & Salon, 2018). The other driving factor would be many incentives across the world in the form of subsidies, tax rebates, exemption from time to time provided by the various governments around the world, which further reduces economic barriers for EV adoption (Mersky et al., 2016).

Environmental Concerns: Another important driver is the increasing concerns regarding the environment, by the people and society. The alarming rate of climate change and the health impacts that emanate from air pollution associated with internal combustion engines force a reevaluation of transportation options – both personal and public. Electromobility promises cleaner and possibly zero tailpipe emissions, especially when combined with renewable energy sources. The environmental benefits that come with the use of EVs in terms of low gas emissions as well as improved air quality are never too far behind with respect to the growing desire among people as well as organizations to have highly sustainable practices (Hawkins et al., 2013).

Policy and Regulatory Frameworks: Government policies and regulatory framework govern their way in the rate of electromobility adoption. Policies such as emissions standards, fuel economy regulations, and EV mandates push automakers into investing in electric vehicle technology. The direct consumer incentives, for instance the purchase subsidies, tax exemptions, as well as access to carpool lanes all promote EVs, since these direct economic advantages make EVs more appealing and accessible to a broad group of consumers. Investing in charging infrastructure is vital as the lack of charging stations is one of the main challenges to overcome (Sierzchula et al., 2014).

Energy Security: Uncertainty regarding energy security and a need to lower dependence on imported oil have driven national strategies to electromobility. EVs present countries with a chance and opportunity to diversify energy sources in the transport sector more so for regions that have lots of untapped renewable energy. The countries can be more stable regarding energy and become self-reliant by shifting from other fuel sources to being employed for purposes of green transportation, once they switch to EVs (Sovacool & Axsen, 2018).

Market Dynamics and Customer Perception: Market dynamics, that is, new and established automakers getting into the EV race, increase competition, drive innovation, and reduce costs. High-profile companies such as Tesla have not only cladded advanced EV technology, but another remarkable fore-sightedness of the company has been to shift consumer perception towards making EVs synonymous with highly performing, innovative and prestigious automobiles. Visibility and social acceptance also increase consumer perception of EVs, as they are more visible and more accepted on the roads, more people see them and have their own experience with them (Egbue & Long, 2012).

In conclusion, there is a confluence of technological, economic, environmental, as well as social factors that drive the adoption of electromobility. With the advancing technology, reduced costs, and increased awareness of the people concerning the environment and the practicality of EVs, electromobility is likely to grow further in the future. In parallel with the market dynamics, government policies will further influence such transition and the velocity to which electromobility is embraced in due course worldwide.

Table 2: Key Drivers of Electromobility adoption

Driver	Description	Impact on Adoption	Key References
Technological Advancements	Improvements in battery technology, electric motors, and vehicle design	Enhances range, reduces cost, and improves the overall appeal of EVs	Nykvist & Nilsson, 2015; Hardman et al., 2018
Economic Factors	Total cost of ownership, falling battery prices, and government incentives	Makes EVs more financially attractive and competitive with traditional vehicles	Breetz & Salon, 2018; Mersky et al., 2016
Environmental Awareness	Concerns about climate change and air pollution	Encourages consumers and businesses to adopt EVs as a cleaner alternative	Hawkins et al., 2013
Policy and Regulatory Frameworks	Emissions standards, subsidies, and investment in infrastructure	Facilitates a more supportive environment for EV adoption through regulation and incentives	Sierzchula et al., 2014
Energy Security	Desire to reduce dependency on imported oil and diversify energy sources	Motivates national strategies and consumer behavior towards adopting Evs	Sovacool & Axsen, 2018
Market Dynamics and Consumer Perception	Entry of new automakers, competition, and changing public perceptions	Drives innovation, reduces costs, and influences social acceptance of Evs	Egbue & Long, 2012

Chapter 3. Market Penetration of Electric Vehicles

3.1 Global Trends in EV Sales

The growth of the global electric vehicles' (EVs) market in the last decade was unprecedented, despite the infrastructure impediments, despite the world pandemic. Ever since the first electric model to be mass produced in the late 1990's, the world witnessed a reshaping in the automotive world and prospective drivers were involved in a paradigmatic shift. This rise in the EVs sales is created by technology advancements, supportive policies by governments, increased concern for the environment, and changes in consumer behavior.

The EV supply chain diverges from that of traditional ICE vehicles in several aspects. While EVs boast mechanical simplicity with fewer components, their production poses greater technological complexities, presenting challenges for large-scale manufacturing. In the early 2010s, electric vehicles were a small market with only a limited model on road and tens of thousands in sales numbers around the world. All that started to change soon after battery prices dropped, technology improved, and all the more automakers entered the market. In global comparison, the number of electric vehicles that were sold worldwide, up until 2020, was barely 3 million. Along with the economic slump due to the COVID-19 pandemic, the EV market displayed a sustained growth that outpaced general car markets (IEA, 2021). Ever since 2020, however, in part the reason why sales went up for electrics, was that the number of models available increased by approximately 40%, giving consumers an option of a total of 370 models worldwide (Deloitte, 2021).

A critical driver of the effort to make EVs more competitive compared to internal combustion engine (ICE) vehicles has been the noteworthy drop in the cost of lithium-ion batteries which was and still is the most expensive component of EVs. In 2019, on average, the lithium-ion battery pack was estimated to have registered an approximate 87% cost reduction since the year 2010, and this trend is going to continue further (BloombergNEF, 2020).

China, Japan, and Korea dominate the EV battery market. Batteries for electric vehicles produced anywhere other than in these three countries make up for less than 3% of the global battery supply. Notably, China boasted 93 mega factories for batteries in 2020, a significant contrast to only four in the US.

Lithium-ion batteries are favored due to their lightweight, compact nature, and high energy storage capacity. The production of these batteries requires key raw materials such as lithium, nickel, and cobalt. Major producers of raw lithium include Australia, Chile, China, and Argentina. Nickel, cobalt, and other metal mining activities are concentrated in China, South Africa, Indonesia, and the Democratic Republic of Congo (DRC). The DRC alone produces over 70% of the world's cobalt, but there are many concerns regarding the labor conditions and working environments in the country, hence, prompting EV manufacturers to seek alternatives.

After mining and production, all raw materials are typically shipped to China, South Korea, or Japan for refinement, processing, and cathode and cell production before reaching the EV manufacturers. This part is the most critical part of the electric vehicles supply chain, its dependence, once again, on the eastern countries.

The growing demand for EV batteries, coupled with their concentrated production in Asia and sustainability concerns regarding mining practices, complicates the EV supply chain for automotive companies outside the continent, making it vulnerable and costly. Hence, EV manufacturers devise new strategies to secure supply and enhance sustainability, such as vertical integration, strategic alliances, local supply bases, and innovation in battery chemistry.

Tesla, for example, boasts one of the most vertically integrated supply chains in the automotive industry. With a commitment to accelerating sustainability, the company aims to expedite factory construction, increase EV production while maintaining affordability, establish its charging network, advance software engineering, mine and refine lithium in-house, and invest in battery innovation, manufacturing robotics, and automation, or as Elon Musk terms it, "Machines that make machines."

The government policies also play an important role in speeding EV adoption. Most of the countries have formed a number of incentives which lure consumers into adopting EVs by means of tax rebates and subsidies. They are also exempted from certain toll charges as well. Furthermore, certain jurisdictions have announced the upcoming prohibitions on the purchase of new ICE vehicles, thereby making it apparent that the era of their sale in the market nears an end (Sierzchula et al., 2014). This regulation scheme, coupled with charging infrastructure spending, has largely influenced consumer behavior and market dynamics.

Another driver that will further propel the EV market going forward is environmental concerns. With the increasing realization of climatic changes and their negative impacts, sustainability conscious consumers move towards alternative transport modes as a substitute for conventional vehicles. EVs, when combined with energy from renewable sources, promise an opportunity to decrease greenhouse gas emissions as well as local air pollution (Hawkins et al., 2013).

Consumer tastes and attitudes have also changed: everybody thinks positively and is sure that EVs are an equally efficient and eco-friendlier option. Part of that shift is due to the growing range of EVs on offer, with models now designed to cater to all needs and all sorts of budgets. Additionally, Tesla and its high-profile EVs have done wonders to promote the idea with high performance and state-of-the-art technology (Hardman et al., 2018).

Zooming in, major regional differences are noticed in the global EV market. With strong policy support along with consumer incentives, countries like Norway, Iceland and Sweden shall have the highest market share in electric cars. China, the largest car market globally, has been showing leadership in volume due to the considerable investment of EV production and infrastructure along with its supportive governments. In the United States, it is California which has the lead in adopting EVs, mainly due to the strict emission regulations and also due to the great number of incentives for the potential drivers (IEA, 2021).

Summing up, the global trend appears to remain upward for EV sales. According to its flagship Global EV Outlook 2021, the International Energy Agency (IEA) projects that by 2030, under current policy settings, the number of electric cars, buses, vans and heavy trucks on the road is projected to reach 145 million, in a scenario already compatible with the goals of the Paris Agreement - if governments accelerate efforts to reach international energy and climate goals, the number could be as high as 230 million cars by 2030 (IEA, 2021).

In conclusion, the EV market penetration is clearly a dynamic and fast changing phenomenon driven through a complex interplay of technological, economic, environmental, and policy factors. With technology around batteries continuing to evolve, with the costs shrinking and with all the more consumers recognizing the upside of owning EVs, electromobility is expected to grow considerably. Government policies will, however, continue to influence the speed and extent of this transition as well as market dynamics, which have been affecting adoption rates for EVs everywhere in the world.

3.2 Electromobility in Europe and the US

3.2.1 Europe’s Country-Specific EV Adoption Rates

Europe has been a major catalyst for the shift to electromobility, high electric vehicle (EV) adoption rates are reflected across most of the European countries. Such transition is due to supportive policy frameworks, as well as environmental considerations and grid infrastructure. However, its rate of adoption varies from one European country to another, depending on the country’s economic growth, its cultural mindset and also on each government’s will to reinforce the trend.

For example, Norway might as well be the global leader in terms of EV adoption. According to the latest data, EVs make over half of the total sales of new cars in the country. An adoption level as impressive as this is attributed to a very extensive range of incentives that include exemptions from paying taxes & tolls, and, among others, free parking as well. More so, the country's strong charging infrastructure and extensive eco-friendly attitude among its citizens also propel the electric vehicle adoption in Norway (Figenbaum & Kolbenstvedt, 2016).

Apart from Norway, leading countries like the Netherlands, Sweden, and Iceland also present an efficient EV penetration. The Netherlands have used aggressive policies setting a base to push EVs, such as benefits on tax and investments on the infrastructure of charging stations. In addition, it gives varied incentives like purchase subsidies and going fossil-fuel-free by 2045 targets, all of which have greatly aided customer behavior change (Mersky et al., 2016).

Among the European countries, Germany is the largest car market where EV adoption pace has been documented to be fast. The German government has presented diverse incentives, among which are a considerable purchase premium for EVs and the expansion of the charging stations’ infrastructure. By, thus, realizing the changing market dynamic, German automakers have also committed to electrifying further their fleets, pushing the market even more (Hildermeier & Villareal, 2019).

The United Kingdom documented a significant increase in EV sales, spurred both by lavish government incentives and also by an increasing awareness of the public concerning the environmental impact of ICE vehicles. Furthermore, the UK government announced a ban on the sale of new ICE vehicles as of 2030, which is sure to accelerate the electrification process (Hardman et al., 2018).

France and Italy, while lagging, have also documented a gradual slow increase in EV sales. France has an array of incentives in place, from a scrappage scheme of the older vehicles to a bonus system which results in rewards for EV purchases, while at the same time penalizing owners of high-emission vehicles. Adoption rates for EVs throughout Italy are generally low, but with signs of interest in smaller EVs and scooters as the respective urban centers continue to remain thickly populated. All sales, however, indicate a slow adoption rate compared to the northern neighbors (Gnann et al., 2018).

