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THE ADOPTION OF PRIVATE ELECTRIC MOBILITY: A ROADMAP TO THE GLOBAL TIPPING POINT & IMPLICATIONS FOR ARGENTINA

AUTHOR: JAMES MICHAEL RUDD

THESIS DIRECTOR: DR. ALEJANDRO PRINCE

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1. Justification

1.1. Problem: New Paradigms in Mobility

The development of modern electric mobility is relatively recent in the history of the private motor vehicle. In the late 1990s, the California Air Resources Board, increasingly concerned with the quality of air in the large urban centres such as Los Angeles, begun to implement a regulatory framework requiring automakers to develop and sell an increasing quota of zero emissions vehicles, starting with 2%, and implementing increasingly tighter emissions standards.

Fast forward 20 years and the principal driver for the change from fossil fuel powered mobility to electric mobility is still climate change and a significantly greater level of consciousness amongst public and private sectors that our reliance on fossil fuels must change if we are to have any chance of safeguarding the planet.

In the intervening period, the discussion around electric mobility is wider than issues surrounding climate change and urban pollution, just as a discussion of modern mobility is much wider than electric mobility. Debate continues as to how ecological electric vehicles really are, particularly considering emissions in the manufacturing process and the implications of mining for Lithium, Cobalt and Nickel and other rare earth metals.

Modern urban theory and design and theories on sustainable transport point to our overdependence on cars and the need to find more sustainable forms of transportation. The rise of the sharing economy and mobility as a service platform, and in the future fully autonomous transport, seek to change our relationship with the privately owned car, one of our most unutilised assets.

Nevertheless, electrification is still an important part of the pathway to more sustainable transportation. In addition to less pollution in our urban centres, electric vehicles emit far less noise pollution and are significantly more efficient in terms of energy use. Technology is advancing at such a rate that the electric cars of the future will be cheaper, better equipped, safer and more connected than the vehicles we see today.

This study undertakes to understand and describe this revolution, how quickly it is happening, understand the accelerators and detractors and seek learning points for implementation in less developed countries such as Argentina.

1.1.1. Climate Change

The Stern Review, commissioned by the UK government in 2006, attempted to perform an economic cost-benefit analysis of the effects of greenhouse gases, predominantly CO_2, and climate change. The review calculated that world GDP could suffer by 5% per annum, rising to 20% per annum if sharp and immediate reductions in greenhouse gases were not implemented. The Nordhaus review of the Stern Review, criticises the use of a near zero discount rate (at the height of the financial crisis) in order to come to these conclusions, arguing that how much, how fast and how costly remain open questions based on current market rates. Nevertheless, Nordhaus does not argue against a necessary reduction, and current scientific thinking agrees that climate change is happening and requires action. Meanwhile the Kyoto Protocol exempted China and India, leading to resistance from the US. (Nordhaus, 2007)

Statistics from the International Energy Agency suggest that CO_2 emissions from energy use[1] and generation in Argentina are caused predominantly by electricity generation (38% in 2014) and transportation (24% in 2014), like levels seen in the US, and amongst the worst in Latin America. The balance of emissions from energy use is caused by Industry and Commerce, Households and Agriculture.

Climate Action Tracker, an independent scientific analysis funded by three research organisations based in Germany, monitors the performance and actions of countries across the globe in their efforts to tackle climate change. During Macri's government, Argentina showed significant development. Since it adopted the Paris Agreement, it has strengthened its Nationally Determined Contributions (NDCs), it encouraged the development of alternative fuels and put in place a 10-year plan for developing renewable sources of energy, as well as announcing a carbon tax on all fossil fuels in December 2017. Nevertheless, neither its

[1] Overall emissions in Argentina are dominated by land use and agriculture and then energy use and generation.

unconditional (voluntary) NDCs or conditional (incentives from high ambition countries) NDCs are sufficient to reverse its rising emissions. Achievement of its unconditional NDCs will still lead to an increase in emissions of 35% compared to 2010 and 80% compared to 1990; conditional NDCs are 3% & 38% respectively. Climate Change Tracker rates Argentina's efforts as "highly insufficient" to "critically insufficient" to maintain temperatures within a 3º to 4º Celsius temperature rise (Paris Agreement targets a 1.5º C rise). (Climate Action Tracker, 2019)

Argentina needs rapid advancement if it is to contribute its fair share in global emissions reductions. As the largest sources of CO_2 emissions from non-agricultural sources, both energy generation and transport need to be tackled if significant headway is to be made. Whilst development of renewable energy sources is underway, the programme is in its infancy (less than 5% of energy generation currently comes from renewable sources according to CAMMESA[2]), clean transportation does not yet form an integral part of a clean energy policy.

1.1.2. The Rise of Electric Vehicles

Global electric mobility is in rapid expansion with a fleet of almost 5 million vehicles in 2018 having double to 10 million vehicles in the following two years, despite the pandemic. China and Europe are market leaders in volume, whilst Norway is the leader in electric share of total vehicles. Policies play a critical role, setting fuel economy standards, incentives for zero-low emissions vehicles, economic instruments to close the cost gap, deploying infrastructure and developing a battery technology value chain. Technology advances are delivering substantial cost reductions in battery chemistry, production capacity and the use of big data to "right size" batteries. Along with many European countries, China and Israel expect to ban diesel vehicles by 2030/2040 and reduce net emissions to zero. Annual sales of EVs are expected to reach at least 23 million by 2030, with a total fleet of 130 million and a 30% market share. Well to wheel emissions from EVs are already lower than internal combustion engines (ICE) and are expected to be half by 2030, assuming decarbonisation of the energy grid. Power mix is critical since hybrid vehicles are better when coal is a dominant energy source. (Bunsen et al., 2019)

[2] Compañia Administradora del Mercado Mayorista Eléctrico – the Argentine electricity regulator.

Government incentives are also critical to EV uptake in the early stages of adoption. Potential barriers are price of an EV compared to ICE, vehicle range/autonomy and availability of a charging network. Perhaps surprisingly, environmental concerns have not always been top of mind for consumers. (Broadbent et al., 2019)

The impact of significant growth in EVs on the electricity grid is a primary concern. A study by McKinsey & Co. concludes that EV growth is not likely to cause large increases in power demand through 2030. Using Germany as an example, it expects that EVs will add about 4% to the total demand for electricity by 2030. Nevertheless, EVs will reshape the load curve, particularly evening peak loads and particularly in urban locations. With an estimated 25% penetration of EVs in the market, the peak load could increase by 30% for households but overall remains low. Peak loads can be managed with time of use electricity tariffs, storage units (batteries) and distributed generation (roof top panels). (Engel et al., 2018)

1.1.3. Disrupting the Automotive Industry

The automotive sector is facing disruption on a massive scale from autonomy, connectivity electrification and the sharing economy (ACES), which may be destined eventually to dramatically reduce private ownership of vehicles and radically alter the way we see modes of transport to the concept of mobility as a service. The development of the so-called axis of zero emissions (electrification), zero accidents (automation) and zero ownership (shared) are still largely conjecture, although with respect to electrification, evidence indicates that market penetration numbers for distinct markets, particularly in China and in Europe are reaching a tipping point. Of the three trends, only sharing has the real potential to reduce the number of private vehicles (the other two are largely replacements for existing vehicles) and whilst ride hailing or car sharing are growing markets, they are still dwarfed by private vehicle ownership, which has yet to experience any real reduction.

When Tesla first appeared, as a company with a vision for clean energy and clean transport, it sought to be disruptive to the old order of a quasi-oligopoly of traditional automobile manufacturers. Tesla's cars have proved popular[3], if you can afford to buy one; it has developed a successful sales and marketing strategy but in the early years struggled with production and fulfilling orders.

However, Tesla itself now faces disruption, partly from a fight back, as traditional manufacturers develop their own electric vehicle models. The market also faces pressure from tech giants with deep pockets, predominantly Amazon (A) & Google (G), but also Apple (A), Microsoft (M) & to a lesser extent Facebook (F), in direct competition for the development of autonomous technology and connectivity.

1.1.4. Battery Technology

As a result of the unexpected pace of EV adoption, the battery industry is expanding as never before, and prior predictions have been unable to keep pace. In 2018, Bloomberg New Energy Finance, predicted that global energy storage would grow to a cumulative 942 GWh by 2040, driven by a 52% reduction in battery costs by 2030. EVs, distributed storage networks and energy access in remote areas[4] would all contribute to this expansion. The battery market, dominated by China & Korea, would by 2020 add an additional 50 GWh of energy storage production capacity, but by the beginning of 2021 capacity more than doubled to over 700 GWh[5] from 300 GWh in 2018. According to the International Energy Agency, 1,000 GWh[6] of global production capacity for batteries will be required by 2025 and 1,500 GWh by 2030. (Eckhouse, 2018)

With the rapid expansion in EVs and associated batteries there are future issues for raw materials such as Lithium, Cobalt and Nickel (the latter two could be in short supply by the mid 2020s), as well as for end-of-life battery management. EV batteries degrade over time predominantly due to charging cycles and temperature. Degradation is strongest over the first five years of a battery's useful life of approximately 10 years. A battery no longer meets the

[3] The Model 3, alone, presold 450,000 units.
[4] A combination of solar energy and batteries for storage is cheaper than extending the grid in remote areas.
[5] Source: S&P Global Market Intelligence and Statista.
[6] 1,000 GWh is enough capacity for 10 million vehicles each with a 100-kWh battery pack or 20 million vehicles with a 50-kWh battery pack.

specifications for EV usage once its total useable capacity is less than 80% or its resting discharge is greater than 5% over 24 hours. Applications for storage, in contrast, are less demanding. The choices for end-of-life batteries are to dispose, recycle valuable materials or reuse. EV batteries could be given a second life by repurposing them for storage to reduce peak loads, store excess renewable energy and grid management. By 2025 second life batteries are expected to be 30% to 70% cheaper than new batteries. (Engel et al., 2019)

1.1.5. Regional Developments & Policy

Policy developments are falling behind ecological change. Core policies across North and Latin America have focussed on carbon trading mechanisms and decarbonization of energy systems through the promotion of renewable energy. In electric mobility, across Latin America, many countries are testing technology with basic incentives and a first round of charging infrastructure. Pace across the region varies, with Colombia and Mexico the most advanced. Local government tends to be more agile than national with developments in electric buses and taxis. Stakeholders, both public and private, will play a critical role in the adoption of new technologies. Nevertheless, the environment is favourable for electric mobility and renewable energy, with both large vehicle producers and large lithium reserves in the region. Incentives, to reduce initial EV prices and accelerate deployment of charging infrastructure, are key, as is collaboration to implement fuel regulations and reduce emissions. (Gomis et al., 2018)

EVs, particularly those employing renewable energy recharging, reduce emissions and long-term energy costs. A lack of infrastructure and high vehicle/battery costs create a challenge for the auto industry and government alike. Governments in the region have a key role to play since the probability of purchasing an electric vehicle greatly increases as the price gap with a conventional vehicle narrow, which can be achieved through government subsidies. (Hong et al., 2012)

1.2. Questions

1. The global adoption of electric mobility is close to reaching a tipping point in China, Europe and the US but Latin America and the rest of the world is far behind. How quickly will we reaching a tipping point in leading markets and when can we expect a tipping point to occur in Argentina?
2. What are the key enablers/detractors, barriers and opportunities for adoption of EVs? What are the key drivers for successful massive adoption of electric vehicles and what can be learned from the success of leading markets to be applied in less developed countries?
3. Modern urban transformation and sustainable mobility models focus on the reduction in use of private, single-occupied vehicles and promote zero emissions (electric vehicles), zero accidents (autonomous) and zero ownership (sharing). How quickly and what possible impact will the appearance of new business models such as sharing, mobility as a service and/or autonomous vehicles have on the private ownership of electric vehicles in the short to medium term?

1.3. Hypothesis

The rate of adoption of electric vehicles across the globe has not yet reached a tipping point. In China, Europe and North American a tipping point will be reached in the next 5 to 10 years, whilst in Argentina the tipping point is still 10 to 20 years away. New urban mobility models such as sharing or autonomous robotaxis will develop in the medium to long term but will not immediately impact the private ownership of vehicles globally.

As will be discussed in Chapter 2, this study is principally a descriptive investigation. As such, the hypothesis above is not truly a hypothesis in the scientific sense, that it will be empirically tested through experiment and collection of primary data but is meant as a guiding statement that frames the investigative questions and objectives of this study.

1.4. Objectives

Primary Objective:

Investigate, describe and understand the development and adoption of electric vehicles in advanced economies, such as China, Europe and the US. Identify the key drivers for and obstacles to the adoption and proliferation of EVs in these markets. Apply this understanding to develop a critical analysis of EV adoption in Argentina to the present date, expected future development and recommendations for a policy framework and roadmap.

Secondary Objectives:

1. Investigate and revise current theories of adoption and diffusion of innovation, disruptive innovation, modern urbanism and sustainable mobility. Apply these theoretical frameworks to the adoption of electric mobility, explain any significant diversions and predict future developments.
2. Describe concepts of privately owned light electric vehicles. What is an electric vehicle and how has it developed? What are the key battery technology developments and history?
3. Analyse the current state of the global market and how it has developed over the past 20 years. Which countries are the key players and why? Describe the development of EVs today in terms of availability of models, competitors, new entrants and other key developments in charging infrastructure.
4. Investigate and quantify how barriers & incentives and other key drivers have impacted the rate of adoption in key markets. Determine whether overall each group of drivers tends to accelerate or slow EV adoption.
5. Describe and evaluate the short to medium term impact of the involvement of Big Tech and the advance of alternative models for transportation: developments in the sharing economy, autonomous vehicles and mobility as a service. Zero emissions, zero accidents, zero property[7]. What potential impact will new mobility models have on the proliferation of EVs?

[7] In 2018, General Motor's CEO, Mary Barra, set out the company´s vision detailed in their 2017 Sustainability Report, describing it as "zero crashes, zero emissions and zero congestion" to be accomplished by a combination of autonomous, connected, electric and shared (ACES) vehicles. (General Motors, 2017)

1.5. Scope

This thesis will focus primarily on privately owned electric vehicles and the rate of adoption in global markets. However, urban transport models also include other forms of sustainable transport, such as public or private buses, trains and metro (electric or using other energy sources), commercial transport (trucks and vans), bicycles or electric scooters (micro mobility), to name a few examples. Development of each of these alternative forms of transportation and changing social values could have an impact upon future demand for privately owned vehicles generally and electric vehicles specifically. These alternative forms of transport and their development in the urban context will generally be outside the scope of this thesis.

In addition, outside the scope of this thesis is an in-depth analysis of existing or future developments of alternative sustainable fuel sources, such as hydrogen fuel cells or biofuels that may reduce the proliferation of Battery Electric vehicles (the focus of this thesis).

2. Methodology & Field Work

2.1. Study Type & Reasoning

Electric Vehicles have been in existence since the turn of the last century (19^{th} to 20^{th}), but it has only been within the last 20 years that modern electric vehicles have begun to pose a substitute threat to Internal Combustion Engine Vehicles (ICE) that dominated transport in the 20^{th} Century. The advance of privately-owned Electric Vehicles has accelerated at different rates across the globe with China, Europe and the US dominating the market.

In consideration of the plethora of information available at a global level, this investigation of the adoption of Electric Vehicles will be a ***descriptive study*** of the key drivers and opportunities for Electric Vehicles at a global level, with a focus, through multiple case studies, on the experience in distinct markets such as China, the US and European countries. Finally, this thesis will seek to apply its findings and make recommendations for the adoption of Electric Vehicles in Argentina

The descriptive nature of the thesis requires a thorough understanding of the distinct markets, drawing on global market data and specific market studies. This thesis will seek to understand and investigate the key barriers and drivers that have led the global market to its current position and hypothesise on the key market tendencies that will drive the adoption of EVs in the future. In this regard there are elements of an explicative study as the connections between cause and effect will be explored in order to draw conclusions for the future of the market.

In terms of reasoning the study will be predominantly hypothetical deductive, in that those theories surrounding the adoption of new technology, learning curves and sustainable transport in urban ecosystems, will be tested against the data available for the proliferation of the Electric Vehicle market. If the data cannot be explained by current theories, and adjustments are required, there may also be elements of the hypothetical inductive to develop a new model or paradigm.

A hypothetical deductive study, with elements of inductive, implies using a ***mixed methodology*** of both quantitative and qualitative instruments. Whilst the methodology will be predominantly qualitative, the use of quantitative instruments may be used to explore alternative correlations between cause and effect, such as the correlation between Electric Vehicle adoption and economic conditions, government incentive programmes or alternative urban mobility models.

2.2. Instruments

The key instrument to be used in the field will be ***case studies*** and ***revision of documents*** to obtain both quantitative and qualitative information on the proliferation of Electric Vehicles in certain global markets. The use of case studies and other industry reports will allow for an in-depth analysis of the key variables and drivers in the field of study.

Case studies will be elected based on their importance and significance to the field of study. For example, China is by far the market leader in the adoption of Electric Vehicles based on total fleet numbers. Europe on the other hand, particularly Scandinavian countries such as Norway, are market leaders when one considers the penetration levels of Electric Vehicles as a percentage of total vehicle fleet numbers. Finally, the US is home to pioneering companies such as Tesla and is the third most important market for Electric Vehicles.

2.3. Triangulation & Data Collection

The two principal axes of field work study will be accomplished though case studies and revision of literature. Both sources will provide predominantly qualitative, but also some quantitative, data from ***secondary sources***. In order to triangulate the sources of information and provide some primary data, this study will conduct a small number of high-quality interviews with industry experts and/or related academics.

2.4. Variable Relationship Table

Variables	Dimensions	Indicators	Instruments
Opportunities for and barriers to the global adoption of Electric Vehicles.	• Adoption and diffusion of electric vehicles in China, Europe & the US. • Key Drivers and Barriers. • Key Benefits • Battery Technology • Industry competition • Integration of EVs into the electricity grid. • Global tendencies.	• No. of electric vehicles globally and per country. • Adoption curve per country. • Total Cost of Operation (TCO) comparison. • Battery technology and cost reductions over time. • Number, cost & type of EV models and competitors. • Timing and gross investments in charging infrastructure. • Amount of Government or industry incentives • Reduction in CO_2 emissions or other pollution and impact on healthcare or other costs.	• Case Studies (China, Europe & US) • Document Revision • Interviews
New models for sustainable urban mobility and the investment of Big Tech in the automotive industry.	• Zero emissions, zero accidents, zero property. • Developments in sustainable urban mobility	• Rate of evolution of sharing and autonomous vehicles. Reality vs. Predictions. • Big tech investments and other market tendencies. • Global tendencies in private vehicle ownership vs. economic or other factors.	• Document Revision • Interviews
The case for Argentina.	• Developments in E-mobility. • Public policy • Integration with renewable energy • Future scenarios and tendencies.	• Energy & Transport policies. • Current developments & tendencies for e-mobility. • TCO analysis for Argentina.	• Document Revision • Interviews

3. Theoretical Framework

3.1. Innovation & Diffusion of Technology

3.1.1. Rogers' Adoption Curve

The study of the diffusion of innovations is the study of how, why and how quickly, new ideas are disclosed, or new products and services are adopted. Rogers describes a sequence of events – knowledge, interest, evaluation, test and adoption - whereby an individual first receives knowledge of an innovation, then an attitude is formed towards that innovation, and from this attitude arises the acceptance or rejection. If the decision is of acceptance, the process concludes with the implementation and use of this idea or product, and the confirmation or otherwise of the decision chain. (Rogers, 1962)

Rogers identifies five main determinants in the dissemination process:

1. The characteristics of innovation that can influence its adoption.
2. The decision procedure, which occurs when individuals consider adopting a new idea, product or practice,
3. The characteristics of individuals who agree to adopting an innovation,
4. The consequences or benefits for individuals and for society of adopting an innovation
5. The communication channels used in this adoption process.

Finally, Rogers defines different categories of members of the adoption curve:

• Innovators: Tech enthusiasts, risk takers, aggressively pursuing new technology.
• Early Adopters: Respected amongst peers, opinion leaders, open to new ideas (visionaries), but more cautious than innovators.
• Early majority: Rational people accept change more quickly than average people do. Pragmatists.
• Late Majority: Sceptical people will use new ideas or products only when something becomes an established standard.

• Laggards: Conservative, critical of new ideas.

Rogers' curve is normally distributed with approximately 1 standard deviation between each of the five main categories. The cumulative rate of adoption forms the characteristic logistic S-curve:

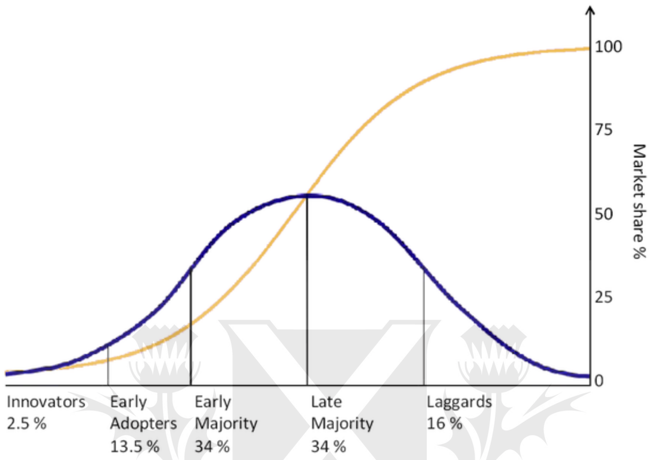


Figure 1: Rogers' Adoption Curve, Diffusion of Innovations (Rogers, 1962))

In 1969, in the work entitled "A New Product Growth for Model Consumer Durables", Frank Bass developed a mathematical modelled, based on Rogers' theory of the diffusion of innovation and tested it with data from eleven durable consumer products, obtaining significantly relevant results.

3.1.2. Diffusion Rates & Tipping Points

Bass' model attempted to estimate the number of consumers who will adopt a new product over time, dividing the consumers between two distinct groups: innovators (Rogers' early adopters), are those who acquire the new product regardless of what the rest of society does, and imitators, who acquire the new product once they have observed that others are already consuming it, and as a result of the interaction and influence of the innovators on the imitators (the contagion effect). Two important consequences of Bass's work are that (1) the model can be used to predict the adoption of products not yet on the market and (2) that whilst media is important in initiating the adoption process, word of mouth (experience) is a far stronger agent for adoption. (Bass, 1980)

Golder and Tellis identified the point where the adoption curve has its great turning point, the take-off, Rogers' critical mass or tipping point. Determining this point or its existence can be an efficient predictor of the serviceable market. (Golder & Tellis, 1997)

Hall in her paper, the Adoption of New Technology, argues that the alternatives in the adoption process are not between adopting or not, but between adopting now or later. The potential adopter evaluates the sunk cost of adoption (purchase price) against the expected or perceived benefits to be received over time. Hall argues that adoption is a "one-way trip" in that it is unlikely an adopter will return to a previous technology. Consequently, for high value items such as electric vehicles there may be a certain reticence to adopt in the early stages of a market, particularly by Rogers' Early Majority. (Hall & Khan, 2003)

In certain cases, the perceived value of a new technology increases due to the increase in the number of users accumulated. This is the case for network goods (e.g., Metcalfe's law[8]) or goods that rely on a network, such as availability and compatibility (standardisation) of the charging infrastructure required for Electric Vehicles. Similarly, in some cases the role of the State in this regard should be recognized, as in the case of subsidies for Electric Vehicles.

Malcom Gladwell popularised the idea of a "Tipping Point" in what he described as "social epidemics" or the emergence of fashion trends, analogous to Rogers' "critical mass". The central premise is that ideas and products are contagious and spread like viruses, typically by word of mouth. Tipping Points can be achieved by seemingly small changes, the proverbial straw that broke the camel's back, and once it occurs, can occur extremely rapidly in a geometric progression. (Gladwell, 2000)

The diffusion of ideas and adoption of trends, according to Gladwell, requires three agents of change, which he defines as the Law of the Few, the Stickiness Factor and the Power of Context. In the early stages of adoption, the Law of the Few suggests that a few exceptional

[8] Metcalfe's law states that the effect of a telecommunications network is proportional to the square of the connected users of the system.

people are responsible for spreading the word and starting epidemics, synonymous with Rogers' Innovators and Early Adopters:

- Connectors, people that are extraordinarily well-connected across diverse social groups.
- Mavens, specialist accumulators of knowledge who want to solve peoples' problems, theirs and others.
- Salesmen, with powers of persuasion.

Stickiness can refer to the way a message is presented or the experience a consumer has in using the new product or service (is it memorable for the right reasons, is it irresistible?). The Power of Context acknowledges what Bass later recognised, that adoption depends upon external factors, such as economic & social dynamics and that people and their preferences are acutely sensitive to their environment, time and place.

Essentially written as a hi-tech B2B market development model, Geoffrey Moore's "Crossing the Chasm", builds on Rogers' adoption theory arguing that the Technology Adoption Life Cycle is not a continuous, smooth curve, transitioning from the early market visionaries to a mainstream market of pragmatists, but that the attitudes of any two psychographic[9] groups are distinct, creating "cracks". Early Adopters and the Early Majority are fundamentally incompatible, creating a "chasm" (see Figure 2). Early Adopters are visionaries and risk takers, looking for revolution, the Early Majority are pragmatists, seeking evolution and incremental change. (Moore, 2013)

[9] Psychographics is a qualitative methodology of studying consumers focused on emotions & values.

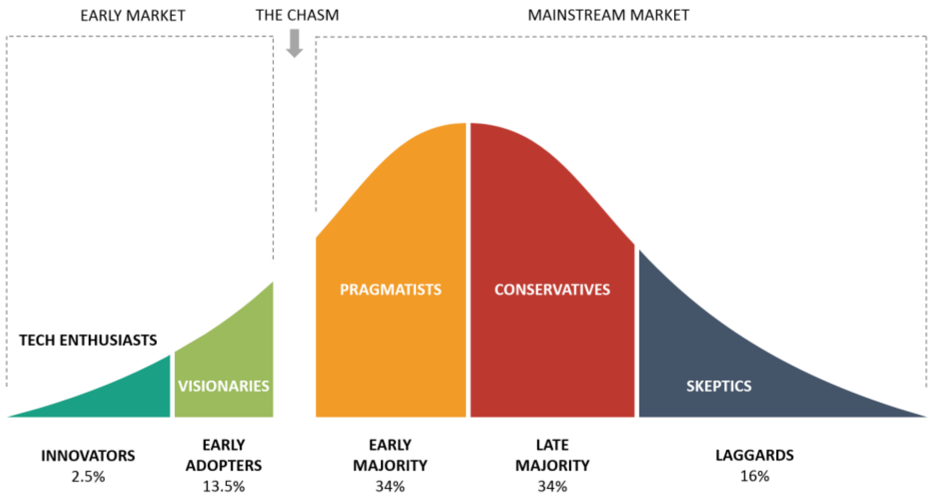


Figure 2: Technology Adoption Life Cycle, Geoffrey Moore, Crossing the Chasm (Moore, 2013)

To cross the chasm, the idea or product or message must evolve and focus on each individual group and its values and behaviours. The concept of developing the "whole product" is fundamental. Moore defines four categories of product - generic, expected augmented and potential – from the basic product to the inclusion of all the ancillary products and services that could be generated in future. In the case of electric vehicles, we can imagine basic ancillary services or features such as service & maintenance, charging infrastructure, increasing in sophistication to include battery or charging as a service, autonomous driving ability, connectivity (with other cars, infrastructure or other services & apps). As we move from left to right along the adoption curve, the requirements (to achieve a compelling reason to buy) of each subsequent group increase and to cross the chasm, generally the whole product must be available. Gladwell suggests that the Law of the Few is also fundamental in overcoming the chasm.

Comin & Hobijn examined the diffusion of 20 technologies across 23 leading industrial economies and found that advanced economies tend to adopt new technologies first and then there is a trickle-down effect to developing economies. The rate of adoption is influenced by the country's human capital, type of government, openness to trade and adoption of previous technologies. The second observation is that the rate of adoption has accelerated markedly in the last 70 years (see Figure 3). (Comin & Hobijn, 2003)

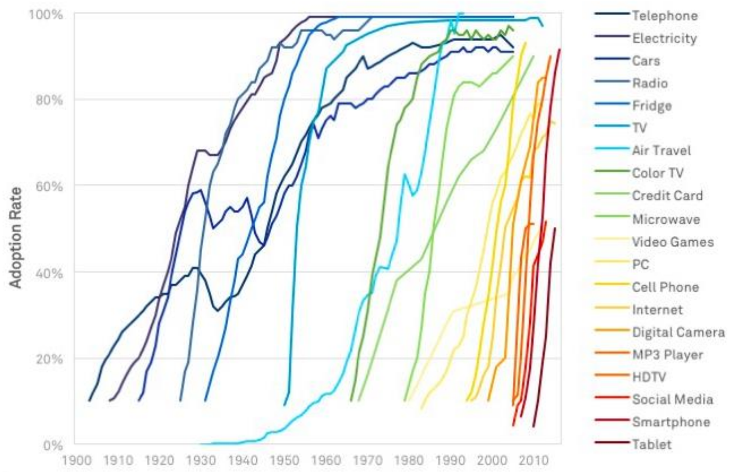


Figure 3: Adoption of Technology in the US 1900 to present (Comin & Hobijn, 2003)

This accelerated adoption is partly because recent innovations require less infrastructure but also that consumers are far more connected, more technologically aware and perhaps more open to trying new ideas and new technology that disseminate globally in a very short time period. Perhaps a greater number of us are Innovators and Early Adopters, particularly for small ticket "must have" innovations.

Bain Capital identifies four forecasting tools for tipping points: Experience Curves (Wright's & Moore's Law), Elements of Value analysis (identifying the valuable features), Adoption Curves (timing, pace of adoption & saturation point). Analysis of Barriers & Accelerators (government policy/regulation, technology, customer attitudes/behaviour). (Gottfredson & O'Keeffe, 2019)

Bain observes that the battery pack curve (which represents approximately 25% of the vehicle cost), points to a tipping point. From 2010 to 2019 the cost of battery packs has fallen 87% from USD 1,100 per kWh to approximately USD 156 per kWh[10]. Prices are falling much faster than predicted and could possibly reach USD 61 kWh, crossing the widely viewed tipping point of USD 100 per kWh[11] between 2020 & 2023 (Tesla is already at an estimated USD 124 per

[10] Bloomberg New Energy Finance.
[11] At this cost Battery Electric Vehicles (BEVs) are expected to reach purchase price parity with conventional Internal Combustion Engine (ICE) vehicles.

kWh). The experience curve doesn't necessarily translate into a reduced purchase price for the consumer but increased value: automakers thus far have added more cell capacity (for range) and improved margins.

The Elements of Value analysis is based on Maslow' hierarchy of needs, including Functional aspects (what does the innovation do), Emotional (how does it feel), Life Changing, Self-Transcendence (value to society). According to research by Bain and Dynata, consumers of electric vehicles place value on complex factors higher up the pyramid than for conventional vehicles such as self-transcendence, aesthetics, a sense of belonging, as well as ongoing cost savings.

Bain observes that adoption curves have a different shape and timing for different consumer segments. For example, commercial users will start to adopt electric vehicle once the Total Cost of Ownership (TCO)[12] compared to a conventional ICE vehicle is favourable, whereas a private consumer is expected to adopt (early & late majorities) when purchase price parity is achieved, which occurs later.

So, given the different requirements for different consumers, can we put a mathematical value on the tipping point? In 2011, scientists at the Social Cognitive Networks, Academic Research Centre at the Rensselaer Polytechnic Institute using computer models of different social networks found that once 10% of the population holds an unshakeable belief, then it will be adopted by most of the society. This is a somewhat lower tipping point than that suggested by Rogers' or Moore's "Chasm", which on a normalised adoption curve occurs at approximately 16%.

3.1.3. Learning Curves (Experience Curves)

Theodore Wright was one of the first to observe the effect of learning or experience curves whilst studying the production of aeroplanes. In his paper "Factors affecting the Cost of

[12] The Total Cost of Ownership of a vehicle incorporates all the costs including the purchase price, the cost of fuel or electricity for a given annual mileage, annual service and maintenance costs, insurance, finance etc. for a given time period, typically five years.

Airplanes", published in 1936, he observed that with the *cumulative*[13] doubling of production the marginal cost per unit produced fell by approximately 15%. In 1965, Gordon Moore observed that the number of transistors on a chip doubled every two years, causing computer costs to have, and that this trend was predicted to continue. In 2012, researchers from MIT & the Santa Fe Institute, published a paper "Statistical Basis for Predicting Technological Progress" found that both "laws" effectively predicted the falling costs of various innovations, but that Wright's law was slightly more accurate. (Handy, 2013)

Research by Ark Invest, a hedge fund focussed on disruptive innovation, goes further and suggests that between 2005 & 2015 application of Wright's law to production and price of semiconductors was 40% more accurate than Moore's law. Applying the same process to the cost of batteries, Moore's law (which focuses on time) suggests that a peak in battery cost reduction had already been reached in 2005 (see Figure 4) but this fails to recognise that a threshold in cost was crossed that permitted mass production of Electric Vehicles. Wright's law (that focuses on production) correctly predicts that costs have continued as production rapidly increased and will continue to fall. When one considers that a BEV typically has the same battery power of 2,500 iPhones (5,000 if considering a Tesla Model S or X) a 1% auto sales conversion will double the demand for batteries required for new smart phones[14]. (Winton, 2019)

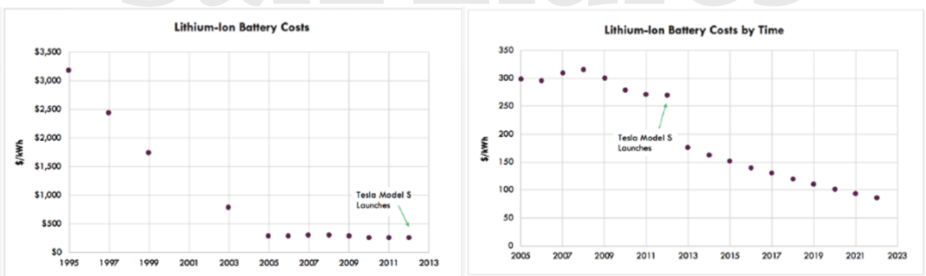


Figure 4: Reduction in Lithium-ion battery costs over time (Winton, 2019)

Learning curves have been studied over the years by various researchers. Lieberman, in his paper the learning curve, diffusion and competitive strategy, explores how the learning rate

[13] The cumulative production implies a geometric progression that becomes increasingly more difficult to achieve.
[14] The average EV has a 45 kWh to 50kWh battery compared to 17.5 to 20Wh for a typical smartphone, a factor of 2500. Global smartphone sales in 2019 were 1.525 billion, equivalent to 610,000 cars, which is less than 1% of global car sales of 75 million in 2019. Source: Statista.

and information diffusion impacts upon competitive strategy in terms of entry barriers, profits and price dynamics. (Lieberman, 1987)

The learning curve predicts that as output or production of a good increases over time its marginal cost (and price) decreases, eventually approaching zero. The fundamental theory is based upon four principal categories of cost reduction: (1) Research & Development; (2) Learning by Doing; (3) Economies of Scale; and (4) Learning by Waiting (innovation by others). (O'Connor, 2016)

Frank Bass, building on his earlier research, merges the theories of adoption of innovations and experience-curve theory to develop a dynamic theory of demand and price for consumer durable technological innovations, recognising that his initial model only considered social and behavioural influences on the timing of adoption, whilst ignoring economic factors. As a result of learning, costs and prices of consumer durables will fall continuously, while demand will grow increasingly rapidly before declining as markets are saturated or innovation appears. (Bass, 2004)

Frank Geels, in his paper "Technological transitions as evolutionary reconfiguration processes" investigates the patterns and mechanisms in transition processes. He argues that technological transitions are the result not just of technological innovation but also as a result of societal influences, such as user practices, regulation, infrastructure, industrial practices and culture. (Geels, 2002)

In more recent paper co-authored by Frank Geels, "Technological diffusion as a process of societal embedding", that successful diffusion and adoption of electric vehicles requires a process of embedding in society that involves multiple actors beyond policymakers and purchasers. The dynamic of activities and struggles during the diffusion pathways shape not only the infrastructure, policies, cultural meaning and user practices but also the specific functionalities: whether adoption is simply a direct substitute of a fossil fuel car for electric or whether adoption leads to a change in the mobility paradigm. The paper further argues that the characteristics (preferences, actors, symbols, markets, regulations & infrastructure) are not known in advance but constructed during the diffusion process. The implication is that the directionality of diffusion is not homogenous but that the multiple technical, economic, regulatory & cultural dimensions can lead to very different outcomes (e.g., different societal preferences & different mobility systems). (Kanger et al., 2019)

Similarly, Kentaro Toyama in his book, "The Geek Heresy", argues that whilst technology has a place in helping to solve social problems, the application of technology in and of itself is not sufficient to cause a social impact. In addition to the application of adequate technology, the outcomes are dependent on the social context and in particular the human context. That is to say that there must be a desire amongst the stakeholders to cause a social impact, as well as a capacity and a desire to effect such change. Technology therefore acts as an accelerator or amplifier of the existing human context. The response to global climate change has certainly pushed governments to support alternative forms of mobility (electric and hybrid vehicles) with future bans on diesel vehicles and subsidies for purchasing EVs and investments in cycle lanes. Can Toyama's social impact argument explain the very recent acceleration in the adoption of Electric Vehicles? (Toyama, 2015)

The implications for the adoption of disruptive innovations such as the electric vehicle is that reaching a tipping point requires a network of consumers who change their behaviour and increase experience, a social willingness to effect change, infrastructure of supporting businesses, innovative companies that increase their return at least in the medium term by reducing costs (and possibly prices) through learning.

3.2. Urbanism & Sustainable Transportation

3.2.1. Modern Urbanism

According to the UN[15] more than 4 billion people live in urban areas and that the point of inflection, where more people live in urban areas globally than live in rural areas, was achieved in 2007. By 2050, the UN predicts that more than two-thirds of the global population will live in urban areas – close to 7 billion people. Existing urban problems, such as congestion &

[15] World Urbanization Prospects 2018.

pollution (air and noise), inadequate infrastructure, economic and social inequality will be exacerbated if our cities do not adapt for the improvement and enrichment of lives.

One of the most influential authors of modern urbanism[16], Jane Jacobs, critiqued the prevailing urban planning paradigm of the 1950s. Her notorious battle against New York city planner, Robert Moses was the backdrop for this battle of ideologies that still resonates today. Jacobs accused the big urban planning projects of sacking rather than rebuilding cities, leading to social disruption, instability and decay. Essentially impacting the social & economic vitality of the "Great American City".

Jacobs understood cities as an immense laboratory of trial & error, failure and success in planning and design, experiments the results of which had not been heeded by planners in real life. Planners since the 1920s had struggled with making cities compatible with automobiles, but Jacob's described automobiles as a symptom rather than a cause of city failure and that the major problems with modern cities were erroneously reduced to traffic congestion or pollution. Jacobs understood that social & economic problems in a city were more intricate. (Jacobs, 1961)

Jacobs critiqued "decentrists" such as Lewis Mumford an advocate of Sir Ebenezer Howard's "Garden Cities" or Le Corbusier's "Radiant City", self-contained (employment, culture, dwelling, commerce), highly planned and controlled suburban new towns to relieve pressure on traditional cities. Jacobs was against these ordered, sterile, planned environments and for varied vibrant, streets with diversity of uses (commerce, restaurants, bars and residences) that enrich the human experience.

Sidewalks are at the core of Jacob's vision for city life, promoting safety, trust and a sense of community that cannot be achieved in artificial public places. Diversity is a key component of lively cities, with districts serving multiple purposes to ensure the presence of diverse people and avoid "homogeny & dullness". To improve city performance Jacobs argued amongst other things there should be subsidised dwellings (in regular building rather than projects) to increase

[16] The study of how the urban population interacts with its built environment.

diversity and equality, attrition of automobiles by widening sidewalks and accommodating city transport to reduce car use and congestion. Lively diverse areas encourage walking.

Richard Sennett, in his book "Building & Dwelling: Ethics for the City", distinguishes between the "Ville" – the physical buildings of the city - and the "Cité" – the way of life, a mentality based on "perceptions, behaviours and beliefs" – this is the essence of urbanism. He explores the tension between these two ideas and whether urbanism should represent how people want to live or seek to change it. Is it possible to engineer a "Ville" that will improve lives? Precisely because cities involve humans and their unpredictable behaviour, the relationship between these two concepts is "crooked" rather than seamless. Sennet argues that consequently modern urbanism needs to be "open", embracing complexity, ambiguity & uncertainty. The ethical and open city is also tolerant to diversity, flexible and provides society with opportunities to share information, choice, freedom to experiment and expand experience. (Sennett, 2018)

Long-term, large scale urban planning is difficulty because of this complexity and Sennet prefers a "modest" approach, aligned with Jacob's small-scale planning, rather than Lewis Mumford's planned metropolis. To Sennet, social & ethnic diversity in the city is a central ethical problem. How we relate and interact to others, the open city is a place to do rather than belong. Urban design has an important function to play, both the architecture and land use planning, including what he refers to "permeable open spaces" – spaces that can adapt, change and expand as required by Society. He advocates for the cooperation between formal planners and communities in this design process. This adaptive, "accretive" method of city building is ideal but in the modern built environment "rupture is inevitable in a rapidly evolving scenario. Rupture can also be an agent for social justice e.g., transport solutions from deprived areas of the city.

This complex interaction between humans and their urban environment is also the theme of Jan Gehl's "Cities for People". For Gehl, the human dimension is often overlooked in the battle for supremacy with the automobile. Pollution, noise, accidents and reducing pedestrianism means that the social and cultural functions of the city are under siege. The growth in vehicular traffic has been explosive in most cities and the competition for city space intense. Gehl argues that lively, safe, sustainable & healthy cities can be achieved by "inviting" people to walk, cycle or stay in city space. Compared with other social investments such as healthcare and auto infrastructure the cost of the human dimension is modest.

Gehl recognises the direct correlation between our cities and the human experience – "first we shape cities, then they shape us", further noting that "cities get as much traffic as space allows". By reducing the space allowed for private vehicles and reducing capacity, traffic will be reduced. Conversely building more roads and parking spaces, as has occurred over the last 50 to 60 years, only encourages and increases traffic. Citing examples such as Copenhagen, London, Venice, and Melbourne, Gehl demonstrates the success of revitalising public urban spaces and city life by focussing on the human dimension.

Understanding the human scale (of the body and our senses) is essential to creating cities for people. Many of the world's cities are too big, too tall and too fast. Since urban planning during much of the twentieth century has focussed on space for the private automobile, the sense of proportion and scale does not invite a pleasurable human experience. A lively city requires a city space that is inviting and popular, that is varied and complex. The city is a meeting place and people come to where people are, it is self-reinforcing. By slowing traffic (promoting pedestrianism & cycling), cities are more attractive, and safer - not only through reducing pollution or traffic accidents but also through Jacobs "eyes on the street". Reduced reliance on fossil fuels for mobility is clearly more sustainable with reductions in emissions, pollution and energy consumption; cycling and walking by comparison are 60 times and 20 times more energy efficient than using and automobile. Pedestrian and cycle traffic also use less space; a bicycle path transports five times more people than a car lane, 10 bicycles fit in one parking space. A healthy city reduces the harmful effects of our increasingly sedentary lifestyles behind the steering wheel and the computer screen. (Gehl, 2010)

In addition to reaching the inflection point for urbanization we have also reached the inflection point online as the billions of networked objects connected to the internet transform and "infiltrate" our cities and our lives. Anthony Townsend, author of "Smart Cities: Big data, civic hackers, and the quest for a new utopia", calls the digitisation and transformation into smart cities "inevitable" and explores how ubiquitous digital technology, particularly mobile, will shape the world and how we live.

Townsend draws parallels between planners such as Moses, building controlled environments based around a network of roads for the automobile, and big tech building a controlled environment around digital networks. Big tech's vision of the smart city is centred on efficiency and control, fixing problems of the past and preparing for future challenges such as congestion, global warming and declining health. Townsend argues that corporate plans for "cookie cutter" smart cities will result in Jacob's dull cities and that development of smart cities should involve citizens in their creation, "civic hackers".

This bottom up, participatory approach, rather than one size fits all top-down design, reintroduces serendipity, the possibility of positive unintended consequences into urban design. It is the modern-day equivalent of Jacobs' activism against paternalism and control. However, Townsend believes that the pendulum swung too far in favour of Jacobs and that activists invoked her ideas to oppose anything perceived as threatening, including carbon footprint projects and affordable homes. Townsend sees a parallel between big tech's rhetoric about efficiency with 1920's traffic engineers and warns that the decisions we make today live with us for a very long time to come.

The Scottish sociologist, Sir Patrick Geddes approached problem fixing by demanding total participation through small incremental changes, but incremental change takes time. Smart cities and ubiquitous computing, predominantly mobile, are a complex integration of human factors, computer science, engineering and social sciences and not a quick fix for urgent problems. Townsend advocates a combinatorial approach to smart city technology, employing the broad innovation of "civic hackers" (one app at a time), as well as big tech in an open-source smart city. The civic hacker, driven by sociability, resilience, serendipity and delight is the antithesis to big tech's control and efficiency. If sociability and collaboration is the goal, then a grass roots approach is advantageous to problem solving, but scaling requires engineering prowess, the domain of big tech. Care is needed to ensure that smart systems don't create exclusions or increase inequality and social tension. (Townsend, 2013)

3.2.2. Sustainable Transportation

Conventional transport planning revolves around derived demand[17] and cost minimisation (both monetary and temporal). As urban distances and speeds have increased, local public transport has become less attractive, as have walking and cycling, with a correspondent use of the car. (Banister, 2008)

Banister proposes an alternative paradigm for sustainable mobility that focuses on urban developments with medium densities, mixed use developments, to minimise the need for and the time for travel, and a preference for public transport. Average trip lengths should be below the thresholds required for maximum use of walk and cycle modes. The intention is not to prohibit use of the car but to design cities of such quality and suitable scale that private cars are not required. In this context some congestion is desirable for environmental and safety reasons as well as to encourage the use of alternative modes of transportation.

Policies for sustainable mobility should be founded on a reduction in the need to travel (mobile working, internet shopping), encouraging a modal shift to public transport, cycling or walking, a reduction in trip lengths and greater efficiency in the transport system. Slowing urban traffic, a reallocation of space to public transport, parking controls, road pricing (congestion charges) and creating desirable urban environments can encourage this modal shift.

A key element to driving sustainable transport policy is involving the public and gaining their acceptance. Rationality and complete knowledge are not enough to overcome the seductiveness of the private car. Using push and pull measures, reallocating space, creating efficient and attractive alternatives (car-pooling, public transport, cycling and walking) and "penalizing" the use of private cars or at least making them pay the full external cost, including health, pollution and road maintenance. Acceptability and behavioural change are essential but often neglected elements of sustainable mobility.

[17] Derived demand is an activity that is undertaken for a purpose other than for the activity itself. The value of the activity (e.g., work) at the destination largely results in travel.

Additionally, the importance of employing technology in incremental improvements, for example through the creation of multimodal MaaS[18] platforms can significantly reduce the use of cars[19]. (Dijkstra et al., 2019)

For others such as Boyd Cohen sustainable transportation is part of a much greater transformation towards sustainable consumption and production. Particularly in high density urban scenarios the concepts of sharing and the circular economy[20] are accelerating through the ubiquity of mobile technologies and are fundamental to sustainable cities and sustainable development. (Cohen & Muñoz, 2016)

The emerging sharing economy in urban centres is of particular interest for transportation when one considers that cars are an underutilised asset spending as much as 95%[21] of their time in parking. The case for sharing cars is compelling as fewer cars means less congestion[22] (time), less pollution (health) and more efficient asset use (economics). The sharing economies of collaborative consumption are notably exemplified by the rise of Airbnb and Uber in recent years. Driven by economic recession, environmental consciousness and the ubiquity of technology new sharing models have arisen to challenge traditional thinking on production and consumption. Cohen explores the rise of carsharing, ridesharing and bike sharing, noting that the private sector has developed these models to address failures in private and public mobility. He examines the interplay between public and private interests, noting that conflicting goals (e.g., environmental versus economic) can occur in an agent and principal relationship. Sustainability in transportation requires optimal congestion not minimal congestion, through fewer trips, modal shift (e.g., shared or public transport), distance reduction (though mixed-use urban development) and energy efficiency. Cohen concludes that aligning objectives amongst public and private interests by moving towards merit-based[23] business models could minimise conflicts. Very often, as we have seen with Peer to Peer (P2P) Ridesharing (Uber) the disruptive

[18] MaaS: Mobility as a service.
[19] Reported reduction of 38% following the introduction of Jelbi in Berlin.
[20] A circular economy is a model of production and consumption that involves sharing, reusing, repairing and recycling materials and products, reducing waste to a minimum.
[21] The 95% level has been claimed over much time by urban planners and transportation experts, including Paul Barter, author of Reinventing Parking.
[22] For every shared vehicle 9 to 13 private vehicles can potentially be removed from the roads.
[23] Merit goods are those goods that are seen as important for providing positive social benefits, for example, healthcare, education, public transport.

nature of the business model and a failure to collaborate could threaten the longevity of the business model. (Cohen & Kietzmann, 2014)

McKinsey envisages a future of seamless mobility by optimising supply and demand, whilst improving sustainability. Lines amongst private, shared and public transport will become blurred in the future of sustainable transportation. Congestions in large cities is increasing with growing urban populations and greater wealth, exacerbated by last mile delivery, which accounts for approximately 20% of congestion. Faced with the worsening urban problems of noise, pollution, congestion and urban decay, sustainable transport solutions will need to be evaluated on their availability, affordability, efficiency, convenience and sustainability. Automakers will eventually evolve from selling cars to selling mobility. (Hannon et al., 2019)

In an urban scenario, where cars provide significant passenger kilometres (baseline estimate of 35% in dense urban centres) even in significant public transport cities, there is little autonomy and few electric vehicles. McKinsey outlines three future scenarios: business as usual where there is little innovation in technology, pricing or government policy – private cars continue to account for 35% of passenger-km; unconstrained autonomy, with the adoption of shared, automated vehicles ("robotaxis" and shuttles) with a 25% adoption by 2050 – regulation lags and tech falls short of its full potential; and seamless mobility where connectivity, autonomy, sharing and electrification combine to unlock the full technological potential. In this latter scenario mobility is provided by robotaxis, autonomous shuttles, managed by intelligent traffic and rail systems, predictive maintenance, all accompanied by effective regulation and incentives (see Figure 5).

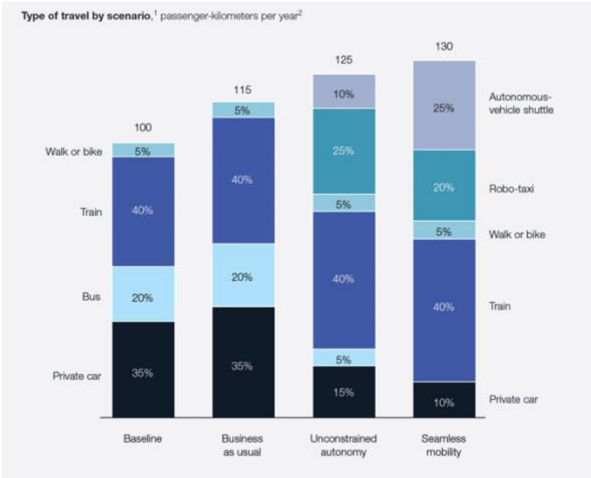


Figure 5: McKinsey prediction of future tyre of travel by scenario (Hannon et al., 2019)

Supply optimisation though connected intelligent traffic systems, minimise wait times and maximise movement. Connected, smart parking minimises movement and time to find a parking space. Predictive maintenance, using big data and machine learning tools, and advanced signalling, increases efficiency and reduces downtime of mass transportation solutions. Connected car communication for automated vehicles, means cars can drive closer together and increase road capacity by up to 10%.

Demand optimisation through incentives for non-peak driving (e.g., congestion charges). Dedicated lanes for shared transportation, shuttles, e-hailing and ridesharing. New modes to connect to major transportation hubs – links with micromobility[24]. Licensing taxis and autonomous vehicles. Encouraging off-peak deliveries.

Sustainability can be improved though management of emissions standards and incentivising both electrification and the use of renewable electricity sources, through electrification of fleet and government vehicles. In many European cities there are already low or no emission zones.

The implications of seamless mobility are wide ranging, with significant impact upon what McKinsey describes as the four layers of an urban transportation system:

[24] E-bikes and e-scooters have a potentially significant role to play in last mile mobility.

1. Infrastructure (roads, rail, transport hubs, parking, energy systems & charging infrastructure): smart and connected, with sensors for traffic management and predictive maintenance.
2. Rolling Stock (cars, buses, trains etc.): autonomous, shared, connected & electric vehicles, as discussed further in chapter 7, have far reaching consequences for vehicle manufacturers who must rethink their product portfolios, investment strategies and value chains. ***ACES[25] means potentially fewer private vehicles, more technology, and a greater focus on passenger experience rather than driver experience***.
3. Data & Analytics: ticketing, payments, maps, vehicle matching & routing, congestion tracking and pricing. Role of technology companies in sensor applications and MaaS.[26]
4. User Interface: navigation apps and payment integration. Multimodal navigation apps may facilitate the use of multiple public & private transport modes for a particular journey and reduce private vehicle ownership.

A key question for the sustainable mobility revolution is which technology will prevail. In 2010, Eberle & Helmolt discussed the relative merits of two types of electric vehicle concept, those driven by batteries and those driven by fuel cells, specifically hydrogen fuel cells. Whilst written over 10 years ago and by two scientists in the employment of General Motors, at a time when the automobile industry was generally dismissive of Battery Electric Vehicles (BEVs) as a total solution, their comparative study does raise some interesting points that this technology would have to overcome if mass adoption were to succeed.

In comparing battery storage technology versus fuel cell technology, Eberle & Helmot identify two critical barriers to adoption: energy storage capacity and charging or refuelling time. A key difficulty in substituting conventional gasoline or diesel ICE vehicles is that fossil fuels are relatively cheap and energy dense. A 500km journey undertaken by a conventional vehicle requires a system (fuel tank and fuel) that weighs considerably less and takes up considerably less space than the Hydrogen and battery systems that would replace them (see Figure 6). In addition, the cost of a hydrogen system was estimated at USD 3,000 compared with an equivalent battery system of USD 50,000.

[25] ACES: Autonomous, Connected, Electric, Shared.
[26] MaaS: Mobility as a Service.

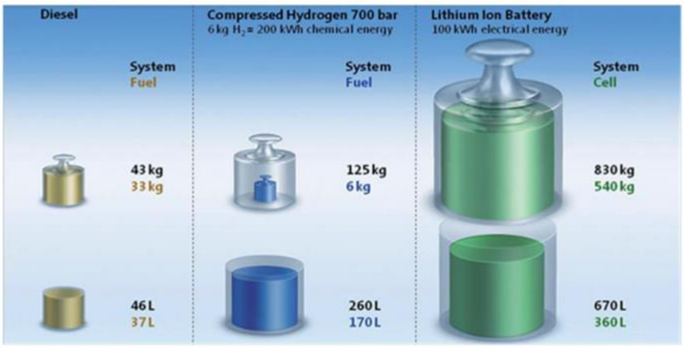


Figure 6: Energy storage weight and volume comparison for a 500 km vehicle.

Eberle & Helmot conclude that it is not necessarily and either-or scenario, but that Battery Electric Vehicles would be more effective for small urban vehicles with light loads and a battery range of up to 150km, with hydrogen and its high energy density[27] being more useful for high load and extended range applications, such as for buses and transportation of goods by truck or longer private passenger journeys. They argue that a small BEV such as the Chevy Volt and its pure BEV range of 60km would satisfy 80% of daily driving profiles. Infrastructure is also a critical barrier for both technologies. Whilst for hydrogen an estimated 12,000 hydrogen filling stations[28] would be required in the US for 1 million vehicles at an estimated cost of USD 10 to 15 billion, those service stations could service hundreds of vehicles per day compared to only a few per day for charging points. Fuelling time for hydrogen is similar to gasoline, whilst charging a vehicle typically takes several hours. Consequently, public chargers would need to approach a ratio of one charger per electric vehicle and whilst individually much cheaper than a hydrogen filling station would approach a similar cost of investment for the network. (Eberle & von Helmolt, 2010)

Like Eberle and Helmolt, McKinsey also argues for the complementary nature of both hydrogen technology and battery electric vehicles. Hydrogen has many advantages including refuel time (15x faster) than fast charging[29], less capital intensive and less refuelling space required (traditional service stations can de repurposed) and the requirement for mining rare metals such as cobalt, nickel and lithium versus hydrogen, which is a by-product of water.

[27] Hydrogen has an energy density of 1600 Watt hours per kilogram compared to 90 Wh per kg for a Lithium-ion battery at the time of writing (2010).
[28] Intra-urban 6,500 at a separation of 2 miles and 5,500 extra-urban with a separation of 25 miles.
[29] The rapid technological advancements in fast charging and alternative services such as replacement of fully charged battery packs (Battery as a Service) have the potential to significantly reduce this differential.

However, hydrogen is costly to produce and extremely energy intensive, highly volatile creating technical and infrastructure challenges for transportation and storage. Heavy vehicles or vehicles requiring greater autonomy (requiring larger and very heavy batteries) represent an opportunity for hydrogen. (Heineke & Kampshoff, 2019)

Antiquated transportation systems are becoming overwhelmed by the rapid growth in people cars and travel. Incremental improvements will not halt the slow deterioration in environmental and urban conditions. A radical rethink of transportation in the 21st century is required. But how does one reverse the ill effects and dominance of the automobile without curtailing freedom of movement and choice? (Sperling, 1995)

Sperling argues that the automotive industry, contrary to the belief of some incumbents, is not a mature industry, but on the verge of technological revolution. Technologies that reduce energy consumption and pollution will transform the industry. America's automakers initial opposition to the pioneering Zero-Emission-Vehicle mandate, introduced by the Californian Air Resources Board in 1990 aimed to slow the rate of technological change. Consumer preference for environmentally friendly solutions, commitment of the local and state government and industry competition would ensure that change is unstoppable.

The automobile population has grown at a faster rate than the human population in the last 70 years. In the 1950s there were approximately 2 vehicles for every 100 people. By the turn of the century, 10 per 100 people, an increase from 50 million cars to 600 million. At this rate there could be over 3 billion cars by 2050 or 20 cars per 100 people, and still far from saturation[30]. If the air in our cities is not to become unbreathable, electric propulsion is of paramount importance.

Though central to his argument, a sustainable future requires more than electric propulsion, involving policies and programs to reduce solo driving, alternative fuels, and "intelligent" technology in transportation systems. He notes that progress has been slow in both reducing automobile use and adoption of electric mobility. Nevertheless, he does not advocate turning back to a pre-automotive age. Instead, motor vehicle users should be made to pay the full cost

[30] The US has a fleet of approximately 70 cars per 100 people.

of their vehicle use, including amongst other costs, congestion, accidents and environmental impacts, rather than the estimated 68 to 80 percent US drivers currently pay[31]. Reducing reliance on private vehicles requires substantial improvements in public transit access and the use of mobile technologies. However, the social benefits of driving - freedom, privacy, convenience and security – are substantial. In most developed countries, the automobile accounts for between 75 and 85 percent of local travel.

Public transport is in decline in almost all advanced economies[32]. Mandates or incentives have failed to induce people to use public transport, bicycles, to telecommute, share rides or change residence or workplace. Technical fixes, such as fuel efficiency and controlled emissions, that reduce the social cost of vehicles, whilst requiring few behavioural changes are more readily accepted by the public but have a limited impact.

Sperling's vision for the next 25 years (to 2020) was a combination of measures and milestones to propagate the adoption of cleaner technologies, including:

- Funding for innovative technology.
- Taxes for polluting vehicles and rebates for clean vehicles
- Tradeable greenhouse emission standards
- Automakers move their R&D budget from ICE efficiency and emissions to zero-emitting fuel cell vehicles.
- Adoption of small neighbourhood electric cars in suburban areas: full size vehicles are banned during daytime hours.
- Mobility companies, including electricity utility companies, rent electric vehicles for a monthly subscription.
- Fuel cell and battery powered vehicles begin to represent a significant participation in the market, led by California, where by 2020 all vehicles are zero emission. Solar-hydrogen farms become prevalent to serve the fuel-cell market.

Sperling may have been ahead of his time with some of his predictions, but he correctly predicted the general direction of sustainable transportation in the last 25 years.

[31] Congressional Office of Technology Assessment.
[32] Only 4% in the US and below 20% in Western Europe.

Government policy is at the forefront of sustainable transportation transformation but is fragmented and often misguided. For example, mandatory emissions testing of older vehicles or cash incentives for exchanging older vehicles have been costly and largely ineffective strategies. New car emission standards, on the other hand have been very effective but further gains are likely to be only incremental, like fuel economy standards. Electric vehicles would provide greater benefits but there needs to be incentives for consumers to buy them and automakers to make them.

Intelligent vehicle and highway systems (IVHS) aim to get more use out of existing roadways by providing up to date traffic information and helping drivers find the most efficient routes, parking availability and other locations. By improving flow and reducing congestion, pollution is reduced. Such systems are also a precursor to autonomous vehicle, with fewer accidents, less lane space and following distance increasing the capacity of existing roads. The obstacles to autonomous vehicles are many, as shall be discussed in subsequent chapters, and the benefits of increased road capacity would only be realizable once virtually all cars are autonomous or only in specified lanes or automated highways reserved for autonomous vehicles. In the meantime, smart paratransit vehicles or shuttles, or other mobile mobility services could bridge the gap between public and private transport, particularly in suburban areas. IVHS can also enable differential pricing strategies to target a reduction in travel at peak times.

The sole justification for Electric Vehicles is air quality, reducing pollution and greenhouse gases, even if the electricity generation source is non-renewable. A kg of pollution in an urban scenario is far more harmful than the same kg in a non-urban location, where, for example, a coal fired electric plant might be situated. Electric vehicles powered by natural gas electric generation, lower greenhouse gases relative to ICEs and renewable sources, such as hydroelectricity, solar, wind or nuclear have nearly zero greenhouse gas emissions.

Sperling describes electric propulsion as inevitable because it is much more efficient[33], has fewer moving parts (cheaper maintenance), is quiet and potentially has no emissions.

[33] Electric motors are over 90% efficient (conversion into kinetic energy) compared to 15% to 25% efficiency for ICEs. Electric motors don't idle, so use no energy when the vehicle is not in motion, and electric vehicles can

Advancement in battery technology is key, improving energy density (and thus range) and long life, so they can compete with ICEs, and of course, cost. Focus on high energy density diminishes the prospect for hybrid vehicles that require high power density for acceleration or climbing. The limitations of the relative energy densities of gasoline and batteries can be overcome by making vehicles more energy efficient, alternatives for range, such as hybrid vehicles, fast charging or battery replacements (battery as a service).

Sperling did not expect that technology and economies of scale would ever reduce the purchase price of an EV to that of an equivalent ICE but that life cycle costs would reach equivalence, and thus leasing would become more prevalent to spread out the high cost of batteries. Consumer preferences will change overtime and currently lack information. Whilst range anxiety often features highly in negative feelings towards EVs, most households typically demand far less range for their day to day needs and is offset by the possibility of home charging, environmental consciousness, and lower operating costs. EVs will not necessarily directly substitute ICEs and could be a second car option.[34]

Sperling envisages that a new fuel distribution system would not be required and would not be a barrier, with low-cost charging facilities set up at home or in businesses, supported by electric utilities. The high cost of EVs would be a barrier to consumers, initially with demand being met by fleet owners (Mobility as a Service) or affluent consumers (Innovators and Early Adopters). Government subsidies and incentives are paramount to kick start demand for and adoption of Electric Vehicles in the early stages. (Sperling, 2018)

Sustainable and equitable transportation of the future requires user and mobility service company incentives, to embrace automated, electric and shared mobility services over private ownership, and redesign of urban centres to reduce car use and encourage sharing, walking or cycling. Battery electrification, particularly with a decarbonized electricity grid, is best suited to light vehicles and buses or trucks used in urban circulation for shorter routes. Hydrogen fuel

use regenerative braking to recapture energy usually lost during braking and have no transmission another source of energy loss for ICEs.

[34] Sperling's view that EVs could be a send household option for different, perhaps more local tasks, is very US centric, where typically a household would have access to more than one vehicle.

cell electrification or plug-in hybrids are best suited for heavier and long-distance transportation.

3.2.3. Symbiosis: Urbanism & Sustainable Transportation

The relationship between modern urban design, creating attractive, enriching and inclusive urban spaces and sustainable transportation share a symbiotic relationship. Much of the current literature focuses on reducing the use of the privately owned vehicle and the space that it occupies in today's cities, and increasing the use of public transport, micromobility, shared taxis and shuttles and the development of technology-led, integrated mobility services.

Transport for Under Two Degree's (T4<2º) report, "Way Forward", sponsored by the World Economic Forum. Recognises the need for a transport transformation to meet the Paris Agreement goals on climate change. The report, based on a survey of 346 experts in 56 countries, advocates redesignating land use towards more cycle lanes and pedestrianised areas, with public transport, bicycles and walking the dominant transport modes by 2050. Personal car use is not sustainable, efficient, or inclusive and there is no magic tech solution to this societal problem. Electric vehicles cannot solve the problem of congestion. Autonomous, shared vehicles are not likely to become mainstream until the second half of the century and in the interim could have more negative effects than positive (urban sprawl, unnecessary travel, energy use). A rethink in sustainable urban planning, shared mobility services and public transport is required, reducing space for cars and promoting efficient transportation. (Reid, 2020)

European cities are beginning to rethink the transformation of urban living taking a more holistic approach. In 2020, Amsterdam launched its City Doughnut, a template or compass for its vision of creating a thriving, regenerative and inclusive city. Drawing on the concepts developed by Kate Raworth, an Economist and Senior Associate at Oxford University, Doughnut Economics advocates for economies that do not surpass an upper ecological boundary and yet maintain minimum social standards. Applying this to a city such as Amsterdam, urban life is looked at through four lenses: social, ecological, local and global.

The impact on the wellbeing of citizens and the impact on the environment at both a local and planetary level.(Raworth, 2020; Raworth et al., 2020)

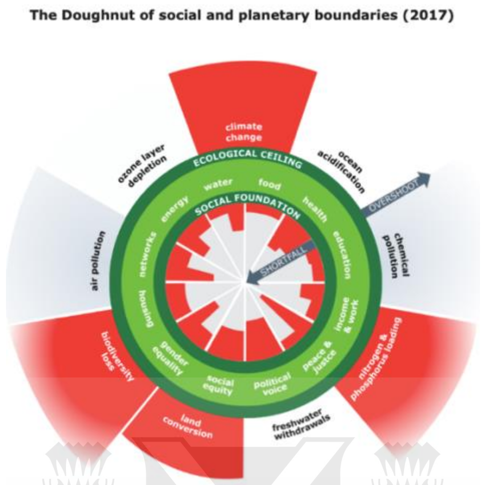


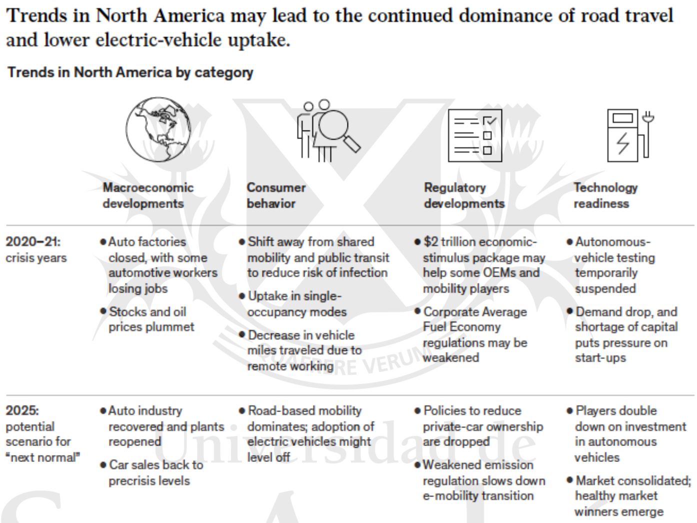
Figure 7: The doughnut model for sustainable cities (Raworth, 2020)

Professor Carlos Moreno, Scientific Director of Entrepreneurship & Innovation at the Sorbonne and a special envoy to the mayor's office in Paris, developed the idea of "la ville du quart d'heure" or 15-minute city to improve city living and the environment. The idea that services and quality of life can be found within 15 minutes of your home, including work, shops, entertainment, education and healthcare. Multi hour commutes are wasteful and damaging to the environment. Through use of mixed use or multipurpose buildings, repurposing land use for cycling and walking, pop-up galleries, markets and city gardens, creating a "amor des lieux", unnecessary car journeys can be eliminated. The idea is not to restrict people to within this 15-minute parameter or recreate villages but to reduce the need to travel further afield and create a sense of community with a live local philosophy. (Moreno, 2019; Whittle, 2020)

Nevertheless, this sense of personal restriction or indeed the economic reality that not everyone can live close to their work creates a potential friction with these ideas. The COVID-19 pandemic has potentially revealed a new vision of modern urban life with more teleworking and the push towards cycling and pedestrian transportation: people cycle or walk more when there is less traffic. Social distancing has forced people away from public transport back towards the private car but particularly to cycling and walking in dense urban cities.

Again, European cities have been at the vanguard of stimulating cycling with government funding to encourage cycling and walking, temporarily or permanently converting roads to cycling lanes or wider pavements[35]. (Butcher & Milne, 2020)

McKinsey warns that the COVID shift from shared mobility and public transport, however, could have longer term effects in North America, with continued dominance of the automobile and slowing the adoption of electric vehicle uptake. (Hausler et al., 2020)


Trends in North America may lead to the continued dominance of road travel and lower electric-vehicle uptake.

Trends in North America by category

	Macroeconomic developments	Consumer behavior	Regulatory developments	Technology readiness
2020–21: crisis years	• Auto factories closed, with some automotive workers losing jobs • Stocks and oil prices plummet	• Shift away from shared mobility and public transit to reduce risk of infection • Uptake in single-occupancy modes • Decrease in vehicle miles traveled due to remote working	• $2 trillion economic-stimulus package may help some OEMs and mobility players • Corporate Average Fuel Economy regulations may be weakened	• Autonomous-vehicle testing temporarily suspended • Demand drop, and shortage of capital puts pressure on start-ups
2025: potential scenario for "next normal"	• Auto industry recovered and plants reopened • Car sales back to precrisis levels	• Road-based mobility dominates; adoption of electric vehicles might level off	• Policies to reduce private-car ownership are dropped • Weakened emission regulation slows down e-mobility transition	• Players double down on investment in autonomous vehicles • Market consolidated; healthy market winners emerge

Figure 8: Impact of COVID on transport trends in North America (Hausler et al., 2020)

Current thinking, post pandemic, envisions a taking back of control of our cities from the dominance of the personal automobile both for our social wellbeing and for the environment. The advent of technology enhanced integrated public and private mobility services, increased emphasis on micro mobility and sharing rather than owning vehicles does not bode well for the private automobile.

What does this mean for the adoption of Electric Vehicles? Even if culturally, we are prepared to reduce or abandon our use of privately owned vehicles, those that do remain will inevitably be electric. A study by Daniel Peters & Daniel Horton at Northwest University, modelling the

[35] The Department for Transport in England has set aside £250 million to encourage cycling and walking, from subsidies for bicycle purchase to creating more cycle only or pedestrian only areas.

cost of carbon and the statistical value of life, estimated that the US could save up to USD 17 billion per annum with just 25% adoption of Electric vehicles and USD 70 billion at 75% adoption, though a reduction in health and climate impact from air pollution and greenhouse gases. (L. Steffen, 2020c)

4. Electric Vehicles & Technology

4.1. A Brief History of the Electric Vehicle

The rise and fall and rise again of the Electric Vehicle is a story of innovation and investment, access to alternative energy sources, infrastructure development and government policy and incentives. In the early years of the passenger motor vehicle, gasoline powered cars and electric cars are developed side by side. Freely available electricity in cities, and poor road conditions outside of cities[36], means that at the beginning of the 1900s, electric vehicles were more popular, particularly amongst women, as they were easy to drive and to start, and silent. In comparison, gasoline cars are noisy, dirty[37] and require a hand crank (and quite a bit of strength) to start.

Battery technology does not evolve at the same pace as the Internal Combustion Engine (ICE) technology and by 1910, Ford's new mass production processes for the Model T meant it was half the price of any available electric vehicle.

Charles Kettering's introduction of the electric starter in 1912, and other advances made ICE cars easier to drive, development of the oil industry (see Figure 9) provided a cheap and plentiful source of fuel and a rapidly expanding network of roads and a refuelling network out of urban centres meant that ICE's greater range and performance was much more attractive.

By the mid 1930's electric vehicles are practically abandoned and forgotten about until an oil crisis in the early 1970s causes a spike in prices. General Motors announces plans to revive electric vehicles in the 1980s, only to abandon the idea as oil prices once again dropped.

[36] Since cars are rarely used outside of cities because of poor road conditions and a lack of a refuelling network, autonomy of electric vehicles is not an issue.
[37] Ironically, early advertisements for the Model Ford T play upon the fact that horses pollute cities by defecating in the street.

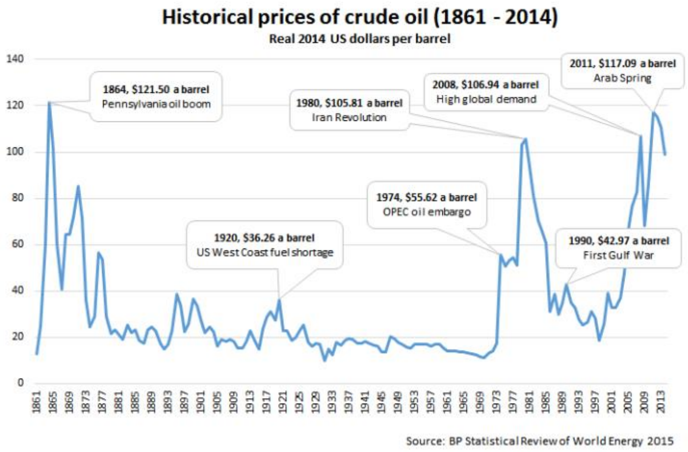


Figure 9: Historical Crude Oil Prices (1864-2014). Source: BP Statistical Review of World Energy 2015.

It is only when California adopts its Zero Emission Vehicle (ZEV) mandate in 1990, on concerns that pollution in its major cities is out of control, that investment is directed toward electric vehicle development, but even then, sums are modest compared to overall R&D spend, as resistance from incumbent automakers consider EVs too costly and too risky, with car batteries’ range and life a further concern.

Still in denial, automakers resort to lawsuits and ultimately agreed to develop next generation vehicles but preferring hybrids and fuel cell technology initially[38]. The recent push for EVs, is due to one concern, air quality, and has been driven by California Air Resources Board and in Washington with the Clean Air Act[39]. It is this push that has caused significant advancements in electric vehicle and battery technology. Ironically, the ability to trade ZEV credits, instead of facing a penalty, has also given rise to incumbent automakers greatest threat, Tesla, allowing the latter to leap forward in the advancement of electric propulsion, whilst banking EV credits from traditional automakers. (Sperling, 1995)

Gasoline powered cars have benefitted from over a century of research and development and whilst electric vehicles were largely forgotten about. The modern impulse for a return to a quieter and cleaner technology has largely been incentivised in the US by federal and state

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[38] Sperling agrees that if significant obstacles, such as the cost of hydrogen production and storage, can be overcome that Fuel cell technology is superior to both ICEs and BEVs.

[39] California’s ZEV mandate originally required that 2% of sales in 1998, increasing to 5% in 2001 and 10% in 2003, for major automakers were ZEVs. Several other States, such as Maine, Maryland, Massachusetts, New Jersey & New York have followed with similar mandates.

government. Battery research has been at the forefront of investment, with the Joint centre for Energy Storage (US Department of Energy), the Argonne National Laboratory and the Advanced Research Projects Agency – Energy at the vanguard of research and development. As battery costs have fallen precipitously the adoption of electric vehicles has once again gathered pace (see Figure 11). As costs fall and demand from environmentally conscious consumers, innovators and early adopters is piqued, the availability of a choice of different EV models and sizes accelerates (see Figure 12).

A brief history of the Electric Car

Year	Evolution
1828	First small-scale electric cars in Hungary Netherlands and the US.
1832	Robert Anderson, a British Inventor, develops a crude electric vehicle, essentially an electric carriage.
1870s	EVs gain in popularity.
1891	William Morrison, a chemist from Des Moines Iowa develops first successful US EV.
1899	Growing popularity versus gasoline and steam particularly in urban areas amongst women. Easy to start and drive, silent and clean. Baker electronic models range 70 to 100 miles.
1900 to 1912	EVs reach their peak accounting for one third of all vehicles on road, with a range of vehicle options, and an extensive network of charging stations.
1901	Henry Ford and Thomas Edison focussed on building a popular and high demand EV, with better battery technology and an extended range of over 100 miles. The project is eventually abandoned.
1901	Ferdinand Porsche develops first gasoline/electric hybrid, Lohner Porsche Mixte
1908-1912	Henry Ford's mass-produced Model T, makes gasoline powered cars widely available and affordable.
1912	Charles Kettering's electric starter further contributes to increasing sales of gasoline cars.
1920-1935	Improved road networks, particularly interurban highways, and the discovery of cheap Texas oil makes gasoline readily available in a growing network of service stations. Gasoline cars' greater range is more attractive and EVs all but disappear.
1936-1968	Cheap abundant gasoline leads to continued improvement in the internal combustion engine (ICE). No need for alternative fuel vehicles.
1968-1973	Oil and gasoline prices soar due to the Arab oil embargo, and Electric Vehicles become attractive again.
1971	First manned vehicle drives on the moon, NASA's lunar rover (built by GM and Boeing), raising profile of EVs.
1973	GM develops a prototype for an urban electric car.
1975	American Motor Company produces electric delivery jeeps for the US Postal Service.

1974-1977	Sebring Vanguard produces 2000 CitiCars with a 50-to-60-mile range and becomes the 6th largest US automaker by 1975.
1979	Oil prices have normalised and interest in EVs once again fades because of their limited performance and range compared to gasoline ICEs.
1990-1992	Federal and State Regulations, driven by a concern for cleaner air, spurs renewed interest in and research and development into EVs. Modifying popular models into EVs and improving speeds and performance
1996	GM produces the first mass produced modern Electric Vehicle, the EV1, which develops a cult following. High productions costs meant it was not commercially viable and was discontinued in 2001. GM literally destroys the EV1s when leases expire; "Who Killed the Electric Car?"
1997	Toyota produces the first mass-produced hybrid, the Toyota Prius. Released globally in 2000 it gains particular success amongst celebrities and those if a liberal political persuasion, helping to raise its profile.
2006	Tesla Motors, a small Silicon Valley start-up launches a luxury electric sports car, the Roadster, with a range of over 200 miles. With a USD 465 million loan from the US Department of Energy it established a manufacturing facility in California.
2009	The US Department of Energy invest over USD 115 million to help build a nationwide charging infrastructure, installing more than 18,000 residential, commercial and public chargers. With automakers and other private enterprise chargers there are over 8,000 public locations in the US.
2010	GM launches the Chevy Volt, the first plug-in hybrid, with battery technology developed by the Department of Energy.
2010	Nissan launches the Leaf, an all-electric, zero emissions car.
2013	US production of the Nissan Leaf financed by the Energy department
2013	Electric vehicle battery costs fall 50% in four years with heavy investment by the Energy Department (see Figure 11).
2014	By 2014 there are 23 plug-in electric vehicles and 36 hybrids, available in the US market (see Figure 12).

Figure 10: A brief history of the electric car. Reproduced from information sourced from the US Department of Energy and Bloomberg. (Gertz & Grenier, 2019; Matulka, 2014)

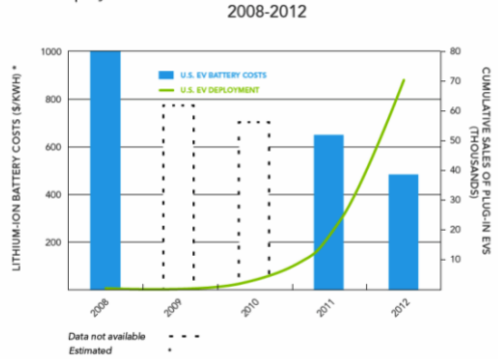

Figure 11: Deployment of electric vehicles versus battery costs (DOE). (Matulka, 2014)

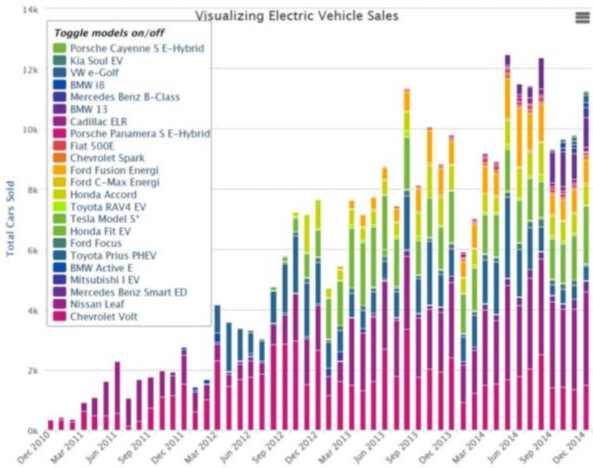

Figure 12: US Deployment of Electric Vehicles by model (DOE). (Matulka, 2014)

Modern day electric vehicles can be divided into three broad categories:

- Hybrid Electric Vehicles (HEV) – do not have the ability to plug in to recharge and do not normally operate in fully electric mode, although may have the ability to do so for a short period of time. The electric drive system enhances the energy efficiency, performance and a reduction in emissions acting in combination with the principal gasoline powered motor, particularly during acceleration or climbing. The battery is recharged through regenerative braking. The most popular example is the Toyota Prius.
- Plug-in Hybrid Electric Vehicles (PHEV) – can operate in either fully electric or fully ICE mode, or a combination of both, and the battery is recharged both by plugging in to an external power source and self-generated electricity. It contains a bigger battery than an HEV and is capable of extended all electric driving. Examples include the Kia Niro and the Chevrolet Volt.
- Extended Range Vehicles (EREV) - are essentially all-electric vehicles or battery electric vehicles that have a small ICE that extends the driving range by driving an electric generator and recharging the battery or driving the electric motor. Examples include the BMW i3.
- Battery Electric Vehicles (BEV) or All Electric Vehicles (AEV) - as the name suggests deriving all their power from its batteries and electric motors and are recharged by plugging into an electric power source through a charger. BEVs have no internal combustion engine, exhaust system, fuel tank or multi speed transmission. BEVs make take several hours to fully recharge but many models offer the functionality of a fast

charge boost in a short period of time, for example 70% in 30 minutes. Examples include any of the Tesla models, the Nissan Leaf, the VW e-Golf and the Chevrolet Bolt.

- A Fuel Cell Electric Vehicle (FCEV) – also generates electricity to power and electric motor but instead of a battery, employs a fuel cell to generate a chemical reaction, generally using compressed hydrogen and oxygen, with a by-product of water. Examples include the Hyundai Tucson ix35 and the Honda FCX Clarity.

All the different types of vehicles above are considered Electric Vehicles and all except HEVs are considered Zero Emission Vehicles (ZEV). (*BEVs, PHEVs and HEVs, Which Electric Vehicle Do You Drive?*, n.d.; Coulter, 2019; Matulka, 2014; Pritchard, 2018)

Hybrid vehicles produce less emissions and consume less energy than ICEs and have an extended range compared to BEVs, but they are more complex than either and must incorporate two drive systems and energy storage. They are useful as a transitional vehicle but are likely to be overtaken by fuel cell technology and squeezed by ZEV mandates[40]. Hybrids occupy a spectrum between pure BEVs and ICEs, from range extended battery hybrid, which operates mostly in ZEV mode, through dual mode hybrids that can operate in either mode, to the fuel engine electric hybrid, which has far lower emissions and energy consumption[41] but is unable to operate in full electric mode. (Sperling, 1995)

4.2. Battery Technology & Fuel Cells

4.2.1. Battery Technology – Current & Future

Successful electrification of vehicle fleets is based on 3 pillars: batteries, electric motors and powertronics (power management system). The single most important factor in the reduction

[40] Hybrid vehicles, except Plug-in Hybrids, do not qualify as ZEVs thus incentives are lower for incumbent automakers to invest in their development.
[41] Operating in hybrid mode vehicles consume 15% to 35% less gasoline than comparable ICE vehicles. Gasoline consumption of a range extended battery or dual mode hybrid is less than 10% of a comparable ICE vehicle.

in cost and improvement in performance and range of the Electric Vehicle is the battery technology.

The development of batteries over the years has involved several different chemistries, from lead acid batteries to the modern-day Lithium-ion batteries. The search for better chemistries is a search to balance high-energy density and high-power density, light in weight, ability to accept fast charge, with a long service life, production scalability, safety and cost. With high energy density materials, greater range can be achieved for a given weight and volume. High power density improves the flow of energy for performance, such as acceleration and torque. A long service life refers to the number of charge and discharge cycles or the ability to accept fast charge without significant deterioration in battery performance, typically 80% of the initial capacity[42]. Research for new generation batteries is focussed on metal-air batteries (Zinc and Lithium) and Li-Sulphur that promise very high energy densities, and lower costs but lower power densities and short life cycles (see Figure 13). (Yong et al., 2015)

Comparison of EV battery Types

Battery type	Nominal voltage (V)	Energy density (Wh/kg)	Volumetric energy density (Wh/L)	Specific power (W/kg)	Life cycle	Self discharge (% per month)	Memory effect	Operating temperature (°C)	Production cost (S/kWh)
Lead acid (Pb-acid)	2.0	35	100	180	1000	< 5	No	-15 to +50	60
Nickel-cadmium (Ni-Cd)	1.2	50-80	300	200	2000	10	Yes	-20 to +50	250-300
Nickel-metal hydride (Ni-MH)	1.2	70–95	180-220	200–300	< 3000	20	Rarely	-20 to +60	200-250
ZEBRA	2.6	90–120	160	155	> 1200	< 5	No	+245 to +350	230-345
Lithium-ion (Li-ion)	3.6	118–250	200-400	200–430	2000	< 5	No	-20 to +60	150
Lithium-ion polymer (LiPo)	3.7	130–225	200-250	260–450	> 1200	< 5	No	-20 to +60	150
Lithium-iron phosphate ($LiFePO_4$)	3.2	120	220	2000–4500	> 2000	< 5	No	-45 to +70	350
Zinc-air (Zn-air)	1.65	460	1400	80–140	200	< 5	No	-10 to +55	90–120
Lithium-sulfur (Li-S)	2.5	350–650	350	–	300	8–15	No	-60 to +60	100–150
Lithium-air (Li-air)	2.9	1300-2000	1520-2000	–	100	< 5	No	-10 to +70	–

Figure 13: A comparison of EV battery chemistries (Yong et al., 2015)

As a result of the unexpected pace of EV adoption, the battery industry is expanding as never before, and predictions are unable to keep up. In 2018, Bloomberg New Energy Finance, predicted that global energy storage would grow to a cumulative 942 GWh by 2040, driven by a 52% reduction in battery costs by 2030. EVs, distributed storage networks and energy access

[42] Battery warranties are typically available for eight years or 100,000 miles but are often for total battery failure or reaching a specified capacity of 60% to 70%. The Tesla Model S has been tested to retain 80% of its capacity even after 500,000 miles. (Gorzelany, 2019)

in remote areas (a combination of solar and batteries is cheaper than extending the grid) would all contribute to this expansion. The battery market, dominated by Asia (China & Korea) would by 2020 add an additional 50 GWh of energy storage production capacity but by the beginning of 2021 battery production capacity increased to over 700 GWh[43] from 300 GWh in 2018. According to the International Energy Agency, 1,000 GWh[44] of global production capacity for batteries will be required by 2025 and 1,500 GWh by 2030. (Eckhouse, 2018) The Rocky Mountain Institute forecasts substantial investments of $150 billion through 2023, with an $87 /kWh cost by 2025. (A. D. Steffen, 2019)

South Korean manufacturers[45] alone are forecast to invest $35 billion by 2030 and the market in terms of value according to SNE Research will multiply over 7-fold from US$ 40 billion in 2020 to US$ 352 billion in 2030. (Kane, 2021d)

The battery market is dominated by Asia (China & South Korea), followed by the US and Europe, who are racing to catch up. The supply of batteries rests with just a few dominant players and the accelerated demand for raw materials and batteries is a bottleneck that could potentially threaten growth[46]. Just 6 Asian companies control 87% of the supply (Morris, 2021f; Venditti, 2021)

- CATL (33%), a Chinese company that has remarkably grown 3,400% between 2016 and 2020, supplying Tesla, VW, Stellantis, BMW, Honda and various Chinese auto companies.
- LG Energy Solutions (22%), a South Korean company, also with an incredible 1,200% growth in 5 years, supplying Tesla, VW, Renault, Stellantis and Volvo.
- Panasonic (15%), from Japan supplies Tesla and Toyota.
- BYD (7%), from China supplies BYD and Ford.
- Samsung SDI (5%), from South Korea supplies BMW, Ford, Stellantis and VW group.
- SK Innovation (5%), from South Korea supplies Daimler, Ford, Hyundai and Kia.

[43] Source: S&P Global Market Intelligence & Statista.
[44] 1,000 GWh is enough capacity for 10 million vehicles each with a 100-kWh battery pack or 20 million vehicles with a 50-kWh battery pack.
[45] LG Energy Solutions, SK Innovation & Samsung SDI.
[46] Adamas Intelligence notes that 3 million vehicles were registered with a battery capacity of 135 GWh, a 40% increase over 2019. As adoption of EVs accelerates can the supply of raw materials and batteries keep up?

Both IHS Markit and Bloomberg New Energy Finance estimate that Lithium-ion batteries will fall below USD 100 kWh by 2023, widely seen as the price parity point at which mass adoption of Electric Vehicles becomes possible. Some E-buses in China have already reached this threshold level but on average, whilst at the battery cell level costs are around USD 100 per kWh, battery packs in China are still around USD 127 per kWh. Battery pack prices have fallen by 89% from 2010 to 2020, from over USD 1000 kWh to around US$ 137 kWh, and could reach USD 58 per kWh[47] to USD 73 kWh by 2030. (Henze, 2020; Loveday, 2020c)

Reduced manufacturing costs with economies of scale through increased BEV sales, battery efficiency, through pack design, cathode material costs, as well as new chemistries for energy density improvements will all contribute to this continuing trend. Wood Mackenzie expects the US$100 kWh threshold to be reached by 2024. EV producers will need to control raw material costs to keep batteries between USD 80 and USD 100 /kWh. (Ruffo, 2020a)

In addition to falling battery pack prices, battery energy densities have tripled since 2010 (see Figure 14), meaning longer range vehicles for the same weight and volume pack or lighter vehicles and smaller packs for the same amount of range. The Tesla Model S was capable of approximately 400 km when it came to market and now is capable of over 600 km. The Nissan Leaf's range has increased from 117 km to 346 km in the last 10 years. (Field, 2020)

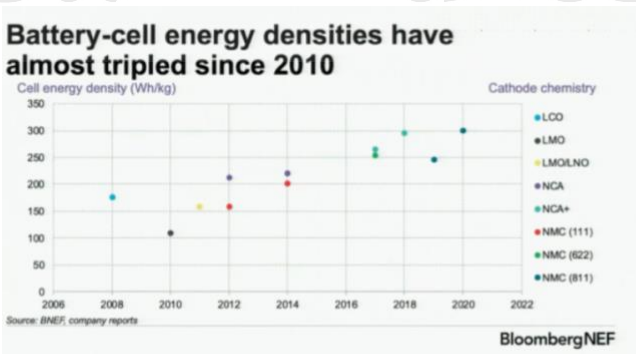

Figure 14: Battery-cell energy densities 2010-2020 (Source: BNEF) (Field, 2020)

[47] Bloomberg New Energy Finance predicts battery pack prices will reduce to below USD 60 per kWh whilst IHS Markit estimates a slightly more conservative USD 70 per kWh.

New battery chemistries such as Lithium Nickle Manganese Cobalt Aluminium (NMCA) or Lithium Nickle Manganese Cobalt Oxide (NMC) promise higher energy density batteries, whilst Lithium Iron Phosphate, the dominant chemistry in China, is the cost-competitive alternative. Solid-state batteries also hold significant promise and could be manufactured for 40% of the cost of current Lithium-ion batteries and double the energy capacity, halving the weight or doubling the range.

Bill Gates through his Breakthrough Energy Ventures has invested in QuantumScape, who also have a strategic relationship with VW that purports to have developed a solid-state battery[48] that will double range, reduce charge time and cost and improve safety. It is expected to be available in 2025 (Ruffo, 2020b). Ex Tesla engineer and now CEO of Sila Nanotechnologies, Gene Berdichevsky believes the future is in Lithium-ion chemistry rather than solid state, with $50 per kWh possible in 5 to 10 years and $30 kWh by 2040, using metal fluoride or sulphur cathodes and silicon anodes (Ruffo, 2020e).

Tesla itself expects a 400 Wh/kg high energy density battery with a high life cycle, produced in volume, to be achievable by 2023 to 2024, 54% higher than those in use today. This would result in either a reduction in cost and weight or an increase in range or some combination of the two. (Kane, 2020c)

General Motors though its partnership with Solid Energy Systems is developing new Lithium-metal cells that boast double the density at 60% cost. The Ultium cell uses 70% less cobalt and employs a wireless battery management system, reducing the need for specific communications systems or redesign of complex wiring systems for each new vehicle model. (A. D. Steffen, 2020d)

Toyota's Fluoride Ion Solid State Battery (FIB), developed in collaboration with Kyoto University and Panasonic, is touted to have a range of 1,000km, has 7x the energy density of current batteries, can fully charge in less than 15 minutes and is lower cost. There are still

[48] A solid-state battery uses a solid polymer electrolyte that is significantly more energy dense and significantly less volatile (they don't catch fire) than liquid electrolytes used in today's Lithium-ion batteries.

problems with the lifespan[49] and mass production is complex, requiring ultra-dry environments meaning volume production is expected only in 2025 to 2030. (A. D. Steffen, 2020b, 2020c)

Graphene Lithium Batteries, under development by US firm Nanotech Energy that can charge 18x faster than current Li-ion batteries. Graphene is highly conductive, is stronger and lighter than steel and these batteries potentially have superior energy density, power density and life cycle. (L. Steffen, 2020b)

IBM is developing a Lithium-ion battery from seawater[50] that are cobalt and nickel free that can charge 80% in 5 minutes and have similar energy and power densities to days Lithium-ion batteries. (A. D. Steffen, 2020a)

Futuristic Nano diamond batteries are literally the nuclear option, using a nuclear waste core protected by a polycrystalline diamond and potentially offering 28,000 years of energy without charging. (Bose, 2020)

The race to reduce reliance on heavy metals, particularly Cobalt and Nickle, is heating up. Iron Air batteries are 10th of the cost of Lithium-ion batteries and suitable for grid-scale energy storage. New Lithium-Sulphur batteries, being developed by Monash University in Australia, contain no rare earth metals, could potentially provide a 1,000 km battery, are cheaper and more environmentally friendly.

New approaches to battery pack design also promises improved energy density and reduced weight, volume and cost, as well as increasing range. CATL, is developing its cell to chassis (CTC) batteries with the promise of range in excess of 800 km. The usual approach is that multiple cells are arranged in modules that are arranged in a pack. Skipping the module phase, saves space and weight, the downside being that in event of a problem the whole battery must be replaced rather than faulty modules. BYD and CATL already use this technology for its LFP chemistry. (Kane, 2020b)

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[49] Toyota is aiming for 90% of initial capacity in the long term.
[50] Seawater contains about 5,000 times more Lithium than on land but at very low concentrations.