As for Eastern Europe, sales remain generally considerably low when compared to Western Europe. However, this begins to show signs of change with increasing investments in infrastructure and growing environmental awareness. Countries like Poland and Czech Republic are, now, slowly beginning to make room for policies for promoting electric vehicles (Petrus & Szewrański, 2018).

In sum, Europe offers a mixed landscape with respect to the adoption of electromobility. Countries like Norway and the Netherlands show the way as early adopters, while others follow due to the combination of policy stimulus, environmental concerns, and technological developments. The future of electromobility in Europe remains bright, backed up by government policies and by the commitment of industries who anticipate the adoption rate to grow further.

3.2.2 US - Adoption Rates and Market Trends

In America, electromobility has been developing, as witnessed by rising adoption rates and significant market trends reflective of increasing acceptance and demand of electric vehicles (EVs). It was there, after all, that the concept of electric vehicles was first developed around the late 1800's. Although the United States has not embraced EVs as fast as some of the European nations, preferences for consumers, governmental policies, and manufacturers' commitments have all shifted significantly over the years, thus, pushing the electric mobility adoption forward.

The EV adoption rates in the United States have been on a steady rising trend. During the early 2010s, EVs represented but a small portion of the total annual vehicles' sales. However, EVs currently account for a little over 7% of the new car market, with expectations for the number to grow further year-over-year due to the increase in models' range. (IEA, 2020). It has, thus, crossed the pivotal threshold of 5%, whereas analysts anticipate that by 2025 a quarter of all light duty vehicles sold will be electric (Taylor et al., 2021). California is a leader in this path, partly because of its aggressive incentive programs and tighter emissions' regulations but also because of the tendency of its culture to be more open towards new technologies and environmental social issues.

There are many market tendencies that have a great influence over EV adoption in the United States. Firstly, this is proved by a significant increase in the number of EV models available on the market, which no longer comprises solely of compact cars but also of SUVs and trucks, vehicles that are considerably more appealing to the American target group. Companies such as Tesla's have pioneered in this regard, but others, like General Motors, Ford, and Volkswagen, who are the traditional automakers, commit to electrifying their fleet and have pledged dozens of models to be rolling out on the roads in the upcoming years (Hardman et al., 2018).

Government policies, at both state and federal levels, have served to promote electric vehicles. In particular, governments at a federal level have offered tax credits for purchasers of EVs, although these commence to phase out once a manufacturer sells a certain amount of vehicles. In addition, some states offer different forms of incentives like rebates or tax credits while in others hybrid users gain the right to use carpool lanes. Finally, a number of states have special mandates known as Zero-Emission Vehicle (ZEV), where a certain percentage of 'clean' vehicles, either purely electric or hybrids, are required to be sold (Sierzchula et al., 2014).

Development and growth in charging infrastructure form part of key market trends. While lack of charging stations has been the bane for the adoption of EVs over range anxiety, this situation is slowly easing with more public charging stations and, in particular, with fast-charging stations being made available across the country. That keeps companies like Electrify America and EVgo busy expanding the nation's charging network to enable electric vehicles' owners to travel away from home (Graham-Rowe et al., 2012).

Concerns over the environment and increasing awareness of its degradation is also a factor favoring rise of interest in EVs. Many consumers view electric vehicles as low emitting, with potential environmental benefits, particularly if part of the electricity grid which powers the cars is fired up via renewable means.

However, there are still some challenges that should be taken into consideration. For example, even with incentives in effect, the purchasing cost of an EV is burdensome for some buyers. There's also the fact that the current charging infrastructure is still not nearly as present as regular gas stations, which turns off prospective buyers. Moreover, there is continuous need for technological advancements in the form of variation in models' range as well as battery autonomy.

Peeking into the future, one could estimate that America's EV market will continue to develop. Increased demand for stricter legislation around ICE vehicles, lower cost of EVs, and rising environmental consciousness should contribute to further penetration. This will also be bolstered by the commitment of automakers to electrify their vehicles and the development of the current charging infrastructure (Nicholas & Hall, 2018).

In short, even though the United States has not embraced EVs quite as fast as other countries, it is without doubt in an upward trend. The continued technological progressions, the supportive government policy as well as the slow and steady change of customer preferences means it will eventually, and to some level, turn to electromobility. As the country wrestles with environmental concerns, EVs will fill an increasingly important void in the American transportation board

3.3.1 Policy Frameworks and Incentives in Europe

The shift to electromobility in Europe is highly influenced by several policy packages and rewards. These are meant to facilitate the shift of consumers towards electric vehicles (EVs), as well as to facilitate the built of relative infrastructure, which would help alleviate greenhouse gas emissions and climate change. Both the European Union (EU) and the member states have put to force a combination of regulations, financial incentives, and supportive policies in order to help the electric vehicle market take off.

EU-Level Policies and Directives: A range of directives and policies at a European Union level has been adopted to promote electromobility. The EU strategy includes the average emissions of new vehicles sold, progressively limited to that currently defined by the regulation on CO2 emissions for new cars. This legislation aims to force automakers add more zero-emission vehicles, such as EVs, into their fleet to counterbalance and succeed in meeting the average target (European Commission, 2020).

Another significant type of EU legislation is Alternative Fuels Infrastructure Directive (AFID). It aims to develop a common framework of deployment of electric vehicle charging stations across Europe as an alternative fuel infrastructure. This clause, therefore, ensures public access to such charging points towards reducing 'range anxiety' and making EVs more appealing to buyers (European Parliament, 2014).

As far as national incentives and subsidies are concerned, individual European countries have also put into place various sorts of national incentives to speed the transition towards electric mobility. Norway, a non-EU country but closely aligned with EU policies, is a leader in EV adoption, in part because of its wide-ranged incentive scheme. Most taxes, such as value-added tax (VAT) and purchase taxes, are all waivered by the Norwegian government for electric vehicles, something that can significantly reduce the final cost. In addition, EV drivers, in certain municipalities, enjoy the benefits of paying reduced road tolls and receiving free access to bus lanes and parking spots (Figenbaum & Kolbenstvedt, 2016).

Among the incentive schemes put to force in Germany, within its National Platform for Electric Mobility, is the direct subsidy to electric vehicle purchases called the "Environmental Bonus." This is funded jointly by the government and the car industry.

Furthermore, Germany has put in place high standards regarding the development of charging infrastructures and intends to be among the main markets when referring to electric mobility (Kampman et al., 2016).

Norway: The Norwegian approach to EV incentives is one of the most aggressive ones. The respective governments of Norway have exempted electric vehicles from most of the taxes i.e., including value added taxation (VAT) and purchase taxes, that can significantly lower the overall cost. In addition, EV owners get discounted road tolls, some places get free parking for EVs, and others reward owners of electric cars with bus lane access. This part of the package is one of the reasons why Norway has per capita globally the highest number of electric cars (Figenbaum & Kolbenstvedt, 2016).

France and the Netherlands: France uses a bonus system to reward the purchase of electric vehicles, while high-emission car owners get taxed through a malus. The Netherlands cuts registration tax for EV owners and benefits corporate tax concerning the use of these vehicles.

The United Kingdom pledges, through its Road to Zero strategy, that by 2040 all new cars and vans will effectively become zero-emission. In the United Kingdom, the government offers a host of grants available to EV buyers as well as funding for the installation of charging stations around homes and workplaces. Additionally, the UK has suggested the development of a nationwide charging network (Department for Transport, 2018).

Far from Europe, in China, the world's largest car market (being one of the world’s most populated countries) has initiated a raft of measures to stimulate EV sales including subsidies, tax breaks and requirements for government fleets to buy EVs. The Chinese government also adopted a quota system that instructs the automakers to produce a vertain number of zero-emission vehicles. These measures such have been very critical in making China the world leader in EV market (Zhang et al., 2018).

Table 3: Subsidies and Incentives for Electric Cars Across Countries

Country	Type of Incentive	Details	Impact/Considerations
United States	Federal Tax Credit	Up to $7,500 tax credit for new EV purchases, phases out after 200,000 units sold per manufacturer.	Significant initial reduction in EV cost but diminishes over time as caps are reached.
Germany	Environmental Bonus	Subsidy for purchasing fully electric and plug-in hybrid vehicles.	Reduces the upfront cost, making EVs more competitive with ICE vehicles.
China	Subsidies and Quotas	Direct subsidies, tax exemptions, and quota system for zero-emission vehicles.	Has spurred rapid growth in the EV market, making China a global leader.
Norway	Tax Exemptions and Benefits	No purchase tax, reduced road tolls, access to bus lanes, free parking in some areas.	Has resulted in the highest per capita number of electric cars in the world.
United Kingdom	Plug-In Car Grant	Reduction in the price of an EV up to a certain cap.	Makes EVs more affordable, encouraging adoption.
France	Bonus-Malus System	Rewards the purchase of EVs with a bonus and penalizes high-emission vehicles with a tax.	Encourages consumers to choose lower-emission vehicles, boosting EV sales.
Netherlands	Tax Advantages	Reduction in registration tax and benefits for corporate EV users.	Makes EVs more attractive, especially for business use.

Table 4 below analyzes the tax benefits and incentives, currently in effect in some of the major European countries, with regards to commercial vehicles:

	Tax Benefits		Incentives	
	Acquisition	**Ownership**	**Purchase**	**Infrastructure**
FRANCE	Regions provide an exemption (either total or 50%) for BEVs, HEVs, CNGs, LPGs vehicles	-	Bonus for a new BEV or FCEV : 6.000€ for households if vehicle is less than 45.000€ and 4.000 € for legal persons if vehicle is less than 45.000€	-
	BEVs, FCEVs and PHEVs are exempt from the mass-based malus		Scrappage scheme for a second-hand or new zero emission vehicle (BEV or FCEV), based on their weight (up to 9.000€)	
GERMANY	-	10 year exemption for BEVs and FCEVs registered, until 2030	KsNI programme (till 2026) for the purchase of new commercial BEVs/ FCEVs vehicles	KsNI programme (till 2026) for electric charging & hydrogen tank infrastructure
		Exemption from the annual circulation tax fro vehicles emitting ≤ 95g CO2/km	For the retrofit of commercial vehicles into BEVs or FCEVs	80% of the expenditure for related projects
			Max €25milion per company, per year for vehicles, research & infrastructure (subsidised by 50%)	
ITALY	-	5 year exemption for BEVs. 75% reduction off the tax rate appilied on petrols, after that	Light Commercial Vehicles: 4.000€ - 6.000€ subsidy	-
		Minimum flat rate on HEVs	Commercial Vehicles: 12.000€ - 14.000€ subsidy	
		Some regions apply discounts on tax ownership		

`	Tax Benefits		Incentives	
	Acquisition	**Ownership**	**Purchase**	**Infrastructure**
SPAIN	Exemption from special tax for vehicles emitting ≤ 120g CO_2/km	Reduction of 75% for BEVs in the main cities (eg. Madrid, Barcelona, Zaragoza etc)	Incentive scheme (MOVES III):	Incentive scheme (MOVES III):
			7.000€ - 9.000€ subsidy on light commercial, plus 1.000€ discount from manufacturers	Self-employed, individnuals, communities & administration > 70% of the eligible
	Canary Islands: VAT exemption for electric vehicles emitting ≤ 110g CO_2/km		Bigger incentives for large companies	
			2.500€ - 25.000€ for scrappage of commercial vehicles (depending on type & Euro class	Companies & public charging > 35% - 55% of the eligible cost
			Incentives from 15.000€ - 190.000€, depending on type of vehicle and company size	
UK	-	-	Small Vans: Up to £2.500 discount	-
			Large Vans: Up to £ 5.000 discount	
			Trucks : Up to £16.000 discount	
ICELAND	tax rate 5% off the custom va	-	BEVs & HEVs: VAT waiver of up to 9.000€	VAT waiver on charging ports & their installation
			No VAT on the retail price, up to 36.000€. Full VAT beyond that	
			Special discount for BEV trucks	
SWEDEN	-	Low annual road tax for zero-emission light commercial vehicles & PHEVs	20% off the truck's purchase price for companies & municipalities	Grants for various types of charging infrastructure from the Environmental Protection Agency
			Premium for BEVs, PHEVs & FCEVs electric buses (up tp 14 passengers)	
			Premium 20% of the purchase price for public authorities or limited companies	Support for DC charging for business vehicles
			For transport companies, the premium is 40% of the diference with the respective diesel bus	
IRELAND	5.000€ relief for BEVs up to 40.000€. The relief tapers off beyond 40.000€ and ends at 50.000€	Minimum rate for BEVs	-	-
		Reduced rate for PHEVs ≤ 50g CO_2/km		
GREECE	0% registration tax for battery electric, plug-in hybdrid vans, lorries & trucks	-	Cashback 30% on the net retail price for BEV vans (up to 8.000€), plus 1.000€ for scrapping	-

City-Based EV Initiatives: Many cities have introduced low-emission zones, where only vehicles that meet strict emission standards can enter. For example, Paris plans to outlaw petrol and diesel cars from 2030 altogether, while London implemented an Ultra Low Emission Zone in which polluting cars pay a daily charge (City of Paris, 2017; Transport for London, n.d.).