Nawa technologies has developed faster electrodes for lithium batteries, using carbon vertical nanotubes, boosting battery performance with 10x power, 3x energy density, permitting ultra-fast charging and a 5x lifespan. This ultra-fast carbon battery technology streamlines the route of ions, is lighter and more compact and minimises the environmental impact. They work with different chemistries and are expected on the market by 2022. (A. D. Steffen, 2020e)

3D printing of electric motor components and development of in-wheel motors (IWMs) electric motors are also set to massively reduce costs. Power increases with speed, and a faster spin means smaller motors can be employed but that there are issues with cooling. As an example, Equipmake, a UK firm, is developing electric motors with the magnets arranged as spokes magnets to increase torque and surface area for cooling, using 3D printing technology. The integration of multiple components into a single component also lowers cost and reduces potential failure. Another UK firm, Protean, is developing IWMs that reduce weight and provide better weight distribution and reduce losses in transmission of torque, which allows for greater range or same range with a smaller battery. No motor compartment or drive shafts is also a great space saver. (Woollacott, 2019)

On Tesla Battery Day 2020, the company announced the development of its "biscuit tin" cell, produced at Fremont, which its sees as crucial to reducing battery prices to under $100 per kWh. The new cells are higher density and bulkier, requiring fewer of them for a given range performance and reducing production costs. Future control of the battery production value chain from mining to assembly is a key Tesla strategy to reduce costs, ensure supply and move towards a USD 25,000 mass consumption vehicle. (Ruffo, 2020f)

Tesla is now using cobalt free CATL LFP batteries in its Chinese production and show potential for a "million miles" (16-year lifespan) battery. Development of its own 4680 "tab-less" cells are 6x more powerful, have 16% more capacity, and can charge from 10% to 80%in 15 minutes (50% in 7 minutes). Panasonic will initially manufacture but Tesla is increasingly taking control of its own supply chain in likelihood to manufacture batteries itself in the future. (Lyons, 2020)

4.2.2. Fuel Cells – Unfulfilled Promise

The Fuel Cell Electric Vehicle (FCEV) is a promising technology but has yet to gain real traction. In the US, only three FCEV models are currently available: the Toyota Mirai[51], the Honda Clarity and the Hyundai Nexo.

The chemical process involved is relatively simple. Oxygen and hydrogen fuel combine in the fuel cell, which strips electrons from the hydrogen, generating electricity, the Hydrogen ions and Oxygen combine to produce water as the only by-product. Refuelling takes only around 5 minutes and autonomy is around 400 miles (640 km), like a traditional ICE car. FCEVs typically also include a small auxiliary battery to recapture energy through regenerative braking. (*How Do Fuel Cell Electric Vehicles Work Using Hydrogen?,* n.d.)

The issue is whether hydrogen is a viable alternative for passenger cars and light commercial vehicles or whether it is better suited to specific tasks such as long-haul transportation, flight or utility level energy storage. The key advantages of quicker refuelling and longer range, relative to BEVs, was valid a few years ago but advances in batteries, fast charging technology, and in China particularly BaaS[52], have closed this gap.

Hydrogen fuelled FCEVs are far less energy efficient than BEVs, particularly in the production of hydrogen from electrolysis and the reconversion into electricity (see Figure 15)[53]. FCEVs add unnecessary complexity and cost and currently suffer from underdeveloped infrastructure, for which there is no equivalent to the convenience of home charging. Finally, the cost of hydrogen is currently relatively expensive: a Toyota Mirai costs approximately 29 cents per mile to run, whilst a Tesla S costs just 2 cents to 8 cents, depending upon electricity source. Even compared to conventional ICEs a kg of Hydrogen, equivalent to a gallon of fuel, costs $16, compared to $3 for the latter. (Morris, 2020a)

[51] Mirai means "future" in Japanese and reflects Toyota's focus on hybrids and FCEVs as the future of mobility and its resistance to the BEV revolution.
[52] NIO, a Chinese EV manufacturer is building out an infrastructure of battery swap service stations (4,000 by 2025) where Battery as a Service (BaaS) by subscription provides the ability to swap and/or upgrade the vehicle battery in just three minutes. A battery can represent up to 25% of the cost of the BEV, by "renting" the battery initial purchase costs are reduced. For BaaS to function properly at scale, standardisation of battery technology will be necessary. Geely, another Chinese automaker expects to have 5,000 E-Energee swapping stations operational by 2025 and estimates a 59 second pack replacement time. (Nedelea, 2021)
[53] Tom Baxter, Chemical Engineer and Senior Lecturer at the University of Aberdeen puts the efficiency difference at 80% for a BEV and 38% for an FCEV, explaining that the process of compressing, chilling, transporting and reconverting to electricity consumes a significant amount of energy. (Baxter, 2020)

Despite the environmental and energy security benefits, development of hydrogen generation, transport, storage and retail refuelling infrastructure remain challenging. (Körner et al., 2015)

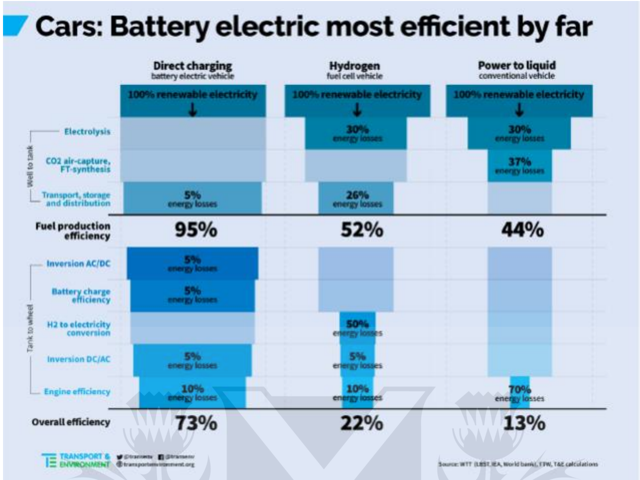


Figure 15: Energy efficiency comparison of mobility technologies (Source: Transport & Environment)

In the US, hydrogen refuelling stations are only available in California & Hawaii. Base prices for an FCEV at USD 60,000 with a USD 15,000 fuel credit appear attractive relative to competing BEVs. Safety features include a carbon fibre tank and stop flow sensors in the event of a collision. (Baldwin, 2020)

Big oil companies are very keen on hydrogen particularly as current production (predominantly for fertilizer) comes from Natural Gas (so called grey hydrogen). Even if hydrogen is a viable future energy source it is likely that green hydrogen will be used, formed by the electrolysis of water using renewable energy sources. These energy giants are facing a huge disruption of their industry and are scrambling to transform themselves into energy companies, investing huge sums in renewable energy generation and EV charging infrastructure. It is possible if not probable that the lobby for Hydrogen is a delaying tactic to slow the advance of electric mobility. (Morris, 2021d)

4.3. Global Automotive Market & Electric Vehicle Brands

4.3.1. Global Automotive Markets

Global production and sale of vehicles have grown steadily over the course of the last 10 years. Since the beginning of the global financial crisis in 2008, annual sales of vehicles have grown by approximately 33% or a CAGR of around 3% to approximately 95 million units. In 2019 and 2020, the global pandemic had a profound impact on the auto industry with sales of new vehicles falling by almost 20% (see Figure 16).

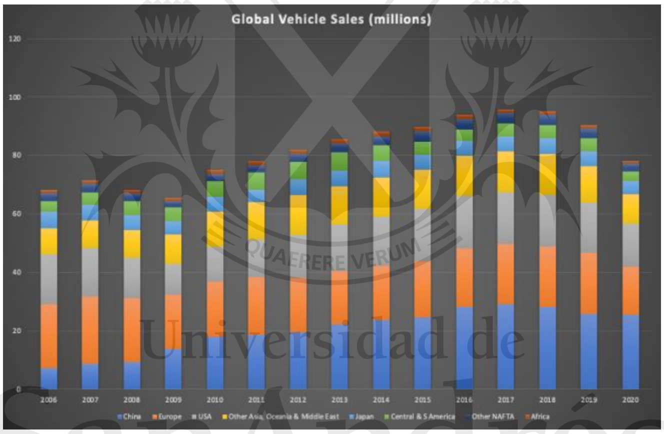


Figure 16: Global Vehicle Sales 2006-2020 (Source: own development from International Organization of Motor Vehicle Manufacturers (OICA))

The traditionally strong markets in North America, dominated by the US, and Europe have lost both volume and share. Whilst European vehicle sales have yet to recover from levels in 2007, their market participation has fallen from 31% to 21%. In North America, sales had just recovered to their 2006 level prior to the pandemic, but market share has also declined from 29% in 2008 to 22%. Asian markets excluding China & Japan experienced modest growth, whilst the Japan market has been flat during the period. Growth in the market over the last 15 years has been almost entirely driven by China. Production and sale of vehicles in China prior to the pandemic have quadrupled. China alone now accounts for almost one third of all vehicle sales globally. Although in recent years, China has shown the first signs of market saturation, it is undeniably the most dominant vehicle market in the world, followed by the traditional markets of Europe and the US.

Vehicle production continues to be dominated by multi-brand OEMs of Japanese, European, and Korean origin. Formerly dominant US OEMs have lost their ranking (see Figure 17).

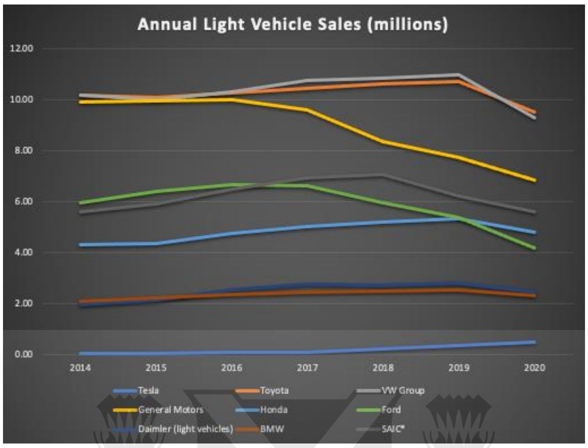


Figure 17: Annual Light Vehicle Sales by Manufacturer 2014 -2020 (Source: own development from Statista & OEM Regulatory filings)

VW and Toyota trade for the lead with approximately an 12% market share each, followed by GM & Honda with 9% & 6%, respectively. The emergence of new players, particularly in China and in electric mobility is providing further disruption to the market. Tesla's role in advancing electric mobility has undoubtedly disrupted and continues to disrupt traditional auto markets. Tesla's growth has been impressive, but its sales still represent less than 1% of the total global market. Toyota and VW currently each produce around 20x the number of vehicles that Tesla produced in 2020.

4.3.2. Electric Vehicle Markets

Electric Vehicles have been in existence since the turn of the last century (19^{th} to 20^{th}), but it has only been within the last 20 years that modern electric vehicles have begun to pose a substitute threat to Internal Combustion Engine Vehicles (ICE) that dominated transport in the 20^{th} Century. New regulations on, safety, emissions, technological advances and shifting consumer needs are driving demand has boosted demand for privately-owned EVs, which has begun to accelerate at different rates across the globe with China, Europe and the US dominating the market.

Spurred largely by US government funded research into EV batteries technology, in 2008 the EV revolution started in earnest. Tesla introduced its roadster, followed by the Model S in 2012. In 2010 Nissan introduced the first new generation mass-market EV, the Nissan Leaf closely followed by GM's plug-in hybrid Volt. By 2017, the global automotive industry was investing in EVs. Battery costs were dropping faster than anticipated and government subsidies, particularly in Norway and China were accelerating sales. (Sperling, 2018)

Electric vehicle sales have accelerated and by 2020 the global EV fleet is an estimated 10 million vehicles, growing by over 40% whilst the global market declined by 14% (see figure 18).

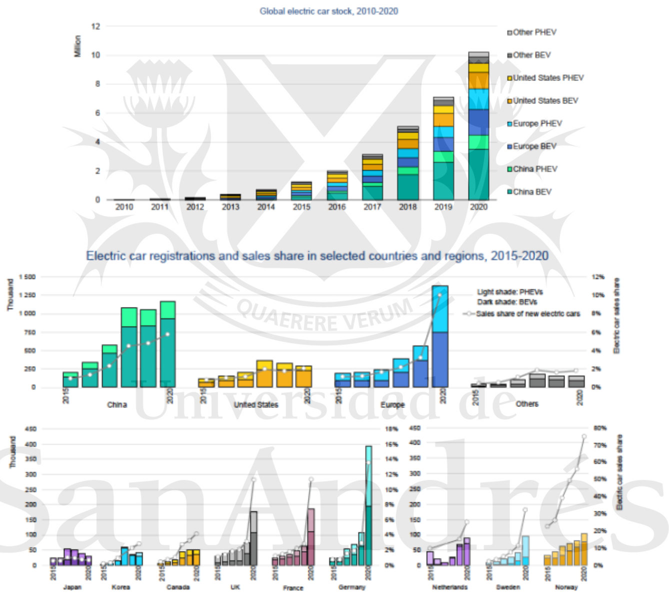


Figure 18: Global electric car stock, sales & share 2010-2020 (Gül et al., 2021)

In 2020, 3 million new electric vehicles (BEVs and PHEVs) were sold, representing almost 5% of the global market, and for the first time Europe overtook China as the market leader in sales, although China still accounts for almost half of the global EV stock. Penetration in European markets has been dominated by the Nordic countries, particularly Norway, but now the large markets of the UK, Germany and France have accelerated the adoption of EVs, with all three shown double digit market share in 2020. Market penetration of Electric Vehicles in the overall market is still generally low (11% in Europe, 6% in China, 3% in the US and less than 2% elsewhere). Norway is the clear market leader in penetration with a penetration approaching 80%. The IEA sponsored, Electric Vehicle Initiative, estimates that annual sales of EVs could reach between 23 million and 43 million with a fleet of 130 million to 250 million by 2030. This would represent between 25% and 50% of pre-pandemic sales volumes and 10% to 18% of the estimated global stock of motor vehicles[54]. Notwithstanding accelerating adoption of electric vehicles, conventional ICE vehicles will still be around for several decades. (Bunsen et al., 2019; Gül et al., 2021)

Key drivers, for both Norway and China, have been regulation around fuel economy standards, emissions, charging infrastructure and subsidies for the purchase of EVs. For example, in Norway EVs are exempt from registration tax. In Shanghai EV plates are free, traditional car license plates are auctioned at prices starting at $14,000. (*EVO 2020*, 2020)

According to the International Council for Clean Transportation (ICCT), EVs are already cheaper to own and run than petrol/diesel vehicles when accounting for the Total Cost of Ownership over 4 years (see Figure 19).

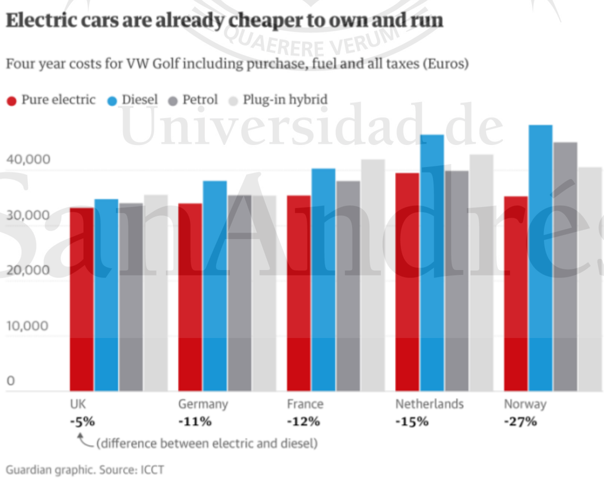


Figure 19: Total four-year cost of a VW Golf by powertrain

The ICCT estimates that capital cost parity is likely between 2025 & 2030. (Campbell & Tian, 2019; Carrington, 2019) EV models available to European consumers are expected to triple by 2021 which could lead to a 22% market participation (Wall, 2019). Established OEMs are

[54] US publisher Wards estimates a total global motor vehicle stock of 1.4 billion in 2019, over 1 billion cars and just under 400,000 trucks and buses.

expected to launch around 400 new electric vehicle models though 2023, and potentially 600 by 2025 (see Figure 20).

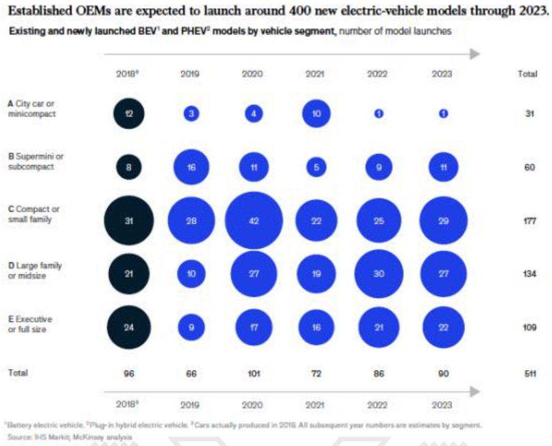


Figure 20: Predicted launch of EV models2018 to 2023 (Source: McKinsey) (Hertzke et al., 2019)

According to US consulting firm, Alix Partners, OEMs will invest USD 330 bn over the next 5 years in EVs, a huge number relative to the historical annual USD 100 bn invested by the global auto industry, according to Statista. Technology is expected to delivering substantial cost cuts not only in manufacturing processes but in battery, electric motor and powertronics technology.

Tesla has led the world in EV production, and until recently has been followed by two Chinese automakers, BYD and BAIC motor. Traditional automakers, however, are beginning to catch-up. In Europe, Tesla’s Model 3, the market leader, is facing competition from VW’s ID.4, BMW’s i3, VW’s e-Up and Hyundai’s Kona BEV. In China, a plethora of local OEM’s and local brands provide compete with Tesla’s locally produced Model 3. Even in the US, where Tesla continues to dominate with the Model Y SUV and the Model 3, the Model S and Model X have been knocked of third and fourth spots by the Ford Mustang Mach E and the Chevy Volt. (Morris, 2021b)

Figure –

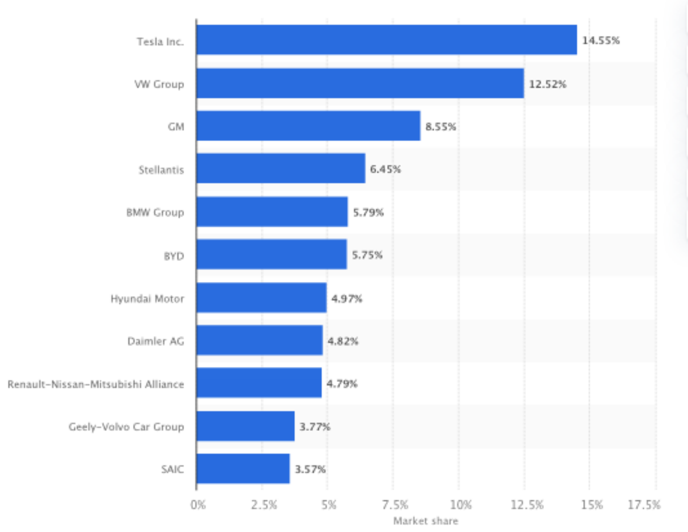


Figure 21: Global plug-in electric vehicle sales market share by OEM H1 2021 (Source: Statista)

Increasing regulation around fuel consumption[55] policies and CO_2 emissions[56] are expected to accelerate EV adoption. Government intervention is shifting from the carrot to the stick; from subsidies for EV purchase to quotas, emissions and fuel economy standards putting the onus on automakers. (Hertzke et al., 2019)

4.3.3. Big Auto Awakes

After initial resistance, automakers appear to have finally woken up to the electric mobility trend are in full throttle mode developing a broad range of EV models. Several automakers have declared they will be all-electric or mostly electric in the next 10 years.

Operational profit margins have been at record levels in recent years (see Figure 22), but OEMs are potentially facing a cyclical downturn in the medium to long term. OEMs face disruptive forces from emissions and fuel economy regulation in the short term and trends such as autonomous, connected, electric and shared mobility (ACES) in the medium to long term. Demand has shifted to Asia and the value chain is evolving. OEMs face a difficult choice: to accelerate EV adoption with potential consequences for short term losses or take a more

[55] Corporate Average Fuel Consumption requirements are prevalent In China
[56] 37.5% reduction in Europe by 2030 and 25% goal in China by 2025.

cautious approach and risk losing ground to more adventurous competitors. (Deubener et al., 2019)

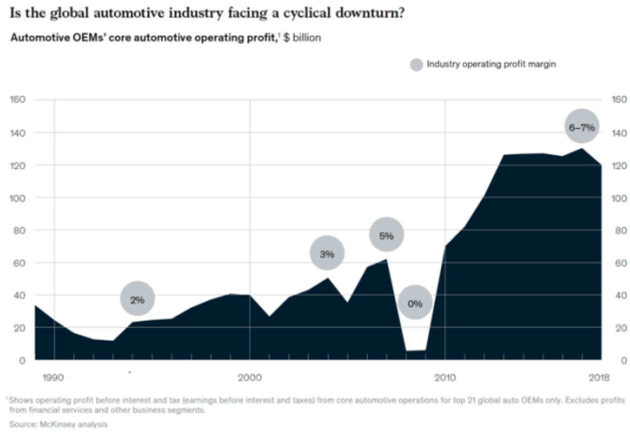


Figure 22: Automotive OEM core operating profit 1990-2018 (Source: McKinsey)

In addition to accelerating electrification of mobility, McKinsey predicts "Growth in personal mobility market will accelerate as new sources of recurring revenues supplement growing growth from one-time vehicle sales". (Mohr et al., 2016)

Key trends prediction (see Figure 23):

1. Shifting markets & revenue pools – shared mobility, connectivity services, feature upgrades, new business models – revenue expansion up to 30%. Shared mobility will limit unit sales growth to less than 2% p.a.
2. Changes in mobility behaviour: 1 in 10 cars sold by 2030 a shared vehicle.
3. Diffusion of advanced technology – Autonomous vehicles 15% by 2030. Electric vehicles?
4. New competition and cooperation. New market entrants initially target specific attractive segments and activities along value chain before exploring other fields.

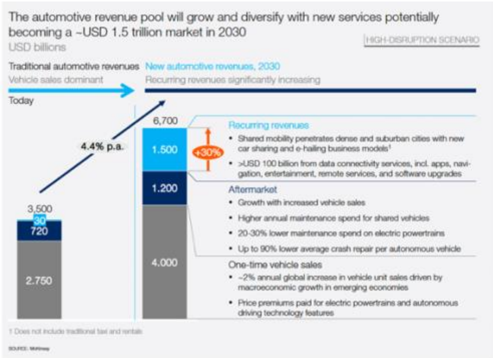


Figure 23: Potential growth and diversity of automotive revenue pools (Source: McKinsey)

The traditional OEM, Tier 1/ Tier 2 supplier competitive landscape is evolving with new entrants such a Tesla, new Chinese OEMs, Big Tech and mobility platform providers seeking or creating new opportunities and services and selectively choosing where they wish to participate in the value chain (see Figure 24). (Mohr et al., 2016)

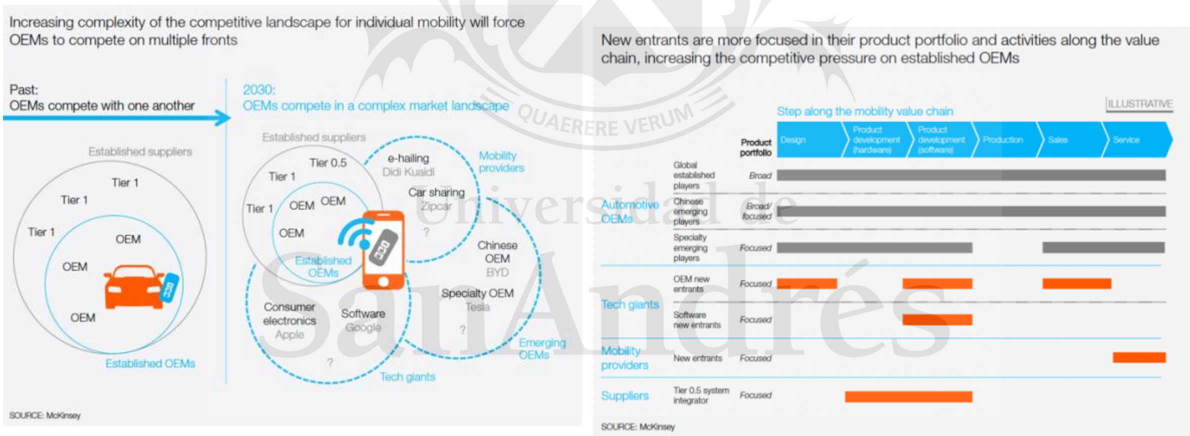


Figure 24: Changing automotive competitive landscape (Source: McKinsey)

A number of these trends are currently speculative in nature, but electrification is happening, automation is happening, and connectivity is happening. The investments and the threats to the existing business model are real. New mobility services such as carsharing or ride hailing are in their infancy and not yet impacting private vehicle ownership, but they do provide new revenue opportunities for incumbent OEMs.

4.3.4. Big Auto Development

4.3.4.1. Volkswagen Group

In January 2019, VW announced that their MEB (Modular Electric Toolkit) electric platform will be open to other manufacturers (see Figure 25). Combining an electric motor in the rear axle, power electronics and gearbox, and a high voltage, space saving battery pack in the floor, VW hope it will become standard across the industry (leading to cost savings and scalability). VW expect to invest $50 billion by 2024 (one third of its total R&D budget and more than 30 times Tesla's current budget) in EVs with the expectation of producing 15 million vehicles by 2025-2030. By 2025 it will increase the number of pure electric models from 7 to 50, 70 by 2028. By 2023/2024 the T-Roc (VW SUV) will be available for less than 20,000 euro. (Jost, 2019)

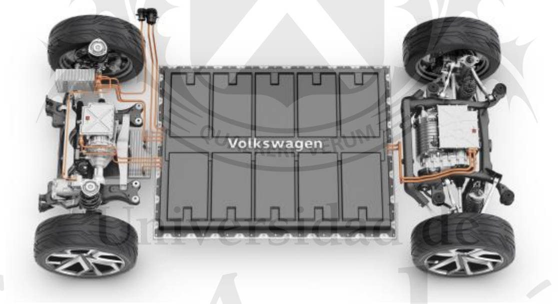


Figure 25: VW Modular Electric Toolkit (Source: Volkswagen)

VW Alliance have also created an alliance with Ford that has 3 strategic goals:

- Establish MEB as an industry standard[57]. VW will supply 600,000 MEB platforms to Ford for its European vehicles by 2023.
- Become the market leader for light commercial vehicles and mid-sized pickups in their EV versions
- Participate in rapidly growing market for mobility services (autonomous vehicles/ sharing). Size makes a difference in electric mobility and autonomous driving.

[57] CEO Diess, states that he doesn't want VW to become the next Nokia and aims to develop a platform that becomes the Android of the EV world.

In Europe, VW has invested in significant charging infrastructure, creating the IONITY network with Daimler, Ford, and BMW, and a fast-charging network in collaboration with BP, Iberdrola and Enel in Europe. In the US its Electrify America[58] subsidiary has 800 locations with 3500 chargers, many with 350kW power; it has established agreements with 12 OEM's (including VW and Audi) for multiple years free charging or limited charging credits on new EV sales (usually for 2 to 3 recharges). In China, there are plans for 17.000 fast public chargers.

In autonomous driving technology there are many challenges including high development costs, lack of global standards, high-quality sensor technology, anticipating customer requirements and talent availability. VW have a joint investment in Argo AI with a 500 million investment from VW and the same from Ford. In addition to 1 billion in financing commitment and adding Audi's Autonomous Intelligent Driving (AID) unit. (Diess, 2019)

4.3.4.2. Toyota

Toyota has continued to resist the full electrification of its brand and continues to focus on hybrids and fuel cell electric vehicles. Emulating Tesla in 2014, it opened licences for 24,000 vehicle electrification patents, in an attempt to create demand for its hybrid cars and fuel cell technology.

Toyota argues that it remains unconvinced that BEVs are the right technology for sustainable transportation and that HEVs and PHEVs maximise the use of what will become a limited supply of batteries. With improving hybrid technology Toyota may be able remain immune to stricter CO2 emissions standards in the short term, allowing it longer to introduce BEVs and PHEVs, but will be unable to avoid outright bans non-ZEV emissions vehicles towards the end of the decade.

Predominantly focussed on hybrid models (see Appendix 1), with only 3 PHEVs available at the current time. Nevertheless, Toyota is investing $13.5bn in battery technology with Panasonic and will shortly offer two BEVs and up to 15 by 2025.

[58] Electrify America was established as a punishment after emissions cheating.

4.3.4.3. Daimler

Daimler, like its German counterparts, is going all in on electric mobility with several PHEVs and BEVs already available (see Appendix 1). It has developed its own EVA platform using NCM 811 battery technology, which offers up to 700km range from a 108kWh battery and over the air (OTA) software updates for energy management.

Announced investments amount to USD 47 billion by 2030 and Mercedes expects to go all-electric by 2030, "where market conditions allow". In charging infrastructure, Daimler is part of the IONITY fast charger network.

Daimler & BMW have combines their carsharing platforms, respectively car2go & Drive Now into Share Now, boasting 20,000 vehicles and 4 million customers globally. They now can count on a global platform of services that incorporates MaaS (ReachNow), ride hailing (FreeNow), parking (ParkNow), charging (ChargeNow), Carsharing (ShareNow).

4.3.4.4. Ford

Ford has been slower to develop pure electric vehicles, a symptom of the slower rate of adoption in its key US market. It offers several Hybrid models but only two PHEVs and two BEVs (see Appendix 1). The Mustang Mach E has proved popular in the US and was recently introduced to Norway, its first European market.

Announced investments of USD 22 billion through 2025 will drive a greater focus on PHEVs and BEVs, particularly in Europe, where a USD 1 billion investment will expand its assembly facility in Cologne, Germany. Production will be based upon VW's MEB platform with 600.000 units being supplied from 2023 over 6 years. Ford expects to be 100% electric in Europe by 2030 and 40% overall.

Unlike VW and Tesla, Ford does not expect to produce its own batteries, preferring to rely on its supply chain. Ford believes that the supply chain is strong enough to support demand, despite limiting first year production of the Mustang to 50,000 units globally because of battery supply, and that as new tech emerges it will have a competitive advantage. (Ruffo, 2020d)

FordPass gives consumers access to 16,000 fast charging stations in the US through Electrify America and Chargepoint. In Europe it is part of the IONITY network.

4.3.4.5. GM

GM was amongst one of the early movers and can be considered a pioneer in electric mobility, initially with its PHEV, the Chevrolet Volt (now discontinued) and now entirely focussed on BEVs predominantly with the Chevrolet Bolt.

GM declares it will be all-electric by 2035 but only if business is not negatively affected. With investments of USD 27 billion by 2025 it intends to introduce 30 new models. Like Tesla, GM is vertically integrating, manufacturing motors, batteries and drive system, and investing in Lithium extraction. Its Ultium architecture developed with LG Energy Solutions will be available on license to third parties. It is also developing its Hydrotec Fuel Cell together with Honda.

GM and EVGo have partnered to create a network of 2.700 fast charger stations in the US.

4.3.4.6. Honda

Honda continue to send mixed messages, lobbying governments on the importance of hybrids, in which it is almost exclusively invested, whilst partnering with GM on a new BEV due in 2024 – the "Prologue" and is using its Ultium batteries for upcoming BEVs in the US.

Honda claims, with some justification, that BEVs are 33% to 50% more expensive and uneconomic to make. Honda believes EVs won't reach price parity until 2035 and warns that uneven infrastructure distribution, expensive raw materials and reaching limits on battery power and performance[59] reduce BEVs' attractiveness. Nevertheless, its inability or

[59] Despite its research into next generation Solid State Batteries.

unwillingness to sell sufficient electrified cars has been expensive in Europe, where it pays Tesla for CO_2 emissions pooling, rather than paying fines.

Honda will invest USD 46 billion over 6 years and aims to stop selling ICE-only cars by next year, focussing on Hybrids and BEVs. Further it will "strive" to be 100% BEV and FCEV focussed by 2040 in its major markets (US, China & Japan).

4.3.4.7. BMW

Like Daimler, BMW already has a strong portfolio of PHEVs and more recently BEVs. BMW expects to invest USD 35 bn by 2025 in both EVs and FCEVs, with plans to develop a BMW iHydrogen car soon. BMW believes that both powertrains will exist side by side.

Whilst BMW doesn't appear to have declared that it will be all-electric, it expects that 50% of all cars will be electric by 2030. In terms of infrastructure, BMW has partnered with EVGo in the US and is a part of IONITY in Europe.

4.3.4.8. Stellantis

Stellantis was formed at the beginning of 2021 from the merger of the Fiat Chrysler and Peugeot Citroen groups to pool resources and focus on electric mobility. In the past two years (2019 to 2021), Fiat Chrysler spent USD 2.4 bn in CO_2 credits to Tesla. Given Peugeot Citroen's already strong credentials in electric mobility it will no longer be necessary (a big number of Tesla to replace).

Already with a strong offering of PHEVs and BEVs, the group will invest USD 35 billion by 2025 and introduce 55 models (21 models by 2023) and construct 5 battery plants in Europe and the US. It expects that 70% of its sales in Europe and 40% in the US will be electric by 2030. It is creating a network of 15,000 charger locations in Europe by 2025, partnering with TheF Charging, a charging start-up, and Engie, the French utility, for home and public charging infrastructure, battery lifecycle management and V2G (vehicle to grid) integration.

4.3.4.9. Hyundai

Much like the Japanese OEMs, Hyundai has a strong offer of Hybrids (HEVs). Where Hyundai differs is that both the Hyundai and Kia brands offer several PHEV and BEV models. Hyundai has big plans, with announced investments of a whopping USD 87 billion in 5 years and the introduction of 44 models by 2025, over half of which will be BEVs. It expects to be 100% electric by 2040, in major markets.

In charging infrastructure, it participates in the IONITY network in Europe and Electrify America in the US. In Singapore, it is working with the SP Group on a fast charger network and Battery as a Service (BaaS) swapping locations.

4.3.4.10. Chinese OEMs and other new entrants

Chinese OEMs have been growing in importance over several years but with the acceleration of electric mobility, the Chinese have declared that it represents a strategic opportunity to leapfrog the traditional OEMs and build a dominant auto industry, on the back of their strength in battery production and supply chain. Many of the traditional state-owned Chinese OEMs have grown in partnership with western OEMs but now a new generation of private companies are establishing themselves as leaders in electric mobility.

The big four are SAIC Motor (VW & GM partnership), Dongfeng (Hyundai, Renault Nissan, Peugeot-Citroen), FAW and Changan (Ford, Mazda) but there are a plethora of other automobile companies competing in in electric mobility.

Amongst the most noteworthy are BYD, the former battery manufacturer and second largest electric vehicle manufacturer in the world (in total units sold), after Tesla. Geely, owner of brands like Volvo, Polestar and Kandi (a low cost citicar now available in the US for USD 10,000 to USD 20,000 after the federal tax credit), is a multinational OEM, present in both

European and US markets. Its Zeekr brand and Lotus Evija model are set to rival Tesla. Xpeng is an EV start-up based on Tesla and owned by Alibaba.

Whilst Chinese OEMs have tended to use less energy dense LFP battery chemistry they have opted to overcome range anxiety by building infrastructure for battery swapping services. Both Geely and NIO, another Chinese start-up EV manufacturer, are building extensive BaaS service stations in China. In Norway, NIO has built 4 swapping stations that can change a battery in less than 3 minutes. NIO aims to be in every EV market by 2024.

Elsewhere in the world, Tata Motors, owner of the Jaguar and Land rover brands expects to be all-electric by 2030 (Jaguar in 2025). In the US new EV start-ups, Lucid, Rivian, Lordstown Aptera, Nikola and Fisker were unknown just a few years ago.

Lucid, a Californian company backed by Chinese and Saudi investors, went public in 2021 with a USD 4.5 billion offering before its Lucid Air model has barely started delivery. With an EPA range of over 800km, 28% more than anything else available, and 500 km of fast charging possible in 20 minutes, Lucid's CEO and ex-Chief Engineer at Tesla, Peter Rawlinson hopes to go toe to toe with Tesla.

OEMs are creating more and more partnerships focussed on shared investment cost (see Figure 26), increasingly with deep pocketed Tech companies. Spurred by rising demand particularly in China, where 86% of Chinese consumers consider purchasing an EV, (64% in Germany, 51% USA), incumbent OEMs will bring more than 300 BEV models to market by 2025 and USD 275 bn have been invested by automakers so far. (Tschiesner et al., 2019)

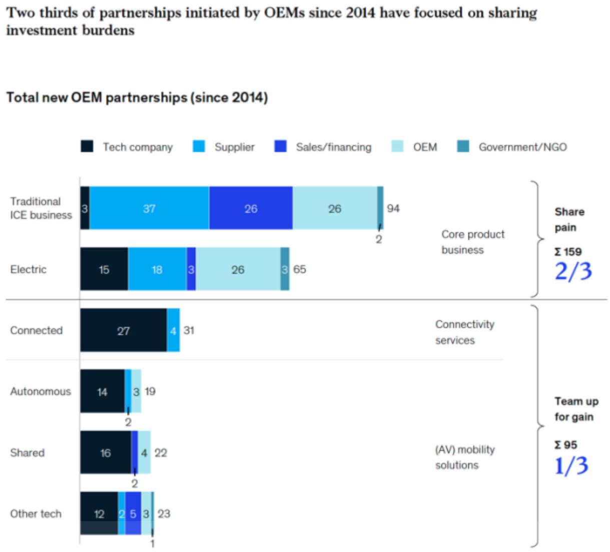


Figure 26: OEM investment partnerships 2014-2019 (Source: McKinsey)

4.3.5. Tesla

4.3.5.1. Tesla – a brief history

Tesla was founded in 2003 by engineers, Martin Ebhard and Marc Tarpenning after GM ended its EV1 program effectively killing its involvement in electric cars. In 2004, Elon Musk invested $6.35 millions of his own funds and became chairman of the board. A joint venture with Lotus in 2005 provided the chassis and body design for its first vehicle the Tesla Roadster, launching a prototype in 2006 and producing the first roadster by 2008 when general production begins.

Beset by early production and delivery problems, Elon Musk takes over as CEO and lays off 25% of the workforce. A cash bailout of $40 million in late 2008 allows Tesla to meet production goals and avoid bankruptcy. In 2009 the Model S, a luxury sedan is launched, and Daimler acquires a 10% stake for $50 million (sold for $780 million in 2014). Further funding is provided by a US Department of Energy loan of $465 million.

In 2010, Tesla goes public, raising $226 million and Toyota buys a stake for $50 million, entering into a joint venture with Tesla to develop electric cars and parts. Tesla takes over the Californian (Freemont) production facilities recently closed by Toyota. New models are launched in 2011 (Model S) and 2012 (Model X – a crossover SUV). Also in 2012, Tesla launches its supercharger network – Model S owners can charge for free. In 2013, Tesla makes its first quarterly profit and is able to raise $ 1 billion in debt and repay DOE loans. In 2014, Tesla sells $USD 2 billion in bonds to fund its Gigafactory 1 in Nevada for its Model 3, its first mass market vehicle, and energy storage units. Semi-autonomous driving is announced later that same year, rolling out in 2015 Tesla models. Further fund raising (3.5 billion) is required to meet aggressive production goals of Model 3 (500,000 units by 2018). Production deliveries fall far short of bold predictions and the autopilot suffers its first accident.

In 2017, Tencent makes a $1.8 billion investment for 5% of the company and Toyota exits. There are rumours of culture clashes between risk-taking Silicon Valley and conservative Japanese executives. Production woes continue and Musk threatens to take the company private in 2018. He is subsequently sued by the SEC for false & misleading statements. In late 2018 Federal tax credits expire, and Tesla is forced to lower its prices. It announces cuts to its staff of 7% in early 2019. Several executives, including the CFO and General Counsel also leave. Musk announces the closure of its stores and then revises the plan in favour of raising the price of its models by 3%.

In 2019, Tesla's $2bn factory (Gigafactory 3) in Shanghai was given the go ahead for beginning production, providing direct access to China. It is the first fully foreign-owned car plant in China. Vehicles will be excluded from a 10% tax on conventional cars and higher import tariffs on US imported cars.

4.3.5.2. Tesla Business Model

Tesla's initial mission was "to accelerate the advent of sustainable transport by bringing compelling mass market electric cars to market as soon as possible" and later broadened "to accelerate the worlds transition to sustainable energy". Its vision: "to create the most compelling car company of the 21st century by driving the world's transition to electric vehicles"

What makes it unique as an auto manufacturer was that it did not initially create a mass production car. On Tesla's mission in November 2013, he stated: "If we could have [mass marketed] our first product, we would have, but that was simply impossible to achieve for a start-up company that had never built a car and that had one technology iteration and no economies of scale. Our first product was going to be expensive no matter what it looked like, so we decided to build a sports car, as that seemed like it had the best chance of being competitive with its gasoline alternatives."

Despite its initial production and delivery problems, Tesla undoubtedly was successful in establishing a brand and producing a concept car. Tesla also disrupted the traditional business model by inhabiting parts of the value chain not traditionally inhabited by OEMs:

- It employs direct sales – through its showrooms and internet sales bypassing traditional distribution networks and improving product development and gaining speed to market advantage (through direct customer feedback).
- Its Service Plus locations and Rangers (home visits) provided direct aftersales care. Wireless uploading of diagnostics and remote servicing (software updates).
- The Supercharger network now has over 2500 supercharger stations with over 25,000 charging points worldwide and, after some back and forth, again offers free for life charging for Model S & X owners. (Moldrich, 2019)
- EVSE's or Electric Vehicle Supply Equipment will also charge some non-Tesla EVs but there are no common plug and charging standards, despite an early offer to OEMs to share Tesla chargers and plugs. The new upgraded V3 Combined Charging System (CCS) will be compatible with other EVs provided Tesla agrees to open its network. V3 supercharging, at 1000 miles per hour, could reduce charging times by 50%.

Musk and Tesla have created a technology product not just a car.

4.3.5.3. Tesla a Disruptive Force

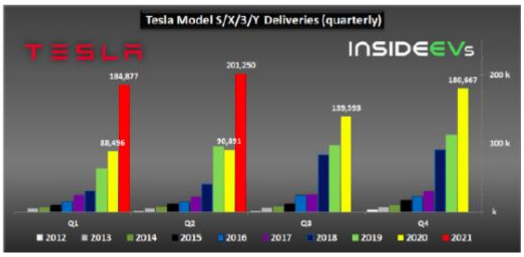
In 2014, Tesla opened its patents citing that:

> "It is impossible for Tesla to build electric cars fast enough to address the carbon crisis… Our true competition is not the small trickle of non-Tesla electric cars being produced, but rather the enormous wood of gasoline cars pouring out of the world's factories every day. We believe that Tesla, other companies making electric cars, and the world would all benefit from a common, rapidly evolving technology platform."

The strategy appears to have been an attempt to create a global standard and provide impulse to EVs. Tesla was concerned with being overwhelmed by Big Auto but EVs were not on their radar. Conversely it also gave up any potential learning benefit (as expressed by Lieberman) that developing the technology might have provided, giving potential new competitors a head start. (Ellis, 2019)

Nevertheless, Tesla has grown from producing 35,000 Model S units in 2014 to 500,000 units in 2020. In the trailing 12 months to September 2021 Tesla is on course to increase sales even further by over 25%. Whilst Model S & Model X sales have stalled, the Model 3 and Model Y, the former globally and the latter in the US, have sold strongly.

Despite only launching in 2018 the Model 3 was already the 5th best-selling car in the US by 2019. In the small and mid-sized luxury category it placed no.1, ahead of the Mercedes C Class; on an all model per brand basis, Tesla's Model 3 outsold any other OEM in the US in its segment. In large luxury vehicles and SUVs, the Model S and Model X are first and second in their respective categories. When we consider only BEV sales in the US, all three models and the new Model Y SUV were well ahead of their nearest rival, the Chevy Bolt. (Shahan, 2019) More recently, the Model Y has become the most popular US BEV, followed by the Model 3, the Ford Mustang Mach E and the Chevy Bolt. Nevertheless, Tesla's dominance of the electric vehicle market in the US EV market continues and the Tesla Model 3 is a big part of that (see Figure 27).



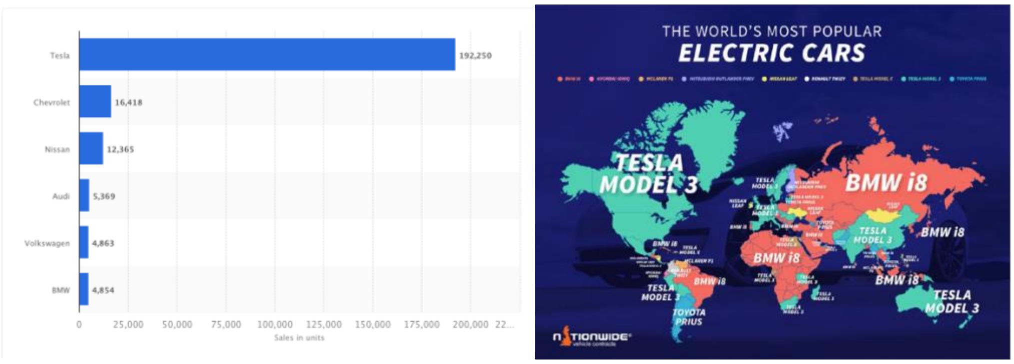


Figure 27: Tesla Production and Deliveries 2012-Q2 2021 (Source: (Kane, 2021b) *); US BEV Sales by brand 2019 (Source: Statista); World's most popular electric cars (Source:* (Loveday, 2020b) *))*

It is clear that Tesla has quickly built a strong brand identity: Tesla has a head start in building the cars of the future that incorporate advanced technology, not only in batteries and drive train that initially gave Tesla superior range (see Figure 28), but also in autonomy and connectivity two of the major trends that are further disrupting the automotive sector. A new USD 25,000 compact to be made and designed in China and exported to the world could help Tesla to maintain its global leadership[60], although its US market share will undoubtedly continue to fall albeit in a rising market, as it has from 80% in 2019 to 71% in Q1 2021. (Morris, 2021b)

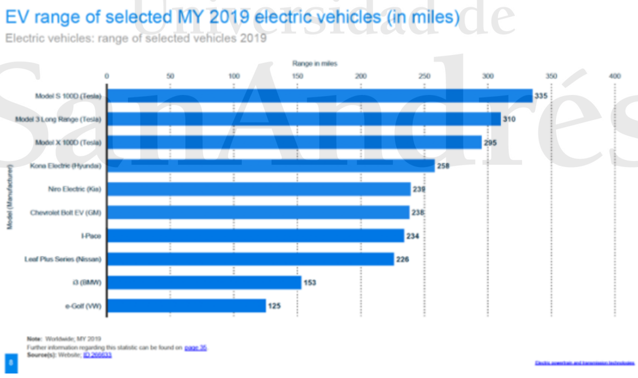


Figure 28: EV range of select EVs 2019 (Source: Statista)

In 2021, Tesla became the second fastest company to reach a market valuation of over USD 1 trillion, 12 years after its IPO[61]. It is now worth more than practically all other automakers combined (see Figure 29). Yet it is a dwarf in terms of sales and revenues, 6 times less than

[60] Competing electric vehicles in the US range in price from USD 30,000 for a Nissan Leaf to USD 40,000 for the Tesla Model 3, VW ID4 Pro or Kia Niro, all with similar ranges. (Lambrecht, 2021) Neither Tesla nor GM are eligible for the USD 7,500 federal tax credit having both produced more than 200,000 electric vehicles, which gives their competitors a potential price advantage.
[61] Facebook is the fastest.

VW & Toyota (see Appendix 2). Its gross profit margins, are above the industry at a round 23%, boosted by regulatory CO_2 emission pooling credits, amounting to USD 1.2 billion globally in 2020. (Kane, 2020e) The market appears to be pricing in the accelerated disruption to the industry and Tesla's rate of growth, and advances in AI, connectivity and electric platforms, valuing the company more in line with a tech company and not an automotive company. Investors are looking at the platform: software wireless (OTA) downloads, perhaps wireless recharging in the future, brand value, high tech, design and autonomous driving. (Wasik, 2017)

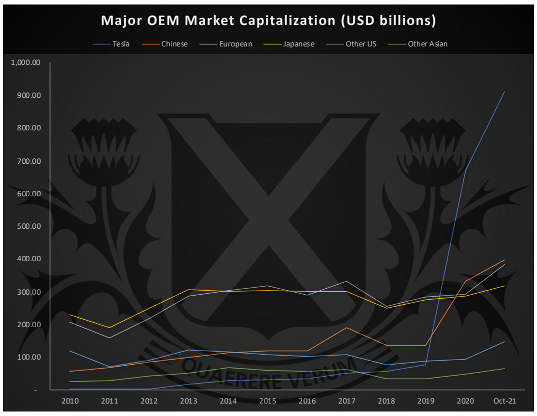


Figure 29: Major OEM Market Capitalisation 2010-2021 (Source: own development from multiple financial websites)

The key issue is whether these clear advances in technology can be sustained to create a competitive advantage in view of open patents and the oncoming pressure from competitors and new entrants. R&D expenditure is in line with its competitors at around 5% of revenues (see Appendix 2) but this is 7% of a far smaller revenue base. VW who has quickly caught Tesla spends more than 10x annually on R&D, and this financial power potentially creates a real disadvantage for Tesla in an area that has been its greatest strength, technology.

4.3.6. Big Tech – Big Money

FAMGA are a potential threat or a potential partner for Tesla and the traditional OEMs. Google, previously rumoured to have been interested in purchasing Tesla, has cash reserves of $117 billion; Apple has $102 billion. (Porter, 2019)

Google is the lead Big Tech investor in the new automotive sector with its key investments in autonomy & shared mobility (Waymo) it has already logged 10 million autonomous miles. Google Ventures holds investments in scooter-sharing unicorn, Lime and ride hailing firms Uber and Lyft. In connectivity, based on the android mobile platform, it has developed Android auto to create "stickiness" and combat competition from Apple & Amazon in the fight for the auto user platform. Android Auto is present in 400 car models from GM, Hyundai and Volvo (see Figure 30).

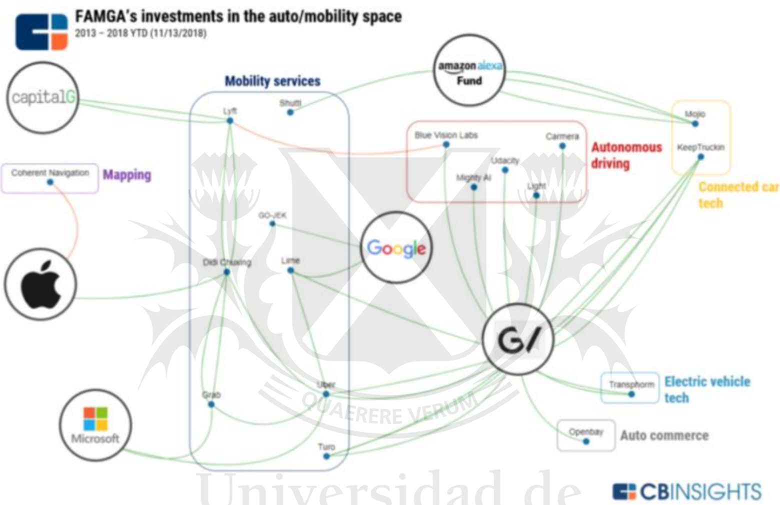


Figure 30: FAMGA Investments in Auto & Mobility (Source: CB Insights)

Apple's, Project Titan was originally to build a fully autonomous EV, but is now focussed self-driving software & EV batteries (already established in the lithium-ion supply chain). It has also partnered with VW vans for its own employee shuttles. It has developed Carplay in the connectivity space to compete with Google's Android Auto. It is partnered with all major auto manufacturers.

Amazon's key interests lie in autonomous logistics and the reduction of last mile delivery costs, as well as auto parts retail (a market that is expected to grow with longer lasting EVs). It is involved in Toyota´s mobility concept the e-palette – a self-driving modular van for logistics, ride-hailing mobile office spaces and medical clinics. It is also bringing Alexa to Audi, BMW, Ford & Toyota as a preinstalled assistant and Echo Auto an aftermarket device.

Microsoft, leveraging its strength in cloud is focussed on car connectivity. It is employing Azure in vehicle design, distribution and sales using AR and VR to enhance user experience. Predictive maintenance, in car productivity, advanced navigation, customer data collection, driver assistance capabilities are key services. Volvo, Nissan & Toyota are partners using the connected car platform. Nissan & BMW are to enable Cortana, Microsoft's digital assistant. They have a formed with VW an Automotive Cloud strategic partnership – cars that can speak to each other and download over the air services.

Facebook is relatively uninvolved although there are potential opportunities for use of its VR product, Oculus, in applications such as testing and customizing car features at point of sale or in the manufacturing and design processes. ("How Big Tech Is Tackling Auto & Mobility," 2018)

Since 2010, over USD 330 billion has been invested in new mobility start-ups across 1100 companies with battery and charging technology accounting for about 50% of patents but only 20% of investments. Traditional incumbents account for less than 10% of these investments but 85% of patents suggesting that incumbent automobile manufacturers are engaged in deploying their massive R&D budgets internally to develop new technology in ACES. Investment focus is an indication of the scale and scope of future developments, with Big Tech focussed on external technology investment and established automotive players focussed internally. (Holland-Letz et al., 2021; McKinsey & Company, 2019)

5. Barriers & Enablers

Almost 10 years ago, Banister, described how a better understanding of the complex relationship between behavioural and technological factors could influence diffusion of BEVs. Diffusion of supply-side technology particularly energy, such as batteries, is described by Wright's law and learning curves. Reductions in cost, and therefore increased diffusion, are achieved with a cumulative doubling of production. Diffusion of demand-side technology, such as BEVs, is influenced by behavioural factors: preference, attitude, lifestyles and social norms. Adoption of BEVs requires sustained policy support, industry investment (vehicle performance and charging infrastructure) and fundamental changes in consumer behaviour. (Tran et al., 2012)

The World Economic Forum estimates that EV production will need to expand 19-fold by 2030 to enable emissions reductions in accordance with the Paris Agreement. There are 3 fundamental challenges: charging infrastructure with an estimated 290 million charging points required by 2040 (from 1.25 million today); the total cost of an EV, and the sustainability of EV batteries, creating a circular, sustainable battery value chain with renewable energy, recycling and V2G technology at its heart. (Mühlon & Eckart, 2020)

For Boston Consulting Group, government incentives and policy (tighter emissions regulation) are the primary driver for faster than expected adoption of EVs, together with falling battery prices (lower Total Cost of Ownership), and extended driving ranges (customer satisfaction). As incentives are withdrawn over the next two to three years, market forces will take over (see Figure 31). (Mosquet et al., 2020)

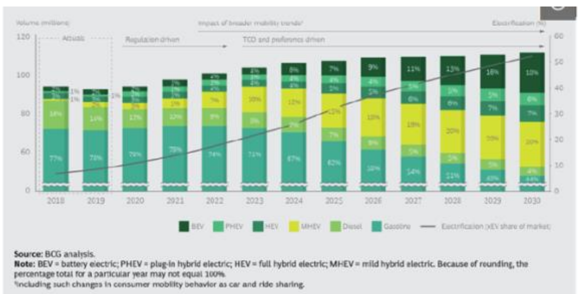


Figure 31: Projected Global Auto Sales by Powertrain 2018-2030 (Source: BCG)

The timing of adoption, when a tipping point occurs, the pace of that adoption and the extent of the adoption (maximum market penetration) are influenced by Consumer Behaviour, Economics, Technology and Regulation. The evolving adoption of electric vehicles has transitioned though the early adoption phase, and is now picking up pace, in what Bain describes as, the rational switching phase, with further acceleration expected in the budget switching phase from 2023 (see Figure 32). (Gottfredson & O'Keeffe, 2019)

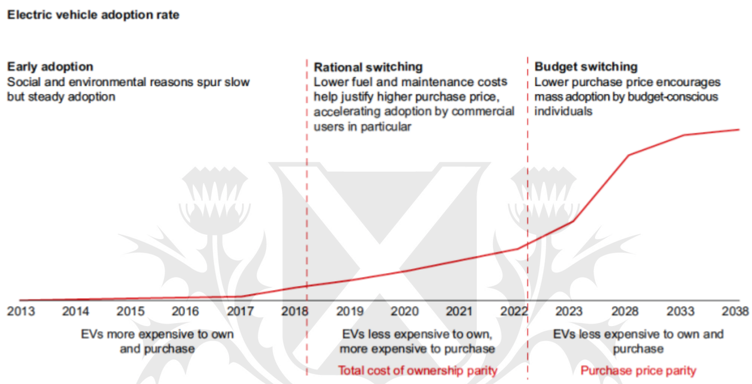


Figure 32: EV Adoption Rate Model (Source: Bain & Company)

Consumer behaviour is driven by a range of factors both enabling and detracting from the willingness to purchase an EV, including environmental consciousness, total cost of operation including purchase price, range anxiety, charging infrastructure, charging time and the availability of customer choice, different models and their aesthetic qualities (performance, design). Heightened public awareness and increasingly available information on relative costs and performance are also important factors in influencing the consumer – Malcom Gladwell's Connectors, Mavens and Salesmen and the Power of Context.

Economic factors and industry preparedness, address economic factors from the point of view of the consumer (TCO) and industry incumbents and other vested interests (including Oil & Gas and Electric utilities). To what extent does industry preparedness across the supply chain hinder or enable the proliferation of electric vehicles?

Technology and infrastructure can be strong enablers or detractors of electric mobility adoption. The evolution of battery technology and its cost, of fast chargers and the ubiquity of fast charging networks, as well as future dynamics of personal mobility, connected-autonomous-shared, are all important factors.

Finally, the regulatory framework and policies at Federal, State and Municipal levels must balance policies across a broad range of issues: health, environment, transport, employment, industry and economic. The public sector has several push/pull tools at its disposal from direct subsidies or incentives, such as cash rebates or tax relief (VAT, road tax, benefit in kind, corporation tax), or indirect, such as use of carpool lanes, preferential parking and free charging (pull) or redesign of urban areas to reduce total car use (in favour of pedestrians or cycling), bans of cars or ICEs in urban centres or emissions penalties for OEMs (push).

The interplay between these different factors is important and complex; each is interconnected in its role to play in driving the adoption of EVs. In the following section advances in each of these areas are discussed in more detail. In summary, the balance of factors at the current time and in the author's opinion tend to enable the adoption of Electric Vehicles (see Figure 33).

Figure 33: Summary of Barriers & Enablers for EV Adoption in major markets (Source: own development)

5.1.1. Consumer Behaviour & Preferences

Key barriers to adoption of EVs by consumers are the overall cost, predominantly the battery cost, mileage capabilities on a full charge (autonomy and so-called range anxiety) and the availability of charging infrastructure. Sales of pure-play BEVs are now surpassing those of earlier plug-in hybrid electric vehicles (PHEVs). (Heineke & Kampshoff, 2019)

New technology nevertheless has teething problems with safety[62] and reliability and first adopters can often pay the price. Even with energy savings, lower maintenance costs or cash rebates and incentives to lower the purchase price, switching to an electric vehicle is not the same as, for example, switching to a smart phone. Existing car ownership represents a significant sunk cost and whilst a portion of the market exchanges vehicles every four to five years, for the vast majority, a vehicle can last up to 10 years or more. Even as and when EVs approach 100% of new vehicle sales, it will still take 15 to 20 years for the entire fleet in a country or globally to convert. (Loveday, 2020d)

Total Cost of Ownership parity occurs when the five-year cost of ownership of an EV is less than an equivalent ICE and Purchase Price Parity when the up-front cost of an EV is equal to or more economic than an equivalent ICE. At the first boundary, the market moves from early adopters to Bain's rational consumers, gradually picking up pace and then accelerating once purchase price parity is achieved.

Consumer preferences are changing. In the US, 10-30% expressed a preference for considering an EV for their next car purchase. In Europe, 40-60% are considering purchasing an EV and over 70% in China, a result of strong government incentives to adopt these vehicles. Greater product availability and consumer choice is reflected in the approximate 120 models introduced a year compared to only 20 per year in the last 7 years. EV price, essentially a function of battery economics, and driving range (range anxiety) were the biggest hurdles to adoption according to a 2017 McKinsey survey. (McKinsey & Company, 2019)

[62] The more anecdotal reports that appear of battery fires or battery recalls, the more the consumer will hesitate to adopt electric vehicles, whether or not safety or reliability is really a widespread problem.

In addition to rapidly reducing battery costs, a 2019 market study in conjunction with Dynata, found that Electric Vehicles outperformed traditional ICEs on Bain's Elements of Value[63]. They found that Electric Vehicle drivers value complex factors, including ongoing costs, design, aesthetics, a sense of belonging and wellbeing that could put a premium on the price they are prepared to pay.(Gottfredson & O'Keeffe, 2019)

Infrastructure investment is a key driving factor or enabler in the adoption of electric vehicles with over 50% of potential BEV buyers concerned over charging stations and limited range. (McKinsey & Company, 2019)

A more recent study by Ernst & Young, the EY Mobility Consumer index, surveyed 9,000 respondents in 13 countries[64] noted for the first time that the environment[65] was the top reason for considering purchasing an EV, overtaking the traditional concerns of cost, range and charging infrastructure. 97% of respondents stated that the COVID-19 pandemic, with cleaner air in urban centres, had heightened their awareness of environmental concerns[66], 67% believe they have a personal responsibility to reduce their impact and 69% believe purchasing an EV is a way to achieve this. This represents a breakthrough in consumer attitudes and is 10% ahead of other issues across all ages and income brackets. Cost (50%), range (33%) and charging infrastructure (32%) are still seen as key barriers but more than 25% see these same

[63] Elements of Value is a registered trademark of Bain & Company, based on Maslow's hierarchy of needs.
[64] US, UK, Germany, China, Japan, Australia, New Zealand, Italy, Sweden, Singapore, South Korea.
[65] The adoption of electric vehicles by a consumer for environmental reasons is potentially a fallacy, particularly if purchased before an existing vehicle is past its useful life or if electricity generation mix is not substantially from renewable sources. Up to 50% of a vehicle's lifetime emissions footprint is in the manufacturing process. VW estimates that its battery system alone is responsible for 43% of lifetime emissions. (Rufford, 2020) A recent Dutch study from the Eindhoven University of Technology, however, defends the green credentials of EVs, stating that emissions from battery manufacture are now thought to be 50% less than previously thought (based on a 2017 study by Romare Dahllöf). Battery lives at 250,000 km are more than 60% greater than previously thought and can be recycled. The power grid is getting cleaner with Bloomberg NEF reporting that solar and wind accounted for 67% of new power capacity in 2019. (Ruffo, 2020c) If the choice is between purchasing a new ICE or purchasing a new EV, then the former wastes hundreds of times more natural resources (17,000 litres of fuel versus 30kg of raw materials, according to Brussels campaign group Transport and Environment. (A. D. Steffen, 2021b) Nevertheless, a more environmental option would be to not purchase a new car and use other modes of mobility.
[66] A Japanese survey of almost 250,000 respondents in 2015 of non-EV users found that environmental awareness had strong effect on intention to purchase an EV and an indirect effect on post-purchase satisfaction. (Okada et al., 2019)

factors as an incentive to buy, signalling shifting attitudes and a potential information gap (see Figure 34). (Miller et al., 2021)

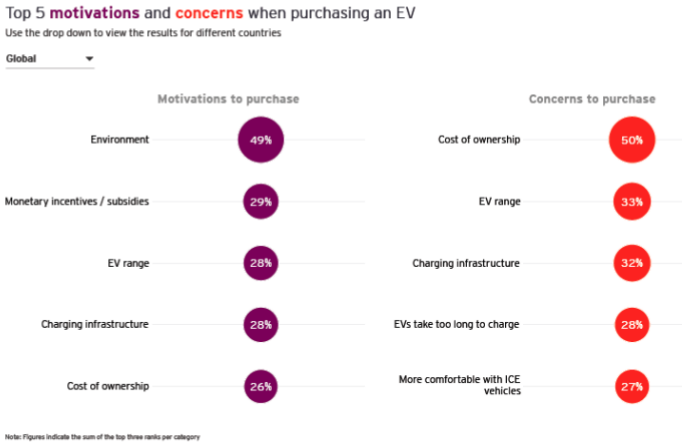


Figure 34: Top motivations and concerns when purchasing an EV (Source: Ernst & Young)

Over 40% of those who plan to purchase a vehicle are considering an EV; 66% in 12 months, 90% in two years 66% of all respondents would pay a premium up to 10% (40% up to a 20% premium); 90% of those already looking to buy an EV would pay a premium. An acceptable driving range for most is between 100 and 200 miles, well within current vehicle capabilities (see Figure 35). (*Electric Vehicle Market Moves into High Gear: EY Mobility Consumer Index*, 2021; *Four in Ten Consumers Plan Electric Vehicle Purchase as Market Moves into High Gear*, 2021)

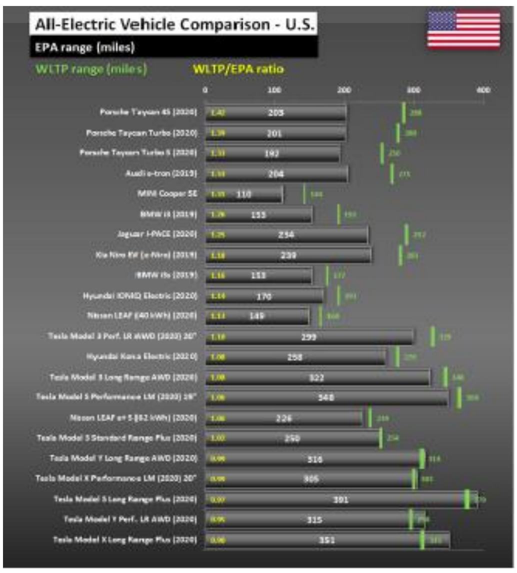


Figure 35: Comparison of EV autonomy by model in US (Source: INSIDEEVs) (Kane, 2020a)

5.1.1.1. Consumer Survey Results

The author conducted an online survey of 150 private individuals, to ascertain their inclination towards purchasing a BEV, a Hybrid, an ICE or no vehicle. The breadth and depth of the study only serves to be exploratory and not representative of the motivations and concerns of consumers towards electric mobility. Of the respondents surveyed, 83% currently owned a vehicle. The respondents came predominantly from Europe (45%) and Latin America (44%), with 11% from the US and Canada. Female respondents represented 52% and Male 48%, with an age range of 26 years old and above (61% over 45).

The respondents were asked if they would choose an EV when purchasing or leasing their next vehicle. 48% responded they would buy a hybrid, 29% a BEV, 18% would continue to buy an ICE and 4% would not buy a vehicle.

Of those willing to purchase an HEV or PHEV, Latin Americans showed a higher preference and female (60%) a marginally higher preference towards hybrids, with other respondents showing a less than average preference. Europeans and US/Canada respondents showed a marginally greater preference for BEVs at a similar level and 60% were male: Latin Americans showed far less preference for BEVs. Of those wishing to continue with ICEs no particular bias was seen from region to region, although males tended to be slightly more in favour of ICEs. The few respondents who would choose not to buy another vehicle, approximately half did not have a vehicle and half currently owned a vehicle. Virtually all respondents were from Latin America and mostly female.

The second part of the survey asked the respondents to choose three from a fixed list of factors that would influence their decision in descending order of importance.

Most important factors for BEV purchasers are purchase price and charging infrastructure, though aesthetic factors like design, driving experience and environment, or range are important. Less important are running costs and charging time. In Latin America purchase price and charging infrastructure are dominant, whilst in Europe range and charging infrastructure feature most highly. In the US and Canada, purchase price and driving experience/performance, are most important. Amongst females, practical factors such as charging infrastructure, range or environment are prominent, whilst males favour economic and aesthetic factors such as purchase price and driving experience.

Most important factors for HEV/PHEV purchasers are purchase price and charging infrastructure (concerns about), though again aesthetic factors like design and driving experience or costs, purchase price and running costs, as well as the environment are also important. Less important are range and charging time. In Latin America purchase price and charging infrastructure are most important, whilst in Europe economic factors feature most highly. In the US and Canada, running costs are dominant. Amongst females, practical factors such as charging infrastructure, purchase price and environment are prominent, whilst males favour economic factors such as running costs and purchase price or charging infrastructure (lack thereof).

Most important factors for ICE purchasers (rather than an EV) are also purchase price and charging infrastructure (concerns about), though again aesthetic factors like design and driving experience, or purchase price are important. Less important are running costs, range and charging time. In Latin America purchase price and charging infrastructure are most important, whilst in Europe purchase price and design quality/brand feature most highly. In the US and Canada, concerns over charging infrastructure are most important. Amongst females, purchase price and design are prominent, whilst males are more concerned with charging infrastructure purchase price and driving experience.

Most important factors for those choosing not to purchase a vehicle are alternative mobility options and the environment. Less concerning are the associated costs of vehicle ownership. In Latin America factors are equally important with alternative mobility and running costs slightly more important, Europe and US/Canada have virtually no respondents who would not purchase a vehicle. Amongst females, environment and alternative mobility are prominent, whilst males are more concerned with purchase price and running costs.

In summary, albeit based on a very limited sample, it is encouraging that almost 80% of respondents would consider purchasing some form of electrified vehicle. For all vehicle choices, charging infrastructure and purchase price appear to be the dominant factors, ahead of aesthetic features. Interestingly running costs, range and the environment are less important and charging time hardly factors. Latin America follows the general pattern, whilst Europe is more complex with all factors given some prominence. In the US and Canada more consideration is given to aesthetic features (design, brand and driving experience), although purchase price and charging infrastructure feature as important.

Please refer to Appendix 3 for graphs of the key results.

5.1.2. Economic & Industry Factors

5.1.2.1. TCO and Purchase Price Parity

The predominant economic factor for consumers is the Total Cost of Ownership (TCO). The TCO is the cost of ownership, usually measured over five years and including the purchase price[67] of the vehicle, finance costs, fuels costs[68], servicing and maintenance and insurance, as well as other tax incentives[69]. The purchase price of an EV can be more than 25% more expensive but fuel costs are typically 33% lower than for an ICE and on average over a vehicle lifetime of 200,000 miles maintenance and service costs are 50% less, at $0,03 per mile, for a BEV or PHEV. (Loveday, 2020a)

According to the International Council for Clean Transportation (ICCT), EVs are already cheaper to own and run in Europe than petrol/diesel vehicles when accounting for the Total Cost of Ownership over 4 years (see Figure 36). The ICCT estimates that capital cost parity or purchase price parity is likely between 2025 & 2030. (Campbell & Tian, 2019; Carrington, 2019)

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[67] The purchase price of the vehicle takes in to account any cash incentives, rebates or any tax incentives, e.g., 0% VAT.
[68] Fuel costs are calculated based on average annual distances travelled for a particular market or country. The greater the positive differential between gasoline prices and electricity prices and the greater the distance travelled on average, the greater the fuel savings of an EV versus an ICE.
[69] Road or vehicle duties or no benefit in kind or corporate tax deductions for company vehicles.

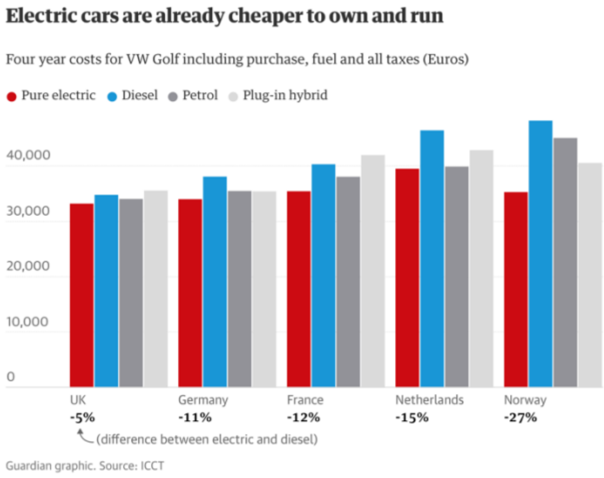

Figure 36: Four Year costs for VW Golf by powertrain (Source: ICCT)

In the US, the TCO tipping point will likely arrive in the 2020s as battery costs continue to fall and emissions standards prevent automakers from producing diesel and gasoline powered cars. Both Bloomberg New Energy Finance and the ICCT predict Total Cost of Ownership (TCO) parity in the early to mid 2020s for smaller BEVs in the US. Market penetration is higher where government has provided strong incentives, and importantly charging infrastructure. (Sperling, 2018)

Boston Consulting Group expects battery prices to lead to a five-year Total Cost of Ownership tipping point globally between 2022 and 2023. PHEVs and HEVs are transitional, as the TCO drives the economic argument for BEVs, for both the consumer and for OEMs, as the lowest cost solution for the industry to meet emissions. Regional variations of the TCO tipping point occur due local purchase price, average kms driven and the differential between electricity costs and gasoline prices (see figure 37). (Mosquet et al., 2020)

	US	China	Japan	France	Germany	Italy	Spain	UK	Nordics
$/gallon[1]	2.68	3.68	5.00	6.45	6.12	6.75	5.57	6.48	6.62
$/kWh[2]	0.13	0.08	0.22	0.19	0.32	0.27	0.24	0.22	0.21
Gas-to-electricity ratio	20.6	46.0	22.7	33.9	19.1	25.0	23.2	29.5	31.5
Number of miles driven	13,476	8,885	5,594	8,076	8,766	5,963	7,789	8,188	8,031
Beneficial to xEVs	2nd	1st	9th	3rd	7th	8th	6th	5th	4th

China provides the most favorable combination of energy prices and mileage for xEV penetration

Sources: BCG analysis; US Energy Information Administration; US Department of Transportation; US Department of Energy; Euromonitor; Enerdata (Odyssee-Mure).
[1]Base case assumes July 2019 average prices, corresponding to about $60/barrel.
[2]Residential average for 2018.

Figure 37: Beneficial relative energy prices by country (Source: BCG)

The US Department of Energy laboratory, Argonne, produced in 2016 and updated in 2021, a comprehensive TCO study across a number of vehicle sizes, powertrains and uses. It concluded that purchase cost and fuel cost (or fuel cost differential) are the two most important factors in achieving parity but that maintenance costs and insurance premiums (also largely related to purchase or replacement cost) also play an important role. It found that for a 2019 model small SUV the lifetime cost of ownership per mile for a BEV was already competitive in the US with a similar ICE (see Figure 38). (Burnham et al., 2021)

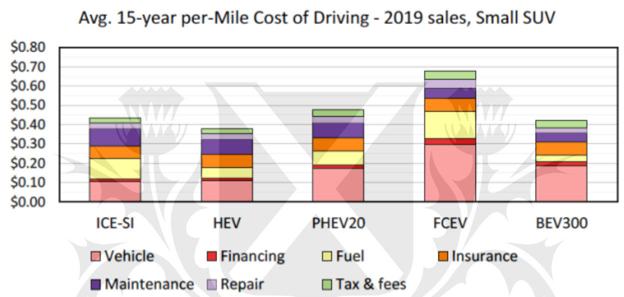

Figure 38: Average 15-year per-Mile Cost of Driving by powertrain (Source: Argonne National Laboratory)

The payback period for a US driver, travelling 13,000 miles annually is five to six years. For an Uber or Lyft driver the EV payback is only 2 to 3 years. A 20% to 25% improvement in battery costs could reduce payback by one year. (McKinsey & Company, 2019)

In a report commissioned by Transport and Environment, Bloomberg NEF, expects purchase price parity (excluding subsidies) to be achieved in Europe between 2025 and 2027 (see Figure 39). Falling battery costs, new vehicle architecture and dedicated production lines will all contribute to falling costs of production. With batteries responsible for approximately 30% of the total cost, the continued reduction is fundamental. Transport and Environment predicts 100% adoption in Europe by 2035. ("BEV vs ICE: A Race to Price Parity," 2021)

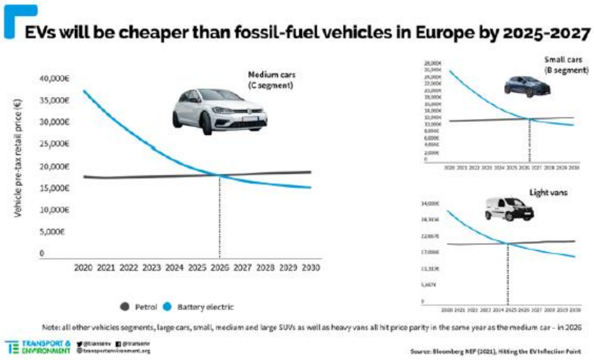

Figure 39: Price Parity prediction of EVs versus ICE vehicles (Source: Transport & Environment)

A tear down of the costs of a Chevy Bolt in 2017, by investment bank UBS put TCO parity in Europe by 2023[70], in China by 2026 and in the US by 2028. Without the OEM profit margin TCO parity was expected in Europe by 2018 in China by 2023 and in the US by 2025. In the latest tear down of VW's ID.3 in 2021, TCO parity has been achieved in most major markets and the UBS team now expects that purchase price parity will be achieved as soon as 2024, the difference falling to only $1900 by next year. The accelerated forecast comes about as the technology-cost breakthrough occurs[71], rapidly increasing consumer choice and a regulatory environment that favours EVs. UBS predicts a 50% share by 2030 and possibly a 100% share by 2040. (Hummel et al., 2017; L. Steffen, 2020d; *The Electric Vehicle Revolution Is Shifting into Overdrive*, 2021)

A detailed study of 125 US car models published in 2016 by a team at MIT[72], and recently updated, affirms that electric cars are much better for the planet and that over the lifetime of the vehicle most BEVs are lower cost too (see Figure 40). A direct comparison of the Tesla Model 3 and the Nissan Altima reveals that despite the purchase price differential, the average monthly cost is comparable. (Dizikes, 2016; Miotti et al., 2016)

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[70] Including OEM profit margin of 5%.

[71] Batteries have been the key battleground, representing 25% to 40% of the cost of an EV, and the threshold of $100 per kWh should be achieved by next year.

[72] Massachusetts Institute of Technology.

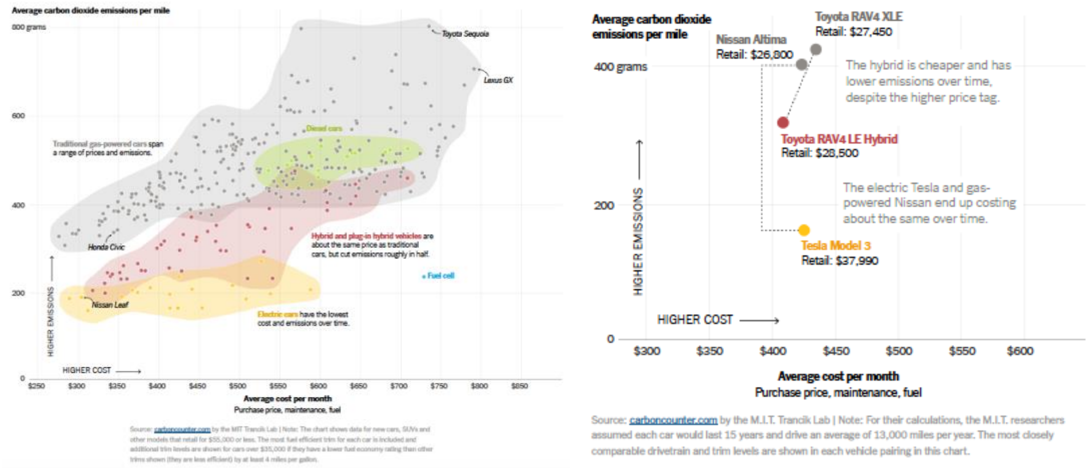


Figure 40: Comparison of CO2 emissions by powertrain and TCO by select models (Source:(Miotti et al., 2016)*)*

According to the DOE the annual fuel cost of EVs is significantly lower in the US, less than 20%, of the cost of a conventional ICE, cased on 15,000 miles gasoline prices between $2.39 and $3.03 for premium and electricity at $0.13 per kWh (see Figure 41). Regional cost variations across the US, both for electricity and gasoline, means that adoptions of EVs will be more attractive in some States than others.[73]

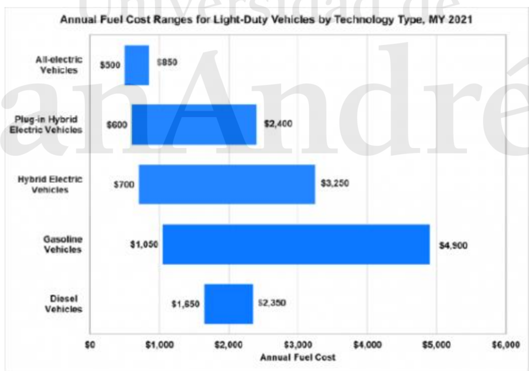


Figure 41: Annual Fuel Cost Range by Powertrain (Source: IEA (Kane, 2021a)*)*

The tech trends that have occurred over the past 10 years, consistently outperforming expectations, will continue and once the technology is better and cheaper a tipping point will occur. ICEs will depreciate quickly and be worthless by 2030. (Shahan, 2020) In 2019, the

[73] Washington State has lower than average electricity costs at approximately $0.10 per kWh and higher than average gasoline prices at $2.83 per gallon, so is particularly attractive as is California with gas prices above $3.0 per gallon. Alaska and Hawaii have electricity prices at two to three times the national average and so are relatively unattractive for EV adoption.

ICCT published detailed breakdown of costs of EVs in the US, with predictions for the falling costs of battery packs. The $120 to $135 per kWh predicted for 2025 has already been achieved. In addition to battery costs, indirect costs including amortization, depreciation and R&D costs area a very significant portion of current costs per vehicle and can be expected to drop rapidly with production volume. Purchase price parity is predicted for 2024-2025 for most vehicle types with TCO parity occurring approximately two years prior. (Lutsey & Nicholas, 2019)

Consensus seems to agree that for most major markets TCO parity has been achieved or is just around the corner and that purchase price parity will follow in the next 3 to 5 years. There are nevertheless dissenting voices. Honda puts price purchase parity for BEVs by 2035, albeit with its own agenda for HEVs and FCEV technology. An Oliver Wyman study of a compact car commissioned by the Financial Times estimates EVs are still 45% more expensive and that even at $85 per kWh they will be 9% more expensive. (Ruffo, 2020g)

5.1.2.2. Industry Barriers and Bottlenecks

Converting plants to EV-only, securing supplies of battery cells and investing in charging infrastructure will impact profit margins in the early stages until scale is achieved. OEMs face a stark choice between accepting lower returns or risking being left behind. Platforms such as VW's MEB, GM Ultium or Rivian's skateboard are the key to scalability and profitability. (Morris, 2020c)

Fewer parts and less labour required to build electric vehicles could potentially lead to industrial action in unionised work forces. In the US alone there are some 35,000 union members in the auto industry. Alix Partners estimates that 40% fewer hours are required to assemble the electric motor and battery than an ICE and transmission. Ford estimates a 30% reduction in labour and 50% less floor space will be required. Deloitte Consulting estimates that the market for a range of parts could shrink by up to 20%. With the domination of Asian battery manufacturers, it is possible that auto jobs could be exported to where the supply chain is already established[74]. (Collingridge, 2021)

The Faraday Institution, a UK government funded battery research organisation, estimates that there are 2,500 suppliers with 180,000 jobs at risk in the UK auto industry with the switch to batteries, power control units and electric motors. An estimated 8 Gigafactories will be needed by 2040 to preserve some 115,000 of these jobs and could provide an employment boost.

Accelerating battery production, and associated investments across the value chain, such as mining for metals, and the availability of small affordable vehicles, particularly in price-sensitive early-stage markets, such as Latin America, will be fundamental to sustainable adoption of EVs. A future problem will be found in recycling second life EV batteries. (Hertzke et al., 2019)

Accelerating sales of EVs, particularly ZEVs[75], will require huge demands on resources not just in terms of manufacturing capacity of the vehicles themselves but also across the whole value chain, from mining of rare metals, such as cobalt, nickel and lithium, to building supply chains for battery production, powertrain, sensors, software and traditional auto-part suppliers, as well as the infrastructure required for public charging. In Europe, as will be discussed in the next chapter, the accelerating adoption of EVs will require four gigafactories for battery supply and 300,000 to 400,000 public charging stations (1 per 5 to 7 cars) to meet the demand for the expected 2.2 million EVs in 2021 and avoid CO_2 penalties. (Kempf et al., 2020; McKinsey & Company, 2019) Whilst consumers may be willing to pay a premium for EV powertrains, OEMs face high investment, initially low sales, high costs and 60% lower after-sales revenues compared to ICEs.

[74] 64% of the Chevrolet Bolt is made in South Korea.
[75] Zero Emissions Vehicles include Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV) and Fuel Cell Electric Vehicles (FCEV) but not Hybrid Electric Vehicles (HEV), which are incapable of driving in fully electric mode.

The scale of the required scale-up is staggering. The International Energy Agency predicts that 1,000 GWh[76] of global production capacity for batteries will be required by 2025 and 1,500 GWh by 2030, an increase from approximately 300 GWh in 2018 and 700GWh in 2021[77].

The Argonne Collaborative Centre for Energy Storage Science estimates that the US will need to build 20 to 40 battery factories over the next 15 years with a combined terawatt of new capacity, a volume for which the materials do not exist. Either materials substitution (new battery chemistries or a shift back to LFP chemistry) and/or a recycling framework will be crucial in the medium to long term. (Morris, 2021f)

The South Korean battery industry will invest USD 35bn by 2030 and is scaling up fast. SK Innovation is targeting 500 GWh of capacity by 2030 up from 40 GWh currently. SKI currently has backorders, over several years, of over 1 TWh[78], and it is suspected that CATL & LG Chem have similar order backlogs.

The recycled battery market could be worth USD 6 billion by 2030, according to Circular Energy Storage, with 1.2 million tons of Lithium-ion batteries reaching the end of their life cycle and requiring recovery of Lithium, Cobalt and Nickel components or converting into second life energy storage applications[79]. (Edel, 2019)

Soaring demand is already putting pressure on the entire supply chain from mining of Lithium, Cobalt and Nickel for batteries and rare earth metals (mostly found in China) used to make magnets for electric motors, to manufacturing capacity, causing delivery days. When demand accelerates a key question is whether the supply chain can keep up or more precisely stay ahead[80].

[76] 1,000 GWh is enough capacity for 10 million vehicles each with a 100-kWh battery pack or 20 million vehicles with a 50-kWh battery pack.
[77] Source: Statista.
[78] 1 TWh = 1,000 GWh.
[79] VW has already started recycling batteries and recovers approximately 70% of the battery weight with a long-term target of 90%.
[80] The impact of the COVID-19 pandemic on the microprocessor supply chain, from disrupted production to increased demand for consumer electronics has caused a critical shortage that will likely last through 2022, impacting not only the auto industry.

Cobalt, Nickel and Lithium scarcities could be a challenge for BEV adoption as soon as 2025. Demand for energy storage[81] is expected to grow by 32% p.a. to approximately 940 GWh in 2025 and 2,300 GWh in 2030 for applications in mobility, utility power storage and consumer electronics; mobility represents approximately 80% of this demand overtaking the previously dominant consumer electronics category. (Eddy et al., 2018) Jeffrey Straubel, co-founder and former CTO of Tesla, feels OEMs "haven't done the math" on supply chains, with many OEMs and countries proclaiming they will be all-electric by 2030 to 2035, equating to the problem to that of an "overbooked flight". (Mihalascu, 2021)

Another study by ABB Robotics and Ultima Media expresses fears that demand may outstrip supply. By the mid 2030s, Electric Vehicles are expected to account for more than 50% of global sales, with many OEMs and European countries also predicting and end to conventional ICEs (i.e., 100% EV sales). If EV sales grow at a compound annual growth rate of 21% over the next decade, battery production and capacity will need to be even higher, as consumers demand increased range. An expected increase in demand from 330 GWh in 2020 to 2180 GWh in 2030, will require an increase of 150% in production capacity for facilities that typically operate at 70% output. (Cantu, 2021)

The electric car battery arms race has already begun and is likely to get worse. Supply bottlenecks have already forced Audi and Jaguar to pause production. Honda moved its production of European destined vehicles from Europe to Asia, where it has well established supply lines. A legal dispute between LG Chem and SK Innovation threatened supply disruption to Ford and VW. In electric mobility there appears to be a power shift away from OEMs to big battery suppliers. (Morris, 2020b)

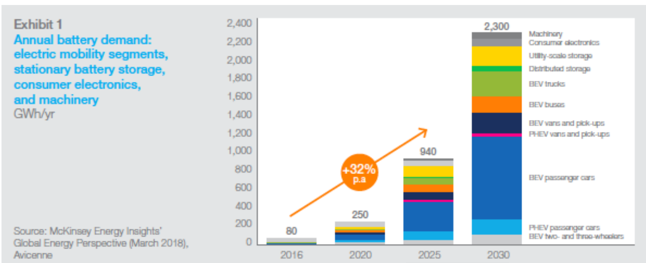
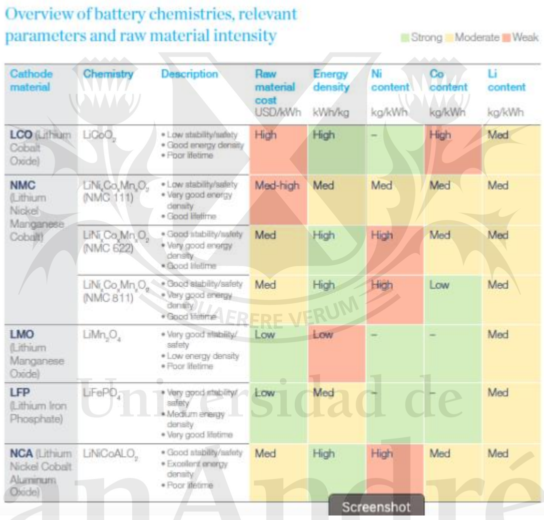


Figure 42: Projected demand for Lithium-ion batteries to 2030 by application (Source: McKinsey)

[81] Energy Storage includes Electric Vehicles, utility storage of renewable electricity generation and other applications such as smart phones and laptops.

Raw materials represent less than 20% of the cost of a battery but this share has increased with rising commodity prices. McKinsey forecasts a radical shift in battery chemistries is expected towards Lithium Nickel Manganese Cobalt (NMC622 & NMC811) that will capture over 90% of the market by 2025[82], even in China where Lithium Iron Phosphate (LFP) dominates with a 55% share. These new chemistries are less cobalt intensive but use much more nickel (see Figure 43) and are more energy dense than Lithium Manganese Oxide and LFP, which had lost favour with OEMs though gaining in popularity again[83]. Projected demand for cobalt increases at 10% per annum, around 5% for Nickle and almost 15% for Lithium. Solid state batteries and Lithium air batteries are potential game changers but only likely by 2025 to 2030. (Eddy et al., 2018)


Overview of battery chemistries, relevant parameters and raw material intensity

Strong / Moderate / Weak

Cathode material	Chemistry	Description	Raw material cost USD/kWh	Energy density kWh/kg	Ni content kg/kWh	Co content kg/kWh	Li content kg/kWh
LCO (Lithium Cobalt Oxide)	$LiCoO_2$	• Low stability/safety • Good energy density • Poor lifetime	High	High	–	High	Med
NMC (Lithium Nickel Manganese Cobalt)	$LiNi_xCo_xMn_xO_2$ (NMC 111)	• Low stability/safety • Very good energy density • Good lifetime	Med-high	Med	Med	Med	Med
	$LiNi_xCo_xMn_xO_2$ (NMC 622)	• Good stability/safety • Very good energy density • Good lifetime	Med	High	High	Med	Med
	$LiNi_xCo_xMn_xO_2$ (NMC 811)	• Good stability/safety • Very good energy density • Good lifetime	Med	High	High	Low	Med
LMO (Lithium Manganese Oxide)	$LiMn_2O_4$	• Very good stability/safety • Low energy density • Poor lifetime	Low	Low	–	–	Med
LFP (Lithium Iron Phosphate)	$LiFePO_4$	• Very good stability/safety • Medium energy density • Very good lifetime	Low	Med	–	–	Med
NCA (Lithium Nickel Cobalt Aluminum Oxide)	$LiNiCoALO_2$	• Good stability/safety • Excellent energy density • Poor lifetime	Med	High	High	Med	Med

Figure 43: Overview of battery chemistries (Source: McKinsey)

Wood MacKenzie expects the supply of raw battery materials to be sufficient this decade but is only predicting that EVs will represent 40% of the new sales by 2040, much slower than most predictions. With an accelerated adoption rate of EVs and growing demand from energy storage for renewable generation, the Cobalt market doubles by 2025, and use of Nickle for EVs grows to 30% of total demand by 2030, up from 5% today. (Gerdes, 2020a)

[82] SK Innovation is developing a fast-charging battery capable of 800 km range with two 10-minute recharges.
[83] LG Energy solutions is reportedly developing new LFP batteries having previously focussed on NMC and NMCA chemistries, as they are cobalt and nickel free, less expensive and safer. CATL & BYD continue their focus on LFP technology with energy density improving. With their cell to pack design, LFP is competitive for the mass market, though less suited to high performance or longer-range applications. (Kane, 2021g)

According to the head of Earth Sciences at London's Natural History Museum, to convert the UK's 31.5 million vehicles to electric vehicles would require an increase of 200% in the global annual production of cobalt, 100% increase in the production of neodymium and a 75% increase in the production of lithium. To convert the world's estimated 1.4 billion motor vehicles would require 40x these quantities, even before the increases in mineral requirements for solar and wind (see Figure 44). (Amos, 2021)

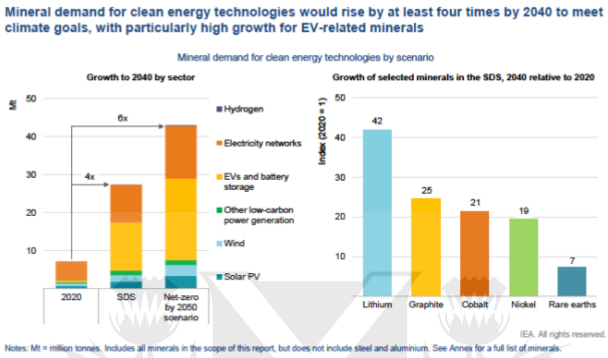


Figure 44: Projected mineral demand to 2050 (Source: IEA (Kim et al., 2021)*)*

Geopolitically, China dominates raw material refining (80%), cell production capacity (77%) and battery component capacity (60%), as well as rare earth metal deposits (60%) and processing (90%)[84]. This is a potential headache for Europe and the US in the evolution of their electric vehicle markets, particularly if supplies become tight and China prioritises its own industry (see Figure 45). (Gerdes, 2020b)

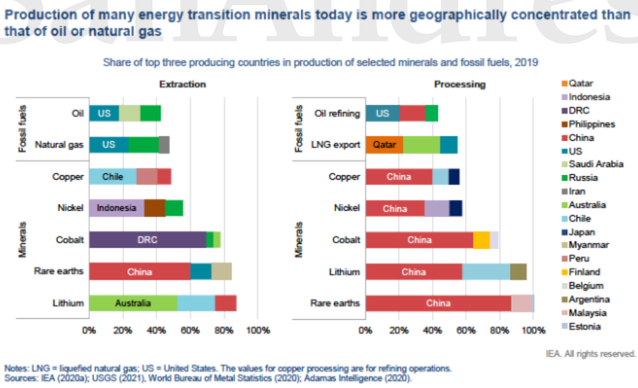


Figure 45: Geographic concentration of energy transition minerals (Source: IEA (Kim et al., 2021)*)*

Another potential bottleneck, at least in the short term, impacts the whole auto industry. As the global pandemic developed demand for new cars dropped and consequently demand for

[84]US Geological Survey: rare earth metals are an important material in the production of magnets for motors and other auto applications, such as power steering.

semiconductor microchips (up to 100 in a car) from the auto industry also dipped. Meanwhile increased demand for connectivity, specifically technology required for home working, shifted capacity to smartphones laptops and computers. As the auto industry recovered this year it has found itself with a shortage. With the semiconductor industry operating at full capacity, and lead times of 12-18 months for new capacity, continued shortages can be expected through 2022. (Burkacky et al., 2021)

It remains to be seen whether a perfect storm created by increased willingness of consumers wishing to adopt electric vehicles, the cost of technology allowing them to do so and the stated intentions of industry incumbents to introduce more models with better technology, creates an Osborne effect[85] for the auto industry, causing a short to medium term dip in the market. Much will depend on how quickly the industry can scale up with offerings that are innovate and free of glitches[86].

5.1.3. Technology & Infrastructure

5.1.3.1. Battery Technology

In chapter 4, we discussed the evolution of battery technology and how the advancement of new battery chemistries, pack design and the learning curve through increased production volumes have dramatically reduced the cost and increased the performance characteristics of batteries.

Energy densities and therefore range have improved consistently over the past few years and most EVs on offer today are capable of over 200 miles (320 km) on a single charge, and some models approaching 400 miles (640 km) far in excess of what most people require for daily

[85] The Osborne effect describes the phenomena where in a period of rapid technological change consumers defer orders for technology that they wish to adopt in the expectations that the current offering will become obsolete and that better, cheaper technology will soon become available.
[86] The recent recall of 69,000 Chevrolet Bolt's because of a risk of fire when charging the battery may damage not only GM's reputation but the safety reputation of EVs in general.

commuting and errands and importantly closing on the range of most ICE cars[87] (see previous Figure 35). Battery lifetime, measured in the number of charge and discharge cycles is usually guaranteed up to 100,000 miles or about 8 years but today's technology should be capable of 200,000 miles or almost 17 years.

Given the convenience of home charging or public on-street charging where available and fast chargers capable of providing quick top-ups in times similar to refuelling and ICE, at what point does extra range or battery life become unnecessary or even undesirable, and consumers prefer less weight (smaller but more energy dense battery) and less cost?