Challenges and Future Directions: While such policies and incentives urged the EV adoption to great heights in Europe, challenges exist. The question-mark over the charging grid infrastructure, as well as the lower-yet-still-high prices lingers, and debate continues on how to best finance as well as incentivize the market.

Moreover, increasing market share for EVs poses implications that would require changing policies along with incentives on behalf of the governments, in order to sustain support without putting the financial burden on the public. This could involve a gradual phase-out of the unsubsidized direct purchase in favor of other modes of support, such as investment in charging infrastructure or supporting the costs of research and development of advanced automotive technologies (Hardman et al., 2018).

In conclusion, Europe & China have successfully utilized its policy frameworks and incentives towards the success of electric vehicles in the electromobility shift across the continent. These actions have not only allowed to increase the number of sales of EVs but also to help develop the required infrastructure and technology on which these vehicles run. As the market becomes more mature, these policies will have to be redefined and adjusted in order to maintain the growth of electric vehicle market on truck.

3.3.2 Federal and State-Level Policies (US)

The proliferation of electric vehicles (EVs) in the United States, to some extent, is dictated by the market but also hinged on federal as well as state level policies. These policies are formed primarily in order to promote the adaptation of EVs through a variety of incentives, regulations, infrastructure development initiatives. All is done in an attempt to mainly address the environmental concerns and to improve energy security, by reducing the dependency on fossil fuels.

Federal Policies: On the other hand, the United States' federal government has enacted a set of policies which help to promote the adoption of electric vehicles. One of the biggest incentives remains the federal tax credit for electric vehicles, which is a return up to $7,500 in tax credits for a new EV purchase. The sum of it all depends on the battery capacity. What this incentive does is to allow a larger number of consumers to afford EVs, in a financial aspect. However, one thing must be stated, that such credits are ceased for any manufacturer once they reach 200,000 electric vehicles sales (Congressional Research Service, 2020).

On the same note, the U.S. Department of Energy (DOE) supports the development of an EV market base by supporting R&D-initiatives. The Vehicle Technologies Office of the DOE ensures the high-level of funding for projects that aim at reducing costs and increasing efficiency of EVs or/& their batteries. In addition, the Alternative Fuel Data Center provides resources and tools essential to adopting alternative fuel vehicles, inclusive of EVs (U.S. Department of Energy, n.d.).

State-Level Policies: While the base of EV support lies on the federal government, several state-level policies play a pivotal role in determining the adoption rates across various states of the country. They have used a combination of incentives, regulations, and initiatives to boost use of electric cars.

California is a leader in environmental regulation and has some of the most comprehensive EV policies. The California Air Resources Board (CARB) oversees the Zero Emission Vehicle (ZEV) program to mandate automakers sell a pre-required number of zero-emission vehicles. In addition, the Advanced Clean Cars II (ACC II) regulation, which was adopted in 2022, requires that, by 2025, 35% of all vehicles' sales in the state of California should be electric, ramping the ratio up to 68% by 2030 and to 100% by 2035. This regulation, aggressive as it may be, is expected to be copied by other states in the following years, an event that is bound to put a great deal of pressure on automakers. Moreover, California provides a number of perks including Clean Vehicle Rebate Project (CVRP) and, also, allows EV drivers to use carpool lanes (California Air Resources Board, n.d.).

Initially launched in June 2018, the Clean Vehicle Assistance Program (CVAP) of California aims at assisting income-qualified Californians in acquiring new or pre-owned hybrid or battery electric vehicles (EVs) through grants. CVAP tackles obstacles to owning clean vehicles, including high initial costs, limited charging infrastructure access, and predatory auto loans. Approved applicants receive grants for clean vehicles, charging stations, and access to fair loans with an interest rate capped at eight percent, all of which are non-repayable. The program supports the acquisition of both new and pre-owned battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs). Depending on the applicant's income, they may qualify for a purchase grant of up to $5,000 and a charging grant of up to $2,000. The maximum qualifying income for an individual applicant is $51,520. By May 2022, the program had disbursed around $22 million in grant funds, facilitating the purchase of 4,330 vehicles, with 860 grants specifically benefiting residents of disadvantaged communities.

On the other hand, the Clean Cars 4 All (CC4A) Program assists low-income individuals in upgrading to cleaner vehicles. Eligible vehicle owners residing in designated zip codes with high pollution levels can exchange their vehicles for more efficient, lower-emission alternatives. As of November 30, 2021, CC4A has allocated $127 million, providing 11,338 grants, with 97 percent of the funds benefiting "priority populations" as outlined in the California Climate Investments 2022 Annual Report. Participants in CC4A can receive up to $9,500 in grant funding toward the purchase of a new or pre-owned EV. Alternatively, they have the option to choose up to $7,500 in incentives for accessing other mobility alternatives such as public transit passes or electric bicycles.

Following California's example, nine states, among which are New York, Maryland and Oregon have embraced the ZEV program, thereby, developing a fruitful market for electric vehicles. Furthermore, additional incentives are extended in many states, including tax credits, reduced vehicle registration fees, and grants to install charging stations (National Conference of State Legislatures, 2021).

Challenges and Considerations: The favoring policies have enabled EV technologies broadly, though associated with certain challenges. A major concern is the consistency of the incentives. As the EV market expands and state and federal budgets are strained, the length and number of financial incentives will naturally be a point of debate. Promoting EV sales and maintaining fiscal balance could prove to be a challenge.

Infrastructure development is undoubtedly another vital area. Incentives might increase the number of electric vehicles purchased, but without provision for adequate charging stations or, even, difficulties in charging could influence the decision to go electric. This underscores the need for both federal and state policies to back charging infrastructure expansion in tandem with the increase in EVs. State fundings for deployment of charging infrastructure (maintenance & strategic interconnection), additional fundings to support research on battery processing and manufacturing as well as new research on critical minerals mining and recycling are only some of the federal acts on route to promote the scope. Finally, the current administration by Joe Biden set target to install 500.000 charging stations in the country by 2030.

Going Forward: As the United States continues its journey towards sustainable transport, so will the evolution of federal and state policies. The focus may shift from incentives for the purchase of the vehicles themselves, towards broader initiatives that sustain infrastructure development, the grid's modernization, and public transport electrification. The development of a broadened effective policy framework will be driven by collaborative efforts among federal, state, and local governments together with partnerships between public and private entities for the support of long-term electromobility growth.

In conclusion, federal and state-level policies are paramount to ensure that the electromobility landscape is adequately shaped in America. Interventions by institutions and cautionary use of the incentives will strive to deal with environmental issues, automatically reducing overreliance on fossil fuels and encouraging the society to embrace electromobility. As the market continues to evolve, so will the policies, reflecting the changing needs and the priorities of society.

Chapter 4. Economic aspect of Electromobility

4.1 Latest EV Sales in Europe

According to the European Automobile Manufacturers’ Association (ACEA), EV sales in Europe went up by 13,9% in 2023. Car registrations increased by a total of 10.545.716, thus making it a good year, in terms of electromobility penetrating the diesel market. If one adds the EFTA & UK registrations as well then, the 2023 actual EV sales rise sums to almost 13.000.000 cars and the increase rate compared to the previous year would be 17%.

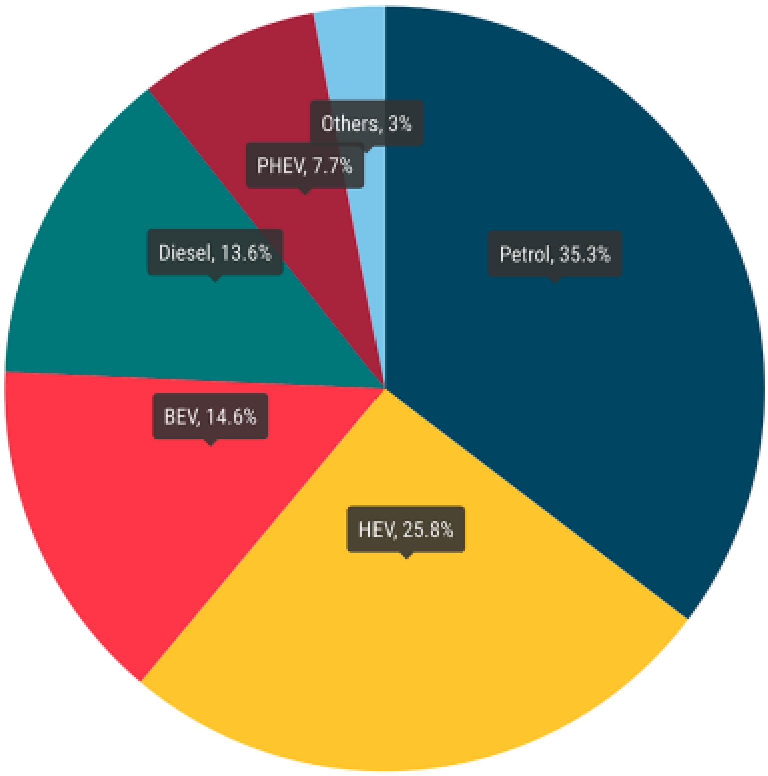
Almost in every European country, people purchased more electric cars in 2023 than in the year before. The markets with the biggest EV sales increase were Bulgaria (+31,5%), Croatia (+31,3%), and Belgium (+30,1%) followed by Greece (+27,7%), Portugal (+26,8%) and Cyprus (+26,7%). The three countries in Europe with the biggest cars sales saw a two-digit increase as well, Italy by 18,9%, Spain by 16,7% and France by 16,1%. United Kingdom, even though it is an independent market within the broader European region now, also raised its EV sales by 18%.

The country within Europe with the biggest drop in EV sales in the year that passed was Norway, where electric vehicles' sales shrunk by 27%.

Greece experienced a great year in terms of electromobility. 105.000 cars' sales in 2022 climbed to 135.000 cars' sales in 2023. The best-selling brands in Greece were Toyota, once again in the lead, followed by Opel, Peugeot, Hyundai and Citroen/DS.