Battery pack cost is the single most important factor in reducing the cost of EVs to parity (and beyond) as discussed earlier in the TCO and Purchase Price Parity section of this chapter. Analyst forecasts have been unable to keep up with the pace of reduction in battery costs. The experience curve that comes from a cumulative doubling of production, as described by Wright, can provide valuable insights into the tipping point. According to Bain Capital, experts expect the tipping point for mass production of electric vehicles will occur when purchase price parity is reached for EVs and ICEs. The threshold of $100/kWh is often quoted and is expected to occur before 2023 (see Figure 46). (Gottfredson & O'Keeffe, 2019) Cumulative doubling of production continues to provide cost reductions of approximately 8% annually for BEV manufacturers. (Nykvist & Nilsson, 2015)

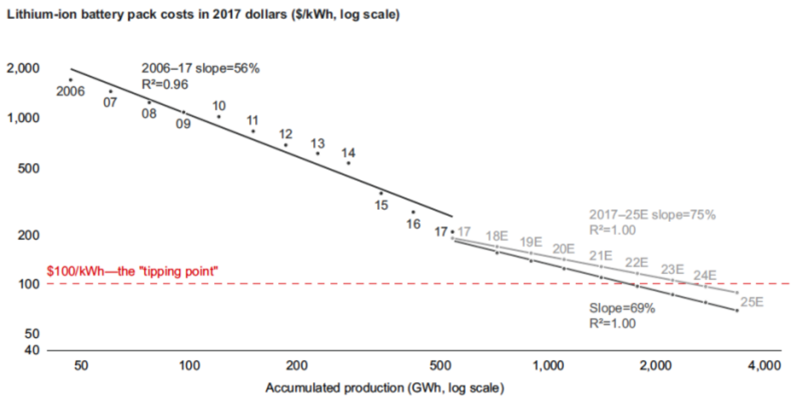


Figure 46: Projected battery pack costs to 2025 (Source: Bain & Company)

[87] Most ICE passenger vehicles are capable of a range of 250 to 300 miles with most drivers filling the car only once a week.

IHS Markit expects costs to reach this tipping point of $100 per kWh by 2023 and a price of $73kWh by 2030. Bloomberg NEF believes battery prices could fall as low as $ 61 by 2030 (see Figure 47). LFP batteries, most commonly used in China, have already reached this threshold.

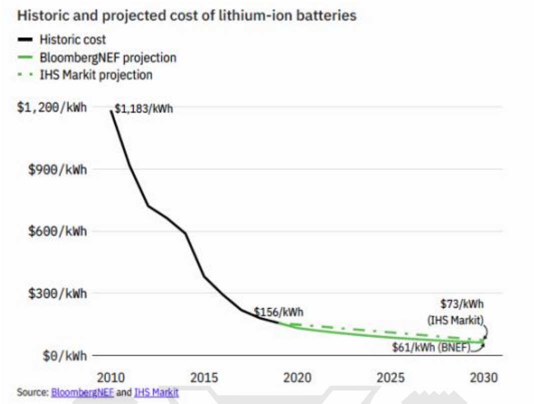


Figure 47: Projected cost of Lithium-ion batteries to 2030 (Source: BNEF, IHS Markit, (Gerdes, 2020b)*)*

EVs will become profitable with advances in battery technology and as economies of scale are achieved, as more than 300 new BEV models are introduced by 2025. McKinsey predicts a 14-fold increase in battery demand by 2030 from 2019, between utilities (renewable electricity plants), EVs and mobile technology. The estimated cost gap of approximately USD 12,000 between an ICE and an EV is most significantly impacted by battery costs (see Figure 48).

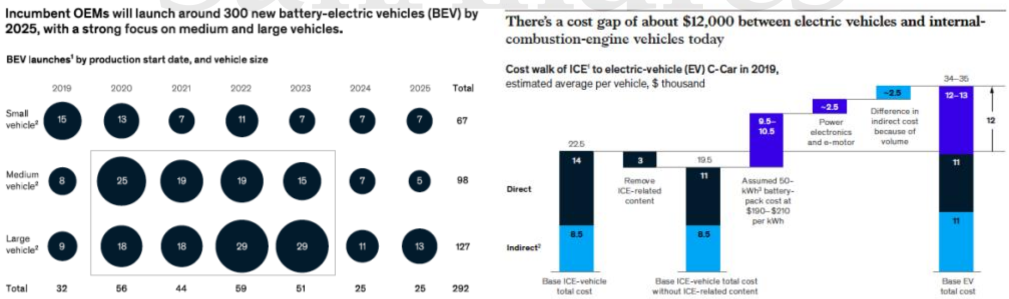


Figure 48: Predicted BEV model launches to 2025 and cost gap 2019 (Source: McKinsey (McKinsey & Company, 2019))

A predicted 50% decline in battery costs between 2025 and 2030, will cause this gap to shrink rapidly, since battery packs represent an estimated 25% of the cost of an EV. (Heineke & Kampshoff, 2019)

5.1.3.2. Charging Infrastructure

A critical barrier in the adoption of electric mobility is the availability of adequate charging infrastructure, and importantly the perception of an adequate network to assuage so-called range anxiety. Just as the proliferation of gasoline service stations accelerated the adoption of ICE vehicles over EVs at the beginning of the last century, charging infrastructure will have a similar critical role.

Japan tried to jump start the EV market investing $1 billion in 2012 and building 7,000 fast chargers by 2016 but faced industry reluctance particularly from Toyota to adopt the standard. This time round although industry scepticism in Japan still exists, there is much more choice, vehicles are cheaper and range much longer and they expect to build 150,000 charging points by 2030 from 30,000 currently. (Kane, 2021f)

As important as the overall number of chargers is, the distribution of the network and the mix of public slow chargers between slow chargers, fast chargers and rapid chargers plays an important role in allowing users to charge at different speeds for different requirements. Whilst charging time and the availability of charging infrastructure is a factor in deterring would be purchasers of EVs, EV owners benefit from being able to charge at home, at their work or an increasing number of commercial locations more than sufficient for typical day to day use, and with the improvements in range and ever faster ultra or rapid chargers can top up in a very short time period on longer journeys.

EV chargers are classified according to the speed at which they can recharge the vehicles battery, with faster charging requiring higher voltage, higher power charging equipment. Level 1 chargers use a standard household power socket to plug into and offer approximately 15 km of charge per hour. Level 2 chargers are specialised standalone charging units, found in public or commercial locations and can be purchased for home charging, and offer a charging rate of approximately 30 km per hour. Level 3 or DC Fast Charging chargers are, as the name suggests, very high power, very high voltage units found in specialised EV charging stations and traditional service stations, allowing a charge rate of up to 300 km per hour. (*BEVs, PHEVs and HEVs, Which Electric Vehicle Do You Drive?*, n.d.)

Charging rate is also determined by the power that a vehicle can accept. The IONITY network in Europe is beginning to offer 350 kW charging speeds, more than can be supported by existing vehicles. The Porsche Taycan comes closest at 270kW allowing a recharge from 10% to 80% in just 20 minutes. The 5-to-10-minute charge will be game changing for EV adoption. 800-volt architecture in EVs is becoming more common.

Installation of public chargers, particularly in the early stages of transition, is critical for the psychological value on the consumer of a large visible network of charging stations and because the revenues from electricity chargers is not likely to be sufficient, at least initially, to justify private investment without some sort of government incentive. Home charging is more convenient and often at subsidised tariffs. Public chargers should be high-power fast chargers that can charge a vehicle in less than 30 minutes. Collaboration amongst incumbent OEMs in setting up fast-charging networks mirrors Tesla's strategy of rolling out its own network alongside EV development[88]. Government incentives or tax rebates can be employed to encourage retail outlets and employers to install chargers. (Sperling, 2018)

There are an estimated 1.25 million charging points around the world as of 2020. Predominantly slow chargers and predominantly in China. China has approximately one charger for every 5 to 6 Electric Vehicles, whilst the rest of the world has an electric charger for every 10 to 11 vehicles (see figure 49). EV fast charging is limited and highly fragmented. EV aftersales, parts, recycling or reuse of batteries is still generally lacking. (Kempf et al., 2020)

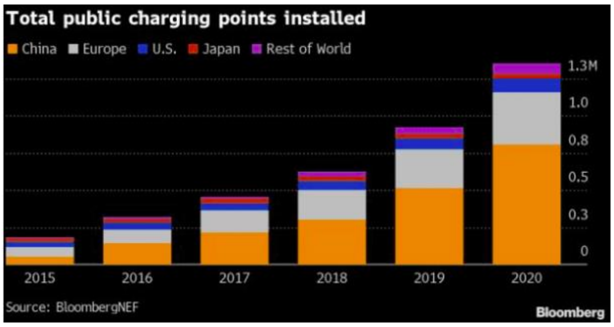


Figure 49: Public charger availability by country or region 2020 (Source: BloombergNEF)

[88] Ford, VW, BMW, Hyundai and Daimler have a fast-charging network across Europe in 24 countries called IONITY.

With 11 million EVs on the road globally and 77 million expected by 2030, EVs will still only represent a small proportion of the total estimated vehicle fleet of 1.4 billion vehicles in existence today. If sale of EVs at this point are close to 100% of new sales, as they will likely be in Europe, then the subsequent 10 years could see the entire fleet converted to EVs. Factor in growth in the vehicle market over this period, particularly in China, unless mobility patterns change, and it is not hard to fathom the targeted 290 million charging points globally by 2040[89]. Just a few years ago purchase price and driving range were the main barriers to EV adoption, now charging infrastructure is the number one concern, according to McKinsey. (Linder & Nägele, 2021)

National and local public investment and funding are critical in the early stages to encourage private investment in infrastructure as business models take time to bed in and become profitable. In Europe, energy companies have been engaged in deploying chargers for several years. In the US, the market is predominantly privately owned with 3,000 companies and 50 regulators across the States bringing complexity to national or regional expansion. The pressure in the US to achieve profitability faster is also greater.

Collaboration amongst technology providers, OEMs, Charging Network Operators, Electric Utility companies and renewable energy players is also fundamental. The IONITY network of 400 fast charging stations across 24 European countries is a collaboration amongst various OEMs and ABB the charger manufacturer. The Open Charge Point Protocol (OCPP) allows interoperability amongst different charging stations.

Traditional Oil and Gas companies, such as Shell and BP have been quick to ramp up activities and leverage their renewable energy assets. Shell, though its subsidiary Greenlots intends to deploy 500,000 stations by 2025 and 2.5 million worldwide by 2030. BP's charging subsidiary, Chargemaster will have installed 400 ultrafast chargers by the end of 2021. Newcomers ChargePoint with 114,000 stations in 14 countries, EV Box in the Netherlands with 190,000

[89] This quantity of charging points, estimated by the World Economic Forum, could service over 3 billion electric vehicles by 2040, although IEA estimated that 300-400 million vehicles will be electric by 2040 of an estimated 2 billion vehicles in total (15% to 20% vehicle stock penetration).

charging points or Blink Charging with 30,000 chargers across 13 European countries, half in the US, were unheard of just a few years ago.

Tesla's coveted supercharger network of approaching 30,000 chargers, will soon be open to non-Tesla owners, despite potentially alienating Tesla owners who could face longer queues. The super chargers with its proprietary connectors are already retrofitted with the CCS connector and are scheduled for the US with the Japanese developed CHAdeMO connector[90]. EV Go has been collaborating with Tesla since 2019, fitting the latter's proprietary connector to its fast-charging stations. In both Europe and the US, charging networks are being heavily subsidised but only for chargers available to all EVs. Factor in Tesla's key strategic aim to accelerate EV adoption and the reducing competitive advantage from having its own network (in the face of growing competing networks), maintaining a separate incompatible network is not sustainable or efficient. Whilst for Tesla owners the network will continue to be free or subsidised, Tesla will be able to charge a premium for non-customers. Though Goldman Sachs' estimate of $25 billion in revenue streams appears optimistic, as charging costs become commoditised and low margin, access to non-customer's information through Tesla's app could be marketing gold. (Morris, 2021e)

Charging commercial fleets will play an important role in increasing utilisation of the network. In the US this market could be worth $15 billion by 2030, according to McKinsey. Fleets of commercial and passenger vehicles are ideally suited for electrification as the comparative TCO is substantially less (15% to 25% by 2030) given the high utilisation of these vehicles. An estimated $11 billion in investment is required to deploy the 13 million public chargers needed in the US for all its EVs by 2030. A substantial investment with uncertain utilisation. The commercial fleets represent certain demand and alone are expected to consume 230 TWh annually, 6% of current US power generation. Opportunities include procurement of off-grid renewable energy, energy management services by storing off-peak power for use at peak

[90] Most chargers have dual plugs for these two standards and adaptors are freely available for purchase. Tesla opted for a proprietary connector because at the time the CHAdeMO connector was considered too bulky and would only permit 62 kW of power (now 100kW), whilst Tesla was already at 120kW (now 250 kW). At 250kW (350kW in the future) 300km of range can be added in just 15 minutes.

requirement[91] and ancillary grid services, such as selling power back to the grid (V2G)[92]. (Bland et al., 2020)

In California alone, an estimated 1.2 million public chargers will be needed by 2030 with 7.5 million electric passenger vehicles, according to the recently published report "Electric Vehicle Charging Infrastructure Assessment". Currently there are 73,000, with another 123,000 already planned by 2025 and a total of 250,000 targeted for 2025. Public funding of $500 million has been made available. EV charging could reach as much as 5,500 MW at peak charging times increasing electricity demand by up to 25%. (Morris, 2021c)

Distribution of charging networks particularly in Europe and the US are naturally denser where EV drivers are concentrated which has tended to favour wealthier segments of society[93]. As EVs become more ubiquitous there will be greater need for public slow chargers where home charging and off-street parking is not an option[94]. US President, Joe Biden, wants EVs to account for 50% of total new car sales by 2030 and is targeting 500,000 public charging stations (with multiple charging points) with $7.5bn allocated from the recently approved infrastructure package. Currently the US has 104,000 public chargers, at over 30,000 locations, and a little over 1 million EVs on the road, or approximately 10 EVs per charging point[95]. (Muller, 2021)

In Europe, where EV sales are predicted to reach 100% by 2035 (2040 globally), the number of EVs currently on the road are still a very small proportion of the overall vehicle fleet. Nevertheless, across the EU there are on average 5 fast chargers available every 100km, with the UK, Netherlands and Germany particularly advanced (see Figure 50). ("The State of EV Charging Infrastructure in Europe by 2030," 2021)

[91] Demand charges for power charged at peak demand can amount to a significant portion of commercial electricity bills. By drawing power at off-peak times and storing it, peak-shaving can result in significant cost savings. Select Tesla Supercharger Stations in California are 50% off at night and Tesla is also installing powerpacks and solar panels at its stations and at 100 to 120 Electrify America stations, to reduce peak energy costs (peak shaving).
[92] Fleets with predictable charging patterns and lower utilisation are ideal for V2G services.
[93] An estimated 10% of Americans have access to public chargers and are predominantly wealthy and white.
[94] An estimated 30% of homeowners in the UK have no access to off-street parking. As a result, central government is providing 75% funding to local authorities under the On-Street Residential Charging Scheme to develop charging infrastructure in residential areas with little or no off-street parking.
[95] International benchmarks prescribe one public charger for every 10 to 15 EVs, although this number is likely to increase as vehicle ranges and charging speeds continue to improve.

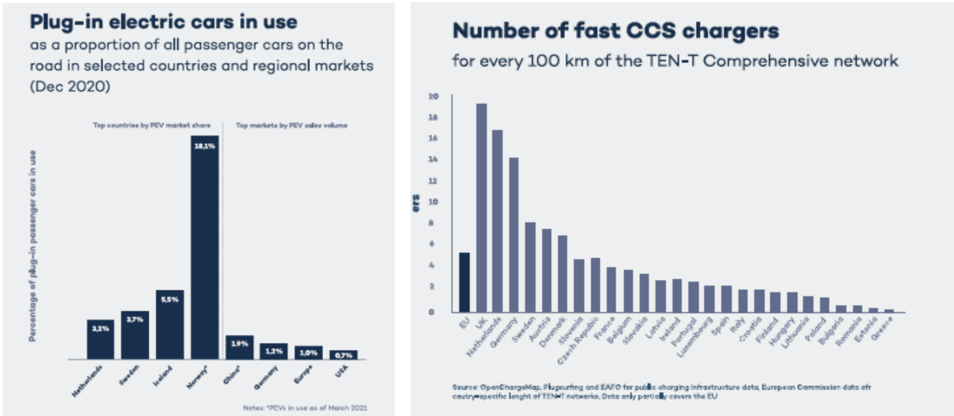


Figure 50: Proportion of BEVs & PHEVs and number of fast chargers in select countries and regions (Source: VIRTA)

The EU aim for a maximum of 10 EVs per public charging point and at 7.5 in 2021 appears to be ahead of the curve so far. In Finland and Sweden chargers are mostly fast, whereas in the UK 75% are slow, potentially creating more pressure on each charger. The ideal mix per country will of course depend on climatic conditions[96] as well as the availability of off-street parking at home or at work (see Figure 51). With an estimated requirement of 1.3 million charging points by 2025 and 2.9 million[97] by 2030 from 200,000 today, the challenge is significant. ("The State of EV Charging Infrastructure in Europe by 2030," 2021)

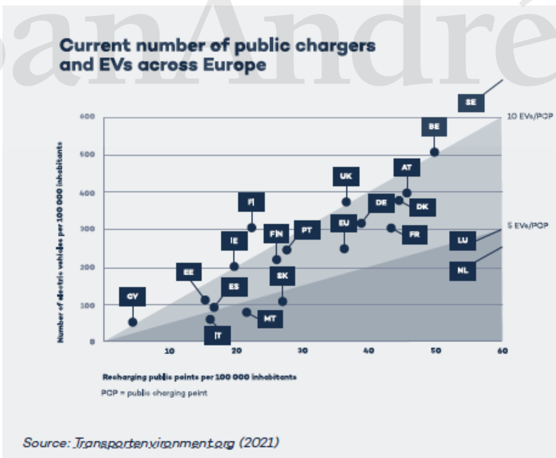


Figure 51: Number of public chargers and EVs across Europe 2021 (Source: VIRTA)

[96] Hot and cold conditions can affect battery performance and range, as can the use of heating (electric motors do not produce much heat as ICEs do) or air conditioning.
[97] An estimated 40 million EVs will be on the road in the EU by 2030 around 14% of the current fleet, meaning that the target number of PCPs is 13 EVs per PCP.

In the UK, there are now over 35,000 public chargers at over 12,000 locations, an increase from 1,300 chargers 10 years ago. Ecotricity now has fast chargers available at 96% of motorway service stations and several IKEA stores. Chargemasters manages a network of lower voltage posts on streets and in car parks. With the UK ban on ICEs by 2030 and HEVs by 2035, the rollout of public chargers will need to increase from 7,000 per year to 35,000 per year over the next 10 years to reach 400,000, according to Policy Exchange. Price caps and a focus on sparsely covered areas will need to be a consideration for allocation of an estimated £1.5 billion in public funding over the next four years. ("Electric Cars: Rollout of Charging Points Still Too Slow - BBC News," 2021)

Germany ascribes a 97% score to range anxiety as the principal factor why EV sales have not accelerated in the country and has allocated $2.8 billion towards building out 7,000 fast charger stations and 70,000 charging stations up from around 30,0000 currently, including in the country's 14,000 petrol stations. (L. Steffen, 2020a)

China has by far the biggest network of chargers at over 800,000 at the end of 2020 to service an electric vehicle fleet of almost 5 million cars (6.25 EVs per PCP), almost as many as the rest of the world combined. It also has by far the greatest challenge with the fasting growing auto market in absolute numbers.

Alongside the rapid building of infrastructure, China is the principal pioneer for battery swapping with NIO, the Chinese EV manufacturer completed its 1 millionth battery swap late last year, twice the cumulative amount 6 months prior, and increasing the number of stations it operates to 155 from 131 in the same period. It has since completed almost 3 million with over 300 stations in service. NIO users benefit from lifetime free swaps and China has encouraged the practice, which requires standardisation of battery packs, by providing subsidies for battery-swap compatible cars, for which NIO, as a premium brand would not otherwise be eligible. (Kane, 2020d)

NIO will install 4,000 stations by 2025, 3,000 in China and 1,000 worldwide, starting this year with Norway. By the end of the year, it will have 700 in operation. The system is fully available to other manufacturers. Each station is capable of 312 battery swaps per 24 hours or just under 5 minutes per swap, about the time it takes to refuel an ICE vehicle. In addition, Battery as a Service (BaaS) subscription allows the user to separate the ownership of the battery from the car, lowering the upfront cost of the vehicle, and permitting flexibility in battery capacity monthly. For example, a smaller battery for everyday commuting, and a lower monthly cost, could be temporarily exchanged for a larger battery for occasional longer journey. (Kane, 2021c)

While the rapid expansion of charging networks is fundamental to EV adoption, private investors will need to keep an eye on business models, particularly as government funding and subsidies are withdrawn. Public policy is to push away from subscription membership to plug and pay[98] for any consumer and the pressure to keep prices reasonable and initially free, will potentially compromise future profitability of these networks. As charging networks become ubiquitous, particularly with home, work and retail locations offering cheap or free charging, even with ultra-rapid chargers commanding a premium, charging will be commoditised. (Auto Express, 2021) EV drivers will shop or consume where they can charge batteries, enhancing revenue streams for operators, service stations, retail outlets and parking owners. VW's Electrify America is installing charging stations with 100 fast chargers at 19 locations in seven states for Westfield Shopping Centres.

Ultra-rapid charging on motorways can be expensive, but this is no different to premium prices for gasoline on major highways. Regular fast charge use, for vehicles that regularly travel long distances, could impact the TCO benefits until the price purchase parity with ICEs occurs, making Hybrids and PHEVs a better option in the short term.

Driver apps, provided by OEMs, charging point operators or third parties that cover multiple networks are becoming more sophisticated and will be of great psychological benefit to potential consumers in the visibility of the charging network. US App, EV Co-Driver's algorithm considers your route, battery charge level, operating conditions of charging points (occupancy and wait time) and charging speed to select the best available charging station on

[98] Most chargers in the UK now accept contactless payment removing the need for multiple accounts and subscriptions, although charging networks often offer preferential rates for signed up customers. In the future, plug and charge, where the car handles authentication and billing as Tesla's vehicles do, will likely become the standard, increasing convenience for consumers.

route. Zap-Map with 6,000 UK charging locations, Plug Surfing with 110,000 charging points across Europe, Apple Maps and Google Maps offer similar functionality.

5.1.3.3. EVs and the Power Grid

In the near term EVs are unlikely to have a significant impact of electricity demand with, in the case of Germany, an increase in total demand of only 4% by 2030 for 8 million predicted vehicles (15% of all cars expected to be in circulation) doubling for an accelerated scenario of 16 million vehicles. (Bermejo et al., 2021) A bigger potential issue to energy capacity is the shape of the load curve and the impact on peak loads, particularly in the evening as EV owners return from work and plug in their vehicles but in comparison to the whole system the increases in load appear to be easily manageable. Time-of -use electricity tariffs and smart chargers, that passively encourage users to charge at off-peak times or remote systems that actively manage charging, could half peak loads. (Engel et al., 2018)

Uncontrolled recharging could have a potentially negative impact upon peak loads but evidence from multiple studies (Bora et al., 2017) suggests that the increases are slight. In McKinsey's German study unmanaged charging could increase peak loads by 8% by 2030. (Bermejo et al., 2021) A conversion of all of Germany's 40 million vehicles could double the peak load but with controlled charging this can be significantly reduced. (Bora et al., 2017) A smart grid that coordinates EV recharging and the requirement to store renewable energy through vehicle to grid (V2G) applications could be mutually reinforcing. (Shuai et al., 2016) In the US existing grid capacity is deemed capable of accounting for a conversion of 75% of light duty vehicles. (Richardson, 2013)

Smart chargers and smart grids, together with distributed energy will also allow charging of electric vehicles at off peak times and reduce the impact on the capacity of the grid. Southern California Edison, the US's second largest utility estimated in 2010 that up to 1 million electric vehicles could be added without additional capacity and up to 2 million if smart chargers were used. Importantly, electric vehicles can make electric utility systems more efficient by smoothing the difference between peak and non-peak use. (Sperling, 1995)

Vehicle to grid technology will eventually allow utilities to use energy from plugged in vehicles to meet peak demand and return that energy at off peak times using unwanted renewables and helping intermittent renewable energy into the grid, considerably lowering the cost of electricity for EV owners. (Sperling, 2018) Lithium-ion battery degradation from constant cycling and its impact on battery life is a potential pitfall and establishing an adequate compensation model is necessary and challenging. (Uddin et al., 2018) As mentioned previously, predictable charging patterns of low use commercial fleets are ideally suited for V2G operations.

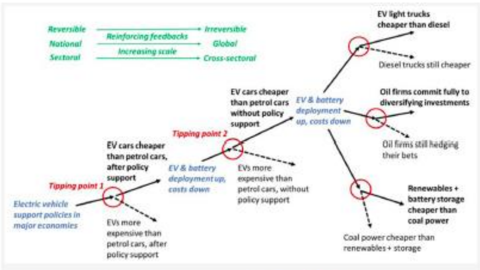
5.1.4. Regulatory Framework & Public Policy

Public policy and regulations have a critical role to play in the adoption of EVs, particularly in the early stages prior to purchase price parity between EVs and ICE vehicles. National and local governments must consider the impact of electrification of mobility across a range of sectors, such as health, the environment, the economic impacts on the industry and other related industries, the impact on employment[99] and the impact of policies on the public purse. Once a decision has been made to support or incentivise the transformation, government must decide on the mix of policies that will best bring this transformation about.

Well targeted government policies, such as pricing policies and targeted investments, can trigger tipping points, which when reinforced by positive feedback loops[100], can trigger subsequent tipping points in a cascade effect that ripples across linked sectors, for example transport and energy (see Figure 52). (Morris, 2021a; Sharpe & Lenton, 2021)

[99] Countries that have strong reliance on auto industries for employment have considerable risk to consider. Do they hold out to protect jobs in the industry in the short term and potentially miss out on the new jobs being created: Tesla's Gigafactory in Berlin will create an estimated 10,000 new jobs? Do governments follow protectionist policies or embrace the revolution to get ahead of the curve: China has designated electric mobility a strategic industry and is now by far the dominant power?

[100] An example of the positive feedback loop is that policies and incentives causing an uptake in EVs cause the cost of batteries and other related technology to fall, further accelerating EV adoption.



Above: Electric vehicle tipping cascade (Source: Climate Policy)

Figure 52: Electric vehicle tipping cascade (Source: Climate Policy)

Policies implemented across the world are varied, including increasingly stringent CO_2 emissions standards and outright bans on ICEs from 2030, direct cash rebates or a variety of tax incentives to lower the purchase price, direct funding of public charging infrastructure and indirect incentives, such as free parking, free or subsidised charging and use of carpool or bus lanes.

Another area of support for electric mobility is in the conversion of government vehicle fleets. Recently the Biden administration announced that all US government vehicles will be electric and made in America[101]. Several police forces worldwide are also experimenting with electric fleet vehicles with positive experiences in reducing running cost.

Tax credits and cash rebates directly reduce the cost of a vehicle, whilst access to carpool lanes and public charging, either provided free of charge or at a subsidised cost, provides further inventive to purchase an EV. In China subsidies have been as great as USD 30,000 whilst in Norway, purchase taxes of up to 100% of the car price have been waived. This is worth as much as USD 80,000 for a Tesla. Subsidies of this size are unsustainable as EV adoption gathers force, and purchase price parity will have to catch up to sustain growth, but they have undoubtedly been the key enabler of early adoption. Generally, in Europe, revenue neutral approaches, and therefore sustainable policy, have been common with so called feebates or bonus-malus strategies, with fees for polluting vehicles and rebates for cleaner vehicles. (Sperling, 2018)

[101] It will cost an estimated $20 billion to exchange the estimated 645,000 vehicles, 22% of which are mail trucks.

An Australian study from the University of South Wales in Sydney, proposes that infrastructure investment us more important than lowering the purchase price of an EV prior to parity with EVs, when market forces take over and mass market adoption becomes possible. A range of incentives also yields better results than a single incentive. (Broadbent et al., 2019)

Since 2012, California, through its ZEV mandate, since adopted by 10 other States, has required that automakers increase EV sales to 15% by 2025. China and Europe have similar mandates. (Sperling, 2018) In Beijing, China, EVs are exempt from the license plate lotteries[102] required to purchase a car. Estimated tax incentives needed to close the average cost gap between an EV and an ICE are USD 12,000, requiring a significant commitment from the public purse until economies of scale in production and new innovations reduce the cost gap. (Heineke & Kampshoff, 2019) Subsidies and tax exemptions bridge the gap between EV cost and willingness to pay. (McKinsey & Company, 2019)

Withdrawal of direct purchase subsidies, rebates or other tax incentives is inevitable, In the US, both GM and Tesla have surpassed the 200,000-vehicle threshold that phases out the US$ 7,500 federal tax credit[103] and China had intended to reduce and eliminate its direct purchase subsidies, although these have recently been extended for two years until 2022/2023 because of the pandemic. Nevertheless, the subsidy in China has reduced to around $4,000 for EVs with a range over 400 km, from $8,500 for a BEV purchased prior to 2015. The exemption from 10% sales tax continues.

In the UK, direct subsidies have declined from £5,000 in 2016 to just £2,500 for cars under £35,000. Nevertheless, a range of other indirect pull factors exist for consumers, including tax exemptions from road/vehicle duties or benefits in kind and corporation tax for company vehicles and cut-price electricity at public chargers. A big stick looms for owners of ICEs with a ban due on new sales in 2030. In October, London extended its ultra-low emission zone to

[102] License plate lotteries were implemented in 2011 in Beijing in an attempt to control congestion and pollution. Each new plate issued has around 2000 applications at a cost of USD 15,000 in 2017, demonstrating the huge demand that could be fulfilled by EVs.
[103] The tax credit has been criticised for targeting predominantly wealthier citizens who earn enough to pay this much tax.

most of Greater London, effectively banning diesel vehicles older than five years. Other major cities are following suit. (Rufford, 2021)

Looming carbon dioxide penalties and the costs of meeting stricter Worldwide Harmonized Light Vehicle Test standards are a challenge for automakers. Most European countries have announced bans on ICEs by 2030 or 2035 with several other countries[104], some cities (independent of their country's stance) and automakers also signing up. Regulatory CO_2 emissions penalties are severe. (Tschiesner et al., 2019) Worldwide 30 countries have a deadline for banning ICEs, most by 2030: California and Massachusetts will ban ICE sales from 2035, Washington State by 2030.

Regulators have frequently been at loggerheads with fuel and vehicle suppliers, on issues of fuel consumption, emissions and safety. A more flexible and incentive-based approach is required. In the US the ZEV mandate has been a crude but effective instrument for overcoming barriers to adoption, particularly the large start-up costs involved in EV development, but in the long term, sustained change is more effectively achieved by collaboration amongst market participants. (Sperling, 1995)

One particular area of collaboration that will continue long past the withdrawal of direct rebates and tax incentives is in the building of infrastructure. The Biden administration in its bipartisan infrastructure plan has set aside $7.5 bn[105] to build a national charging network of 500,000 charging points, which represents 57% of the US's estimated charging requirement by 2030. China has long invested heavily in charging infrastructure, investing close to $1.5bn annually. China has by far the largest charger network, with an estimated 900,000 public chargers installed and an equivalent number of chargers in homes and workplaces. (Moloughney, 2020)

Non-financial incentives, such as free parking, free public charging, the ability to use carpool or bus lanes or China's exemption from license plate lotteries can also be highly effective without a significant burden on the taxpayer. (Sperling, 2018) Government subsidies will

[104] Notable exceptions include the US, China and Germany.
[105] A further $7.5bn is available for electric school buses, transit buses and other public transport.

eventually decline as adoption accelerates and price purchase parity between EVs and ICEs is achieved and market forces take over.

At the local level, city policies can be an important driver for EV adoption. Indirect regulations such as bans on ICEs in city centres in 10 to 20 years, will force people to look at their car purchase ahead of time as the resale of those ICE vehicles purchased today or in the next 10 years will have a reduced resale value. Modern urbanisation and policies that support the reduction of space for cars and the incentivisation of other modes of sustainable transportation could also potentially slow the adoption of electric cars or substantially reduce the size of the market.

6. Adoption of Electric Vehicles[106]

Rising consumer demand and tightening regulation particularly in Europe has spurred a rapidly increasing adoption of electric cars. (McKinsey & Company, 2019)

Global EV sales were below trend in 2019 and 2020 as in Europe many popular PHEVs were forced to upgrade their e-range and a crackdown in China on substandard safety and range combined with the global pandemic and reducing incentives to slow EV sales growth. Reversal of incentive withdrawal in China and increased incentive support in Europe, together with a heightened sense of public awareness put EV sales back on track in 2021. (Irle, 2021)

A global fall in EV sales in 2019 and the first quarter of 2020, was only prevented by Europe growing an impressive 44%. The global market only achieved a 9% increase in sales over 2018, compared to a 65% increase between 2017 and 2018. China stagnated whilst in the US, EV sales fell. In China subsidies were due to be withdrawn in 2020 but were extended, albeit at reduced levels, to 2022 to counteract the effects of the COVID-19 pandemic. In Europe, increased purchase incentives, tighter regulation, growing infrastructure and the availability of new models[107] were responsible for the regions continued growth. PHEVs grew more slowly than BEVs and with the range of the latter constantly improving (now around 400km) and the removal of subsidies for PHEVs in some countries, following environmental impact concerns, we will likely see this trend continue. Only in Finland, Iceland and Sweden PHEVs continue to dominate. (Gersdorf et al., 2020) In China, Sweden and the UK there was a strong reaction to incentive changes. To continue the trend towards mass adoption OEMs must affirm the positive attitudes towards EVs (subsidies and driving experience) and disprove customer fears (range anxiety and infrastructure availability).

In 2020, despite the pandemic and a global fall in the auto market of 16%, the sale of EVs increased 41% selling a little over 3.1 million vehicles for a 4.6% share of the market (and increase in share of over 70%). The global fleet of EVs surpassed the landmark of 10 million

[106] For the purpose of analysis in this chapter, Electric Vehicles includes BEVs and PHEVs. Hybrids and Fuel Cell Electric Vehicles are not included in the data unless otherwise mentioned.
[107] An estimated 450 new models are expected to come to market between 2020 and 2022, predominantly in the mid-size and large vehicle categories.

vehicles on the road (see Figure 53). Resilience of the EV market in the face of a global pandemic, was based on three fundamental pillars: regulatory frameworks, including CO2 emissions standards and ZEV mandates; increasing incentives in Europe and extended incentives in China; the number of EV models and continuing reduction in cost of battery packs. (Gül et al., 2021) The top 20 OEMs representing 90% of passenger car registrations have continued to expand EV portfolios and have ramped up production.

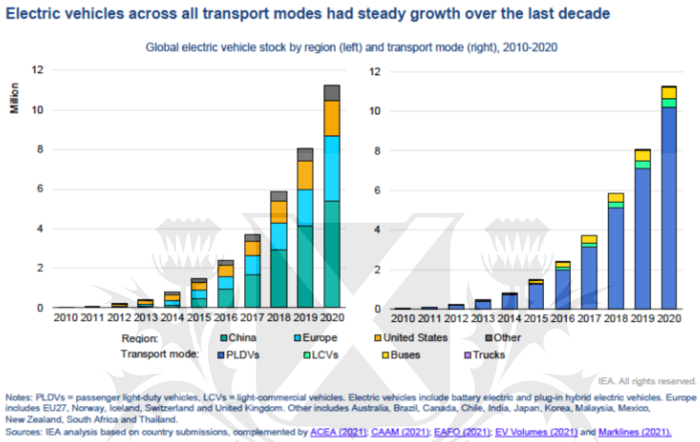


Figure 53: Electric vehicle sales 2010-2020 by select countries and regions and by vehicle type (Source: IEA)

Europe and China continue to dominate the market for Electric Vehicles (BEVs and PHEVs) and for the first time Europe took the #1 spot from China. The US is a distant third, dominated by California and Tesla. These three markets in 2020 accounted for over 96% of the global market for BEVs and PHEVs (see Figure 54).

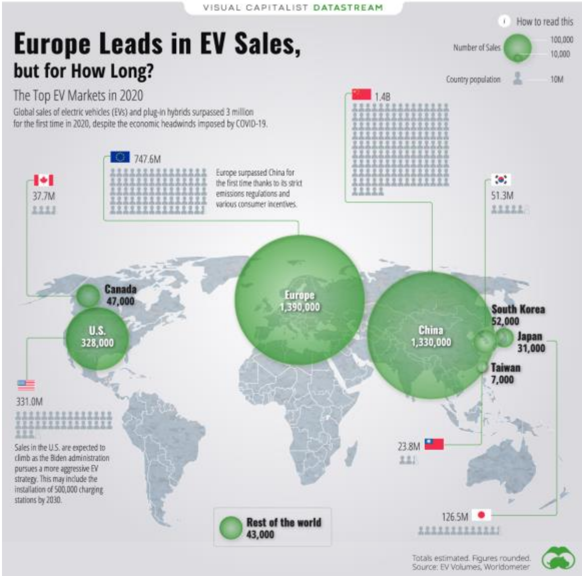


Figure 54: Top EV markets in 2020 (Source: Visual Capitalist)

In the journey towards 10 million EVs, PHEVs have played an important role in the transition, especially in Europe, but as BEV models have become more prevalent and costs of batteries have reduced the latter have begun to dominate. By 2020, BEVs represented 2/3rds of registrations and of the total fleet of EVs. The rate of growth in 2020 was almost entirely due to accelerated growth in Europe's three major markets: in Germany and France, EV sales more than tripled, and in the UK EV sales more than doubled. The rate of growth in China slowed considerably from 2018 to 2019 but recovered well in the second half of 2020. In the US EV sales have declined since their peak in 2018. Key factors were increased or extended fiscal incentives and more competitive TCO comparable (see figure 55). (Gül et al., 2021)

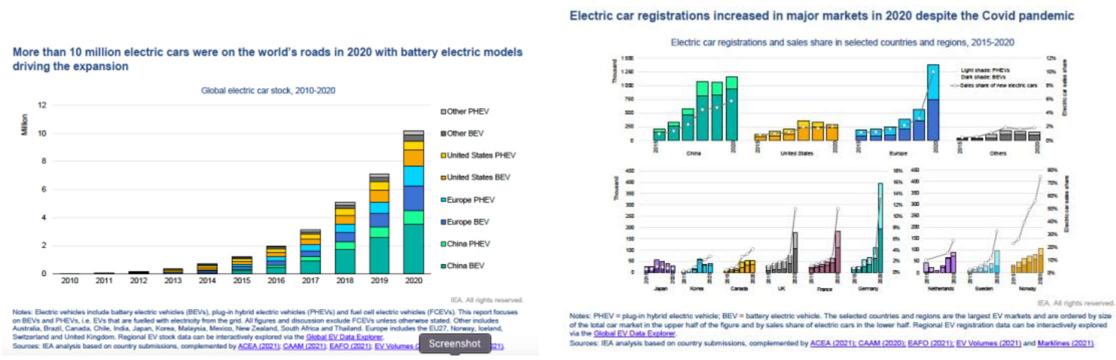


Figure 55: EV Sales 2010-2020 by EV type and registrations in major markets (Source: IEA)

In Europe, whilst the total auto-market declined 22% in 2020, sales of EVs more than doubled to 1.4 million, the three largest markets, Germany, France and the UK, accounting for 54%. The key Nordic countries and the Netherlands achieved record increases in market share, Norway up to 75% from 55%, Iceland over 50%, Sweden 30% and the Netherlands 25%. BEVs represented 54% of registrations and are particularly popular in the Netherlands (82%), Norway (73%), the UK (62%) and France (60%). PHEVs continue to be popular elsewhere, particularly in Germany, whether due to range anxiety or the lower cost due to a smaller battery size.

In China the total car market fell by 9% in 2020 and in the first part of the year EV sales underperformed. Purchase subsidies that were due to be phased out by the end of the year were extended to 2022 but reduced by 10%. Further economic measures to support the auto industry during the pandemic relaxed licenses for conventional ICE vehicles and whilst the EV market grew the rate of growth was far below pre-pandemic levels. Approximately 80% of EVs are BEVs.

In the US the auto market suffered a 23% decline overall, like Europe. EV sales declined for the second year running since the Federal tax rebate became unavailable for both Tesla and GM, both having reached annual production of 200,000 EVs. Nevertheless, the EV market fell less than the overall market and its share increased marginally to 2%, 78% of those EVs are BEVs.

In a market worth an estimated $120 billion in 2020, government spending on incentives was $14 billion, a nominal increase of 25%, but a decrease as a percentage of overall spending as EVs become more attractive: the share of spending has reduced from 20% in 2015 to 10% in 2020. Consumer spending increased by 50% (41% due to increased sales and 6% due to average price increases). Europe accounts for a greater share of the total value of the market and most of the increase in spend with its preference for SUVs and medium to large cars, versus China's preference for mini EVs or small and medium cars. (Gül et al., 2021)

In 2020, there were 370 models available, a 40% increase from 2019, with around 200 models available in China, around 100 models in Europe and around 50 in the US. PHEV models, more popular in Europe, tend to be skewed towards the larger vehicle segments where more range and performance means an even larger battery for an equivalent BEV. In the SUV segment, particularly in Europe and in the US, but also in China, PHEV models are dominant.

Of the announced new model launches 55% are SUVs and pickup trucks. It is as segment that is the fastest growing in Europe and China and has the largest market share in the US. Typically, these vehicles command higher prices and profit margins. They also consume more energy, making electrification of the segment more attractive from both a TCO standpoint and emissions[108]. The introduction of Europe's Zero Low Emissions Vehicle (ZLEV) credit scheme from 2025 will provide even stronger incentives for producing and selling e-SUVs. (Gül et al., 2021)

Battery production increased by 33% to 160 GWh in 2020 against the 41% increase in vehicles, with an average battery size of 55kWh for BEVs and 14kWh for PHEVs. China dominates the market with 70% of market supply and 50% of demand (80GWh), versus 33% in Europe (52 GWh) and 12% in the US (19 GWh), reflecting Europe's even split between BEVs and PHEVs compared to China's preference for BEVs, despite similar market sizes in vehicles sold. The predominant chemistry is Nickle Manganese Cobalt (71%) with Nickel Cobalt Aluminium representing most of the rest. Lithium Iron Phosphate, once most popular in China, but with lower energy density now represents less than 4%. BNEF reported average pack prices decreased 13% in 2020 to $137/kWh and is on track to achieve the expected critical threshold of $100/kWh in two to three years. In Europe, demand exceeds capacity of 35 GWh but an announced up to 400 GWh of capacity is to come online by 2025.

An estimated 1.3 million public chargers were available in 2020, an increase of 45% in 2020 and just under 8 vehicles per PCP. The public charging network has increased 7 times in the last five years and appears to be keeping pace with the adoption of EVs thus far. 70% of the chargers are slow and 30% are fast or rapid. China again is dominant with around 50% of the total and an average of under 6 EVs per PCP, reflecting fewer home or work charging options than in Europe or the US. Europe had around 288,000 chargers, mostly slow, for 3.2 million vehicles: 11 EVs per PCP. Its fast charger network is currently relatively small but growing

[108] The electric SUV market in Europe has a higher penetration than the overall market share.

fast. The US had just under 100,000 chargers again mostly slow, for 1.8m vehicles: 18 vehicles per PCP. 60% of its fast charger network is Tesla's supercharger network. Whilst the overall market appears to be on track there is great disparity between countries that are achieving Europe's AFID[109] recommendation of 10 EVs per EVSE[110] or 0.1 EVSEs per EV. Most European countries are behind schedule, due in part to the sudden acceleration in EV adoption. Only a handful of countries, South Korea, Chile and China included are well in excess of this benchmark (see Figure 56). Italy and the Netherlands are ahead but mostly with slow chargers. The Nordic countries, with higher adoption rates, have the lowest ratios but there are also more options for private off-street parking and charging and these countries also have a higher proportion of fast chargers[111].

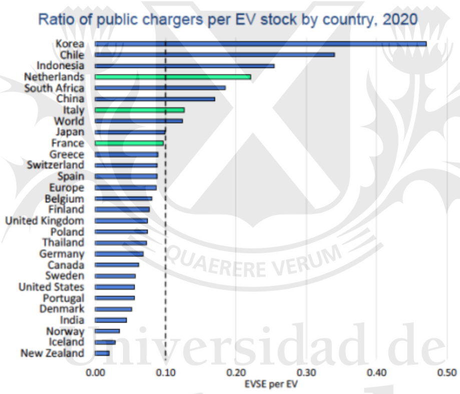


Figure 56: Ratio of public chargers per EV by country, 2020 (Source: IEA)

Government policy has been a key driver for developing EV markets, centred on purchase subsidies and/or vehicle registration and purchase tax rebates, to reduce the up-front cost, tightening of fuel economy and CO_2 emission standards, mandatory targets for EV sales[112], support for charging infrastructure direct investment and home charger incentives, or at a local level preferential circulation and access and zero emission zones in urban areas. In addition, 20 countries have announced full phase out of ICEs over the next 10 to 30 years (see Figure 57).

[109] Alternative Fuel Infrastructure Directive
[110] Electric Vehicle Supply Equipment.
[111] Iceland 40%, Norway 31%, Denmark 17%, compared to only 9% in Italy and 3% in the Netherlands.
[112] California's ZEV mandate was established over 20 years ago and requires 22% of credits from ZEVs by 2025. China's New Energy Vehicle mandate currently requires 14% credits rising to 18% by 2023 (with up to 3 credits per vehicle based on range, weight and energy density). Europe's new ZLEV mandate will be in place from 2025 starting with a 15% requirement.

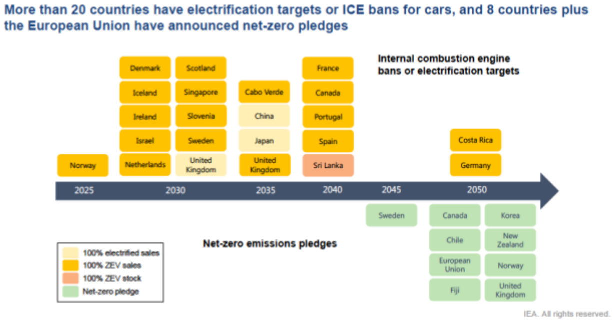


Figure 57: Electrification objectives and ICE bans by country (Source: IEA)

Purchase subsidies increases in Germany, France and Italy greatly contributed to the uptick in EV adoption. In Germany, subsidies for BEVs increased from around $7,000 to over $10,000 and for PHEVs from around $5,000 to just under $8,000. Limited incentives in the US at a Federal level have undoubtedly supressed faster EV adoption and only reducing costs, model availability and adoption by fleet owners (for whom TCO calculations are more important) have sustained the market (see Figure 58).

Current zero-emission light-duty vehicle policies and incentives in selected countries

		Canada	China	European Union	India	Japan	United States
Regulations vehicles	ZEV mandate	British Columbia: 10% ZEV sales by 2025, 30% by 2030 and 100% by 2040. **Québec**: 9.5% EV credits in 2020, 22% in 2025.	**New Energy Vehicle dual credit system**: 10-12% EV credits in 2019-2020 and 14-18% in 2021-2023.				**California**: 22% EV credits by 2025. **Other states**: Varied between ten states.
	Fuel economy standards (most recent for cars)	114 g CO_2/km or 5.4 L/100 km*** (2021, CAFE)	117 g CO_2/km or 5.0 L/100 km (2020, NEDC)	95 g CO_2/km or 4.1 L/100 km (2021, petrol, NEDC)	134 g CO_2/km or 5.2 L/100 km (2022, NEDC)	132 g CO_2/km or 5.7 L/100 km (2020, WLTP Japan)	114 g CO_2/km or 5.4 L/100 km*** (2021, CAFE)
Incentives vehicles	Fiscal incentives	✓	✓	✓	✓	✓	✓
Regulations chargers**	Hardware standards.	✓	✓	✓	✓	✓	✓
	Building regulations.	✓ *	✓ *	✓	✓		✓ *
Incentives chargers	Fiscal incentives	✓	✓	✓	✓	✓	✓ *

Figure 58: ZEV policies and incentives in selected countries (Source: IEA)

Legislation involving batteries and waste is not fit for the purpose of automotive scale and requires work to regulate material sourcing, design, product quality and safety and traceability. A regulatory framework is important to ensure industrial competitiveness, harness know how, guarantee employment and safeguard the environment.

Global plug-in electric sales achieved the first double digit market share of 10% in September 2021, signalling a move toward a global tipping point although there is significant divergence between Europe & China and the rest (see Figure 59).

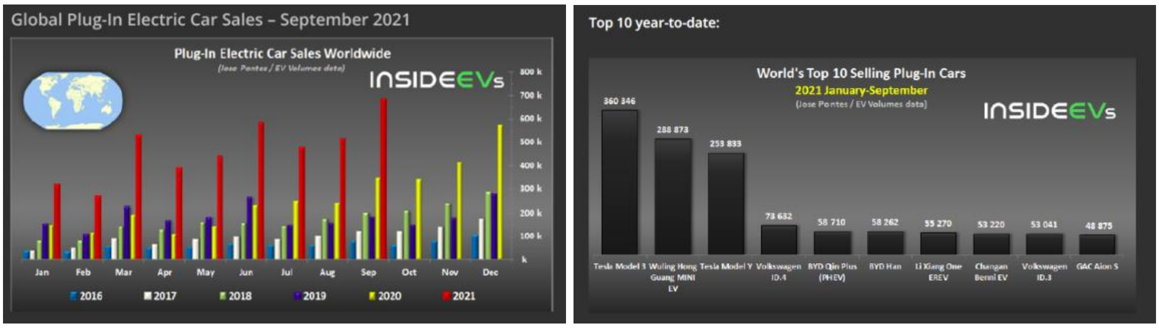


Figure 59: Global EV sales to Q3 2021 and top selling models (Source: INSIDEEVs)

In the first nine months of 2021 there were 4.3 million EVs sold, 40% more than the whole of 2020 and achieving a 7% market share. Tesla has two of the top three selling vehicles, followed Wuling's (SAIC) Hong Guang Mini EV. In terms of top OEMs Tesla (15%), is followed by VW (12.3%) and SAIC (10.9%).

Bloomberg New Energy Finance estimates that globally there are currently 12 million passenger EVs on the road today, in addition to 1 million commercial vehicles (including trucks and buses) and 260 million two and three wheelers. In terms of passenger cars this represents approximately 1.2% of the global fleet. BNEF expects sales of EVs to reach almost 6 million by the end of 2021, almost double the total in 2020 and triple the total of 2019. By 2025 sales of 14m could be achieved globally with a market share of 16%. The global auto market will continue to be fragmented with low levels of adoption in emerging economies. (Bloomberg New Energy Finance, 2021)

Europe and China will continue to dominate because of the former's ever tightening CO_2 regulations and incentives, and China's fuel economy regulations and new-energy-vehicle credit system. Recent policy changes in the US will have limited impact in 2021 but renewed focus on electric mobility should see EV sales climb in the short to medium term. PHEV sales are likely to compete with all-electric BEVs, in Europe, to meet CO_2 targets but can be expected to fade as battery prices fall and charging infrastructure becomes ubiquitous. BNEF expects only Europe and Japan will have significant PHEV markets and that 80% of global EVs will be BEVs by 2025. An estimated electric passenger car fleet of 54 million by 2025 would still only account for 3 to 4% of the total global fleet and will continue to be dominated by China, Europe and the US, with the rest of the world accounting for approximately 8%.

The rapid acceleration of EV adoption has occurred through stricter emissions and fuel economy regulations, consumer incentives and of course reducing costs, with average battery pack prices falling to $150 kWh in 2020[113]. The European Green Deal[114] aims for net zero auto emissions by 2050, the US has joined the Paris Agreement again and California will ban the sale of ICEs by 2035, along with 15 other nations. These strong signals encourage OEMs to invest, alongside investments in infrastructure, supply chains and electricity grids and are strong enables for the future acceleration in adoption of EVs. (Arora et al., 2021)

Electric Vehicles are nearing a tipping point. If globally, a 10% market share for new car sales is at the beginning of the upturn in the adoption curve, Europe is well ahead and accelerating. Norway, approaching 90% penetration thanks to tax breaks that make EVs marginally cheaper than comparable ICEs, is forging ahead and will likely achieve close to 100% next year. Other Nordic countries are also much further along the adoption curve, and full EV disruption is inevitable. Germany has also achieved mass adoption with a 24% share, whilst France and the UK are closer to the average European penetration of 16% but still past the tipping point. In the month of September Europe achieved a 24% penetration. China is also arguably at the tipping point with a 13% share for the first nine months of the year and a 20% share in the final month. The US and the rest of the world however are far behind with less than 2% market participation. California is a bright spot with a market share like China's but outside of a few west and east coast States, the US has failed to make significant headway towards adoption of EVs at a national level (see Figure 60).

[113] New battery chemistries with higher energy density, pack assembly & design, production scale and manufacturing processes are all part of the learning curve that has conspired to reduce battery pack costs.
[114] Europe Green Deal targets a 55% reduction in emissions by 2030 from a 1990 baseline, 90% by 2050. The US estimates only a 75% reduction by 2050.

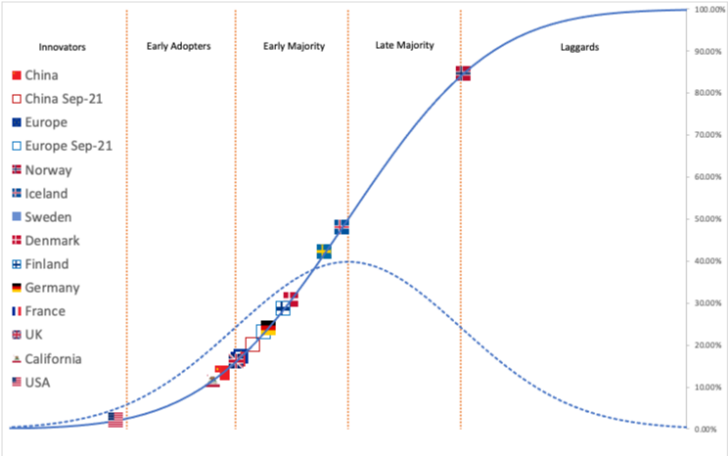


Figure 60: Electric Vehicle Penetration in key markets to Sept 2021 (Source: own development from multiple sources, including IEA, INSIDEEVs and others)

Tim Lenton, a professor at the University of Exeter in the UK has observed the non-linear effect of crossing the purchase price parity barrier. In Norway in 2019, EVs were typically just 0.3% cheaper and it had achieved a 48% market share, whilst in the UK, EVs were 1.3% more expensive after subsidies and it had just a 16% market share. The point where EVs become cheaper than ICEs without subsidies, expected by 2023 to 2025, is critical to the long-term sustainability of EV adoption. (Sharpe & Lenton, 2021; A. D. Steffen, 2021a)

A study by Castrol, surveyed 9,000 drivers, 750 fleet owners and 30 automotive professionals in the US, UK, Norway, France, Germany, India and China, put the price tipping point for mass adoption of electric vehicles at USD 36,000[115] with a 470km[116] (294 miles) range and a 31-minute charging time. Ideally, prices will fall below USD 30,000 for a vehicle with 480km range (300 miles) and a sub-30-minute charging time. Whilst these metrics exist in certain vehicles, they are not yet mainstream, particularly price[117] (see Figure 61). (Castrol, 2021)

Price is a key issue and whilst most surveyed indicate a readiness to purchase an EV by 2024, 61% are currently holding off in the expectation that there will be significant technology advances in the next five years, potentially a prime example of the Osborne effect previously

[115] The average price of an EV is USD 40,000 and a PHEV USD 50,000, according to Global EV Outlook 2021.
[116] The average range of an EV in 2020 is 350km, according to Global EV Outlook 2021. Average range has steadily increased from about 200km in 2015 but plateaued in 2020.
[117] EVANNEX an automotive accessories manufacturer and retailer for the electric mobility market analyzed 11 popular EV models – Tesla's S/X/3/Y, Audi e-Tron, Jaguar I-Pace, BMW i3, Nissan Leaf, Hyundai Kona, Kia Niro and Chevy Bolt. The average price in the US was $46,385 with a range of 422 km (264 miles).

discussed in this paper. Most of those surveyed believe mainstream adoption will occur around 2030.

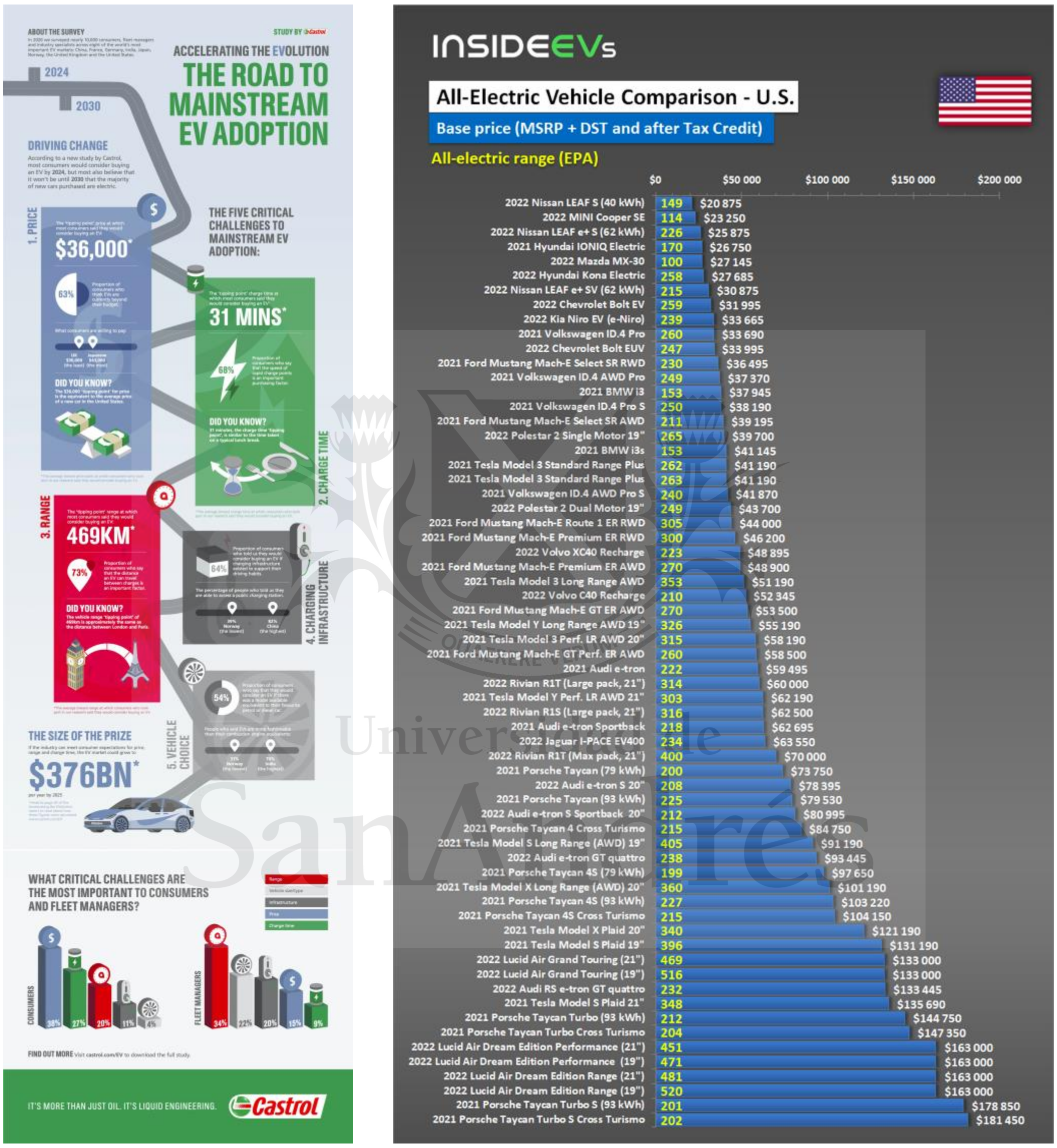


Figure 61: Critical Challenges to Mainstream EV adoption (Source: Castrol) and average EV prices in US by model (Source: INSIDEEVs)

The McKinsey EVI Index measures the readiness of 15 key markets worldwide for EV adoption using two dimensions: markets and demand, which evaluates market share, availability of subsidies, infrastructure and choice of EVs, and industries and supply, which measures automotive support and preparedness, particularly e-motor and battery development. Only the Nordic countries score higher than China on the market side of the equation whilst

China is the leader on the supply side, followed by Germany. China and Norway have some of the highest levels of spending on consumer and supply side subsidies, but several countries have made significant progress in the last 6 years, except for Japan. Localisation of production facilities has been a key theme, particularly for incumbent OEMs, with Tesla installing production capability in Shanghai in 2019 and a planned facility in Berlin in 2021. VW and Toyota also have plans for production facilities in China (see Figure 62). (Gersdorf et al., 2020; Hertzke et al., 2018)

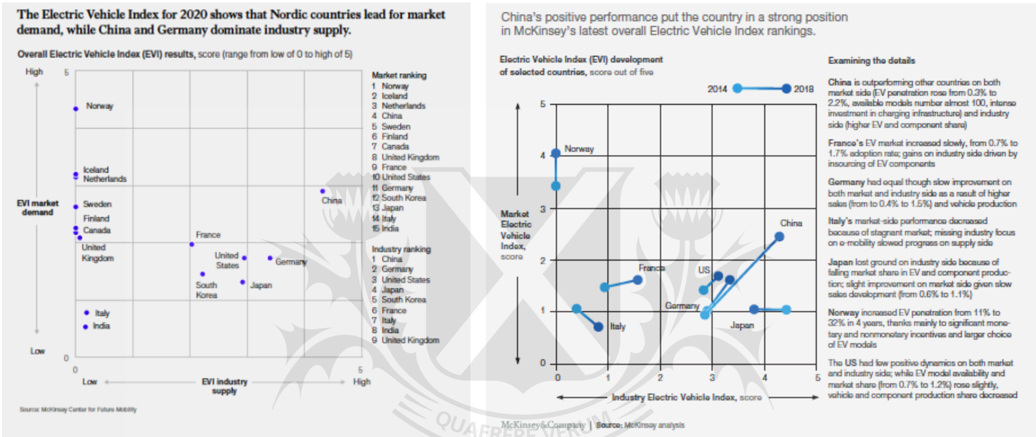


Figure 62: McKinsey Electric Vehicle Index (Source: McKinsey)

6.1. China

Government monetary incentives from 2014 caused explosive growth in the adoption of EVs with the market growing by over 550% in 2015. With a price sensitive consumer low-cost micro EVs proved popular accounting for 40% of the market in 2015, whilst ICEs continued to be more popular choices for premium and luxury categories. Newly established domestic private manufacturers in South China drove growth whilst incumbent State enterprises were less proactive. (Ou et al., 2017)

Contrary to the revolution in Europe and in the US, the Chinese market focussed on the low-end market segment, whilst the high-end segment continued to be dominated by foreign brands. With market growth and subsidies OEMs were quickly able to generate profits. Chinese consumers cared less about quality and comfort and EVs were cheaper with generous government subsidies. Between 2009 and 2012, incentives were directed towards public fleet owners to quickly gain scale and then from 2013 to 2015 extended to all purchases. From 2016 to the present subsidised have gradually reduced and become more restrictive to transition to manufacturer bonus-malus schemes such as fuel economy standards (CAFE) and the NEV Vehicle Credit system plus exemption from sales tax. Additional subsidies and support were afforded to OEMs to transform the sector and create a globally competitive battery production capacity.

China continues to dominate in terms of total number of EVs on the road with continuous introduction of new models, mostly BEVs; government subsidies were to reduce from 2020 but have had a reprieve until 2022. (McKinsey & Company, 2019) China has been motivated to get ahead of a rapidly accelerating consumer demand, increasing problems with air pollution and congestion in its cities, as well as a desire to create a world class automotive industry (including dominating battery production) to dominate globally. (Sperling, 2018)

In the month of September 2021, EV sales achieved a 20% market share, with 2 million EVs sold in the first 9 months of the year, more than 50% more than the whole of 2020 and achieving a 13% market share over the 9 months: BEVs accounted for over 80% of the volume. The Wuling Hong Guang, a tiny affordable mini-EV that costs just $4,500 after subsidies, is still the most popular model with 14% of the market, followed by the Tesla Model 3 and Tesla Model Y (see Figure 63). (Bank, 2021) If the pace of growth continues, sales of EVs could reach more than 3.5 million by the end of the year, more than the global market in 2020.

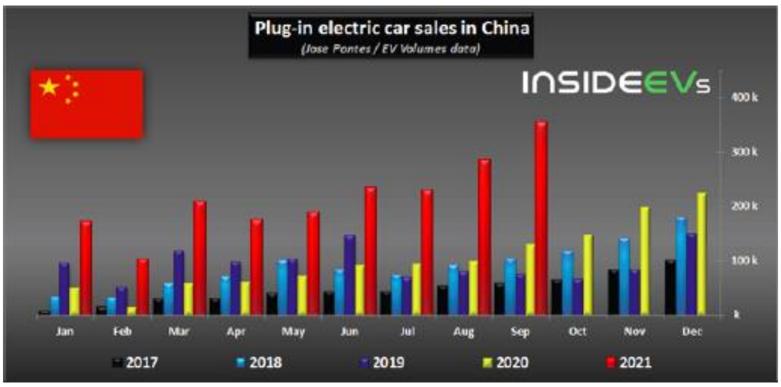


Figure 63: EV Sales in China to Q3 2021 (Source: INSIDEEVs)

Chinese OEMs use existing manufacturing technology and concepts but off the shelf components and a high level of modularisation and have a highly evolved BEV market and ecosystem. Consequently, Chinese models offer better range to price ratios (see Figure 64). (Erriquez et al., 2020)

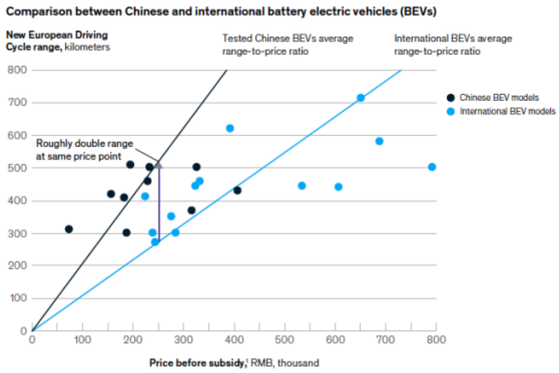


Figure 64: Comparison between Chinese and International BEVs (Source: McKinsey)

Subsidies and tight regulation have driven growth. License plate lotteries and auction exemptions for EVs in some cities and green license plates allowing preferential treatment in addition to generous subsidies have enabled a rapid transition. The market is still dominated by Chinese OEMs[118], although there is increasingly greater participation of Western brands, particularly in more expensive categories. (Hertzke et al., 2018)

Subsidies have evolved with increasing requirements for minimum range (from 100km to 200km) energy density, increased subsidies for longer range (over 400km) and lower support for PHEVs (reduced to $3,500). The slow growth in in the 2019 market, caused by an overall decline in the auto market and significant cuts to the subsidies as China sought to transition to non-monetary forms of support. Subsidies were eliminated for vehicles with less than 200km all-electric range and long range (+400km) subsidies were cut by 67%. The plan to phase out subsidies in 2020 had to be rescinded, as mentioned, due to continued weakness in the auto market because of the global pandemic. (Gersdorf et al., 2020) In 2020 a vehicle price cap and a NEV[119] sales limit of 2 million NEVs per year was introduced as well as a 10% cut in subsidies and reduced fuel consumption limits for 2021 (4 L/100 km).

[118] 94% in 2018.
[119] NEV is new energy vehicle that incorporates BEVs, PHEVs and FCEVs.

In place of the eventual phase out of subsidies, China introduced in 2017 a credit system for OEMs based on the type of vehicle, its energy consumption, weight and range, with penalties for failing to earn or purchase a prescribed percentage of credits against total production. For 2014 the NEV target is 14%, rising to 16% in 2022 and 18% in 2023. OEMs can earn between 1 and 3.4 credits per NEV produced and can also trade credits.

At national level other ZEV policies exist to encourage investment in charging infrastructure, battery reuse and recycling. Whilst restrictions were eased in 2020 at the city level, ZEVs are generally supported through purchase subsidies, charging rebates and traffic restriction waivers. The New Energy Automobile Industry Plan targets 20% of ZEV share by 2025 and 50% by 2035, whilst achieving international competitiveness for its national industry. Many major cities have EV friendly policies, including car plate restrictions (lotteries) and ZEV direct access, traffic restriction and ZEV waivers, lower cost or free parking, subsidised charging and direct purchase subsidies. China will invest $1.4 trillion in its infrastructure public spending programme. Ten major cities have targets for 1.2 million public chargers by 2025. (Gül et al., 2021)

Battery production regulations and subsidies favour large scale production (8 GWh or more per annum), consolidation and competition. Smaller players (3 to 5 GWh per annum) are encouraged to consolidate and reduce costs. In 2018, measures were introduced for collection and recycling, including standardisation of design to facilitate battery swaps, production and verification processes, and repairing and repackaging for second life use.

6.2. Europe

In 2018 the transport sector in the UK accounted for 28% of greenhouse gas emissions more than any other sector spurring the government to bring forward its ICE ban to 2035 from 2040 to achieve carbon neutrality by 2050. A report commissioned by The Department of Transport describes five barriers to overcome, based on human behaviour, that should guide government policy in order to achieve mass EV adoption:

- Awareness and Knowledge: How the technology works, charging availability, model availability, costs and other information.

- Financial factors: Purchase price, TCO, incentives and depreciation. There is a tendency to focus on up-front costs and discount the benefit of lower running costs.
- Charging Infrastructure: Availability and access to charging infrastructure at or near home and work. Nationwide public charging network for long journeys.
- Vehicle Attributes: Range anxiety, charging times, long-term battery performance.
- Customer Attitudes: development of positive attitudes (symbolic (value), affective (emotion) and instrumental (practical)).

A holistic approach to policy is necessary, including expert stakeholders, public sector, consumer bodies and academia. Carrots are generally preferred over sticks. The "perceived" cost of EVs and availability of EV charging infrastructure is as important as the actual cost and availability. Often perceptions are worse than reality.(Reiner et al., 2020)

Most European countries have opted for a combination of tax benefits and direct purchase subsidies in support of EV adoption. The advantage of tax incentives over direct purchase subsidies is that by penalizing ICE purchases and incentivising EV purchases (bonus-malus schemes, such as in France) such strategies can be revenue neutral for public spending at least in the early to mid-stages of EV adoption. Tax payments at the point of purchase have a stronger influence than relief for annual tax payments. (Wappelhorst et al., 2018)

In Norway and the Netherlands there are substantial differences in tax breaks available for purchase of EVs (see figure 65) whilst in Germany and the UK the tax breaks are insufficient to reduce the cost advantage of ICEs. Instead, these markets offer one time purchase subsidies to reduce the up-front cost, but this can only be transitional since as EV adoption progresses it is unsustainable. In a self-sustaining tax system, high emission vehicles pay for low emission.

Vehicle taxes can include VAT, registration tax, annual motor vehicle tax, fuel consumption taxes[120], income tax for company cars[121] and road charges. In Norway, particularly high VAT and registration taxes, from which EVs are exempt, can double the price of a car. Registration taxes are charged in 25 of 32 European countries and vary based on emissions, fuel consumption or weight.

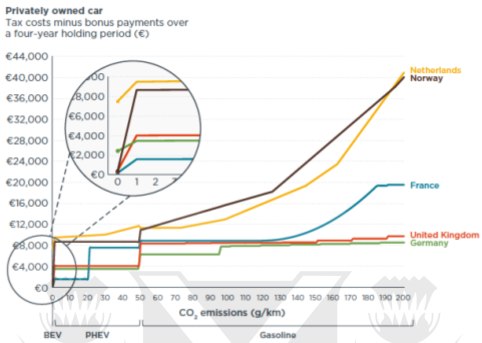


Figure 65: Tax Costs minus bonus payments over four years in select European countries (Source: ICCT)

Through broad, innovative tax incentives Norway dramatically reduced the upfront cost and running costs of EVs to below that of ICEs (see Figure 66).

The Norwegian EV incentives:

- No purchase/import taxes (1990-)
- Exemption from 25% VAT on purchase (2001-)
- No annual road tax (1996-2021). Reduced tax from 2021.
- No charges on toll roads or ferries (1997- 2017).
- Maximum 50% of the total amount on ferry fares for electric vehicles (2018-)
- Maximum 50% of the total amount on toll roads (2019)
- Free municipal parking (1999- 2017)
- Parking fee for EVs was introduced locally with an upper limit of a maximum 50% of the full price (2018-)
- Access to bus lanes (2005-).
- New rules allow local authorities to limit the access to only include EVs that carry one or more passengers (2016)
- 50 % reduced company car tax (2000-2018).
- Company car tax reduction reduced to 40% (2018-)
- Exemption from 25% VAT on leasing (2015)
- Fiscal compensation for the scrapping of fossil vans when converting to a zero-emission van (2018)

	Volkswagen Golf	Volkswagen e-golf
Import price:	22 046	33 037
CO2 tax (113 g/km)	4 348	-
NOx tax:	206	-
Weight tax:	1 715	-
Scrapping fee:	249	249
25% VAT:	5 512	-
Retail price:	34 076 €	33 286 €

Figure 66: Norwegian EV Incentives and Price Comparison VW Golf and e-Golf in Norway (Source: Norsk Elbilforening)

[120] The high positive differential between taxes on diesel and gasoline and tax on electricity consumption can be a useful tool in lowering the TCO for EVs.
[121] Company car tax benefits is a crucial element of EV policy in Europe since a high percentage of car registrations in Germany, France and the UK are company cars.

Norway has no subsidies; advantage being created entirely by the tax differential (see Figure 67). In France, low emission vehicles are exempt from the registration tax and BEVs receive a bonus of approximately 6,000 euros. Above a certain threshold for emissions, vehicle registration tax increases to a maximum value of 10,000 euros, creating a 16,000-euro differential. In Germany there is no registration tax but annual ownership and company car taxes for EVs are reduced. Insufficient to create a substantial differential, Germany has a generous purchase subsidy program combining federal and local purchase subsidies of up to 10,500 euros (see Figure 68). VAT in Germany was temporarily reduced from 19% to 16% in the second half of 2020. Similarly, the UK reduces registration, ownership and company car taxes and also provides direct purchase subsidies. (Wappelhorst et al., 2018)

		France	Germany	Netherlands	Norway	United Kingdom
Tax payments						
Purchase and registration of a new vehicle (one-time)	**VAT**	**20%** for all fuel types	**19%** for all fuel types	**21%** for all fuel types	**25%** for all fuel types, **0%** for zero-emission vehicles	**20%** for all fuel types
	Registration tax	**Yes**, based on CO_2 emissions	**No**, only a registration fee	**Yes**, based on CO_2 emissions and fuel type	**Yes**, based on CO_2 emissions, NO_x emissions, and vehicle weight	**Yes**, based on CO_2 emissions and fuel type
Ownership of a vehicle (in regular intervals)	**Motor vehicle tax**	**Yes**, based on CO_2 emissions (> 190 g CO_2/km)	**Yes**, based on CO_2 emissions, cylinder capacity, and fuel type	**Yes**, based on vehicle weight and fuel type	**No**, in 2018 replaced by a traffic insurance fee	**Yes**, based on CO_2 emissions and fuel type
Consumption of fuel and electricity	**Tax share of gasoline (end price)[1]**	61% (€0.173/kWh)	60% (€0.166/kWh)	64% (€0.190/kWh)	65% (€0.187/kWh)	63% (€0.161/kWh)
	Tax share diesel (end price)[1]	58% (€0.149/kWh)	52% (€0.132/kWh)	53% (€0.141/kWh)	58% (€0.162/kWh)	61% (€0.151/kWh)
	Share of taxes and levies on electricity (end price)[II]	38% (€0.161/kWh)	56% (€0.280/kWh)	55% (€0.185/kWh)	32% (€0.128/kWh)	22% (€0.168/kWh)
Use of transport infrastructures	**Road charges**	**Yes**, national toll scheme	**No**, but infrastructure fee in planning	**No**, only for crossing two tunnels	**Yes**, national and city toll schemes; partial exemptions or reduced rates for zero-emission vehicles	**No**, only for about 20 road sections; some congestion charging schemes at city level
Private use of company car	**Taxable benefit in kind per year[III]**	**9% or 12%** for all fuel types	**12%** for all fuel types (starting January 1, 2019, **6%** for BEV/FCEV and PHEV)	**4%** for zero-emission vehicles **22%** for vehicles emitting > 0 g CO_2/km	**30%** of the list price up to €31,700, **20%** of the rest of the car's list price for all fuel types; reduced list price (60%, instead of 100%) for zero-emission vehicles	**13%** for zero-emission vehicles **13%–37%** for other fuel types including diesel cars with RDE2-standard (> 0 g CO_2/km), **17%–37%** for other diesel cars (> 0 g CO_2/km)
Refunds						
Subsidies	**Grants**	**Yes**, maximum of €6,000 for cars between 0 g CO_2/km and 20 g CO_2/km	**Yes**, maximum of €4,380 for zero-emission vehicles, maximum of €3,285 for PHEV (< 50 g CO_2/km); price cap at €60,000	**No** national grants for low-emission vehicles	**No** national grants for low-emission vehicles	**Yes**, maximum of €5,100 or €2,800, depending on CO_2-emissions and all-electric range; partial price cap at €68,000 (until November 2018)

Figure 67: Comparison of subsidies and incentives in select European countries (Source: ICCT)

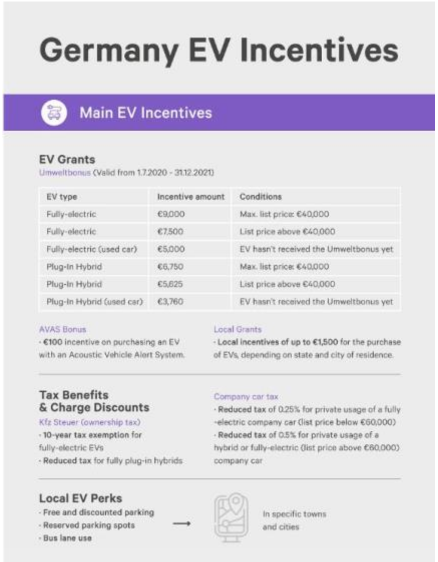


Figure 68: Germany EV Incentives (Source: Wallbox)

Europe experienced significant growth in EV sales in 2019, increasing 44%, with emissions standards tightening to 95g CO_2 per km, the strictest standard worldwide. The growth in pure BEVs was 70% with the Tesla Model 3, Hyundai Kona and the Audi e-tron at the forefront of this growth. Most countries experienced double digit growth as increasing government incentives primed the market.

Whilst China's EV market declined 31% in the second half of 2019 with the phasing out of subsidies and the UK suffered a drop of 15% in sales of PHEVs, as subsidies were eliminated, Germany experienced a significant increase in EV sales with a reduction in company car tax rom January 2019. In 2020, France revised its bonus-malus scheme that rewards production of low-emitting vehicles and more heavily penalizes high emitters. Germany extended its tax incentives for company cars through to the end of 2030 and increased purchase price subsidies thorough to the end of 2021. (Gersdorf et al., 2020)

Competitive premium-EV models have been launched and new CO_2 emission targets for 2025-2030 introduced. To meet these emissions targets there needs to be steep ramp up of EV Sales, an estimated 2.2 million units in 2021, equivalent to total global sales in 2018. From a level of 95 g CO_2 /km in 2021, the toughest in the world, the EU's Green Deal targets emissions decrease of 15% in 2025 and 37.5% by 2030 from the 2021 level, leading to lower emissions targets. Modifications in the role of ZLEVs are expected by taking a well to wheel approach rather than tailpipe (tank to wheel) approach. Several countries are urging the EU to accelerate the phase out of ICEs and enforce national bans, whilst continuing to support EVs through subsidies and other measures.(Gül et al., 2021)

In Norway, by 2017, 35 percent of vehicle sales were EVs, a result of years of collaboration amongst government, local EV manufacturers (Think Global and Pure Mobility) and an abundance of hydroelectric power. From the early 1990s, Norway has introduced various incentives including exemption from high sales taxes (including VAT), reduced road taxes, exemption from road tolls or ferries, free parking, access to bus lanes and a reduction in company car tax. In 2009, it launched a program to build out charging infrastructure. Norway's commitment is commendable in that it spans different governments over 30 years and because of its position as one of the largest producers of oil and gas. From 2018, Norway has begun to transition away from incentives to a system that imposes the full cost of a vehicle on its owner. Norway's goal is that all vehicles sold are ZEVs by 2025.(Sperling, 2018)

As of October 2021, Norway has a fleet of approximately 600,000 electric passenger cars and is rapidly approaching 90% penetration of new car sales. It is likely that next year Norway will approach 100% penetration of electric car sales, three years ahead of the 2025 ban on the sale of ICE vehicles. This is not the end of Norway's electric revolution, however. With an estimated 3m vehicles on the road, 20% of which are electric today, 2.4 million vehicles have yet to convert. Annual sales of approximately 180,000 light duty vehicles means that, in the absence of additional incentives, it will take 10 to 15 years to convert the entire fleet once the 100% penetration mark is reached (see Figure 69). (Kane, 2020d)

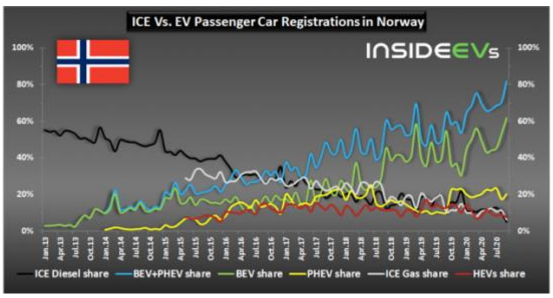


Figure 69: EV versus ICE registrations in Norway 2013-2020 (Source: INSIDEEVs)

In Europe as a whole, EV sales achieved a 23% market share in the month of September 2021. In the first nine months of the year the European market sold 1.58 million EVs, more than 20% higher than the whole of 2020, with a 17% share of the market (see Figure 70). With registrations typically rising towards the end of the year, Europe will undoubtedly breach 2 million EV sales and possibly double the total in 2020. Tesla's Model 3 is the most popular model followed by VW's ID4 but European OEMs dominate the market, with VW including Audi in first place with 25%, followed by Stellantis, Daimler and BMW, with another 23% of the market between them. More than 15 countries, including the three largest markets, are above a 10% share and Norway is approaching a 90% penetration.

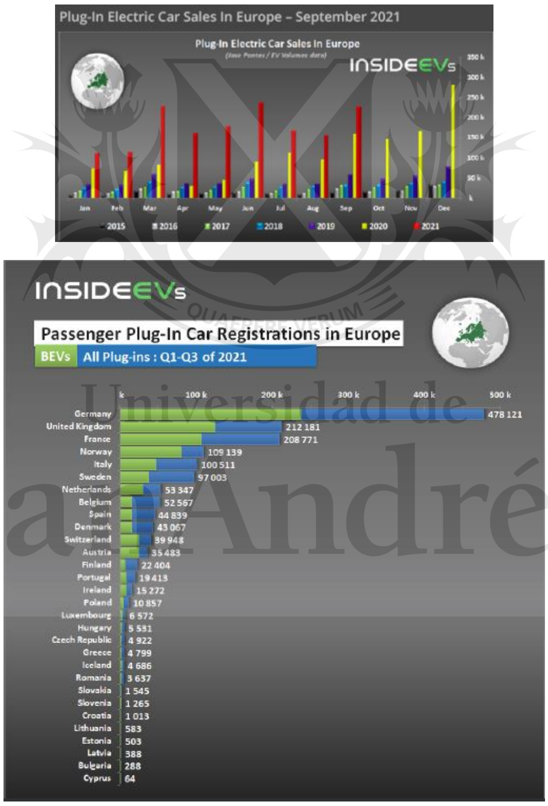


Figure 70: EV Sales in Europe to Q3 2021 and by country (Source: INSIDEEVs)

The European Commission on Climate Action will introduce its Zero Low Emissions Vehicle (ZLEV)[122] credit scheme from 2025, which targets 15% of sales from 2025 and 35% from 2030. For every percentage point in excess of the target an OEM will be able to relax (increase) its average fleet CO_2 emissions target (in g CO_2/km) by up to 5%. For every g/km in excess

122 ZLEVs are defined as vehicles that produce less than 50 g CO_2/km.

of the target penalty of 95 euros per vehicle will be payable by the manufacturer. Pooling of credits will be permitted.

Through AFID EU members are required to set charging deployment targets to 2030 for charging infrastructure at a recommended minimum 1 public charger per 10 EVs. The Green Deal targets 1 million public chargers by 2030 and there are targets for deployment of chargers along the Trans-European Transport Network (TEN-T) the core transborder network. The European Energy Performance of Building Directive set requirements for residential and non-residential buildings to improve access to charging points. Leading countries have their own national policies, targets, incentives and financial assistance.(Gül et al., 2021)

The EU intends to build a competitive local battery industry and establish the global standard for environmentally and socially responsible batteries by issuing directives for mandatory collection and recycling, battery passports to allow traceability across the whole life cycle and a 2.9-billion-euro support package for research and development. Poland is becoming a central EV hub for Europe with an LG Chem facility supported by the European Investment Bank.

6.3. US

US market has largely been driven by Tesla with the model 3 now fully scaled up. Under Trump, emissions targets were relaxed until 2025. New models are expected from a range of auto manufacturers.

A gradual phase out of the $7,500 federal tax credit for Tesla and GM (Chevy Volt), having reached an annual production of 200,000 vehicles, began in 2019, causing EV sales to decline, for which new models from VW, Audi and Hyundai could not compensate. The previous Federal government's decision to loosen regulations[123] risks further weakening the market and low oil prices significantly reduces the TCO benefit. (Gersdorf et al., 2020)

The Safer Affordable Fuel Efficient (SAFE) Vehicle's rule replaces the Corporate Average Fuel Economy (CAFE) with weaker energy efficiency targets for 2021 to 2026. Whilst

[123] The 2026 fuel economy standard was reduced to 40 miles per gallon from 54 mpg.

California has been a pioneer in EV adoption, with particular thanks to Tesla and to GM, the revolution is not as widespread as in Europe or China. Several States including New York, New Jersey, Massachusetts have followed California's regulations and now represent 33% of US car sales. California will ban ICEs by 2035 with again several States following its lead. Tax credits and purchase incentives at the State level, and financial and technical assistance for charging infrastructure, compensate for diluted federal support[124]. (Gül et al., 2021) The current administration, despite weakened fuel economy standards, appears supportive of the EV revolution with the recent announcement of $7.5 billion in charging infrastructure with 500,000 chargers planned by 2030. US battery regulation is underdeveloped with the Battery Recycling Advisory Group in California due to report recommendations in 2022.

After a market that stagnated in 2019 and 2020, EV sales have experienced a resurgence in 2021, California and Tesla are still dominant but with the introduction of new models such as the Ford Mustang, VW ID4 and Chevy Bolt, their influence has been reduced (see Figure 71). (Halvorson, 2021) As of July 2021, EV share was approximately 2.6% up from 1.6% a year ago. The Tesla Model Y and Tesla Model 3 are the number one and two most popular EVs with a 66% of the market, raising the question of whether people are buying Tesla or EVs. A year ago, it was closer to 80%. California retains 36% of the market, followed by Florida and Texas, but again in 2020 its share was 42%. The total vehicle market in California increased in 2021 by 24% and EVs increased by over 80%, achieving a record 11.6% share, with PHEV sales increasing at almost double the rate of BEVs, albeit from a smaller base. (Kane, 2021h) Whilst the West Coast and Tesla is still dominant it is a positive development to see EV adoption spreading to other parts of the country and other OEMs (see Figure 71).

[124] In the absence of Tesla and GM from the Federal tax rebate scheme, only 30% of EVs sold in the US benefitted.

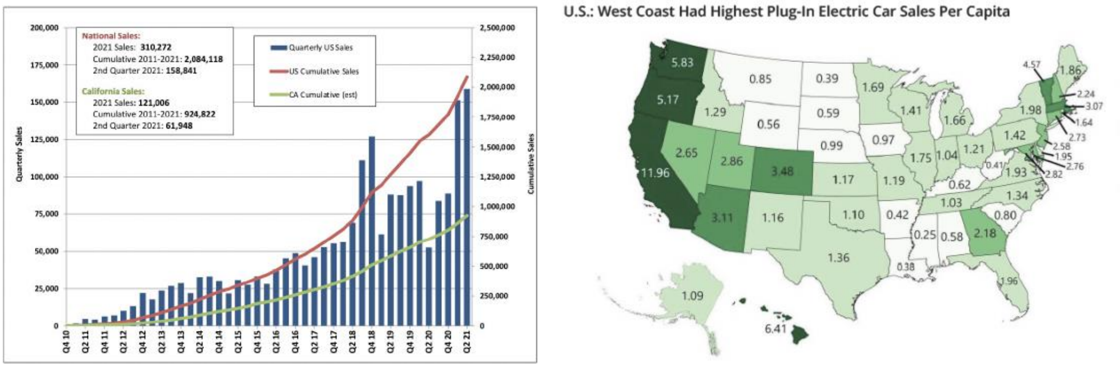


Figure 71: US EV Sales 2010-Q2 2021 and sales per capita (Source: Green Car Reports & INSIDEEVs)

6.4. Outlook

BNEF predicts, in its Economic Transition Scenario (ETS)[125], that unsubsidised purchase price parity will be achieved in the late 2020s in most vehicle categories and countries, which will spur rapid growth through to the late 2030s, as saturated markets in Europe and China begin to slow. The US will accelerate in the mid 2020s as model choice, purchase parity and home charging availability reduce barriers to adoption. Europe's larger markets reach 90% penetration by 2040: its smaller markets much sooner. Sales of EVs in emerging markets grow rapidly in the 2030s as economics, both purchase price parity and total cost parity improve. By 2040 EVs account for approximately 33% of the passenger vehicle fleet[126] (see Figure 72). (Bloomberg New Energy Finance, 2021)

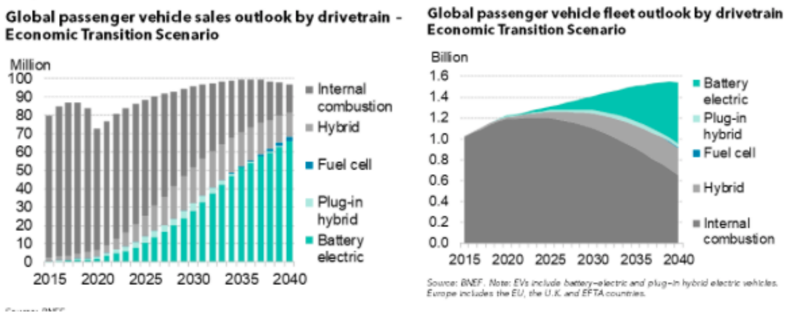


Figure 72: Projected EV Sales and vehicle fleet to 2040 (Source BNEF)

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[125] BNEF forecasts EV adoption with two core scenarios. The Economic Transition Scenario is driven by existing economics and technology trends if existing policies and regulations remain the same. The Net Zero scenario predicts the rate of adoption required for global transport sector to reach net zero emissions by 2050.

[126] BNEF recently increased its forecast from 495 million ZEVs by 2040 to 677 million, citing reduced costs, charging infrastructure, longer range EVs and increasing variety as the primary drivers.

BNEF's Net Zero Scenario (NZS) requires 60% penetration of global EV sales by 2030, compared to 34% in the ETS, with a fleet of 218 million EVs compared to 169 million for the ETS. Continued government policy support will be critical, in the form of fuel economy or emission standards, mandated electrification of public fleets and transport operators, restricted access in urban areas for non-ZEVs, and banning new sales of ICEs from 2035. China, Europe, the US and Korea have invested heavily in enabling the transition. As the cost of batteries and the cost of infrastructure[127] continues to fall, other growth markets and emerging economies will be able to complete the transition with much lower levels of investment.(Bloomberg New Energy Finance, 2021)

The impact on supply chains is significant as the ETS requires a 15-fold increase in demand for energy storage[128]. BNEF expects mining supplies to be sufficient to 2030 and does not expect metal supply constraints to derail EV adoption. Recycling, however, will be critical otherwise by 2050, lithium demand will exceed known reserves. Charging networks will need to exceed 309 million charging points by 2040[129], although the vast majority will be home chargers (270 million). The estimated cumulative investment of $589 billion for the ETS[130] pales in significance compared to the global investment in renewable energy capacity of $304 billion in 2020 alone. (Bloomberg New Energy Finance, 2021) As the use of infrastructure rises (efficiency gains) and power delivery increases (charging time reduces) the number of EVs per public charger can increase to 30 to 40 from between 5 and 20 today. Demand for electricity increases rapidly but in the context of total demand is manageable[131] (see Figure 73).

[127] BNEF predicts that the cost of going electric will be negative in the next five years. The benefits will outweigh the costs as purchase price parity and total cost parity is achieved, reducing the need for subsidies. Battery pack prices will be below $100/kWh by 2024 and $58/kWh by 2030.
[128] BCG predicts a 10-fold increase, but its adoption scenario is less aggressive.
[129] BCG predicts 100 million by 2030.
[130] In the NZS the estimated number of chargers required is 504 million by 2040 and 722 million by 2050 with a cumulative investment of $939 billion and $1.6 trillion, respectively.
[131] BCG estimates that in the US a $1,100 investment in grid upgrades will be required for each BEV sold for a total of $25 billion to 2030.

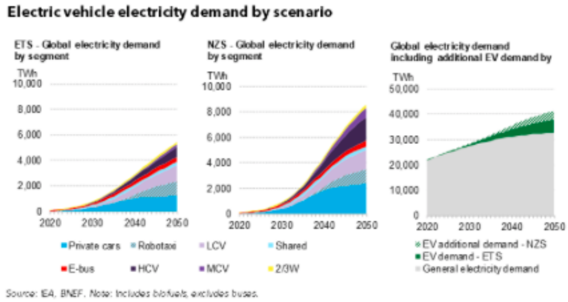


Figure 73: Projected EV Electricity Demand to 2050 (Source: BNEF)

Driven primarily by CO_2 emissions and fuel economy standards BNEF predicts market share of 25% to 32% by 2025 in Europe, increasing to 60% to 83% by 2030; in the US 24% by 2026 and 50% by 2030; in China targets of 20% by 2025 and 40% by 2030. Ernst and Young, in a recent report, predicts a 50% market share in sales of electric vehicles will be surpassed in Europe by 2028, in China by 2033 and in the US in 2036, which seems to coincide with BNEF's view except for the US, which is far less optimistic. Boston Consulting Group predicts that electrified vehicle[132] sales will represent more than 50% of the global market as soon as 2026 (47% by 2025), bringing forward its previous estimate by four years, and that ZEVs will dominate by 2036[133]. The EU will develop much quicker than China and the US, and larger developing nations such as Brazil and India will develop much more slowly.(Arora et al., 2021)

Will carmakers focus on Latin America and Africa to keep selling ICEs that no one else wants and will used cars from North America, Europe and Asia end up in poorer countries? Brazil for example has far lower levels of emissions from its transport sector and has been promoting biofuels (ethanol from sugar cane), which it deems net zero emissions, for many years. In the region there is a general lack of regulatory standards, financial incentives and commitment to charging infrastructure. In addition, EVs in Brazil are 3 times more expensive than a comparable conventional ICE. BCG does not expect that penetration of EVs and HEVs to be more than 2% to 10% by 2030.

BCG describes the pathway to global electrification in terms of three phases:

[132] Electrified vehicles include Hybrid Electric Vehicles (HEVs).
[133] It will likely take more than 20 years to change the entire global stock of conventional vehicles, since even when 100% sales penetration is achieved most cars on the road will still be conventional. If half of sales in 2035 are ZEVs an estimated 70% of vehicles on the road will still be ICEs.

- Phase 1 - Incentive and Early Adopter Electrification: Driven primarily by regulation and government incentives, increasing customer choice with over 300 BEV and PHEV models on offer, and TCO parity for most BEVs in the next five years.
- Phase 2 – Ownership-Cost Driven Electrification: By 2030 the cost advantages in terms of both TCO parity and purchase price parity are clear. Battery pack prices fall to \$75/kWh and BEV penetration reaches 28% (over 40% in Europe and China). Announced bans on ICEs begin to take effect.
- Phase 3 – Supply-Driven Electrification: From 2030, OEMs beginning to exit ICE manufacturing programmes. 45% penetration of BEVs achieved in 2035 (see Figure 74).