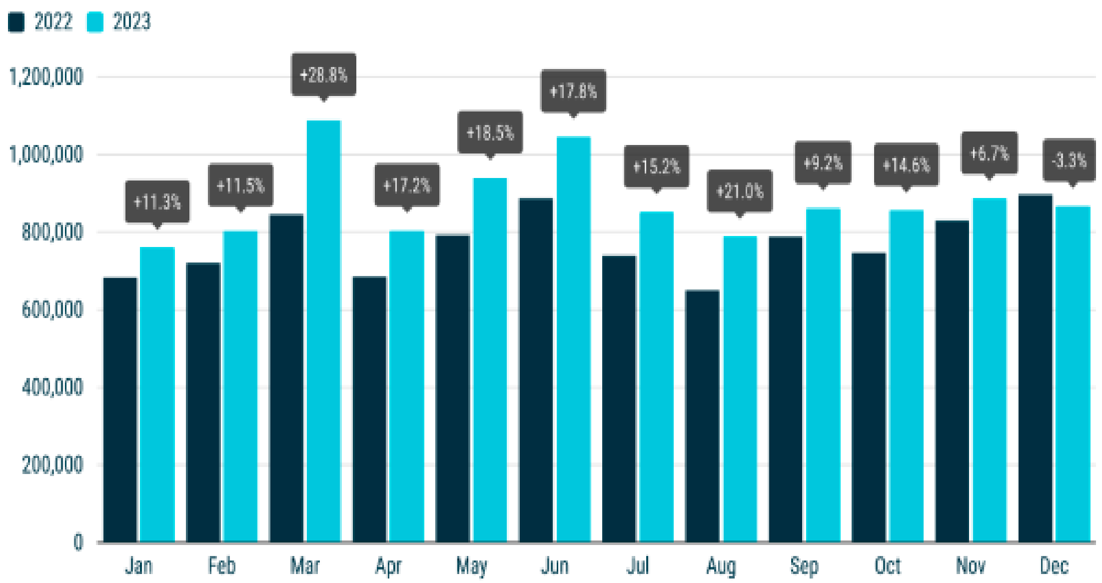
The share for battery electric cars in the European market, for 2023, was 14,6%. Research has shown that, in order for the EV market to be viable, its share in the market needs to exceed 5%, a minimum level therefore met. The biggest share, as always, was the petrol cars followed by the hybrid electrics.

Table 5: EU's new cars' % market share, based on power source (2023) :



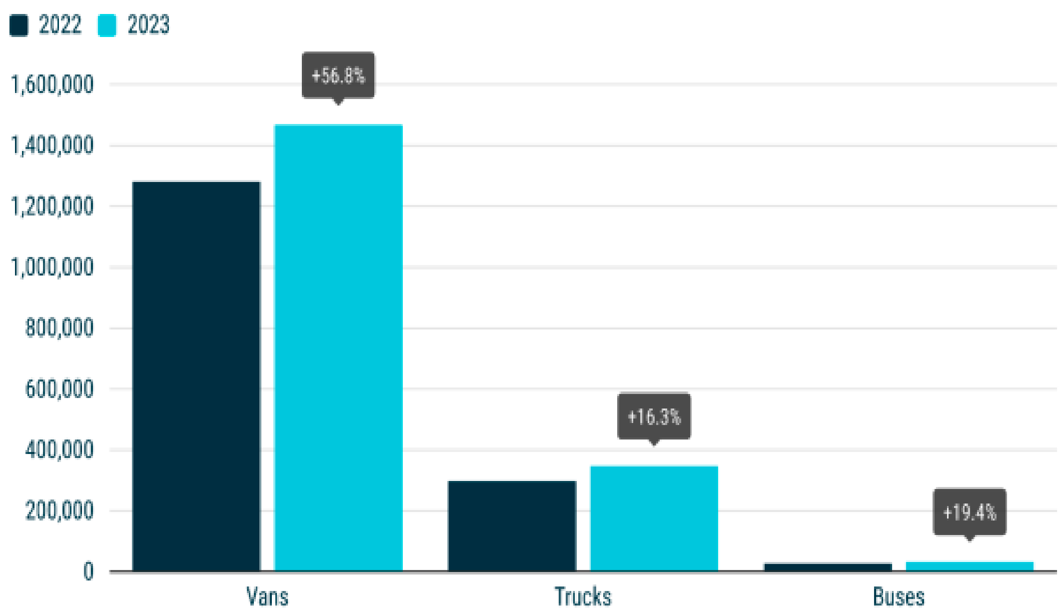
Data source ECEA

Table 6 : EU's car market share, by power source, in the last 2 years (based on new cars' registrations):



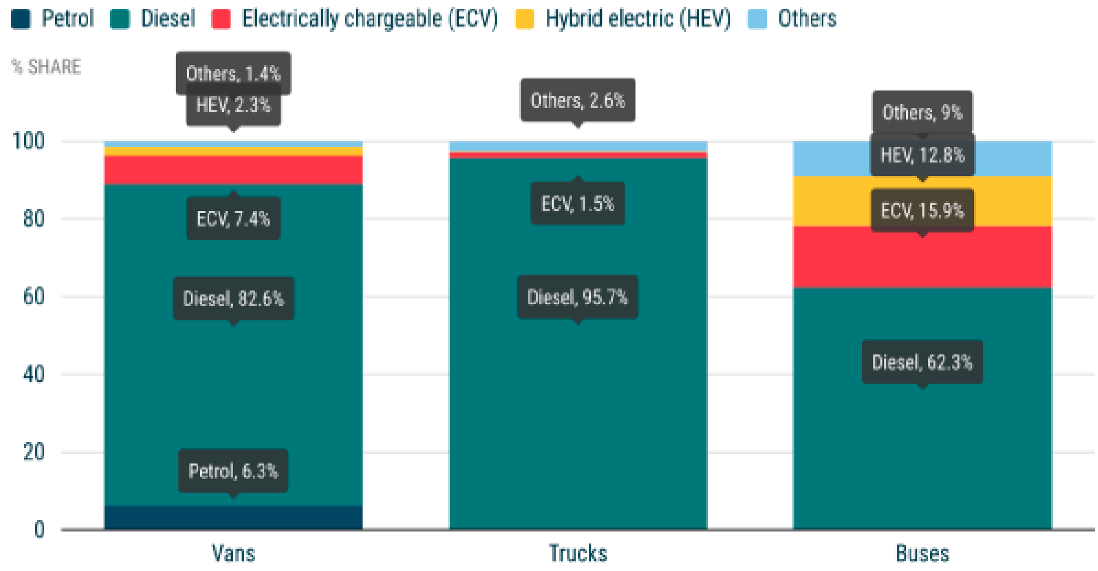
Data source ECEA

Table 7: EU's commercial vehicles' market share by power source of the last 2 years (based on new commercial vehicle registrations):



Data source ECEA

Table 8: EU's commercial vehicles' % market share, based on power source (2023):



Data source ECEA

4.2 Cost Comparison: Electric vs. Diesel Vehicles

Economic considerations are at the center of understanding and making electromobility viable. Particularly common is the comparison between the cost of electric vehicle (EV) relative to its diesel counterpart. This comparison refers initially to the purchase price, but also to the total cost of ownership (TCO) including the fuel costs, maintenance costs, taxes, and depreciation over the planned life of the vehicle.

Upfront Purchase Price: Over time, EV's compared historically to diesel vehicles have had a higher upfront purchase price. This has mostly been due to the cost of the battery, the most expensive component in an EV. However, the gap in purchase price has shrunk over recent years. In effect, the price of lithium-ion batteries - which are used to power a typical modern EV - dropped by approximately 87% between 2010 and 2019 (BloombergNEF, 2019). With the further evolution of battery technology and its bigger production toward economies of scale, the upfront cost of EV is nowadays quite close to the level of diesel vehicles.

Fuel Costs: One of the key advantages of EVs is the economic benefit of its electric charge at costs much less to that of diesel fuels. On an average per-mile basis, cost 'fueling' EVs usually runs far lower than which run with diesel. Actual saving amounts are dependent on local electricity rates and diesel fuel prices; however, in many cases, the cost to charge an EV can be less than half the cost to refuel a comparable diesel vehicle. Moreover, better access to residential solar installations and other renewable sources of energy has seen some EV owners offset these cost elements (U.S. Department of Energy, 2020).

Maintenance Costs: Maintenance costs for diesel vehicles, in general, tend to be higher than those equated to EVs. They have fewer parts and hence require a low number of oil changes, timing belt replacements or other routine maintenance checks that come with internal combustion engines. Electric vehicles feature regenerative breaking systems which translate to slower wear of brakes. In reality, EVs have been found to offer 30% lower maintenance cost over the life of the vehicle as compared to conventional ICE vehicles (Ma et al., 2017).

It is safe to say, given the above-mentioned info that comparing economic data between petrol and electric vehicles is an ambiguous task. Apart from the everyday operational costs of a vehicle, there are also the upfront purchase costs, the cost of domestic charging port, its insurance and maintenance. Additionally, comparing data among different countries becomes more complex due to the varied electricity tariffs, the availability in car models and the charging infrastructure. However, using an “average” petrol and an “average” electric car, an analysis was carried out by Gulf Oil to draw info regarding cost per 100 miles in 33 different countries of the world. The price of petrol is based on Global Petrol Prices.

EV vs Petrol Price Index - Cost / 100 miles			
COUNTRY	**PETROL (€)**	**EV (€)**	**COST SAVINGS**
ARGENTINA	8,58	0,70	7,88
AUSTRALIA	9,95	5,22	4,74
AUSTRIA	16,03	15,26	0,77
BELGIUM	17,50	14,29	3,21
BULGARIA	13,12	3,04	10,08
CANADA	12,40	2,68	9,73
CHINA	10,35	1,62	8,73
CYPRUS	14,79	8,06	6,72
CZECH REPUBLIC	15,82	9,99	5,83
DENMARK	19,52	13,81	5,71
FINLAND	18,97	8,12	10,85
FRANCE	18,34	4,86	13,49
GERMANY	18,15	13,53	4,61
HUNGARY	15,94	2,54	13,40
ICELAND	21,23	3,35	17,89
INDIA	11,45	1,67	9,78
IRELAND	16,60	13,23	3,38
ITALY	18,86	17,24	1,62
JAPAN	11,26	5,39	5,87
NETHERLANDS	19,96	11,41	8,55
NEW ZEALAND	16,19	4,10	12,09
NORWAY	19,89	4,13	15,76
PAKISTAN	8,12	1,14	6,98
POLAND	14,74	4,41	10,33
QATAR	5,21	0,67	4,54
ROMANIA	13,72	3,88	9,84
SPAIN	16,16	6,67	9,50
SWEDEN	17,22	9,71	7,51
SWITZERLAND	19,04	7,48	11,56
TURKEY	11,40	1,73	9,67
UNITED ARAB EMIRATES	7,10	1,70	5,39
UNITED KINGDOM	16,79	10,80	5,99
UNITED STATES	9,27	3,71	5,56

Data source GulfOilLtd

Residual Value and Depreciation: Another important aspect of the TCO (Total Cost of Ownership) is the residual value of a vehicle after the utilization tenure. Previously, EVs recorded higher depreciation rate than diesel vehicles, in part reflecting the rapid pace of technological changes and concerns over battery life. However, as technology matures and consumer confidence develops, the differential in depreciation rates is now narrowing. Furthermore, because environmental concerns urge regulators to tighten rules on diesel vehicles, these residual values could be hit (Ellingsen et al., 2016).

Externalities and social costs: In addition to electric vehicles, diesel vehicles face a key issue from an economic aspect, which is not a part of the TCO through the individual owners, but certainly based on the externalities and the social costs. Diesel vehicles emit pollutants that contribute to poor air quality and have associated health costs. On the other hand, EVs more so when powered from renewable energy, have much lowered emissions with respectively limited associated health and environmental costs. These are often the factors that design the policies and incentives by governments regarding vehicle electrification.

In brief, regardless of the older high costs of EVs against diesel vehicles, the cost gaps are closing due to the progression of battery technology and the benefits that associate with economies of scale. Using the cost of fuel, the cost of maintenance, and the incentives offered to get the total cost of ownership, EVs are becoming not just a sustainable option but also a cheaper one. The most important factor for most households when buying a car is economic, and, in that note, the case for electric vehicle options will strengthen in the future.