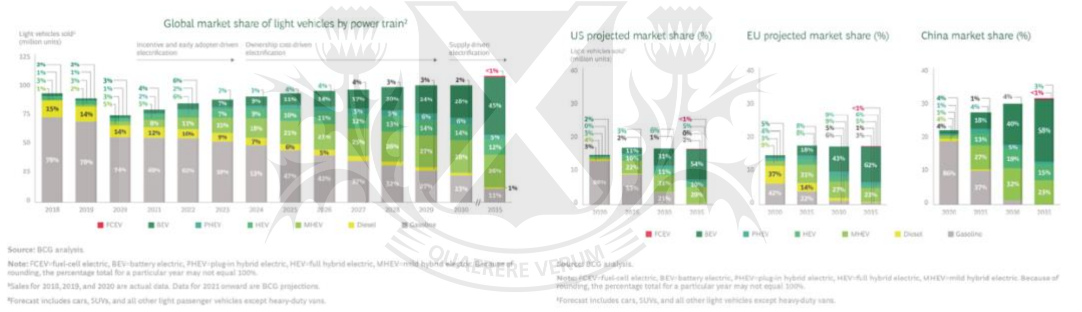


Figure 74: Projected Global Market Share by powertrain to 2035 (Source: BCG)

Even at this rate of adoption Europe will only achieve a 28% penetration by 2030, only around half of the targeted reduction in the Green Deal. BCG argues the transition needs to be speeded up by bringing forward ICE bans, strengthening financial incentives and investing in charging infrastructure, as well as strengthening alternative transport modes. (Why EVs need to accelerate).

The International Energy Agency (IEA) and the Electric Vehicles Initiative (EVI), a multi-government policy forum established in 2010, also develop impact assessments based on two EV adoption scenarios, the Stated Policies Scenario (STEPS)[134] and the Sustainable Development scenario (SDS)[135]. In the first scenario EV adoption increases the number of

[134] STEPS reflects all existing policies, ambitions and targets announce or otherwise legislated for.
[135] SDS is based upon requirements to reduce emissions in order to meet targets under the Paris Agreement and assumes these targets are met. Broadly these targets seek net zero emissions by 2070, a temperature rise of no more than 1.7º C to 1.8ºC with a 66% probability, impacting both electricity generation and transport sectors.

EVs on the road to 145 million by 2030, accounting for 15% share of sales and 7% of the total fleet of approximately 2 billion vehicles and reducing emissions by 33%. Under SDS, an accelerated effort to reach climate goals, there are 230 million EVs by 2030, accounting for a 30% share of sales in 2030[136] and 12% of the global fleet and reducing emissions by 66%. China achieves a 35% market share for EVs by 2030 under STEPS and over 40% under the SDS. Europe is at around 40% under STEPS and just under 80% under the SDS scenario. The US reaches only 15% under STEPS but 50% penetration under SDS and the rest of the world will only achieve 5% to 15%.

To achieve the SDS will require that continued advances in battery technology and production at scale continues to reduce costs, CO_2 measures and fuel economy standards that are increasingly strict, taxing ICEs at their full environmental and social cost (thus improving revenues for government to invest in the transition), decarbonising electricity generation, integrating EVs into the power system and creating a circular economy for battery manufacturing and recycling. Effective government policy will continue to address the up-front costs of an EV versus its ICE counterpart and promote EV charging infrastructure, as well as the smooth integration of charging demand into power systems. (Gül et al., 2021)

Based on OEM announcements for all-electric targets, cumulative sales could reach 55 to 73 million EVs by 2025, which is in line with the SDS scenario (see Figure 75).

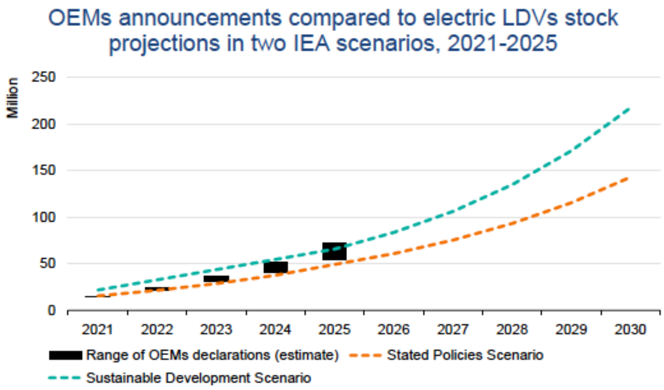


Figure 75: Projected EV fleet to 2030 (Source: IEA)

136 Signatories to the EV30@30 involves 15 countries including China, the EU, the European Free Trade Agreement and the UK, plus New Zealand, Chile and Canada.

The type, location and frequency of charging infrastructure depend on EV stocks, travel patterns, transport modes, urbanisation trends and access to off-street parking at home or at work. The estimated private 9.5 million chargers, comprising 7 million residential and 2. 5 million workplace chargers will need to grow to between 105 million and 190 million by 2030 under the two scenarios. The private charging network dwarfs the public charging network by number of points (90%) but accounts for only 70% of installed power capacity due to the lower charging rate required. The public network of approximately 1.3 million chargers will need to grow to between 16 million and 24 million, at a ratio of one fast charger for every five or six slow chargers.

Battery manufacturing capacity will need to increase from 300 GWh (50% capacity production currently utilised) to between 1.6TWh and 3.2TWh, a 10-to-20-fold increase. Planned productions capacity would be sufficient for the SDS scenario if operating at full capacity. Current electricity demand for EVs of 80TWh represents only 1% of total electricity consumption in 2020 but will increase by 6 to 11 times by 2030 and represent 2% to 5% of total consumption. Management of peak load will be more critical than overall capacity.

7. Autonomous, Connected & Shared - Disruptive Trends

The information technology revolution has finally come to transportation to create the potential for shared, electric and automated vehicles, with access for all, elimination of congestion and pollution, and all at a lower cost, but the dream could become a nightmare if not properly managed. Decisions made today about technologies, infrastructure and urban planning will strongly influence the outcome (path dependence). Electrification and increasing levels of automation are inevitable but sharing, perhaps the most critical, is less certain. Will consumers accept shared services particularly post-pandemic? Will automakers and other incumbents provide mobility services, and will they be accepted by incumbent transport operators? (Sperling, 2018)

EVs reduce pollution and emissions, shared vehicles reduce the number of cars on the road, impacting congestion and emissions. Automation should increase safety and increase road capacity once a tipping point is reached (narrower lanes and reduced space between vehicles). Urban space designated for private vehicles (roads and parking) could be repurposed for public use, revitalising city centres. Together, an electric, automated and shared vehicle will radically transform transportation, its emissions and energy use, and would be provided at a substantially lower cost than heavily subsidised public transport. On the other hand, local governments face significant reductions in revenue streams from road taxes, parking, and fines, as well as increased unemployment of public transport, delivery and taxi drivers.

Industry investments in new mobility technology companies continue to accelerate with particular emphasis on ridehailing, semiconductors and autonomous vehicle sensors, with over USD 330 billion invested in new technology companies since 2010 (see Figure 76). An estimated USD 70 billion investment is required to gain a defensible position across ACES tech. In this new mobility paradigm, there is much greater collaboration than we have previously seen to share the investment burden with tech companies, venture capital firms and private equity dominating ACS[137] technology[138]. (Holland-Letz et al., 2021) According to

[137] Automated, Connected, Shared.
[138] Two thirds of this amount have been invested in autonomous and smart mobility; the latter dominated by ride-hailing. 93% of these investments in future mobility companies are by non-incumbents; 65% by VC and PE firms. Incumbents have allocated over $200 billion since 2014 to develop these capabilities in-house, 80% into electrification.

Crunchbase, automakers invested USD 6 billion in 2019 in start-up funding, besides their internal investments, predominantly in autonomous driving, EVs and batteries, and ridehailing applications. Collaboration will continue to make sense for automakers unable to compete with the deep pockets of tech companies.

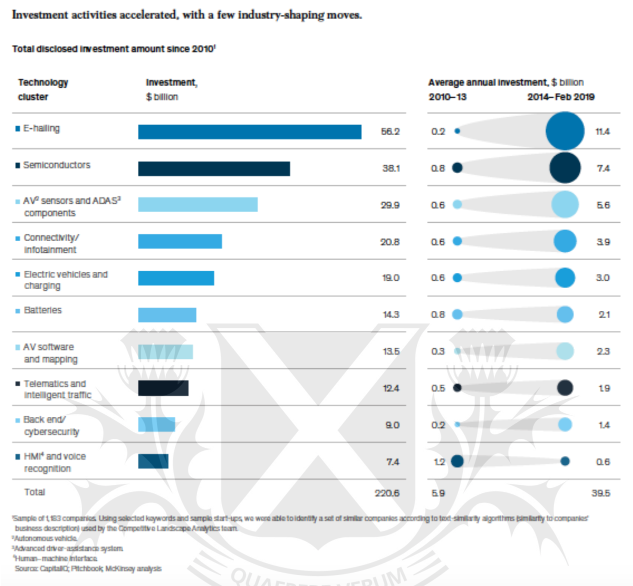


Figure 76: Investment activity by technology to 2019 (Source: McKinsey)

The future of mobility could see a fundamental shift away from personally owned, driver-driven vehicles to AVs and shared mobility. As with electrification, governments need to be catalysts for innovation and avoid being inhibitors. Just as Oil and Gas companies are redefining themselves as energy companies, OEMs are already responding[139] to the need to transform themselves into mobility companies, not just assemblers of vehicles, and collaborate with the disruptors rather than try to compete with them (see Figure 77). (Corwin et al., 2016)

[139] GM has a significant investment in Lyft and created its own Maven car sharing service. Ford Smart Mobility has a growing suite of mobility products and services. Daimler and BMW have combined forces to create a joint mobility company, to name just a few.

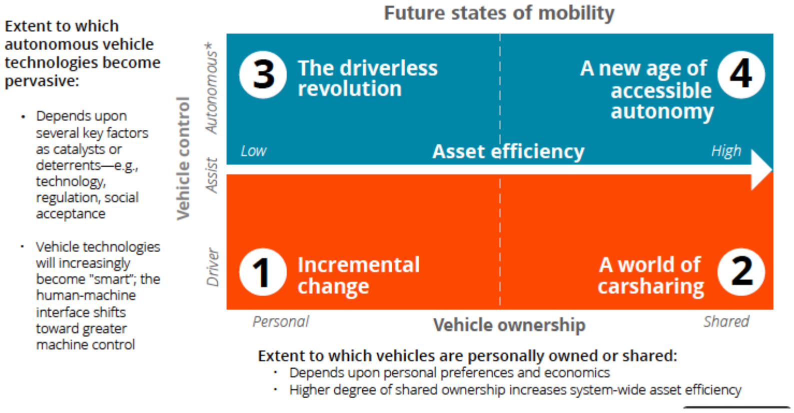


Figure 77: Future states of mobility (Source: Deloitte)

Mobility as a Service (MaaS) platforms, for example Whim in Helsinki, Finland, involves the entire ecosystem of transport options available in an urban context, not just new forms of mobility, and aims to reduce or eradicate the use of private vehicles for commuting. Combining real time information on public mass transit options, taxis, ridesharing, carsharing and micromobility with recommendations for best routes and transit options and the ability to pay for the entire journey, either pay as you go or subscription, all through one app. MaaS has the potential to move people faster, cleaner and more economically and is a real alternative to simply adding more roads or more mass transit. (Goodall et al., 2017)

Whilst journey apps are commonplace the seamless planning and paying for a single journey requires collaboration amongst the various transport options. It is data driven with the user at the centre and requires mobile connectivity and cashless payment systems, which are important considerations for making it accessible to and inclusive of all.

IHS Markit sees MaaS as potentially the most disruptive force for the auto industry, selling miles travelled rather than vehicles, and a driver for EVs, given the favourable economics for ride-hailing, ridesharing and carsharing applications, with revenues for these new mobility modes growing to $1 trillion by 2040 from around $200 billion currently. (Yergin et al., 2017)

Whether the lasting effects of the COVID-19 pandemic on new mobility trends and work patterns are permanent remains to be seen. Certainly, in the short term, greater emphasis on health and safety concerns[140] and home working practices have reduced the demand for urban mobility and reduced the use of public transport[141] in favour of higher use of private cars, walking and cycling. Many cities around the world have converted car lanes to cycle lanes, including Milan, Paris, Brussels, Seattle Montreal and Berlin. McKinsey expects a dramatic decrease in private car usage in Europe by 2030 but less so for North America. In Asian countries and South America, already heavily dependent on public transport the transformation will be less significant (see Figure 78). (Hausler et al., 2020)

In terms of regulation and policy we are at an inflection point where governments will decide to "build back better" or relax rules to support struggling industries[142]. These policy decisions will influence investment decisions in the short to medium term, potentially causing postponed investments in autonomous, electric and shared mobility.

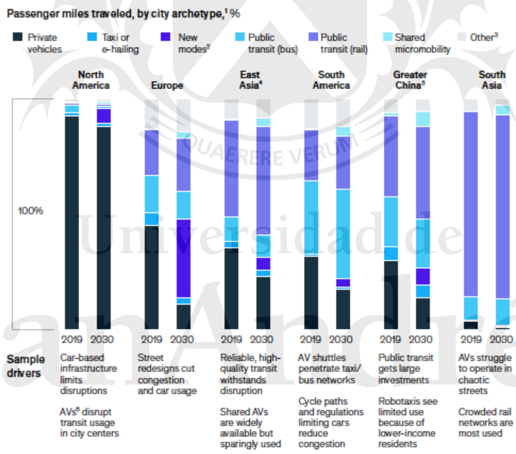


Figure 78: Projected passenger miles travelled by transport type in select regions to 2030 (Source: McKinsey)

BCG also reports in a survey of 5,000 residents in US, China and Western Europe a pandemic reduction in public transport, ride-hailing and carsharing in favour of walking, cycling and the use of private cars. Two ongoing challenges to the trends in urban mobility are shifting

[140] According to a recent McKinsey survey, Risk of Infection is the # 1 consideration for choosing a mode of transportation for both business and private trips, followed by time to destination.
[141] Public transit use is down 70% to 90% and ride-hailing down 60% to 70% during the pandemic.
[142] We have already seen a relaxation of emissions standards in the US, which combined with generally weak support for EVs at the Federal level, could see EV adoption slow or stagnate. China also relaxed rules for ICEs but conversely is still very supportive of EVs, extending incentives through to 2022; the EV revolution will continue. In Europe, the overall auto market may shrink with the popularity of shared mobility solutions but there is no stopping the EV revolution with stringent emissions standards and ICE bans towards the end of the decade.

consumer behaviours and attitudes and a reduction in disposable income. Despite consumers reporting a much higher likelihood of using or purchasing a private car, the survey was conducted prior to vaccines becoming widely available. BCG expects public transit and shared mobility to make a comeback once the pandemic eases. (Bert et al., 2020)

It remains to be seen whether younger generations will forgo the status and convenience of owning their own cars with the availability of new, more efficient forms of mobility available to them that were not available to previous generations. It appears car ownership is not as popular amongst Millennials as it was for baby-boomers, although this can change as newer generations have families or life circumstances change.

Large capital purchases may be unattractive for a generation saddled with student debt and ridesharing, ridehailing and carsharing or micromoblity are easy options and freely available in many cities, even if currently more expensive per km. Ownership headaches, such as scarce parking and ongoing costs, combined with worsening urban traffic, means driving is no longer a pleasure. Fear of missing out (FOMO) as technology changes so quickly, including car models, means younger generations are less inclined to tie themselves to a decision for 5 years or more; MaaS means you don't have to.

Heightened ecological and ecosystem awareness and shifting patterns in society and culture could change forever the notions of driving and car ownership, with driverless cars owned by mobility companies. Even if you do own a car, it is likely to be autonomous and electric so that it can go and earn money for you whilst you are not using it. The unattractive experience in car dealerships will need to change to attract younger generations used to buying everything online. Tesla's D2C model or a version of online D2C is likely to become the standard for vehicle sales going forward, not only improving the consumer experience but also removing dealership profits from the overall cost. (Eliot, 2019)

7.1.1. Autonomous

Autonomous Vehicles will need to be electric for the practical reason that higher voltage electrical architecture of EVs is required. The 12-volt architectures of modern ICEs are insufficient to power the computing and sensing equipment needed, whereas the 400-to-600-

volt architectures of EVs already have this capability. (Murray, 2019) Factor in the energy efficiency of EVs and the TCO considerations for shared mobility applications of AVs and it is likely that the future AV will be electric. Although autonomous mobility is some way off, compared to the current tipping point we are experiencing in electrification, the development of AVs could accelerate EV adoption further down the curve.

Explaining continued delays in the launch of Tesla's Full Self Driving beta version 9.0, delivered mid 2021, Elon Musk, perhaps understatedly, described automation as "a hard problem to solve". VW CEO, Herbert Diess, describes self-driving as the biggest revolution facing the automotive industry, more so than electrification, as autos switch from being driver focussed to passenger focussed.

The degrees of freedom involving real world artificial intelligence is certainly a very complex problem, which is why, despite the investments, overall autonomy is still at Level 2 driver assistance applications (see below). Advanced Driver Assistance Systems (ADAS), such as autonomous emergency braking and assistance in staying in lane, will be mandatory in Europe in 2022[143].

More intensive use of cars and eliminating the driver means that automation will drastically improve the economics of vehicles, particularly for commercial use. The Society of Automotive Engineers defines six levels of automation:

- Levels 0 to 2: use of automation technology but requiring driver attention e.g., adaptive cruise control, lane keeping and automatic brake technology.
- Level 3 cars will drive themselves in limited situations but require occasional human intervention e.g., Tesla's Autopilot. The car communicates the need for intervention
- Level 4 completely self-driving but with a human driver in the car. The driver can completely disengage and are only called upon in exceptional circumstances.
- Level 5 fully self-driving and driverless. There is no requirement for steering wheels or brake pedals.

[143] Germany appears to be set to permit fully self-driving vehicles (Level 5) across the nation as early as 2022, a world's first, initially in low driving density locations.

Automated buses that operate on fixed routes or rideshare cars that operate in specific pooling lanes are the most likely first application of level 4 and 5 automation. Sperling puts full scale automation several decades away, due to massive V2X[144] infrastructure investments and the time required for the adoption of automated vehicles first to dominates sales and then dominate travel. (Sperling, 2018)

The potential multiple benefits of Autonomous driving are the reduction of accidents, lower energy consumption through driving style[145], less congestion[146] with the use of smart traffic systems and the ability to travel closer together, and less space needed for parking.

KPMGs Autonomous Vehicles Readiness Index measures a countries progress in preparing for AVs against five enablers/barriers: Safety, Privacy, Digital Infrastructure, Impact on Transport Systems and Cross-border Travel. (Herring et al., 2020)

According to the WHO there are an estimated 1.35 million road deaths and 50 million injuries annually, 95% caused by human error. Advanced vehicle safety technologies are effective and becoming more widespread in new models, but society has a low tolerance for accidents caused by technology meaning an equilibrium needs to be found between improving safety and not setting the bar too high, for example GM's zero accidents. A focus on safety can come at a cost of efficiency, congestion and speed, as Level 5 AVs drive more defensively.

Connected, autonomous vehicles will optimise road capacity by knowing the position and destination of all other vehicles, optimising routes and speeds though intelligent traffic management systems but clearly tracking vehicles and sharing personal information creates additional challenges for cybersecurity. Digital infrastructure will require vast sensor networks, smart traffic systems, high quality digital mapping and the capacity to process massive amounts of data in real time using artificial intelligence.

[144] Vehicle to everything denotes connection of vehicles to other buildings, traffic infrastructure and buildings.
[145] More efficient control over acceleration, braking and speed will significantly lower energy consumption but potential for increased passenger-km travelled could reduce this benefit.
[146] It is possible that the convenience and eventual low cost of autonomous vehicles increases congestion through journeys that would not otherwise have been taken, or that shared AVs substitute for mass transit modes, walking or cycling.

Driverless private cars or fleet owned vehicles and taxis could lead to more cars on the road if not shared or pooled. AVs will remove labour costs from the equation making remote public services economically viable and driving adoption for commercial applications such as deliveries and mobility service companies. COVID-19, however, has made shared transport and public transport less popular.

International standardisation of regulation and policy will be important for cross border travel, particularly at a regional level. Ethical or moral decision making and liability in the case of accidents[147] all need to be addressed.

KPMG puts Singapore as the most advanced market, followed by the Netherlands, Norway, Finland and the US, measured by advances in policy and legislation, technology, infrastructure and customer acceptance. In all these countries advanced testing of AVs on public roads is in progress, with extensive use of smart traffic management systems. Predominantly driverless buses are already employed or due to be employed next year. The US is second only to Israel in technology and innovation with 420 AV companies headquartered in the US. Apple (Xnor.ai & Drivte.ai), Google (Waymo), Intel (Moovit & MobilEye), Tesla, GM (Origin[148]) & Ford (Argo.ai) are just some of the major companies at the frontier of investment in the sector. (Benitez, 2019)

A report by CEPE[149] of the Universidad Torcuato di Tella, in Buenos Aires, and IADB produced a report on autonomous vehicles in Latin America and the Caribbean (LAC), based on a Delphi survey of 136 experts from 14 countries in the region, including consultants, public sector officials, academics, international organisations and industry experts. There are significant challenges to prepare cities in Latin America and the Caribbean, from influencing consumer preferences for shared AVs over their private cars, to integration of sophisticated traffic systems with mass public transport and regulatory frameworks. Vehicle training and sensor programming, ethical or moral priorities for decision making in emergency situations

[147] Liability addresses who will be the responsible party in case an AV has an accident. Will it be the owner or mobility operator, the manufacturer or the system programmer, or some third party responsible for smart infrastructure, for example?
[148] Origin is an AV designed by GM owned Cruise and Honda Motors, specifically for the purpose of ridesharing.
[149] CEPE – Centro para la Evaluación de Políticas basados en la Evidencia.

or determining acceptable levels of safety, liability for collisions and cybersecurity are unique issues for this mode of transport. (Benitez, 2019)

The panel of experts believe that Level 4 AVs will be available for purchase in developed countries by 2025 but in LAC only by 2030. Penetration of the vehicle fleet will grow to 25% by 2040, 50% by 2050 and 100% by 2065 and vehicles will command an average premium of USD 7,000 over conventional vehicles. (BID et al., 2019; Calatayud et al., 2020)

The general cost of journeys for AVs should reduce, despite increased purchase costs, due to lower operating costs, particularly if electrified and shared, lower journey times and more productive use (and value) of time. The modal choice of transport and whether it is private or borrowed, individual or shared will influence the location of individuals and firms[150]. Health (pollution), safety and social equality (access) and urban redesign resulting from more efficient use of space not needed for cars are amongst many additional factors to be considered, along with impact upon the workforce of commercial drivers, including taxi drivers and other commercial or public transport driver. It is estimated that AVs travelling close together could increase existing road capacity by 80% to 100% and that up to 90% less space for parking would be required if fleets are shared. Above all, availability and integration of real time data across the whole transport system is critical.

Progress is not as fast as anticipated, but the underlying logic remains for robotaxis, with congestion[151], crowded parking spaces and pollution critical in many urban areas globally. McKinsey predicts that Autonomous Vehicles (AVs) could account for 66% of passenger-km by 2040, representing 40% of new vehicle sales and 12% of the installed vehicle base, largely driven by China from 2027. China is the largest and most important auto market, where rapid growth is overtaking infrastructure and causing significant problems for congestion and

[150] As mobility becomes cheaper and more accessible, particularly in last mile and first mile links to mass transit, urban dispersion can occur as it becomes more attractive to live further away. Autonomous shared and electric vehicles can complement train and metro mass transit that are used for longer journeys but will likely be significantly cheaper. Ride hailing on an individual basis can be twice as expensive per km than mass transit which is twice as expensive than using a private vehicle. A pooled E-AV could more than halve today's costs of using a private car with the advantages of faster travel times and greater convenience (no parking required). (Axsen & Sovacool, 2019) A 2018 study by the American Automobile Association (AAA) put the cost of ride-hailing at twice the cost per km of owning a private car.
[151] According to General Motors, congestion in the US costs an estimated USD 87 billion annually in lost time.

pollution. AVs have the potential to reduce vehicles on the road (see Figure 79). (Pizzuto et al., 2019)

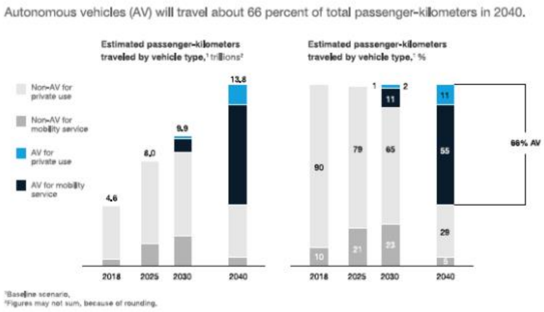


Figure 79: Projected share of Autonomous Vehicles in China by 2040 (Source: McKinsey)

AVs will shift a substantial share of mobility market value away from products (buying vehicles) towards services. However, non-standardised traffic lights and signage in China could slow algorithmic learning, which will require more data and AI training. China is already adopting MaaS at a double-digit rate with approximately 10% of all car sales sold to mobility services companies.

The AV technology stack, incorporating sensors, computing platform, software and system integration, mapping and location-based services will be the critical component of the drive system. Automakers must become software companies and/or seek greater collaboration with tech companies.

If the US fully adopted AVs, McKinsey estimates that the benefit would exceed USD 800 billion per year by 2030, predominantly through the health and safety benefits of fewer accidents, the redevelopment of parking spaces and more productive commuting time. The benefits do not come without consequences, however. Energy consumption (electricity) could increase as a result of latent demand being tapped. Revenues from vehicle taxes and licences would fall. (Heineke & Kampshoff, 2019; McKinsey & Company, 2019)

Tesla & Google (Waymo) have been pioneers in automated technology. Mobility service providers, such as Uber, are keen to switch to automated cars as this will eradicate their most significant cost: the driver. Technical progress is only one limiting factor, together with for example, regulatory issues over licensing, transition of automakers into mobility service companies, transition of vehicle design focussed on driver experience to user/passenger experience, legal, ethical or moral and insurance liability issues around algorithm decision making. The tech company culture of moving swiftly and asking for forgiveness later, will be tested as they enter a highly regulated arena that will demand rigid testing, regulations and certification. (Sperling, 2018)

The full benefits of automation are only realised once most or all vehicles are fully autonomous, and the reality is that, even in China, this is likely only in the second half of the century. Until then automakers will likely incrementally introduce self-driving features as premium options.

Automation without pooling and electrification has the potential to increase energy consumption, travel and pollution. Vehicle use could increase by up to 20%, and emissions by 50% by 2050. With pooling and electrification, vehicle use drops by 60% and emissions by 80 percent. Overall costs drop by 40% representing USD 5 trillion annually[152]. Many uncertainties surround the advancement of automation including technological, consumer adoption, regulatory and physical infrastructure. The principal benefit for automated cars is safety and efficiency in time and asset use, in addition to drastically reducing the need for parking space. Much parking space can be repurposed, and the remaining spaces made much smaller without the need for human access. (Sperling, 2018)

7.1.2. Connected

Connectivity is a critical component of future mobility. Complex digital systems required for autonomous driving technology, from driver assistance to full self-driving, over-the-air (OTA) software updates for power system control and plug and pay charging applications, are all key to advancing autonomy and electrification in cars. Moreover, as we have seen in China, consumer preference for connectivity, smartphone replication and advanced infotainment systems will only increase with advances in autonomous technology, as drivers become passengers. The digital architecture required for both autonomy and connectivity is

[152] Based on research at the University of California.

incompatible with modern ICEs, which is why electrification, connectivity and autonomy are mutually supportive trends.

Autonomous vehicles will necessarily be connected to traffic signals, other vehicles and other roadside information and infrastructure (V2X - vehicle to everything). Automakers will become specialist providers of both software and hardware, including cameras, radar, lidars sensors and computing power, that uses data from sensors to connect to other vehicles and infrastructure. Though as vehicles become more like computers, they will be more susceptible to hackers. Cybersecurity and data protection or privacy will be key issues not previously faced by automakers. (Sperling, 2018)

High resolution mapping that is continually updated by the vehicles themselves, access to transport information from a variety of sources and GPS data will become integral sources of information to the automated vehicle.

Cars will become information platforms with a better experience for drivers and new revenue streams for businesses offering products & services. The focus of advances in car design over the last century has been dominated by driver experience. As autonomous vehicles and shared mobility become more prevalent focus will shift to improving passenger experience. The role of the car shifts from a mode of transportation to a multimedia environment.

McKinsey predicts 5 levels of connectivity with 45% of vehicles reaching level 3 by 2030:

- Hardware connectivity: tracking basic vehicle usage and technical status.
- Individual connectivity: access to digital services and platforms.
- Preference based personalization: infotainment and contextual advertising.
- Multisensorial live interaction: all occupants interact live with the vehicle – proactive service and function recommendations.
- Virtual chauffeur: cognitive AI predicting and performing complex unprogrammed tasks.

(Heineke & Kampshoff, 2019)

Chinese automakers are showing the way for what connectivity means, with Chinese consumers apparently willing to pay twice as much as western countries for better connectivity and 56% willing to change brand[153] to have their car become an extension of or mimic their smartphone. Core digital capability in Chinese EVs start with the purchase experience through direct online sales channels, eliminating the 25% dealership margin. Features include advanced facial recognition to adjust preferred car settings, targeted advertising and recommendations, voice recognition, valet charging services, and plug and charge with payment validation through the infotainment system. New mobility will require refocus on core manufacturing skills with growing demand and competition for digital talent to develop software, connectivity and autonomous technology. (Heineke et al., 2021)

7.1.3. Shared

Shared mobility is a potential boost for electric mobility because the TCO economics of an EV in constant use are attractive, particularly when autonomous, either as part of a carsharing or ridesharing/ride-hailing mobility fleet or a private autonomous car that seeks additional income when not in use by the owner. The costs of an EV are substantially less to run (fuel and maintenance) and a shared autonomous vehicle in constant use will reach a tipping point far earlier than a car used solely for private use. Conversely, whilst sharing might accelerate the penetration or market share of EVs the overall number of vehicles required in some markets could decline or the conversion of private vehicles to EVs might slow.

BYD the Chinese EV manufacturer has already created a Level 2 Autonomous EV specifically designed for ride-hailing co-developed with DiDi Chuxing, a mobile transport platform[154]. The BYD D1 will include driver assistance with emergency braking and, lane departure warning and pedestrian collision warning, driver monitoring systems using facial technology, ride-hailing flow and fleet management systems. (Kane, 2020g) GM also recently introduced through its AV subsidiary, Cruise, the Origin, a purpose-built AV shuttle for ride-hailing, expected to go into production by 2023.

Shared mobility encompasses a wide spectrum from ride-hailing and shared use of vehicles or micro-mobility, which make more efficient use of underutilised assets[155] than private

[153] Compared to 36% in the US and 19% in Germany.
[154] The Didi platform is a giant in ride-hailing with 550 million registered passengers, 31 million drivers and 1 million EVs (which makes it the largest shared EV fleet), and completes 60 million trips a day, 10 billion per year.
[155] It is well publicized that private vehicles are unused for around 95% of the time and that very often there is only a single occupant to each vehicle.

ownership, to ridesharing or vehicle pooling that increase the number of passengers per vehicle and reduce the number of vehicles on the road. Shared mobility with pooled rides is paramount to unlocking the potential for electric vehicles and automation and reduce pollution, energy consumption and congestion, as well as offering greater mobility choice at a lower cost. (Sperling, 2018)

Embracing shared transportation and moving away from the auto ownership culture in many countries is complex, but will be facilitated by smart mobile technology, social networking and the advent of new location-based mobility services. Lyft founder, John Zimmer, saw ridesharing as the first step to ending car ownership and removing significant numbers of vehicles from our cities, and reclaiming cities for the community. Peer to peer transportation platforms such as Uber and Lyft are most effective in these aspirations when rides are pooled[156].

Collaboration with public transportation and local government authorities, rather than the conflict we have seen in several cities, is important. Pooled transport facilitating first and last mile connections and bridging gaps in the public transport system would be a good place to start but there is no denying that shared rides and eventually automation is not good for the thousands of taxi drivers that inhabit our cities. (Sperling, 2018)

Prior to the COVID-19 pandemic there was significant momentum in the carsharing industry with over 1000 cities adding this form of mobility service. Today, carsharing is available in 59 countries covering 30% of the world with 236 operators in 3,128 cities. The predominant business model is station-based, accounting for 61% of operators and 51 countries and is much more fragmented due to the lower initial investment. Free-floating business models are present in 160 cities in 36 countries and require a much larger up-front investment[157]. A third business model that has yet to achieve significant penetration is peer-to-peer carsharing principally due

[156] A 2016 study in the city of Lisbon Portugal, conducted by the International Transport Forum, found that replacing car and bus trips with automated shared shuttles and taxis would require 97% fewer vehicles, 95% fewer parking spaces, and 37% fewer kilometers travelled. A similar study by MIT concluded that taxis in New York could reduce by around 80% if replaced by shared vehicles.

[157] Station-based carsharing operators can launch their business to focus upon a very specific geo-localised market because the vehicles must always be collected from and be returned to a station and consequently can begin with a small number of vehicles. On the other hand, free floating cars cand be picked up and left at any location within an urban context and so a much larger volume of vehicles is needed to provide adequate coverage.

to insurance restrictions, where the ownership and costs of the vehicle are the responsibility of the individual and is therefore scalable much more quickly. The US leads in number of operators but Moscow, where Yandex, Russia's Google is a major player, is the car sharing capital of the world with over 23 million rides in 2018. (Phillips, 2019)

Only two players in carsharing have global reach, Zipcar, the station based carsharing company based in the US and acquired by Avis in 2013, and ShareNow, the free-floating joint venture of mobility services that brought together BMW's DriveNow and Daimler's Car2Go. Zipcar started by strategically positioning itself on university and college campuses to attract students that could not afford their own car and now has over 1 million members. ShareNow has over 4 million customers and 20,000 vehicles in 160 cities across 36 countries. It is the carsharing element of the mobility hub created by BMW and Daimler that includes, MaaS (ReachNow), Ridehailing (FreeNow), parking (ParkNow) and charging (ChargeNow). In Argentina, Ford's Keego and Toyota's Kinto have entered the market with carsharing applications, promoting mobility as a service over car ownership. Uber and Cabify have also penetrated the market in Ridehailing and Ridesharing, but electrification has yet to make a significant impact.

Carsharing addresses the problem of underutilised assets whilst providing consumers with attractive flexibility to be able to use different car models for different purposes, without the underlying costs of vehicle ownership. It does nothing, however, to address problems of congestion, since most rides will continue to be single occupancy, or pollution unless those vehicles are electrified, which for fleet vehicles makes economic sense.

Pooled rides are typically 40% to 50% cheaper as compensation for the slight inconvenience of a small delay in arriving at the destination. As shared vehicle use is much more efficient since vehicles are used more intensely, adoption of EVs is accelerated since Total Cost of Operation parity is reached much more quickly. (Sperling, 2018)

Culture and economics influence a consumer's willingness to share rides with strangers, as well as safety and security. Car-pooling is in many ways like public transport but on a smaller scale and if the economics, convenience and travel time are similar to or better than using a private car or public transport that consumers will share rides. Automation will greatly enhance the economics of pooling with more intense vehicle use and the removal of the driver.

Mobility needs to become smarter and more integrated amongst public and private transport modes. Multimodal transport involving private cars, public transport, robotaxis, robo shuttles, micromobility, cycling and walking. Shared transportation is a key ingredient in reducing congestion and pollution and pre pandemic, carsharing and ridesharing services had become more prevalent in many urban centres globally, particularly in Europe. The advent of ride hailing services, such as Uber[158], however, has created a spike in congestion with an estimated 50% of ehailing trips constituting new passenger-vehicle miles. Cities and urban planning departments are important stakeholders, as we have discussed, in providing push (parking fees, congestion charges, low emission zones) and pull incentives (integrated mobility services) towards more sustainable transportation.(McKinsey & Company, 2019)

In 2007, the release of the iPhone specifically and smart phones and mobile technology in general opened the door for the sharing economy in transportation, pioneered initially by Uber and Lyft. Lyft line and Uber pooling allow consumers to share rides with strangers and were very successful in San Francisco, where by 2016 they experienced a 50% penetration for pooled rides (versus single occupied rides). Cultural and safety dynamics, however, cannot be ignored in the widespread adoption of shared rides. (Sperling, 2018)

The ridesharing market is still comparatively small, even in the US where the vehicle miles travelled in ridesharing assets represent only 1%. Ridesharing and ride hailing economics will improve immeasurably as autonomous vehicles eliminate the driver and electrification reduces running and maintenance costs, as will be the case for vehicles used for last mile delivery.

[158] According to a Schroder's investment report, taxis rather than car ownership have been the biggest losers, but ride sharing has also impacted walking, cycling and public transport, pre-pandemic. Only an estimated 20% of rides substitute for private car use and an estimated 20% of journeys would not have otherwise been made. This increase in vehicle miles travelled and partial substitution for other transport modes could have a negative impact on congestion and pollution if not electrified and shared. (Davidson, 2018) Uber has declared that it intends (to encourage its 5 million drivers) to go 100% electric in London by 2025 and in Europe, Canada and the US by 2030, and to become a zero-emissions mobility platform by 2040, through discounts for EVs from OEM partners, GM and Renault Nissan Mitsubishi.

Public policy and information technology will be the main drivers for pooling, with decisions over reclaiming land use, such as parking and other road infrastructure, to favour pooling and other forms of sustainable transportation. Data sharing will smooth first and last mile connections to public transportation through mobility service applications, as well as providing safety and profile information to fellow passengers. (Sperling, 2018)

Beyond electrification, sharing and pooling represent the best chance for reducing emissions, urban pollution, and congestion. High dependence on cars is neither desirable or sustainable and contributes to the decline in quality of urban life. (Sperling, 2018) Shared mobility will rebound to 2019 levels in the next two years but will still only account for 6% of the annual passenger vehicle kms by 2025, according to BNEF. (Bloomberg New Energy Finance, 2021)

8. Implications for Argentina

8.1. Regional Challenges and Trends

Despite several countries being signatories to the Paris Agreement on climate change, emissions standards in Latin America are far less stringent than in Europe. Developing economies also have far less fiscal capacity to implement incentive programmes and invest in charging infrastructure than Europe China and the USA. Designing long distance charging networks in the massive geographies of Brazil and Argentina is complicated. Disruption to established auto manufacture industries and their supply chains must be carefully managed as they are important sources of employment and export dollars, in Mexico, Brazil and Argentina. Even locally produced EVs will find it difficult to compete on price with the very successful manufacture of low-cost vehicles, particularly in Brazil. Finally, the full benefits of electric mobility are achieved when powered by renewable energy sources. Penetration of renewable energy in the region is still low[159]. (SIOMAA & ACARA, 2021a)

Despite the challenges there are several trends that are spreading from the more developed economies to the region. The use of EVs in last mile delivery is already being implemented in Chile by Mercado Libre and DHL. Installed and currently underutilised charging infrastructure, for example in shopping malls and supermarkets, is an opportunity for Charging as a Service companies to offer recharging to commercial EVs overnight. Distributed energy generation allows the selling of excess energy back to the grid and lowers even further the cost of home charging, particularly in conjunction with smart grids and peak/off peak tariffs. Standardisation of charging, payment methods and batteries will lower the cost of developing an adequate charging network. (SIOMAA & ACARA, 2021b)

Brazil is an important partner to Argentina in the automotive industry, its most important partner, both in the import of vehicles for sale in its domestic market and as a destination for Argentinean exports. It is likely that OEMs with a presence in both countries will take a regional approach to electric mobility watching these two important markets closely for developments in demand and government support.

[159] In Argentina 60% of electricity generation comes from Natural Gas, 26% Hydroelectric, 4% Nuclear and only 10% Renewable, although in 2020 63% of increased capacity came from renewable sources (CAMMESA).

A study by ANFAVEA and BCG suggests there are three scenarios for the development of EVs in Brazil over the next 15 years:

a) Inertia – maintaining the current (slow) rhythm of development without much organisation or collaboration amongst the transport and energy sectors, with no significant development of state policies or incentives.
b) Global convergence – accelerated adoption to accompany developments in the rest of the world.
c) Leadership in biofuels – focus on biofuels such as ethanol already produced and deployed in abundance with favourable regulation and technological development of Flex motors able to run on ethanol or conventional gasoline, but with an increase of 15% in the amount of ethanol used on gasoline.

Even in the first and third scenarios, ANFAVEA estimates that between 12% and 22% of all vehicles sold could be electrified by 2030 and 32% by 2035, from only 2% currently. This would imply a volume of between 432,000 and 1.3 million vehicles. In the Global Convergence scenario this could increase to 65% by 2035 or 2.5 million vehicles. In all scenarios the importance of supportive public policy and investments is paramount to encourage private enterprise to consider their strategies. Given that these volumes can't be imported without a significant negative impact on the balance of payments, Brazil is likely to begin focus investments on electrification in the next few years. ("Estudo ANFAVEA-BCG Aponta Cenários e Desafios Do Brasil No Caminho Da Descarbonização Do Setor Automotivo," 2021)

With sales of 2.5 million vehicles per annum by 2035 the natural renewal of the fleet will be very slow. Over 80% of cars will still be Flex. The impact on emissions and reduction in pollutants will be insignificant, so incentives should be directed towards removing older, dirtier vehicles. Given the high incidence of taxes in Brazil, and indeed Argentina, there is no need for direct purchase subsidies. A reduction in taxes on clean technology and/ or a green tax charged on ICEs, like France's bonus/malus programme, can be coupled with discounted or free charging, preferential road charges, access ("rodizio") and parking to incentivise demand and minimise cost to the public purse. Global convergence will require at least 150,000 public chargers at an estimated cost of R$ 14 billion as well as significant investments in energy generation assets, estimated at 1.5% of current capacity.

There is opportunity for Argentina as a world leader in Lithium reserves. BMW invested USD 334 million in lithium extraction in 2021, for processing in Europe but indicated that in the future it could produce batteries in Argentina in the future. To transpire, however, the sales potential in local markets will need to improve dramatically. Currently BMW only sells around 300 EVs in Argentina versus 3,000 in Brazil and 5,000 in Mexico. Scale is important[160].

Argentina's Lithium production is increasing exponentially. In 2019, installed capacity was for 42,000 tons of Lithium Carbonate Equivalent (LCE) or 7,900 tonnes of Lithium[161]. There are projects for Lithium extraction in 23 salt flats in the provinces of Jujuy, Salta and Catamarca, of which only Olaroz in Jujuy and Fénix in Catamarca are operative. Planned expansion could increase production capacity to 129,000 tonnes LCE by the end of 2022. Fénix is operated by US company Livent Corp with an installed capacity of 22,000 tonnes LCE and Olaroz, with a capacity of 17,500 tonnes LCE, is a joint venture between Australian company Orocobre, Toyota and JEMSE, the state-owned energy and mining company. Both are expected to expand to 40,000 tonnes LCE. (Calzada & Sigaudo, 2019)

Exports of the mineral have tripled between 2008 to 2018 to USD 251 million, to the US, Japan, China and South Korea, with only a 50% increase in volume to 29,000 tonnes LCE, although still a relatively small proportion of mining and total exports. Nevertheless, exports of Lithium are expected to quadruple by 2025 increasing participation in exports to around 5% and attracting investments of in excess of USD 1.5 billion.

Despite BMW's optimism for local battery manufacture the reality is that there are significant challenges to overcome. The plethora of raw material is a positive, but the manufacture of batteries requires a high level of specialisation and technical know-how. Major markets in China and Europe are a great distance away and local regional markets lack scale and clear

[160] The minimum capacity for an economically viable battery factory is approximately 250,000 cars or 3 million motorcycles. (Baruj et al., 2021)
[161] One tonne of Lithium metal is extracted from 5.323 tonnes of Lithium Carbonate.

policy for incentives. Batteries packs are extremely heavy[162] and can't be transported by air, which means it is inefficient to export batteries, which is why so far, we have observed battery manufacturing capacity globally localised close to EV manufacturing capacity.

A potential threat to the region is that OEMs focussed on electric vehicle development in more advanced regions divert foreign direct investment away from Latin America leaving manufacturing capacity to deteriorate in the region. With slower development of electric mobility expected with 15% to 20% penetration versus 60% in China, Europe and the US by 2030, foreign owned companies may look to divest there manufacturing assets across the supply chain. Qell Latam Partners an investment fund run by the ex-president of GM in Brazil, was established specifically to purchase subsidiaries in Latin America. There are some 700 companies 80% owned by foreign capital in the region. (Silva, 2021)

A further threat to Argentina's auto industry is that its larger neighbour with a domestic auto market that is more than six times its size attracts a far larger portion of investments. Bravo Motors a manufacturer of EVs (taxis, vans and buses) developed its city car the Nacho One, designed for car sharing, in Argentina but lack of interest, incentives and investments lead the company to develop its products in the US. Attracting 750 investment partners and 2 investment funds, Bravo recently announced that a USD 4 billion investment in the state of Minas Gerais in Brazil will install an EV factory and battery production facility with capacity to build 22,790 EVs and 43,750 battery packs per annum from 2024, creating 13,800 jobs (as many as are currently employed in Argentina's auto industry[163]) and exploiting Minas Gerais' Lithium producing capacity. (Oliveri, 2021)

Furthermore, BYD at the end of 2020 inaugurated its factory in Manaus, Amazonas to assemble Lithium Iron Phosphate cells (LFP) to supply its electric vehicle factory in Campinas. In the second half of 2020, together with Marcopolo, BYD produced the first chassis for an articulated electric bus 100% Brazilian. (Mánez Gomis et al., 2021)

[162] A 55-kwh battery with a NMC622 cathode takes approximately 7.4 kg of LCE a 77-kWh battery with a NMC811 cathode uses approximately 8.4 kg LCE. The average battery weighs 30 kg per kWh (Kane, 2021e), which means that the weight of LCE in a battery pack represents less than 0.5%. The weight of Lithium metal in each cathode for the varying chemistries is less than 5%.
[163] According to ADEFA, in 2020 13,522 people were employed in the industry, although this a reduction from almost 25,000 in 2019, pre-pandemic.

The high cost of EVs relative to conventional ICEs and concerns over currency controls and balance of payments deficits, particularly in Argentina, represent perhaps the greatest barrier to adoption of EVs in the short to medium term. Development of national or regional production facilities and integrated supply chains will be paramount. A possible alternative is the conversion, particularly of larger vehicles, from conventional ICEs to EVs. The Centre for Aerospace Technology at The National University of La Plata has partnered with the province of Jujuy to convert 100 micro buses from diesel to electric, hoping to generate know how with a view to scaling up and providing an alternative to purchasing new electric vehicles from overseas. ("La UNLP Covertirá a Propulsión Eléctrica Con Baterías de Litio Cien Unidades de Micro-Omnibus de Jujuy," 2020)

Chile is perhaps the most advanced country in South America at least in terms of planning. The Energy Road Map from 2018 to 2022 seeks a 10-fold increase in EVs by 2022 relative to 2017. Around 600 EVs, were sold in 2020, doubling from 300 in 2019, 200 in 2018 and 140 in 2017. The EV market is still at a very small scale compared to annual motor vehicle sales for 300 to 400 thousand units, but Chile has big ambitions for its National Electromobility Strategy, achieving a 40% penetration of the motor vehicle stock by 2050 and 100% of public transport by 2040. (Gül et al., 2021)

8.2. Regulatory Framework

Development of a regulation and policy for electric mobility is in its infancy in Argentina. Thus far it has been limited to reducing extra-zone (outside of Mercosur) import duties on electric vehicles, in addition to defining categories of electric vehicles and requirements for homologation processes and driving license classification.

National decree 331/2017 reduced import duties from 35% to 5% for HEVs, 2% for BEVs and 0% for FCEVs, with an initial quota of 6,000 units over 36 months. Previously only available to OEMs established in the country, decree 230/2019 widened the reduction of duties for other importers of vehicles. Decree 846/2020 extended the reduction for a period of 6 months and 1,000 units. Decree 617/2021 extended reduction again for 18 months and 4,500 units to March 2023. Decree 51/2018, reduced import duties for buses, with a quota of 350 units over 36 months and 2,500 chargers of 50kW or higher. Import duties were reduced to 0% for companies with an approved production plan[164]. (Máñez Gomis et al., 2019)

Other legislation has been passed regulating the provision of charging services in service stations (disposition 283/2019) with specifications for installation and safety and the definition of foundation rules for electric installation of charging infrastructure ("Asociación Electronica Argentina").