Table 9: Economic Comparison of Electric vs. Diesel Vehicles

Cost Factor	Electric Vehicles	Diesel Vehicles	Notes/Considerations
Initial Purchase Price	Generally higher due to battery costs but decreasing with technology advances.	Lower, but may increase due to stricter emissions regulations.	Battery costs are a significant factor for EVs but are decreasing over time.
Fuel Costs	Lower per mile due to cheaper electricity rates.	Higher due to the cost of diesel fuel.	Savings depend on local electricity and diesel prices. Renewable energy can further reduce EV costs.
Maintenance Costs	Typically, lower due to fewer moving parts and less wear on brakes.	Higher due to regular maintenance like oil changes and more mechanical components.	EVs require less frequent and less costly maintenance.
Taxes and Incentives	Various incentives like tax credits and rebates are available. Subject to phase-out after manufacturer sells a certain number of vehicles.	May face higher taxes in some regions due to environmental impact.	Incentives for EVs can significantly reduce the effective purchase price but vary by location and over time.
Residual Value and Depreciation	Historically higher depreciation but improving as technology matures and market expands.	Depreciation affected by market demand and regulatory pressures on emissions.	The resale value of EVs is improving as market acceptance grows and concerns about battery life are addressed.
Externalities and Social Costs	Lower emissions and associated health and environmental costs, especially when charged from renewable sources.	Higher emissions leading to air quality and health issues, resulting in societal costs.	While not part of direct TCO, these factors influence policy and societal preferences.

4.3 The Economic Viability of Electromobility

It is crucial to understand the economic implications of a transition into electric transportation as countries try to put effort to reduce greenhouse gas emissions in the bid to combat climate change.

Initial Costs and Total Cost of Ownership: Original acquisition cost of electric vehicle was and still is greater than that of a conventional ICE car. Recent research, however, indicates that this gap is shrinking. From 2010 to 2019, battery prices fell about 87%, and it is expected to drop further (BloombergNEF, 2019). In an important milestone for EV adoption called 'price parity,' the upfront cost of EVs is expected to be on par with ICE vehicles 'in the next few years.'

Adding in the total cost of ownership (TCO) - maintenance, fuel cost, and depreciation - makes EV even 'more price effective.' Electricity is, in general, cheaper than the per-mile-equivalent of gasoline or diesel, and a smaller number of parts on EVs mean fewer things to maintain apart from the natural wear-and-tear items: tires and brakes (Palmer et al., 2018). Government incentives, where available, can further amplify the economic viability of EVs for consumers (Palmer et al., 2018).

Infrastructure and Energy Costs: The availability and cost of charging infrastructure are also critical in the viability of electromobility. Investment in public and private charging stations is vast. Both the governments and private entities take significant steps to expand the grid. Another factor is the cost related to electricity, the EV's primary "fuel." Favorable compared to gasoline at present, the increase in demand caused by the further adoption of electric cars could result to electricity pricing structure adjustments (Bunsen et al., 2018).

Indirect Economic Pros: The indirect advantages of electromobility also need to be counted for the economic valuation of electromobility. ICE vehicles cause enormous emissions that lead to health issues & environmental degradation. The use of EVs can enable substantial savings brought in by the reduced healthcare costs that would otherwise be required to deal with major respiratory or other health issues caused from carbon emissions. (Holland et al., 2016).

Job Market and Transformation of Industry: The changes brought by the electromobility effect have a serious impact on industries and their corresponding jobs. It is a fact that job opportunities might be lost from the internal combustion engine industries, anything that has to do with building it or maintaining it. However, new job opportunities might be created from the automobile battery industry, anything that has to do with its raw materials sourcing, its assembling, or its end-of-life use (ex. recycling). The net employment effect is specific to the region in question and depends on the policies adopted and on the supporting actions with regard to workforce transitions (Hardman et al., 2018).

Market Dynamics and Consumer Behavior: The cornerstone for each product's economic viability is consumer acceptance. Only to the extent that battery technology sees continuous improvement and its costs decline while addressing range anxiety and charging time concerns, EVs will be more acceptable to a large part of the population. Now, the variety of EV model options expands to include SUVs and trucks as well.

Policy Influence and Future Trends: Governments' policies enable the viability of electromobility. In fact, the subsidies, tax incentives and regulations can seriously mold EVs TCO and market dynamics. Once the market is more mature and the costs of technology start to decay, these policies would possibly change their focus from direct consumer incentives towards the support for infrastructures or research & development.

All in all, the economic viability of electromobility shifts to positive signs as technology advances, costs decrease, and societal and governmental forces direct towards sustainability. Although challenges still exist, particularly in developing infrastructure and transforming industry, the potential economic, environment, and health benefits are very compelling reasons to continue expanding electric transportation. In conclusion, with the development of the market, constant reevaluation of an economic landscape is essential in order to know and take advantage of benefits from electromobility.

Table 10: Economic Viability of Electromobility

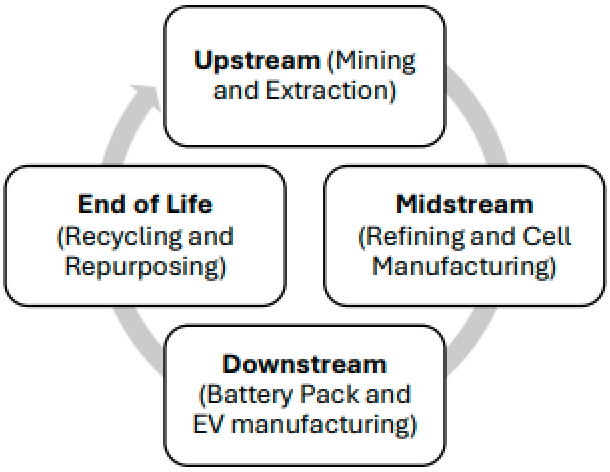
Aspect	Details	Impact on Economic Viability	Key References
Initial Costs	High upfront cost due to battery technology, decreasing over time.	Initially a barrier, becoming less so as battery costs decrease.	BloombergNEF, 2019
Total Cost of Ownership (TCO)	Includes maintenance, fuel costs, and depreciation. EVs generally have lower TCO due to cheaper 'fuel' and reduced maintenance.	Improves the long-term economic case for EVs.	Palmer et al., 2018
Infrastructure Costs	Investment in charging infrastructure is necessary.	A significant upfront cost, but essential for widespread adoption.	Bunsen et al., 2018
Economic and Environmental Externalities	Reduced emissions lead to lower healthcare costs and environmental damage.	Societal savings improve the overall economic viability of EVs.	Holland et al., 2016
Job Market and Industry Transformation	Shift from industries related to ICE vehicles to those associated with EVs.	Could result in job displacement but also new opportunities in emerging sectors.	Hardman et al., 2018
Market Dynamics and Consumer Behavior	Consumer acceptance is influenced by the variety of EV models, cost, and practicality.	Critical for widespread adoption; positive trends as technology improves and variety increases.	Hardman et al., 2018
Policy Influence	Subsidies, tax incentives, and regulations impact the TCO and market dynamics of EVs.	Government policies can significantly accelerate adoption and economic viability.	Palmer et al., 2018

Chapter 5. EV Battery Supply Chain, Technology & Economics

5.1 EV Battery Supply Chain

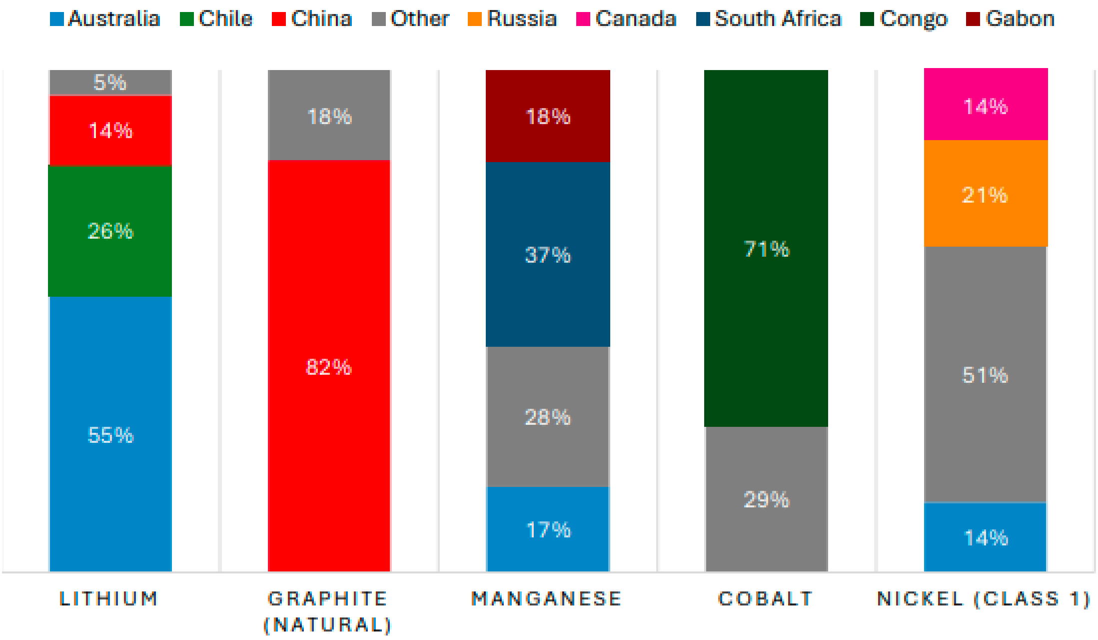
Electric vehicles' batteries rely for their production on minerals, much more than conventional vehicles rely on fossil fuels. Extraction of the minerals needed for their production may take place elsewhere in the world than where they are refined or manufactured. In addition, the battery manufacturing supply chain comprises of three main parts, which are the cell manufacturing, the module manufacturing, and the pack assembly. Each of these 3 stages can be conducted in the same or even in totally different locations. The supply chain of EV batteries, therefore, is, up to date, a very complex and, consequently, volatile industry that, as the years progress and the EV market reaches its demand climax, will require ameliorations.

Table 11. The EV battery life cycle



Below table shows the counties where the minerals required to produce electric vehicles' batteries are in high concentration.

Table 12: Critical minerals' countries' concentration



Data source: USGS & McKinsey

Analysis from the International Energy Agency stated that in 2022 the cost of critical minerals increased significantly. Cobalt and lithium doubled their price since the year before. Surging demand for electric vehicles as well as the challenges of the supply chain, tend to push the costs of minerals even higher. Relying continuously on foreign sources for minerals crucial to electric vehicles (EVs) has significant implications. The uneven distribution of these minerals has a big impact on the EV battery industry. In 2021, China acquired nearly half of all new lithium resources, aiming to dominate the rapidly growing critical minerals' market. In addition, China leads in critical minerals processing. As per the info of the 100-Day Review by Executive Order 14017 in June 2021, China is the biggest processor of lithium carbonate into lithium hydroxide, cobalt into cobalt sulfate, uncoated spherical graphite, and manganese refining. Another significant consequence pertains to environmental sustainability and human rights, exemplified by cobalt, a vital component in long-range EV batteries. Currently, two-thirds of global cobalt supply originates from the Democratic Republic of the Congo (DRC), a country associated with documented human rights abuses and environmental harm. Consequently, the industry is exploring alternatives to this contentious metal.

On the cons side, EV battery supply chain is hard to assess, mainly because of the raw materials' uncertain factors, such as the reliance on Ni- and Co-based cathodes, the variety of mineral types, and ratios in batteries, as well as the lack of supporting policies. On the pros side, however, the supply chain industry of batteries is less vulnerable to disruptions compared to the one of fossil fuels. In case of a critical raw material supply chain interruption, the consumers will take much time to feel affected, as the life cycle of LIBs is relatively long. Fossil fuels require repetitive inputs onto the conventional cars, whereas the minerals of the batteries can be recycled and reused. So, technically, it is rather unlikely that there will ever be a worldwide supply crisis on the EV battery supply chain.

A stable supply chain is crucial for the sustainable development of lithium-ion batteries. Undisruptive and sustainable raw materials' supply chain is a prerequisite. Aligned with this idea is the recycling of used EV batteries.

5.2 Battery Life Cycle and Recycling

5.2.1 Current Recycling Practices

Battery recycling presents an opportunity to reduce reliance on virgin materials. Recycled EV batteries show promise in performance, with some techniques even yielding batteries outperforming those made from primary materials due to their unique microstructure. Given the high recycling rate of lead-acid batteries (around 99 %), there's potential for a profitable business case for scaling up recycling of other battery types with appropriate policy support and economic incentives.

Recycling of electric vehicle (EV) batteries, particularly based on lithium-ion battery (LIB) technology, has emerged as an important facet attached to the sustainable paradigm of the EV industry. Bassim and Siller's studies unveiled that technological innovations and advancements have guided contemporary practices, followed by environmental concerns, and economic considerations. Understanding these practices provides insights into the challenges and opportunities in the battery recycling sector.

In a publication by Makuza et al. (2021), the authors reviewed pyrometallurgical options for recycling spent LIBs providing a thorough view on thermal pretreatment methods employed in the recovery of active cathode material as well as an insight on extractive pyrometallurgical options for recycling. This aspect further highlights the need for effective recycling systems to handle a higher number of spent LIBs in a cradle-to-cradle manner.

Ali, Khan, and Pecht (2021) presented several methods of assessing reuse versus recycling. They analyzed the practices and commercial capabilities of battery recycling in the industry, as well as the ones recommended by worldwide research centers to provide potential novel next-generation recycling processes. Their proposition adds value to the notion of trading off economic benefits with environmental savings in Li-ion battery recycling.

Neumann et al. (2022) reviewed regulations and new battery directive demands covering current practices in material collection, sorting, transportation, handling, and recycling. The predictions present the challenges of future battery recycling processes, concerning battery components and their chemical composition with respect to the future approaches to battery recycling.

Pinegar and Smith (2019) reviewed current commercial-scale recycling processes and reusing applications of end-of-life LIB parts. They pointed out the need to recycle LIB material parts based on resource availability, additionally to current processes for recovering and recycling LIBs. The study underscores the importance of developing a robust recycling system to handle the growing number of end-of-life EV batteries.

Quijano-Ortiz and Seepersad (2022) analyzed a design for reusability and recyclability of EV batteries by using recommendations from published literature. Their work is vital in defining the tradeoffs between performance, economics, recycling, and reuse in battery design.

Meng et al. (2019) reviewed the lithium recovery process from minerals, brines and spent LIBs. In this review, they analyze the sustainability of lithium recycling from different sources, with a focus on the recycle-friendly cathode chemistries, on the recycling of three major sources of lithium, as well as on the future trends and challenges to establish sustainable recycling towards recovering metals from the full stream of LIBs.

Yu et al. (2022) summarized the difficulties in recycling LIBs and proposed possible solutions to deal with these challenges. The work discussed different aspects of techniques in recycling/upcycling, commented on the different government policies on a global scale and underlined the importance of making a big social and economic impact via recycling/upcycling, so as to apply effective suggestions towards the promising circular economy.

Ji et al. (2021) reviewed the recent direct recycling technologies of the cathode with a focus on the materials in LIBs with the most economic value. The study covered the process sequence of direct recycling, pointing out that innovative approaches should be implemented to treat different cathode chemistries together in a direct recycling process.

Therefore, EV battery recycling, more so lithium-ion batteries, is a complex and evolving process. The current practices are a combination of pyrometallurgical, hydrometallurgical, and direct recycling methods with challenges and advantages. The use of more environmentally friendly materials, the need for sustainable management of the increasing volume of used batteries, the recovery of valuable materials, and the minimizing of environmental impact are some of the factors that lead developments in the current recycling technologies. These recycling practices will ensure the sustainability of the battery supply chain and in turn, support a circular economy as the EV market continues to grow.

Table 13: Key aspects on current recycling practices for electric vehicle batteries

Authors	Title	Key Focus
Makuza, B., et al. (2021)	Pyrometallurgical options for recycling spent lithium-ion batteries: A comprehensive review	Overview of pyrometallurgical recycling options for spent LIBs
Ali, H., et al. (2021)	Circular economy of Li Batteries: Technologies and trends	Methods of assessing reuse vs. recycling of LIBs; commercial practices and novel recycling processes
Neumann, J., et al. (2022)	Recycling of Lithium-Ion Batteries—Current State of the Art, Circular Economy, and Next Generation Recycling	Overview of regulations and practices in material collection, sorting, and recycling of LIBs
Pinegar, H., & Smith, Y. (2019)	Recycling of End-of-Life Lithium-Ion Batteries, Part I: Commercial Processes	Review of current commercial scale processes for recycling or reusing EOL LIB components
Quijano-Ortiz, F., & Seepersad, C. (2022)	Design Recommendations for Reducing the Environmental Impact of Battery Packs	Design choices that facilitate reusability and recyclability of EV batteries
Meng, F., et al. (2019)	Review of Lithium Production and Recovery from Minerals, Brines, and Lithium-Ion Batteries	Lithium recovery processes from various sources including spent LIBs
Yu, X., et al. (2022)	Current Challenges in Efficient Lithium-Ion Batteries' Recycling: A Perspective	Challenges and solutions in LIB recycling; environmental and economic impacts
Ji, Y., et al. (2021)	Direct recycling technologies of cathode in spent lithium-ion batteries	Review of direct recycling technologies for the cathode in spent LIBs

5.2.2 Recycling Facilities in Europe and Asia

Electric vehicle (EV) batteries' recycling is the trending and crucial challenge in the root towards a sustainable development of the EV industry across Europe and Asia. This thesis depicts the current recycling practices and challenges, as well as a future perspective of these strategies in the same regions.

Europe: In Europe, the market boom of EV sales dictates the need for development of efficient EV lithium-ion batteries (LIBs) recycling and re-use systems. According to Harper et al. (2019: 1), their study provides an overview on the current set of approaches relating to EV lithium-ion battery recycling and re-use in Europe. They presented the current processes for dismantling and recycling LIB packs of scrap EVs, focusing on the need for necessary innovative recycling technologies and policies so as to manage the increasing number of end-of-life batteries.

Baars et al. (2020) illustrated how strategies of the circular economy can reduce the reliance on raw materials such as cobalt, used in EV batteries, across Europe. Using material flow analysis, the researchers analyzed the current and potential future flows of cobalt embodied in EV batteries within the borders of the European Union. Basically, the study emphasizes that the input gained from the new technologies and the appropriate recycling systems in managing the resource restraints associate with the automotive battery supply chain.

Asia: Asia and particularly China has seen a tremendous increase in the number of EV sales over the years, hence, leading to a subsequent increase in end-of-life EV batteries. Jiang et al. (2021) estimated the amount of waste of end-of-life EV batteries in China and analyzed opportunities and challenges for subsequent utilization. The results presented that battery recycling for energy storage would create more economic benefits, compared to practicing solely material recovery. However, the imbalance between demand and supply of energy storage capacities requires national coordination in recycling and reutilization activities of end-of-life EV batteries.

Choi and Rhee (2020) reviewed the present situation of recycling policies and technology for end-of-life batteries of EVs in Korea. They emphasized the regulations on storage, transportation, and recycling of the end-of-life batteries as important factors for safety management. They proposed an extended producer-responsibility (EPR) system which aims to secure stability in the recycling process.

The existing recycling facilities across Europe and Asia adapt to the challenge of the continuously rising number of end-of-life EV batteries. Unlike Europe, where there practices innovative recycling technologies and circular economy strategies, the Asian countries, including China and Korea, simply aim at developing national policies and lay a basis for the recycling systems of high effectiveness. The two regions have been proactive towards such initiatives in an attempt to find sustainable solutions for the management of EV batteries throughout their lifecycle, which is imperative for the long-term viability of the EV industry.

Table 14: The key aspects on recycling facilities for electric vehicle batteries in Europe and Asia

Authors	Title	Key Focus
Harper, G., et al. (2019)	Recycling lithium-ion batteries from electric vehicles	Overview of current approaches to EV lithium-ion battery recycling and re-use in Europe, focusing on innovative technologies and policy needs.
Baars, J., et al. (2020)	Circular economy strategies for electric vehicle batteries reduce reliance on raw materials	Analysis of circular economy strategies in the EU to reduce reliance on raw materials like cobalt in EV batteries, emphasizing the importance of new technologies and recycling systems.
Jiang, S., et al. (2021)	Assessment of end-of-life electric vehicle batteries in China: Future scenarios and economic benefits.	Estimation of waste from end-of-life EV batteries in China and analysis of opportunities and challenges in recycling and utilization.
Choi, Y.-B., & Rhee, S. (2020)	Status and perspectives on recycling of end-of-life battery of electric vehicle in Korea (Republic of).	Discussion on the status of recycling policy and technology for end-of-life EV batteries in Korea, with a focus on developing national policies and efficient recycling systems.

5.3 Evolution of EV Battery Technology

One of the factors that has contributed to the growing global acceptance of electric vehicles (EVs) is the evolution of electric vehicle battery technology. The advancements conquered regarding the quality of vehicle batteries include better energy density, efficiency, cost reduction, and smaller environmental impact. The analysis of the research reflects a comprehensive image about the progress and challenges in EV batteries technology.

Yan, Deng, and Mei (2021) carried out an analysis based on the patent data of the European patent database and provides certain information about the general tendency in the electric vehicle battery field as well as regional distribution of patent applications, and distribution in the technological field. Their research signals an alignment in the trend of evolution of EV battery technology and that of fuel cell technology being looked at as one of the important strands in the overall development of this technology. This points out the fact that the trajectory of EV battery technology is devised by innovation.

Stübler, Lahyani, and Zayoud (2020) stated a thesis on modeling the lithium-ion battery for the sake of efficient developments of EVs. They tried to find an accurate circuit model of the battery that should consider state of charge, internal resistance, differential capacitance, and efficiency identification. This research adds knowledge to the complex behavior of lithium-ion batteries, which is the base of the current EV technology.

Benveniste et al., 2018 compared the electromobility application of lithium-sulphur battery against lithium-ion battery. The authors provided a comparative evaluation of technical, modeling, environmental and economic dimensions of these technologies by outlining major challenges and advantages. The above-described comparative evaluation is to be of high importance in the perspective of potential change of lithium-ion ones to lithium-sulphur ones in EVs with the use of higher values of energy density.

Gómez Vilchez and Jochem (2019) performed a review regarding the system dynamics models of electric vehicle diffusion along with its powertrain technologies. The study provides insights over modeling exercises for better comprehension in terms of battery prices to public market diffusion of B/PEVs. This approach is instrumental in anticipating future trends in battery technology and its impact on EV adoption.

Chakraborty et al. (2022) further analyzed the prospects of conducting Redox flow battery- based electric transmission systems for greater harnessing of renewable energy within EV technology. They contrasted their study with this work to show how much better and greener alternatives can be exercised regarding the power transport unit that EVs require in general from existing ones.

In conclusion, the evolutionary path of EV battery technology is one that represents continuous innovation by developments in lithium-ion technology, the exploration of alternative chemistries such as lithium-sulphur and new techniques for management of these systems as well as modeling them. Such developments are critical in improving the performance, reducing the cost and minimizing the environmental impact of EVs, therefore ensuring their increased adoption.

5.4 Impact of Batteries on EV Price

One of the most critical factors when assessing the adoption and market penetration of electric vehicles (EVs) is the impact of batteries on the price of electric vehicles. The battery lies at the heart of an electric vehicle, mush as the engine does for conventional cars, not only in determination of the range and performance of a car but also with major influence on the cost of a vehicle.

Heitel et al. (2020) researched the impact of battery price developments into global electric vehicle sales, bringing out the strong influence of costs for batteries on the competitiveness of EV compared to conventional vehicles. The work used system dynamics models based on global learning to model the battery prices and showed that the battery learning rate has far larger effects on the global electric car sales than numerous market-inducing policy measures. This points to the significance of technological innovations in battery technology that can reduce the costs and hence, make EVs more popular.

Ginigeme and Wang (2020) studied the economics involved in V2G based on the costs of battery degradation. By incorporation of the battery degradation cost into optimal V2G models, they showed that effective management of EVs batteries can yield enormous economic benefits both in reducing peak demand and in minimizing total cost related to EV charging/discharge. This shows the economic potential of smart battery management for the increase of the value proposition with what concerns EVs.

Philippot et al. (2019) did a broad analysis regarding the environmental and economic parameters that drive overall production pertaining to lithium-ion batteries, of which some parameters include the scale effect, commodities prices, and energy density. Thus, the study established that while there is a reduction in the cost of EV batteries with falling prices of commodities from which they are made, this relationship between commodity price and battery cost is significantly lower compared to that between production volume and battery cost. This means that scaling up production and improving the energy density are additional strategies through which manufacturers can increase volumes and reduce the cost of EV batteries.

Xiong, Ji, and Ma (2019) have researched the environmental and economic impact when remanufacturing used batteries of electric vehicles with lithium-ion. As a conclusion, they found out that due to remanufacturing, it is possible to achieve lower energy consumption, lower emission levels of greenhouse gases as well as costs, respectively proving that battery remanufacturing can be considered as sustainable and at the same time, economical.

Mo and Jeon (2018) probed into the prices of raw materials for lithium-ion battery with respect to EV demand using Vector Error Correction Model (VECM) analysis. It concluded that the demand of EVs puts an immediate upward pressure on cobalt price. It also outlined the significance of recycling policies for stabilizing raw material prices of lithium-ion batteries.

In conclusion, the economics of electric vehicles are driven by the costs of batteries. Improved technology of the batteries, economies of scale in production, good management and sustainable practices through remanufacturing and recycling do manage to lower battery costs. These practices make EVs more viable from an economic point of view but also support the long-term environmental sustainability of the product.

Chapter 6. Broader Implications of Electromobility

6.1 Electrification of Commercial Vehicles

Electrification of commercial vehicles is one of the biggest challenges when it comes to penetrating the market. There are implications but also many opportunities to overcome them. Based on recent academic literature, this review takes a look at the context as to where the commercial vehicle market stands today and where it will move towards, regarding electrification trends.

Charging Infrastructure and Strategies: Al-Hanahi et al. (2021) note that the most critical areas of focus are the electric commercial vehicle of medium- and heavy-duty. Their elaborate review and analysis are based on the charging mechanism used by commercial vehicles, whereby two fundamental charging strategies receive great intensity of review:

the return-to-base model as well as the on-route charging. They study the challenges that these types of vehicles meet, especially detailing future research needed for the accommodation of vehicle-to-grid technology for use in commercial vehicles.

Battery Swapping as a Strategy: According to Ban et al. (2019), battery swapping is considered one of the most viable alternatives when it comes to transportation electrification with regards to the impact on light-duty commercial vehicles, among others. This eliminates the problems of long recharging durations and poor infrastructure, offering an ambitious solution to make electric commercial vehicles more practical.

Commercial Vehicle Electrification: Gao et al. (2018) present a comprehensive analysis of commercial vehicle electrification through energy consumption estimation and proper charging considerations to electric vehicles. The study assesses the possible battery electric vehicle technologies making them applicable to the medium and heavy-duty applications that present significant energy and fuel savings on all the vehicle classifications.

Environmental Impact and Cost Analysis: Liu et al. (2021) conducted an environmental and climate benefits study of electrification of commercial vehicles in the public services sector within Guangdong. From their research, they compared the emissions of battery electric commercial vehicles (BECV's) and internal combustion engine vehicles. They concluded that with a satisfactory level of vehicle electrification in the public service sector, there would be a huge reduction of pollutants as well as the greenhouse gases.

Challenges and solving towards electrification: Muelaner (2021) touches on all options within power for decarbonized commercial vehicles. He first investigates the constraints faced by critical metal supply and economic competitiveness of hydrogen power. From the findings, the study recommends electric road systems, which could possibly be an available solution to efficient direct electrification of commercial vehicles, thus reducing the necessity for large battery volumes.

The process of electrification of commercial vehicles has been established as complex with the influence of technological advancement, infrastructural development, and environmental considerations. All the approaches we mentioned above are innovative, battery-swapping vs on-route charging have quantitative evaluations. The pivotal part, however, that which will drive the transition towards electrified commercial will be the environmental impact analyses. While challenges may be found, specifically in terms of infrastructure and technology, the potential gains in the reduction of energy consumption could be enormous.

6.2 Electrification of Public Transport and Trains

Public transport and trains' electrification are part of the transforming step in reaching sustainable mobility and, also, change one's perspective concerning urban planning, regarding environmental emissions as well as energy consumption. The implications, challenges as well as the implication aspects of what lies in the future transition for this sector have been previously analyzed.

Public Transport Electrification: Simão, Cellina and Rudel (2020) presented the electrification of public road transport in Southern Switzerland with the use e-buses. The authors simulate the evolution toward electric bus powertrains and compare the selected most promising electric technologies. They found that "opportunity charging" schemes are most prospective for urban lines but short-term adoption is not the best solution because of challenges like service reliability in case of delays, high costs, staff training needs and time required towards installation of charging stations.

Heavy Vehicle Electrification: A research was done by Allwright, Rahman, Coleman, and Kulkarni (2022) about heavy multi-functional freight vehicles in Australia with respect to their electrification. They compared the electric type with the conventional diesel and, hence, predicted a major reduction of tailpipe emissions. However, if batteries are charged from the grid, overall greenhouse emissions could be worse, compared to charging off renewable energy concepts.

Technological Innovations in EVs: Belkacem, Mustapha, Katia and Ahmed (2018) communicated about the design and investigation of the machines for Axial Flux Permanent Magnet Synchronous Machines applied for electric vehicles. Their work highlights advanced motor-based technologies helping to escalate the efficiency and performance of electrified public transport.

Automated and Electric Buses: Ainsalu et al. (2018), presented the state of the art in automated electric minibuses for the first and last mile transportation in public service.

Their work emphasizes the need to incorporate automation and electrification on improving both the energy efficiency and the passenger's safety in urban transportation.

Hydrogen Trains: The recommendation of Sabillon, Singh, and Venkatesh (2019) with technoeconomic models discussed the inclusion of hydrogen trains in the electricity markets as a renewable option for direct electrification of rail lines. Its scope described an optimal scheduling model regarding hydrogen production, while illustrating Hydrail functioning as a practical solution to public transport concerning low level carbon emissions.

Electrification of public transport and trains has been identified as a key factor to achieving sustainable urban mobility. Some of the challenges include the development of relevant infrastructure, a stride of technological innovations, and economic relevance in terms of cost-saving measures. Integration across renewable energy sources and advanced propulsion technologies facilitates better results and, therefore, bigger environmental benefits.

6.3 Implications for Urban Planning and Infrastructure

Implications of electromobility on urban planning and infrastructure involve not only the environment but also the social aspect. The implications concentrate mainly on air pollution, charging infrastructures, and other socio-economic factors from available updated academic literature.

Environmental Benefits of Electromobility: The effects of electromobility on the reduction of air pollution in urban settlements were investigated by Pietrzak and Pietrzak (2020) with a special emphasis on sustainable transport systems in cities. The research of their paper focuses on the general reduction of greenhouse gas emissions and air pollutants that are related to climate change by means of using electric vehicles (EVs), while emphasizing the environmental contribution of electromobility in urban areas.

Charging Infrastructure and Legal Requirement: One of the elements of electromobility discussed by Ehring (2019) is with respect to legal requirements regarding public charging infrastructure. The research analyzed an inclusive legal framework aiming to support construction of charging infrastructure, which is essential in promoting penetration of EVs across a range of urban and suburban spaces around the globe.

Socio-Economic Impacts and Development Potential: Macioszek (2019) explores the e-mobility infrastructure and development potential in the Metropolis of Górnośląsko-Zagłębiowska, Poland. The work reflects on social, economic and legal aspects of the project with the scope to design and manufacture, purchase and use EVs and, also, to provide insight into broader impacts of electromobility on urban development.

Di Blasio et al. (2022) refer to the development of a BIM-based tool that will help integrate electromobility into the design of urban construction. They emphasize the importance of building considerations related to electromobility in areas or neighborhoods from the very early time they are designed, which then gives the guidance to set up projects in an optimal way.

Smart Mobility and Electromobility Solutions: Tundys and Wiśniewski (2023) state in their work about smart mobility and its role in supporting smart city concepts, paying attention to electromobility as a global trend that supports principles of sustainable development. Consequently, research delves into the challenges and barriers for the implementation of electromobility in urban markets where focus falls on matters of energy and charging infrastructure.

Equalizing Electromobility Implementation: Sierpiński and Macioszek (2020) research the implementation of electromobility in various levels of its development, searching for possible locations of charging stations for electric vehicles in a different urban environment. The research is based on contemporary technologies, with multimodal travel planning serving as an example that would help local authorities' representatives in decision-making, regarding the optimal location of the necessary infrastructure for electric vehicle charging.

The transition to electromobility offers mind-blowing new possibilities for considerable improvement of urban sustainability, minimization of environmental risks, and reorganization of urban infrastructure. It is, therefore, imperative that the sustainable and green cities of the future base their decisions on the integration of electromobility into urban planning and design.

7. Environmental Impact and Carbon Neutrality

7.1 Lifecycle Emissions of EVs

Lifecycle emissions from an electric vehicle (EV) have been studied across a range of fronts given the pivotal part they play in reducing greenhouse gas (GHG) emissions and helping move the world further to a neutral GHG status. This review provides a thorough look into the environmental impact across all parts of the lifecycle of electric vehicles.

Environmental Benefits and Life Cycle Emissions: Ahmadi (2019) thoroughly outlined the life cycle emission and life cycle cost comparison between different electric vehicle types incorporating hybrid electric vehicle (HEV), full battery electric vehicle (EV), plug-in hybrid electric vehicle (PHEV), and hydrogen fuel cell electric vehicle (FCEV). The study identified significant reductions, about half of their emission levels, in terms of GHG emissions caused by both FCEVs and full EVs compared to internal combustion engine (ICE) passenger cars. The study also identified better results in terms of air quality-related emissions for FCEVs as well as for full and partial EV categories, which is a very important environmental indicator.

Athanasopoulou, Bikas, and Stavropoulos (2018) carried out a Well-to-Wheel analysis to compare emissions between ICEVs with BEVs. This study demonstrated how the BEVs significantly reduce the levels of pollution compared to vehicles running on conventional engines, whether it be gasoline or diesel they operate with. It, therefore, underlined the necessity to take into consideration the whole process of energy flow when evaluating environmental impacts produced by various vehicle technologies.

Teoh, Kunze, Teo, and Wong (2018) performed a life cycle costing and carbon dioxide emissions analysis in urban freight transport with the use of EV40. The study considered various opportunity charging (OC) strategies for EVs with the conclusion that OC reduces the vehicle’s lifecycle cost while, at the same time, having no negative impact on the cars’ carbon dioxide emissions. This, thus, highlights the potential of smart charging strategies in enhancing sustainability for EVs within urban freight transport.

Wu, Guo, Field, De Kleine, Kim, Wallington and Kirchain (2019) performed a regional lifecycle assessment of light-duty electric vehicles in the U.S. The study came to find large regional heterogeneity in greenhouse gas emissions benefits, mainly due to the fact that there are regional differences in climate, electric grid load as well as different driving patterns, all of which played a decisive role in the level of gas emissions.

Gan, Lu, He, Wang, and Amer (2023) compared lifecycle greenhouse gas emissions (GHG) of gasoline versus electric vehicles in China using a cradle-to-grave (C2G) approach. The study points out that based on the current technologies, the average national C2G GHG emissions for BEVs are lower than those of gasoline ICEVs, which indicates advantages to emission mitigation by vehicle electrification.

In summary, the lifecycle emissions of EVs encompassing the production, operation, and disposing-of phases draw a complex picture. While EVs generally yield significant GHG emission reductions compared to ICEVs, the quantum of these reductions is subject to the electricity mix consumed for battery-charging, to the regional differences, and, finally, to the type of vehicle technology. In this way, the transition to electric mobility calls for a 360-degree consideration of these multidimensional aspects so that the environmental benefits be optimized.

Table 15: Key aspects on the lifecycle emissions of electric vehicles (EVs)

Authors	Title	Key Focus
Ahmadi, P. (2019)	Environmental impacts and behavioral drivers of deep decarbonization for transportation through electric vehicles	Comprehensive lifecycle emission and cost comparison among various types of EVs, highlighting significant emission reductions compared to ICE vehicles.
Athanasopoulou, L., Bikas, H., Stavropoulos, P. (2018)	Comparative Well-to-Wheel Emissions Assessment of Internal Combustion Engine and Battery Electric Vehicles	Well-to-Wheel framework to compare emissions of ICEVs and BEVs, emphasizing decreased emissions by BEVs during their use phase.
Teoh, T., Kunze, O., Teo, C.-C., Wong, Y. (2018)	Decarbonization of Urban Freight Transport Using Electric Vehicles and Opportunity Charging	Evaluation of lifecycle costs and carbon dioxide emissions of urban freight transport using EVs, focusing on opportunity charging strategies.
Wu, D., Guo, F., Field, F., De Kleine, R. D., Kim, H. C., Wallington, T., Kirchain, R. (2019)	Regional Heterogeneity in Emissions Benefits of Electrified and Lightweighted Light-Duty Vehicles	Lifecycle assessment showing regional heterogeneity in GHG benefits of electrification, emphasizing the need for diverse fuel-efficient offerings.
Gan, Y., Lu, Z., He, X., Wang, M. Q., Amer, A. (2023)	Cradle-to-Grave Lifecycle Analysis of Greenhouse Gas Emissions of Light-Duty Passenger Vehicles in China: Towards a Carbon-Neutral Future	Comparison of cradle-to-grave lifecycle greenhouse gas emissions of gasoline and electric vehicles in China, showing emission reductions for BEVs under current technologies.

7.2 Challenges and Prospects for True Carbon Neutrality

True carbon neutrality is both a challenging and a promising idea within the context of global climate change. A closer inspection into recent academic study may unveil insights into few optimal factors aiding this effort, including that of careful strategy, technology innovation and policy considerations for the sustainable transition. This analysis draws on these studies to explore the intricacies of attaining genuine carbon neutrality.

Carbon Neutrality Strategies: The aspect highlighted by Mora Rollo, Rollo, and Mora (2020) revealed an initiative called the Carbon Neutrality Challenge, where people calculate their CO2 footprint and plant trees to neutralize it. This approach upholds that community-based strategies are vital. They underline the need for personal responsibility and proactive participation with the aim of battling climate change.

Export Diversification and Technological Innovation: Iqbal et al. (2021) consider export diversification and environmental innovation as some of the tools towards carbon neutrality in the OECD countries. The study demonstrates the positive effects that can be derived from renewable energy consumption and environment-related technological innovation, making it clear that this approach is very important in achieving sustainable development goals.

Wang, Huangfu, Dong and Dong (2022) perform a bibliometric analysis of carbon neutrality research literature, categorizing it per themes and trends. This study suggests that future research is more prone to be focused on energy structure transformation, technology for carbon dioxide capture arrangements, and policy for urban carbon neutrality.

Green Openness and Environmental Sustainability: Zhang et al. (2023) examines the effect of energy productivity and renewable energy with respect to OECD economies on becoming carbon neutral. The findings exhibit the fact that renewable energy and energy productivity are fundamental for decarbonization as well as transforming conventional energy into green energy.

Challenges of Energy Revolution and Carbon Neutrality: Huang and Xie (2021) analyze the challenges of carbon neutrality commitment in China, where they put their focus on energy revolution that would lead to electric decarbonization. The Chinese economy could see its carbon levels significantly low while, at the same time, benefiting both its demand and supply.

Challenges in Governance on the Path to Carbon Neutrality: Wang (2021) observes that through this path to carbon neutrality targets, key governance challenges are portrayed to be the state competition as well as the inequalities among major political powers and other countries. The path to true carbon neutrality is indeed a complex project. It will require to take simultaneous steps to achieve innovations in green technology, renewable energy, economic policies, efficient governance, and community participation. All these steps together will play an important role in pushing through the barriers in order to help nations unlock the global potential for a carbon-neutral future.

Chapter 8. Conclusion

8.1 Concluding Remarks

After considering all aspects, companies operating in the automotive industry, including both suppliers and manufacturers, must adapt and ensure a seamless shift towards electric vehicles (EVs) while effectively managing their traditional internal combustion engine (ICE) vehicle operations. Original Equipment Manufacturers (OEMs) need to evaluate their supplier base to determine whether or not it is aligned with their EV transition strategy. Moreover, they should explore new competitive advantages, assess their level of vertical integration, and invent ways to secure the supply chain, all while prioritizing sustainability. As the path to electromobility is yet uncharted and there is no right or wrong way to go about it, they must tailor their strategies to their specific requirements.

The progression of electric vehicles in the transportation sector is not a simple case. It requires parallel investing of time and money on many forms. It requires investments in the energy production sector to create solid charging infrastructure. It also requires investment from EU governments to finance research on new battery technologies, and it also requires the coordination from local authorities for the expansion of charging stations. In addition to these, the automakers will also have to invest in producing new models that are cheaper, safer and more city friendly. Finally, EU will require to play her role carefully directing the parties involved.

Even though 5% market share is all it is needed to make electromobility a viable solid alternative to petrol cars, automakers estimate that EVs' market share will continue to grow in the years to come. Petrol and internal combustion engines will remain the main source of power and the main type of vehicles used in the transportation sector, but battery electric cars are estimated to grow a share of up to 18% in the European market till 2025 and of up to 30% till 2040.

What is said less often is that sustainable mobility is not solely about being friendly to the environment. Combined with access to domestic charging, it is also a smart economical move. While steering our way through the maze of the yet complicated supply chain, one thing is certain: we cannot achieve a solid shift away from conventional engines without technological advancements and governmental contribution. As long as batteries keep evolving their technology, cars keep improving price-and-model wise and governments, along with local authorities, keep investing on energy infrastructure, this alternative mode of transport will remain present, and, if combined with renewable energy use Cradle-to-Grave, then it will always also be a very efficient, carbon neutral option for our transports.

The integration of technology and acquisition of relevant skills will be pivotal during this transition to the EV supply chain. Therefore, business leaders and supply chain managers should embrace lean thinking, eliminate irrelevant practices and draw insights from successful strategies in other industries that can be adapted to EVs. The transition requires significant investments. However, stakeholders in the automotive sector, alongside governmental bodies, must recognize that global warming is an urgent reality, progressing faster than anticipated. As a result, alternatives to the internal combustion engine must be pursued as we confront a critical situation with far-reaching consequences.

In conclusion, this work joins the main findings from the addressed areas in offering a profound analysis of the present state and future possibilities prevailing in the landscape of sustainable transportation and urban development.

i. Electromobility and its Broad Implications:

It is apparent that electromobility, referring to the electrification of vehicles, has an overt role in relation to greenhouse gas emissions and global climatic changes. Studies by Ahmadi (2019), Athanasopoulou et al. (2018), and Teoh et al. (2018) inform us of the lower - by close to 70% - emissions that electric vehicles (EVs) present compared with internal combustion engine vehicles (ICEVs). However, in order for this transition to be successful, reference should be made to a study of Al-Hanahi et al. (2021) who supported that infrastructures for the increasing volume of electric vehicles and extensive integration of renewable energy sources should be developed as key drivers for maximizing the benefits related to electromobility.

ii. Infrastructure and Urban Planning:

From another point of view, it is supported that the electrification of transportation requires substantial changes with the main focus being on urban planning and infrastructure. As Pietrzak and Pietrzak (2020) and Ehring (2019) mention, making EVs run would need not only blooming of charging infrastructure but also re-conceptualization or re-configuration of the cityscape for these developments. Di Blasio et al. (2022) identify the integration of electromobility in urban planning to deliver sustainable and livable cities.

iii. Environmental Impact and Carbon Neutrality:

The most important aspect while considering the making of an environmental impact ascribed to EVs is the life-cycle emissions incurred from EVs. As stipulated by Wu et al. (2019) before their recent amendment and Gan et al. (2023), regional electricity mix should be put into consideration in calculating the carbon footprint of electrical vehicles. The fight towards carbon neutrality should not only limit the emissions emitted by vehicles but also the ones produced during energy production. In this regard, the articles by Mora Rollo et al. (2020) and Yu (2022) best capture how technological innovation, economic development, and environmental sustainability are interwoven in complex ways along the path to full carbon neutrality.

iv. Challenges and Opportunities of Full Carbon Neutrality:

According to Iqbal et al. (2021) and Wang et al. (2022), it still makes a big challenge to achieve true carbon neutrality. For once, it would require breakthroughs of green technology, sharp economic policy interventions, and effective governance. In this regard, along with the need for indulging in an energy revolution as proposed by Huang and Xie (2021), renewable energy as discussed by Zhang et al. (2023) takes a center stage.

Transition to more sustainable and environmentally friendly transportation modes, on the basis of electromobility, is a very important direction in the fight against climate change. Despite this fact, the importance of such a transition involves changes in urban planning, development of infrastructure, as well as production of green energy. This requires the incorporation of sophisticated technology in vehicle designs, improved efficiency in batteries, and favorable policy frameworks. Carbon neutrality turns out to be not only a technological issue, rather an economic one as well.

This work analytically presented the present state of electric vehicles' industry, mostly in Europe and the US. It made reference to its actually long history, its current market share and legal and economic framework surrounding the industry. It depicted the complexity of batteries' supply chain and emphasized the need to overcome the supply related hurdles. It connected supply chain with the scope of a sustainable net-zero emissions future, by noting how important it is to face the environmentally costly issues of the batteries' mining, refining, manufacturing, and recycling phases. The analysis helped acquire a bigger picture of how the EV market stands in early 2024 and draw insight on what needs to be done in the coming years to come closer to the desired environmental targets.

8.2 Limitations and Recommendations for further research

The study on carbon neutrality provides a dynamic field of investigation into the challenges, constraints, and areas that should still be researched in order to point towards the most promising future directions.

i. Limitation of the Present Research:

The most recurrent research consideration is the limitation posed by current energy infrastructures and technologies. Wu et al. (2019) and Gan et al. (2023), together with other studies, emphasize the impact of regional electricity mixes on the lifecycle emissions of electric vehicles (EVs), thus urging for further integration with energies from renewable sources. Furthermore, as emphasized by Katoch and Eswar Moorthy (2020), battery technology for EVs is one of the major areas of concern regarding their efficient thermal management, which, in turns, further influences carbon footprint.

ii. Future Directions of Research:

The following points need to be considered, with regards to future research:

Technological Innovations: The technological advances, like the power conversion efficiency and the innovation in vehicle designs tend to have positive effect on the reduction of the cars' emissions (Kachhawa et al., 2020; Ahmed et al., 2022). The materials, the battery technologies, the new efficient designs are all required to be focussed on developing, researching, and proposing.

Policy and Governance: Iqbal et al. (2021) and Zhang et al. (2023) point out that the policy frameworks and governance structures are instrumental towards driving the carbon-neutral transition. In the future, research should be based on effective policies, appropriate mechanisms, international collaborations as well as governance modalities that will foster this transition.

The pursuit for carbon neutrality is a difficult endeavor requiring the harmonization of technological, policy, economic and societal aspects. Limitations identified in previous studies point at the necessity for innovative solutions, comprehensive policy frameworks, and interdisciplinary approaches. These gaps need to be addressed in future studies , through providing frameworks for actionable insights as well as strategies that will be useful in transitioning us into the future of sustainability and a carbon-neutral world.

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