At a provincial level Santa Fe, Buenos Aires, CABA and Neuquén there are various projects t to promote industrialisation of EVs and technologies linked to alternative energy, including tax exemptions and promotional tariffs. Included in "Plan Movilidad Límpia 2035" CABA plans a pilot to introduce 8 electric buses in 4 transit corridors. (Mañez Gomis et al., 2018)

Since 2018, Argentina has been working on a national strategy for electric mobility with support from the UN. In 2020, Argentina introduced a new project for a legal framework for sustainable mobility[165]. At is core, as a signatory to the Paris Agreement at COP 21 in 2015, is the drive to reduce greenhouse gas emissions[166], particularly CO_2, from transport. Argentina sees sustainable mobility as an opportunity to revive a flagging auto industry that has lost competitiveness over the last 20 years, especially to neighbouring Brazil, by investing in new technology. The new legal framework would create promotional regime with a special fund to finance benefits and incentive for both supply and demand of EVs. Such incentives would focus on reduction of import tariffs and VAT on vehicle sales, exemption from wealth taxes on personal goods and green plates[167]. Benefits would be scaled back over time[168]. (Kulfas, 2021)

[164] The production plan must be on a scale similar or greater than the volume of imports and with national content of 10% in the first two years and 25% from year three onwards. A report Published in 2017 by the Transport division of the Ministry for the Environment ("Plan Nacional de Mitigacion") defined its objective of promoting electric buses with a target of 30% in greater Buenos Aires by 2030.

[165] Proyecto Ley de Movilidad Sustentable (2020) – Ministerio de Desarrollo Productivo. Updated in October 2021.

[166] Transport accounts for approximately 26% of global energy use and 30% in Argentina.

[167] In CABA EVs and HEVs are exempt for registration tax, which accounts for between 3 to 5% of the value of the vehicle per annum. In other provinces such as Rio Grande, Neuquén and San Juan have a similar policy. Mendoza has a 50% reduction and San Luis a 75% reduction.

[168] The project envisages 100% benefits for the first 8 years to be scaled back to 66% for a further 7 years and then 33% in the final year to the end of 2040.

The new legal project for the promotion of sustainable mobility aims to reposition and increase the capabilities of the Argentine auto industry in the world. By 2030 it projects that there will be 12,500 job positions with OEMs, 6,000 in the auto parts supply chain, 1,500 in battery production, total investments of USD 8.3 billion and exports of 5 billion. An accumulated reduction in GHG emissions of 10.7 million tonnes of CO_2 equivalent is expected, representing approximately 3% of annual emissions (2017). The opportunity to strategically reposition the auto industry, creating new scientific and technological capabilities and know-how, echoes China’s push to become a dominant force in global electric mobility, albeit on a much smaller scale.

Central premises of the legal framework:

- Create a policy that will promote design, research, innovation, development, production, marketing, reconversion and/or use of vehicles powered by sustainable energy sources, as wells as supply chains and auxiliary services.
- Promote the growing and sustained use of nationally produced vehicles powered by non-conventional power sources.
- Sets a target of 2041 by when no new ICE vehicles will be sold in Argentina.
- Establish a system of benefits for both demand and supply of vehicles, batteries, auto parts and charging infrastructure.
- Establishes a timeframe of 20 years, with decreasing benefits over time to accelerate investments.
- Creation a national agency for sustainable mobility focussed on R&D, scientific and technological development and specific objectives for promoting sustainable mobility and local production.
- Creation of a trust fund for sustainable mobility Trust Fund (FODEMS) to guarantee the availability and sustainability of financing the program over 20 years.

Amongst the benefits, the project talks job creation without specifying if these are new jobs. As we know, electric mobility must have an impact (possible reduction in employment), not only in the automotive industry but also in oil and gas, downstream commercialisation of fuels, the entire value chain of auto parts, service and maintenance. Other jobs in computing, software, and the service economy may emerge, but education and training programs will need to be in place to prepare for these changes.

Fuel Cell Vehicles is not a technology that will advance for light vehicles in the next few years, there are very few sales worldwide. It may develop in the next 20 years, but with the advances in battery technology and fast chargers, the main arguments for Hydrogen (autonomy and speed of "recharging") disappear. It could be a good alternative for heavy vehicles, where the weight of the battery matters much more but it will need hydrogen infrastructure on top of an electric charging infrastructure, in addition to hydrogen production and more electrical capacity to do so. It may be better for Argentina to focus on one new technology given the limited resources at its disposal.

2041 seems optimistic to achieve 100% EV sales. In the US, the goal for 2030 is 50%, but they have a head start of more than 10 years. Argentina is going to benefit from the development of global technologies, but it will need to accelerate rapidly to get there in 20 years. In the TCO Analysis below, we estimate that an electric car in Argentina would probably be competitive in total cost of operation only from 2030 and in purchase price in 2035, unless local production or tax incentives accelerate this trend.

Incentives have a very important role to kickstart the market, but they have to be sustainable in the long term. Resources need to be made available, particularly as adoption accelerates, or governments must adopt "bonus-malus" strategies that are neutral for the public purse. The problem is that incentivizing EVs and penalizing ICEs can impact the poorest in society in favour of the richest, at least at the beginning. Argentina's fragile fiscal position and currency controls and restrictions on imports will not make the transformation to electric mobility any easier, despite the best intentions.

8.3. Domestic Auto Market and EVs

The Argentine domestic auto market has suffered a substantial decline due in part to financial crisis as well as the global pandemic, declining 46% from 2018 to 2019 and a further 15% decline in 2020, followed by partial recovery of 7% in 2021. Traditionally the market has been heavily reliant on imported cars with over 60% of all cars and light commercial vehicles (LCV) imported in the last 10 years, almost 90% from Brazil. In 2021, for the first time since 2002, the number of nationally produced vehicles outsold imported vehicles.

Argentina has developed expertise in the manufacture of higher value LCVs and utility vehicles, such as the Toyota Hilux, Toyota SW4, VW Amarok and Ford Ranger. Of total sales in the domestic market, 30% are utility vehicles and Argentina produces over 70% of those vehicles. Argentina is also a significant exporter of cars and LCVs, regularly exporting over 55% of production (70% LCVs), around 66% to Brazil and another 14% to other neighbouring countries. The recovery in exports in 2021 to pre-pandemic levels meant that despite continued weakness in the domestic market, production of nationally produced vehicles almost recovered to volumes last seen in 2018.

The importance of Brazil as a source of imported vehicles and as a destination for nationally produced vehicles will likely continue for electric mobility.

The eradication or reduction of extra-zone import duties since 2017, initiated the electrified[169] vehicle market in Argentina (see Figure 80). Of 10,735 units sold in Argentina since 2010, 96% were sold in the last four years and 55% in 2021 alone.

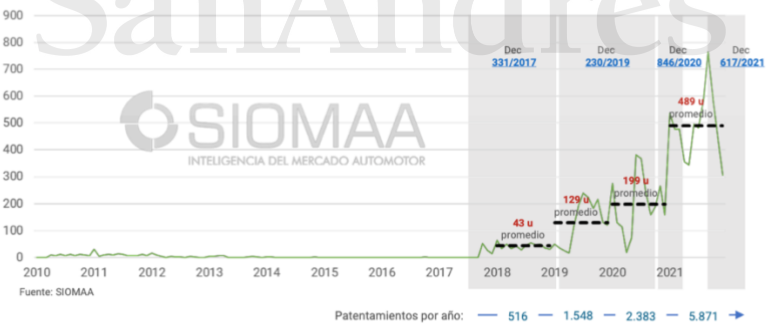


Figure 80: Registered sales of "Electrified Cars" in Argentina 2010-2021 (Source: SIOMAA)

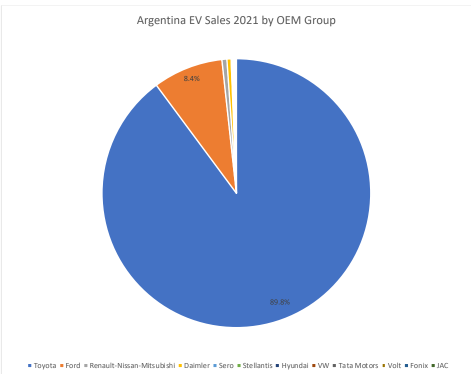
In 2020, 2,383 units were sold compared to 1,548 units in 2019. Toyota and its luxury brand Lexus are dominant with almost 90% of sales, 67% from the Toyota Corolla & Rav4. Ford is in second place with a 10% share. Sales of BEVs such as the Nissan Leaf (9 units) and Renault

[169] It is important to make the distinction between electrified cars, which include hybrid and mild hybrid vehicles as opposed to electric vehicles that are rechargeable from an external energy source.

Kangoo (35 units), or PHEVs such as MB GLC 350e (PHEV- 26 units) represent less than 1% of total electrified vehicle sales: 99% are hybrid or mild hybrid. (SIOMAA & ACARA, 2021b)

In 2021, 5,781 EVs and HEVs were sold in Argentina, an increase of 148% compared to 2020. Toyota continues to dominate with 88% of sales with the Corolla HEV the most popular model with 2,549 units (44%), followed by the Corolla Cross and Rav4 HEVs with 1,768 (31%) and 725 units (12.5%), respectively (see Figure 81). Ford is a very distant second with 495 units (8.4%) with its HEV models, the Kuga and Mondeo hybrid models. In third place is Lexus, also part of the Toyota group with 98 units (1.7%) across 5 different models. These three brands currently account for 98% of the market for electrified vehicles and electrified vehicles accounted for 1.8% of all cars sold in 2021. (*Informe Sobre La Movilida Eléctrica En Argentina*, 2022; “La Venta de Autos Híbridos y Eléctricos Alcanzó Un Nuevo Récord En Argentina,” 2022)

Model	OEM Group	Type	Units
Toyota COROLLA (hîbrido)	Toyota	HEV	2,549
Toyota COROLLA CROSS (hîbrido)	Toyota	HEV	1,768
Toyota RAV4 (hîbrido)	Toyota	HEV	725
Ford KUGA (hîbrido)	Ford	HEV	322
Ford MONDEO (hîbrido)	Ford	HEV	172
Toyota C-HR (hîbrido)	Toyota	HEV	120
Lexus NX (hîbrido)	Toyota	HEV	55
Mercedes Benz GLE 450 (hîbrido)	Daimler	HEV	26
Renault KANGOO (eléctrico)	Renault-Nissan-Mitsubishi	EV	25
Lexus RX (hîbrido)	Toyota	HEV	21
Lexus IS (hîbrido)	Toyota	HEV	19
Nissan LEAF (eléctrico)	Renault-Nissan-Mitsubishi	EV	10
Toyota CAMRY (hîbrido)	Toyota	HEV	9
DS DS7 CROSSBACK (hîbrido)	Stellantis	HEV	7
SERO CARGO BAJO (eléctrico)	Sero	EV	7
Hyundai IONIQ (hîbrido)	Hyundai	HEV	6
Toyota PRIUS (hîbrido)	Toyota	HEV	6
Audi E-TRON (eléctrico)	VW	EV	4
Land Rover EVOQUE (hîbrido)	Tata Motors	HEV	4
Mercedes Benz E53 (hîbrido)	Daimler	HEV	3
Lexus ES (hîbrido)	Toyota	HEV	2
Porsche TAYCAN (eléctrico)	VW	EV	2
SERO SEDAN (eléctrico)	Sero	EV	2
VOLT MOTORS W1 (eléctrico)	Volt	EV	2
Ford F-150 (hîbrido)	Ford	HEV	1
FONIX K5MS (eléctrico)	Fonix	EV	1
Lexus GS (hîbrido)	Toyota	HEV	1
SERO CARGO ALTO (eléctrico)	Sero	EV	1
VOLT MOTORS E1 (eléctrico)	Volt	EV	1
Audi A8 (hîbrido)	VW	HEV	
JAC IEV7S (eléctrico)	JAC	EV	
Lexus UX (hîbrido)	Toyota	HEV	
Mercedes Benz GLC 350 (hîbrido)	Daimler	HEV	
			5,871



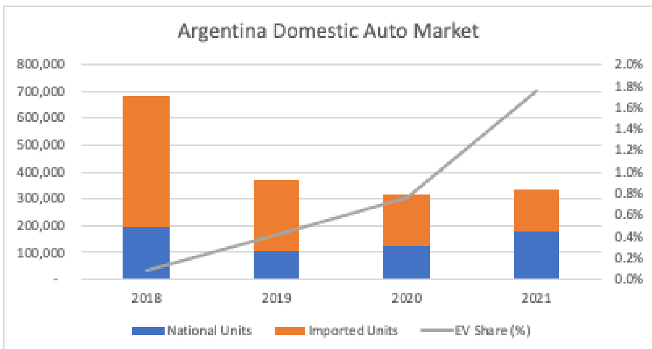


Figure 81: Argentina 2021 Electrified Vehicles sales by model and OEM group and Argentina Domestic Auto Market 2018-2021 (Source: own development from SIOMAA and ADEFA data)

Electric vehicles, which include, BEVs, PHEVs and FCEVs only sold 55 units with the Renault Kangoo ZE, a commercial van, selling 25 units, the Nissan Leaf and Sero Electric, each selling 10 units Audi e-tron 4 units and Volt Motors 3 units[170]. This represents less than 1% of electrified vehicles and as a share of the whole is negligible.

Hybrid cars may have a more significant role to play in Argentina certainly in a transitional mode, but they are not a long-term solution for mass adoption of electric mobility. Hybrids provide greater fuel efficiency than ICEs but tend to be more expensive because they carry both conventional power trains and electric power trains. The relatively small battery size means that they are unlikely to significantly benefit from reduced battery costs over time or from positive TCO benefits. Furthermore, they will have little impact on reducing emissions, since they continue to be driven by gasoline.

Given the negligible volume of BEVs, PHEVs or FCEVs sold in the Argentinean market thus far, it is arguable that the electric vehicle transformation has yet to start. There is much to do in development of infrastructure, consumer confidence, improvements to technology and regulation that impacts both the TCO and Purchase Price Parity. (SIOMAA & ACARA, 2021b)

8.4. Charging Infrastructure

Development of charging infrastructure in Argentina is still in its infancy, perhaps unsurprisingly as 99% of electrified vehicles sold in Argentina are Hybrids that do not require charging. Nevertheless, there is currently a network of 250 charging stations across Argentina with 15 distinct brands. In addition to private enterprise and concentration in Buenos Aires, other provinces such as San Luis, Neuquén and Santa Fe are inaugurating charging corridors within their territory. (Mañez Gomis et al., 2018; Máñez Gomis et al., 2019)

[170] Sero Electric, Volt Motors and Fonix are three new Argentinean enterprises building commercial utility vehicles and city cars. Also, electronics group Coradir of San Luis has developed a citicar, Tito, and a small utility pickup, Tita. Presales of 200 units are reported to have occurred with deliveries due in 2022.

Founded in 2017, Chargebox is the largest network in Argentina with 15 stations in CABA and Greater Buenos Aires already operating by 2019 and with 200 planned by the end of 2020 and 1500 in 10 years. The chargers are 22kW type 2 chargers and charge A$150 per hour using prepaid cards. In 2020 Chargebox Net and EV Box signed a contract to install and maintain 100 chargers (7.5kW to 22kW) in locations around Argentina for Carrefour. McDonalds intends to install 30 type 2 chargers, that allow a 20% charge in 40 minutes by 2023. Audi & Siemens intend to offer charging in their dealer network plus a home charging kit for the Audi E-tron, with 10 currently operative and 50 planned by the end of this year. (Máñez Gomis et al., 2019)

In 2017, YPF announced plans for 220 charge points to be placed in 110 service stations but so far has only two fast chargers (50kW) operative in Palermo, Buenos Aires[171]. EnelX is providing fast charging equipment (Juicebox) for deployment in Axion's service stations, each with three charging points. Currently five charging stations have been installed. Enel X also recently completed a charging corridor along the Pan American Highway from Ushuaia in Argentina to Mexico, covering 11 countries with 220 charging stations, of which Argentina has 62. The government of CABA has also installed two Enel chargers for a pilot programme to test the Renault Kangoo ZE in its fleet vehicles.

8.5. Tensions and Opportunities

It is the unenviable task of the government to manage and coordinate the advance of electric mobility, balancing the interests of diverse stakeholders both locally and regionally. The future of mobility increasingly involves services and connectivity, different commercial business models (D2C or e-stores on Mercado Libre), as well as electrification. OEMs will most likely take a regional approach to their core production strategies. Brazil and Argentina for example currently have different production models that complement each other: Brazil specialises in the production of small to medium sized affordable models, whilst Argentina specialises in

[171] Soon after the announcement EDESUR the Buenos Aires energy utility lodged a complaint with the regulator ENRE claiming exclusivity in distribution and commercialization of electrical energy. ENRE ruled that selling energy to EVs will be a non-regulated business permitting competition.

pick-up trucks, sport utility vehicles and light commercial vehicles. How will this translate into the world of electric mobility?

New opportunities will be balanced by new entrants across the ecosystem from energy generation and mining to mobility services[172]. Ridesharing, for example, has been in the Argentinean market for a while with the two main protagonists Uber and Cabify. Shared micromoblity has also seen development as a last mile solution with electric scooters joining bicycles in the city of Buenos Aires. Now carsharing joins the new mobility paradigm in Argentina with a number of players have recently joined the market. Kinto part of Toyota Mobility offers rental (days weeks) and carsharing (hours minutes) of Toyota models through its dealership network. Keego in partnership with Ford offers station based carsharing through a mobility app. New entrant Keko owned by RDA mobility and BINIT has recently invested USD 3 million for 150 vehicles in a station-based carsharing venture. Other new players include Awto and VoyenAuto.

Transformation across the region will be slow. Excess installed capacity and large sunk investments that have yet to be amortised create a barrier to further investment in regional EV production capacity, particularly without a proven market. Regulations and policies have been slow to develop, and consequently positive TCO benefits, and purchase price parity (see section below) are a long way on the horizon. Brazil has already made a large bet on Flex vehicles, for decarbonisation, that can run on ethanol or gasoline or a mix, with over 84% of light vehicles having a Flex motor. Ultimately the emissions from transport are less critical in the region than in more developed countries and therefore the benefits from decarbonisation of transport will be lower[173].

[172] We already see the vertical integration of OEMs such as Toyota and BMW involved in mining projects for Lithium or Oil & Gas companies, such as YPF or Pan American Energy expanding into renewable energy generation.

[173] According to the International Transport Forum only 15% of GHG emissions in Argentina come from the Transport sector and only around 5.6% from private vehicles. Agriculture, land use and energy generation emit over 70% (International Transport Forum, 2020). In Brazil, emissions from transport amount account for approximately 9%, according to the Energy and Environment Institute (IEMA). Again, land use and agriculture are by far greater problems (Barcellos, 2020). This compares to 29% in the US, according to the US Environmental Protection Agency and 25% in Europe, according to the European Environment Agency.

The new ecosystem of sustainable mobility involves multiple industrial sectors, including energy companies, oil & gas, mining, public transport, auto industry, technology, as well as the public sector. In order to advance the adoption of electric vehicles, public policy will need to address and balance the interests of each of these players.

Electrical energy companies will generally be promotors of electric mobility with increased demand for electrical energy, more efficient utilisation of capacity through off peak charging and a quasi-monopoly/oligopoly for generation and distribution. New investments in peak load, particularly from renewable sources will be required and they may face competition from new entrants in distribution and commercialisation or distributed generation of electricity from renewable sources. They will require a long-term strategy and transparency on tariffs, but the existing infrastructure should be able to absorb the additional capacity. New opportunities in charging infrastructure, energy storage, charging as a service (CaaS), battery as a service (BaaS) and smart grids will arise.

Companies in the Oil & Gas industry as we have seen at a global level recognise the need to transform themselves into energy companies, investing in renewable energy sources and the distribution and commercialisation of electrical energy. They tend to be largely neutral about electric mobility since these new opportunities detract from their core business, particularly in the downstream monopoly on fuel distribution and associated maintenance services. Sunk costs in fuel service stations that will eventually become obsolete are nevertheless strategically placed real estate assets that can be redeployed as charging stations. New opportunities in developing charging networks, CaaS and BaaS will offset medium term reduction in the demand for fuel. Great changes in business models are required pushed not only by public policy but global externalities. Whilst resistant to an accelerated rate of change they nevertheless recognise the inevitability of change and have the financial capacity to do so.

The mining industry will benefit from increased capacity, investments and exports, not only in Lithium but also copper and other metals. It is expected to be a strong supporter of electric mobility and there are opportunities for collaborating or vertical integration in energy storage.

The auto industry possibly faces the most disruption and is potentially more resistant to change although at a global level this resistance is changing to promotion. Several new opportunities arise for the Argentinean auto industry to reinvent itself, take on board new technologies and put itself at the centre of transformation in the region. In addition, vertical integration of supply chains from lithium mining and battery production to direct sales, connectivity, mobility services and charging infrastructure could create new pools of value for the auto industry in the medium term. In the short term, the auto industry and its supply chain face substantial disruption with obsolete production capacity and jobs (EVs require less parts and less employees)[174]. Long term public policy is a sine qua non for OEMs and their supply chains to determine their strategic plans for the region.

Public and private transport will continue to be resistant whilst new technology remains expensive. TCO benefits, in the absence of additional incentives, will occur within a few years for commercial vehicles but private transportation may take until the end of the decade before EVs are competitive with conventional vehicles and price parity only five years thereafter (see section on TCO analysis). Sunk costs in public transportation assets will make public transport reluctant to reinvest in high-cost electric mobility, despite future TCO benefits, in the absence of incentives and financial support. Demand will be driven by purchase price parity, TCO benefits and the availability of charging infrastructure. Opportunities in new mobility services will be available to transport operators.

Technology companies will be strong promoters of new mobility services, charging applications, connectivity & IOT, sharing and other associated services, either in collaboration or competition with other sectors.

Finally, the public sector will need to balance the positive factors against the negatives and determine the optimal rate of transformation. In the plus column are benefits to public health, the environment and meeting its international commitments on climate change. In addition, the possibility of creating a regional hub to produce EVs, batteries, chargers, IOT and

[174] In the auto industry supply chain, the production and export of gearboxes is under threat: VW in Cordoba and Scania in Tucuman.

associated IT services, would attract significant foreign direct investment to the country. In the negative column, the fiscal impact of increased demand for electricity (at subsidised tariffs) and reduced demand for fuels (highly taxed) could be significant in the medium to long term. Disruption in the labour markets is likely to cause political fallout with unions if jobs cannot be replaced, potentially with more highly skilled jobs. Failure to attract production capacity would require greater reliance on imports, with an associated deterioration in the balance of payments or a deceleration of the transformation towards electric mobility. Weak levels of foreign currency reserves, and consequent restrictions on imports, and a weak fiscal position will limit the Argentinean government's ability to accelerate the transformation. Nevertheless, the transformation is global and if Argentina is not to be left behind it must develop its long-term strategy now and determine how much and how quickly is desirable.

8.6. TCO Analysis

The importance of the initial cost of an EV to a conventional ICE to the rate of adoption has been amply demonstrated through the success of incentive programs, particularly in Europe and China. Total cost of operation, which considers purchase price, financing, servicing and maintenance, insurance and energy or fuel costs is also an important consideration, particularly for rational consumers or commercial users with higher-than-average mileage.

In this section, the evolving purchase price and operational costs were modelled for the Nissan Versa and its electric equivalent the Nissan Leaf, for the purposed of comparison in three markets Argentina, Chile and Colombia. The objective of the exercise is to estimate, that in the absence of incentives to accelerate adoption of electric vehicles when and at what rate is adoption likely to occur. Of course, other factors, such as consumer information and preferences or adequate charging infrastructure will also have a bearing but by isolating the cost factor an attempt is made to assess the scale of the challenge. For full details please refer to Appendix 4.

The first step is to estimate the evolving cost of the EV over time. Two main factors will drive down the costs of EVs over time, the battery cost and a reduction in indirect costs such as amortisation of research and development, as economies of scale reduce the cost per unit.

Based on information from Bloomberg New Energy Finance, IHS Markit, the UBS Evidence Lab Electric Car Teardown and specifications for the Nissan Leaf, the cost structure and cost reduction rate can be estimated. For example, battery costs per kWh are expected to reduce by an average 7.4% per annum to the end of 2030 and the battery cost for a Nissan Leaf represents approximately 20% of its total cost. According to the UBS study, indirect costs will fall from 30% per unit to 12% over an eight-year period. Applying these metrics to the initial cost of a Nissan Leaf in each market and applying a standard rate of inflation to the cost of a Nissan Versa in dollars, an estimated relative price evolution is constructed (see Figure 82)

		USD	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Argentina	Nissan Leaf EV	59,342	59,342	51,652	46,123	41,550	39,459	37,614	36,734	35,916	35,153	34,443	33,755	33,079	32,418	31,770	31,134
	Nissan Versa	23,705	23,705	24,298	24,905	25,528	26,166	26,820	27,491	28,178	28,882	29,604	30,345	31,103	31,881	32,678	33,495
Chile	Nissan Leaf EV	35,732	35,732	31,102	27,773	25,020	23,760	22,649	22,119	21,627	21,168	20,740	20,325	19,919	19,520	19,130	18,747
	Nissan Versa	14,946	14,946	15,319	15,702	16,095	16,497	16,910	17,333	17,766	18,210	18,665	19,132	19,610	20,100	20,603	21,118
Colombia	Nissan Leaf EV	36,883	36,883	32,103	28,667	25,825	24,525	23,378	22,831	22,323	21,849	21,408	20,980	20,560	20,149	19,746	19,351
	Nissan Versa	17,415	17,415	17,851	18,297	18,755	19,223	19,704	20,197	20,702	21,219	21,750	22,293	22,851	23,422	24,007	24,608
											Price Parity			Price Parity		Price Parity	

Figure 82: Projected cost comparison for Nissan Versa & Nissan Leaf to 2035 (Source: own development from multiple sources including BNEF, IHS Markit, UBS and others - see Appendix 4)

As a starting point the retail price of a Nissan Leaf in 2021 was 2.5x & 2.4x more expensive than a Nissan Versa in Argentina and Chile, respectively, and approximately 2.1x more expensive in Colombia, which in the absence of further incentives creates an estimated 5-year gap in reaching purchase price parity between Colombia and Argentina.

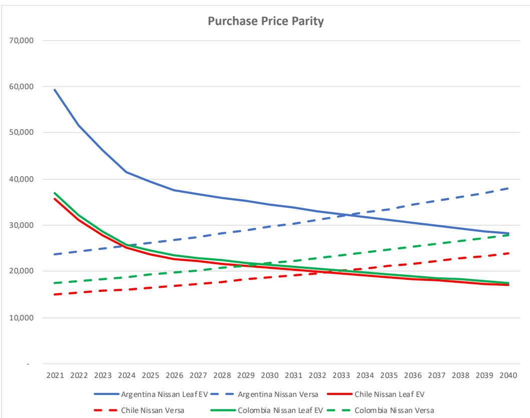
The second part of this analysis calculates the five-year running costs of the two cars in each market. By modelling finance costs and terms based on current market conditions, fuel/electricity consumption specifications for each car, projections for electricity tariffs, gasoline prices and interest rates provided by economic consultancy firm ABECEB, and estimates for service and maintenance costs and insurance, the relative cost of owning the Nissan Leaf can be compared to the Nissan Versa. This analysis evolves over time as purchase costs for the EV reduce relative to the ICE and varies significantly for the average annual km travelled (see Figure 83).

Annual Km	TCO COMPARISON											
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
2,500	2.2154	1.8928	1.6627	1.4764	1.3780	1.2910	1.2373	1.1873	1.1404	1.0965	1.0545	1.0141
5,000	2.1774	1.8594	1.6325	1.4494	1.3524	1.2671	1.2144	1.1656	1.1198	1.0768	1.0357	0.9961
7,500	2.1408	1.8272	1.6035	1.4234	1.3279	1.2440	1.1924	1.1447	1.0999	1.0578	1.0176	0.9789
10,000	2.1054	1.7962	1.5756	1.3983	1.3043	1.2218	1.1713	1.1246	1.0807	1.0396	1.0001	0.9622
12,500	2.0712	1.7662	1.5486	1.3742	1.2815	1.2005	1.1509	1.1052	1.0623	1.0220	0.9833	0.9462
15,000	2.0382	1.7373	1.5227	1.3509	1.2596	1.1799	1.1312	1.0865	1.0445	1.0050	0.9671	0.9307
17,500	2.0062	1.7093	1.4976	1.3285	1.2385	1.1601	1.1123	1.0685	1.0273	0.9887	0.9515	0.9158
20,000	1.9753	1.6823	1.4733	1.3068	1.2181	1.1410	1.0940	1.0511	1.0108	0.9728	0.9364	0.9014
22,500	1.9453	1.6562	1.4499	1.2859	1.1984	1.1225	1.0764	1.0344	0.9948	0.9576	0.9218	0.8874
25,000	1.9163	1.6309	1.4273	1.2657	1.1794	1.1047	1.0594	1.0181	0.9793	0.9428	0.9077	0.8740
27,500	1.8881	1.6064	1.4054	1.2461	1.1610	1.0874	1.0429	1.0025	0.9644	0.9286	0.8941	0.8609
30,000	1.8608	1.5826	1.3842	1.2272	1.1432	1.0708	1.0270	0.9873	0.9499	0.9148	0.8809	0.8483
	-16.00%	-16.39%	-16.75%	-16.88%	-17.04%	-17.06%	-17.00%	-16.85%	-16.71%	-16.58%	-16.46%	-16.35%

Figure 83: Evolution of the relative TCO for the Nissan Leaf & Nissan Versa in Argentina to 2032 (Source: own development from multiple sources - see Appendix 4)

In Argentina, the 5-year cost of owning the Nissan Leaf in 2021 is approximately 2x that of the Nissan Versa. The cheaper operating[175] and energy costs for the EV are unable to overcome the much higher purchase price. As the relative purchase price reduces over time the EV TCO is more competitive and by 2031 is cheaper than the ICE at the average annual driving distance of 12,500. An important observation is that for high mileage users, such as government or company vehicle fleets of light commercial delivery vehicles this "tipping point" will come much earlier. For example, at 30,000 km per year the EV is cheaper to operate a full five years earlier.

The results of this analysis are summarised in the Figure 84 below. The first illustrates the relative costs of the EV and ICE and the point at which they cross. The second adds the TCO analysis for each market.



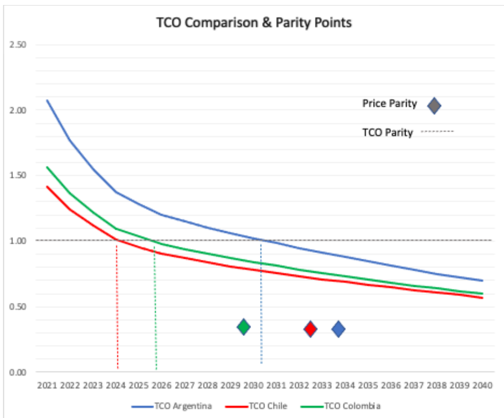


Figure 84: Purchase Price & TCO Parity in Argentina, Chile & Colombia (Source: own development from multiple sources - see Appendix 4)

[175] The numbers in the table are the relative cost of the EV compared to the ICE. A number greater than 1 denotes that the five-year cost of the Nissan Leaf is more expensive than the Nissan Versa. A number less than 1 denotes the EV is cheaper.

Argentina: The high cost of the EV and the relative high cost compared to the ICE means that purchase price parity, in the absence of government intervention/subsidies, is unlikely to be achieved before the middle of the next decade, almost a full 10 years behind the equivalent moment for the more advanced economies. The relatively high difference between the cost of gasoline and electricity per km travelled in Argentina (5x) is not enough to offset the high purchase price differential and cost of financing. TCO parity is only expected to occur a few years earlier in 10 years from now. As a result, it is likely we will see only minimal adoption of EVs in Argentina before the end of this decade without additional incentives, following which we could see adoption at an increasing pace through to 2040. *The elimination of 21% VAT on EVs, as indicated in the sustainable mobility legal project, according to the model brings forward both purchase price parity and TCO parity by five years. For high mileage users TCO parity could be reached in only 3 years-time.*

Chile: The lowest nominal EV purchase price is offset by an even lower ICE price, which means that, like Argentina, price parity is only achieved midway through the next decade. Although the relative difference between gasoline and electricity prices per km at 3x is not as great as in Argentina, the far lower starting purchase price and lower finance costs means the relative weight of running costs in total costs is double. Coupled with a much higher average annual distance travelled per car, it is expected that Chile will reach TCO parity in only a few years. As a result, we can expect to see adoption of EVs to begin relatively soon and progress gradually over the next 10 years when they should begin to rapidly accelerate once purchase price parity is achieved.

Colombia: A similar initial cost of the EV as in Chile together with a lower relative difference with the ICE means that purchase price parity could be achieved by the end of the decade, only a few years after more advanced countries. The relative difference between gasoline prices and electricity is the lowest (less than 2x), which slows the achievement of TCO parity to one two years after Chile, despite a similarly high average distance travelled per annum and reaching purchase price parity much sooner. As a result, we can expect to see a lengthier delay in the start to adoption of EVs in Colombia but with a much sharper acceleration than either Argentina or Chile as price parity approaches.

8.7. Panel of Experts

According to Dr Susana Finquelvich, "smart cities are cities that worry about their citizens" and mobility is a significant part of this discussion. Pre-pandemic, this means less cars and more public transport or other forms of mobility, prioritising pedestrians and micromobility and giving cities back to their residents not their cars. It means more local neighbourhoods, more pedestrianised areas and redesigning cities to reduce the need for mobility. The "supermanzana" originating in Barcelona[176], the concept of 15-minute cities, originating in France or Amsterdam's doughnut are European examples of this trend. The strategic problem is how do you adapt a super metropolis, such as Mexico City, São Paulo or Buenos Aires to a15 minute city? According to Dr Finquelvich there needs to be a national political and economic strategy that values smaller cities and prevents migration. The vision needs to be territorial not just urban.

The challenge is great, requiring intelligent territorial planning, stimulating smaller cities through production and innovation. Creation of centres of excellence and specialised populations, for example Information and Communications Technology (ICT) hubs in places like Tandil, Bahia Blanca, Mendoza and San Luis.

In urban transport, new forms of mobility particularly platforms, such as ride hailing or car sharing (but not pooled) have developed successfully until the pandemic slowed their progress in Argentina, along with reduced use of public transport. Private cars are still heavily favoured, together with travel on foot and micromobility where travel distances permit. The coexistence of pedestrian areas and the surge of micromobility is complex and potentially dangerous if not properly managed. The development of modern urban transport needs to answer the question who do we favour? The pedestrian, the bicycle, public transport, the private car or other forms of mobility? The pandemic has complicated the issue, at least in the short term.

In order to transform urban transport into more sustainable form, there needs to be political, social and cultural impulse against the use of private automobiles, rather than just a

[176] There are heavy anti-car restrictions with pedestrians and bicycles or other micromobility prioritised. Cars are either excluded from certain areas or limited to a velocity of 10 km/h. Green areas have been increased by 91%.

transformation in the energy source (ICEs to EVs). For Dr Finquelvich it is a question of marketing. The private car, in many parts for the world is seen as a status symbol. If bicycles became seen as a status symbol (or better an expression of social consciousness), then this would provoke cultural change. In this way marketing can influence culture: it is not always the utility or functionality of the product that matters but the perception of its usefulness. It is easier to influence perception than convince based on functionality, convenience, environment or urbanism. The implications of transforming mobility into more sustainable forms means fewer private cars and if that happens in Argentina's cities that means that the impulse for electrification will be driven by commercial application of vehicles in last mile delivery or new mobility companies in ridehailing and car sharing.

The transformation towards a new energy source for mobility, such as the move away from hydrocarbons to electricity, will be influenced by geopolitical tensions at the global level. According to Dr Sebastian Cortez, the oil and gas industry still has a significant part to play, particularly in the developing world where oil and gas exports are a significant part of the economy. OEMs are still developing their catalogue of new energy vehicles, and have a considerable sunk investment in old technology, companies such as Tesla are in their infancy and relatively minor in terms of production. Outside of Europe and China, direct promotion of EVs is currently weak and oil prices continue to be cheap, reducing the operational cost benefits of EVs.

Rather than the advance of technology, Dr Cortez suggests that geopolitics, especially in China and the US, will determine the tipping point for adoption of EVs. A tipping point globally has not been reached and will only be achieved once OPEC decides to put its resources into Lithium production, rather than petroleum. The pandemic has exacerbated the low price of oil, briefly turning negative in 2020, and it is unlikely to recover significantly over the next few years.

Access to EVs, even in the developed world is much more expensive than an equivalent conventional vehicle and whilst electric motors are much more energy efficient, great advances in the efficiency of ICEs have been made and are continuing, particularly with the advent of hybrids and mild hybrids. Dr Cortez believes that hybrids and CNG[177] vehicles that have far

[177] CNG – Compressed Natural Gas.

lower emissions than conventional vehicles will be important as an intermediate step in the transition.

The geopolitical discussion and decision are particularly important in countries such as Argentina who have no sovereignty over the technology. Dr Cortez argues that even though as mass demand appears costs are lowered through the learning curve, EVs are not economic yet, otherwise they would already be produced at scale. The technology is available, but a decision must be made globally, regionally and at country level to make the transition.

In the urban context decentralisation and recovery of urban spaces with cities transformed into small self-contained capsules (15-minute cities), with a tendency for greater density will reduce the need for mass urban transport or private cars and increase the importance of platforms and new forms of mobility. As opportunities for employment, residence and leisure are more localised. The need to travel great distances reduces. Teleworking as a phenomenon accelerated during the pandemic and is likely to continue, at least in partial form, as companies see opportunity to reduce their cost structures disposing of underutilised corporate offices. The identity of a corporation as a building is transformed into "bits".

Post pandemic most countries will be 20% poorer – Argentina's GDP is at a level it was 20 years ago – and private vehicles are an unnecessary cost. The fleet of private vehicles could reduce significantly. The pandemic has made people used to reduced mobility and not using their cars. With less movement and shorter distances, collective ownership, through carsharing platforms becomes a more attractive alternative if ubiquitous. The political movement for vehicles to become more sustainable through electrification, despite EVs also having a significant carbon footprint in production, will likely develop more rapidly in these new mobility services and movement of goods, particularly in the last mile.

The territorial logic needs to be understood in the context of countries such as Argentina for widespread adoption of EVs. The scale is very different in comparison to Holland or the Nordic countries. Dr Cortez cites the case of the development of YPF service stations together with the Automobile Club Argentina (ACA) in the 1930s as an example of how to implement a change in the energy matrix. Not only was this an energy policy to transform from horses and steam powered transport to roads and petrol consumption, but also an urban policy, transforming the national territory into a network of nodes or small dwellings spread across the country providing fuel, food and other services, giving rise to small dwellings and eventually productive centres and larger towns. This is like the transformation in the US but with greater depth and territorial scale.

Dr Cortez sees "technology as a consequence of a social position or social structure", arguing that whilst technology does sometimes provide disruption and provoke social change, for example the internet, often technology develops because of social change. The development of automobiles and ICEs over other forms of technology, including EVs in the early 20th century was the result of political, social and territorial strategy. At the global level geopolitics continues to be the main driver for or against electrification of mobility and renewable energy sources. These cultural, social and political tensions are often behind a new technology falling into a vacuum rather than being implemented, despite its fundamental utility or characteristics.

In the development of EVs, only in Europe is the environment and carbon footprint the principal driver for adoption, and the leading country, Norway, has a conflict with its oil producing status, a disassociation with its leading economic actions. The US support is regional and very dependent upon politics, whilst China has chosen its path for global strategic regions, to produce a leading new energy automotive industry but also by the scale of necessity to diversify energy sources. For Dr Cortez, "one model of mobility will not replace another but there will be coexistence" of electromobility, hydrocarbons and other sources, such as hydrogen.

Connected vehicles are imminent and inevitable and could provide an impulse for electric vehicles given design and electrical architecture constraints. They will also provide an impulse for mobility platforms as a value structure but there is an urgent requirement to develop 5G communications for connectivity and later autonomous vehicles. Dr Cortez believes that accelerated advancement of telecommunications will occur much more quickly than electromobility, with the pandemic already providing a catalyst for the consumption of data. "It is much easier to digitalise" than to electrify". Massive adoption of electric vehicles will not occur for a significant period in Latin America, Africa and smaller Asian countries for many years. Mobility services, including delivery services will be at the vanguard[178]. Lithium production could be a geopolitical driver for Argentina but the coup against Evo Morales in Bolivia shows how plans to industrialise processing and upskill technology knowhow, if not responsible for political tension, can be used as a weapon by political opponents.

Maximiliano Scarlan is very clear that the path to electromobility is inevitable globally with the climate change agenda ostensibly driving politics in more advanced countries. Adoption of EVs globally, however will be at very different rhythms, with Europe and China continuing to forge ahead, whilst the rest of the world lags. In contrast to Dr Cortez, Mr. Scarlan believes that at the global level the technology is very close to being economically accessible due to falling battery prices and that purchase price parity will be achieved within the next few years, even in the absence of direct incentives and tax relief. The largest auto markets are at a tipping point and the acceleration of adoption will be exponential.

Argentina on the other hand has barely started the transformation. The cost of access is prohibitively high, there are significant barriers to imports, including quotas, import duties[179], budget constraints & currency controls, low per capita levels of income, lack of local production for EVs and very slow progress in policy support. All this combined is likely to significantly reduce the rate of progress.

Andrés Civetta agrees that adoption of electromobility is inevitable, driven by increased environmental awareness amongst governments and consumers alike, and that the rate of adoption will be uneven across different regions. Local production capacity and the accelerated participation of clean energy in the energy matrix will be important if the full benefits of electrification are to be achieved. Mr. Civetta argues that Argentina is at least 10 years behind more advanced countries with significant investments required in infrastructure, roads, energy and lowering the cost of vehicles to permit local accessibility. Meanwhile Argentina's important auto industry is significantly invested modern production facilities for conventional

[178] As an advisor to Argentinean EV manufacturer, Volt, Dr Cortez relates that the homologation process with INTI took more than 3 years to complete. Political tension caused by lobbying from Fiat and Renault in Cordoba was at least partially responsible for the delay.
[179] The reduction of extra-zone (outside of Mercosur) import duties in Argentina from 35% to between 0% and 5% applies to a limited quota of vehicles and given budget constraints and currency controls cannot be relied upon to continue indefinitely.

vehicles, as it is in Brazil, investments that need time and production volume to amortise. Lobbying from the auto industry as well as the alcohol & sugar industry in Brazil is likely to seek to extend the life of these assets. Chile on the other hand has no such industrial constraints and can advance more quickly.

Mr. Scarlan concurs, that even within the region there is likely to be a two-scale velocity to adoption, with auto producing countries such as Argentina, Brazil and Mexico delaying development of EVs and the Andean countries, much more open to foreign trade and more advanced in their culture of sustainability, able to accelerate more easily.

New mobility models, regulations and vehicle restrictions in urban centres, and a change of habits enforced by the pandemic in teleworking and ecommerce have accelerated the ACES trends globally and in Argentina, albeit still very niche. Whilst autonomous vehicles are still some way off[180] and shared mobility has slowed (but will recover) growth in electrification and connectivity (generally not just in vehicles) is growing exponentially. The pandemic has brought about a significant change in our need to be mobile, potentially increasing the cultural, social and economic arguments for multimodal mobility through apps and platforms – "buy less use more". Generational change and the diminishing desire for car ownership as a status symbol is also likely to have an impact. A good offer of services will be crucial to foster convenience and reliability. Importantly, Mr. Civetta notes that in Argentina car ownership is not just a status symbol but also a reserve of value, an asset that doesn't depreciate in a high inflationary scenario. This is also the case in Brazil and could help to sustain car ownership in the region. Like Dr Cortez´s view the most sustainable vehicle is no vehicle at all and as these new mobility services become ubiquitous, we could see less cars but with more of them electric. The balance between commercial ownership for cars and private ownership will likely change.

According to Mr Scarlan and Mr. Civetta, Argentina is at least 5 years behind before any meaningful adoption of electric vehicles will occur[181] and at least 7 years behind in the

[180] In China, Didi mobility services are already starting to use autonomous vehicles.
[181] Virtually all the "electrified" vehicles to date are hybrid vehicles and only in very small quantities due to reduced extra-zone import duties but with limited quotas. Meaningful adoption of EVs will only occur once production is localised, or incentives are broader. Of the large car manufacturers, only Toyota so far has announced plans to produce locally its Hilux hybrid by 2025. If the political and corporate strategy is to import, adoption will take significantly longer.

development of charging infrastructure. The cultural change for more sustainable transport is already occurring as we have seen in the rapid adoption of micromobility, accelerated by the pandemic. In Argentina, however, price sensitivity and the lack of charging infrastructure remain major barriers to the adoption of electric vehicles. Nevertheless, commercial application of EVs will advance more quickly since for delivery companies and mobility fleets the economic logic will appear sooner[182], as well as corporate image for companies concerned with the "triple bottom line".[183]

Globally the auto industry is undergoing a digital revolution as tech companies, particularly in China and Korea, turn to the manufacture of vehicles. Auto companies will have to collaborate and or change their business models to compete. The implications for traditional auto companies in Argentina and Brazil is that, despite their potential inclination towards delaying the progression of electrification in the region, sooner or later they run the risk of losing their dominance and allowing new competitors to appear.

Both Mr. Scarlan and Mr. Civetta agree that electrification will be the dominant technology for mobility in the future. CNG and hydrogen powered vehicles (FCEV) may have their place, particularly considering Argentina's large reserves of natural gas, in heavier transport of passengers and goods. Conversion of Argentina's bus fleet, which today is 100% diesel except for a few pilot programs of electric buses operating in certain cities, is an enormous challenge. Operating costs may be lower, but the upfront investment is too high (more than three times the investment for a conventional bus). The public transport system is in crisis, with only 60% capacity utilised, and unsustainable[184]. Heavily subsidised, approximately 90% of the operating companies' income comes from public funds. To transform this sector, either the government needs to finance the investment, or the subsidy structure needs to be changed[185]. The transformation to electric mobility will most likely be bottom up, with municipal

[182] The TCO for an EV compared to a conventional ICE vehicle improves significantly with the greater average distance travelled because of the differential in fuel/energy, service and maintenance costs.
[183] Mercado Libre is already beginning to use electric utility vehicles for its deliveries in the region.
[184] Heavily subsidised tariffs lower the average cost of a trip to approximately 20 cents (USD) at the official exchange rate.
[185] In Argentina the bus fleets are owned by the transport operating companies who will be reluctant to make such a heavy investment without financial aid or a significant change to their earnings. In Chile, for example the bus fleets are owned by the government and pays private companies to operate them. Here it is much easier to transition.

governments taking the initiative before federal government. Mercedes Benz and Agrale in a joint venture with UK company Equipmake are already developing electric bus chassis in the region. "The technology is here; the problem is economic".

There is an element of cultural change to the adoption of electric vehicles, but economic factors dominate. Building sustainable charging infrastructure across the Argentina's extensive territory, for owners of private vehicles is a huge challenge. Who will subsidise charging assets that for large periods could go underutilised? This reinforces the view that initially the transformation is likely to be urban and driven by commercial fleets in Argentina. For Messrs Scarlan and Civetta, the tipping point for Argentina is someway off between 2035 and 2040 and very dependent upon infrastructure development.

Gaston Turturro observes that globally the electrification of vehicles has already begun, is accelerating and will accelerate further. Globally the key drivers have been the deployment of subsidies and incentives and increasing competitiveness through an exponential reduction in battery costs, and increasingly costs of scale. In countries such as China and in Europe demand is currently much greater than supply, hence long waiting times for delivery (exacerbated by the microchip shortage). Whilst TCO costs are increasingly more competitive, the up-front cost is still an important barrier, even for commercial fleets and especially in Argentina. With a USD 40,000 to USD 50,000 purchase price for even the most basic of EV models in Argentina, the TCO advantage is difficult to achieve.

"The advance of shared mobility and eventually connected and autonomous vehicles are the pillars to the future mobility paradigm, with electrification as the energy source". There is a need to shift consumer mentality from its comfort zone in the status quo to these new forms of mobility. Infrastructure is vital and not just for electric chargers but also natural gas and hydrogen infrastructure, which will also have their part to play particularly in long distance heavy transport of passengers and goods. Mr. Turturro argues that there will be strong dependence on electric mobility, particularly in urban centres but with a mix of other technologies that will co-exist. Argentina is at least 5 years away from meaningful adoption or mass consumption of electric vehicles with Argentina's legal framework project expected to be ready by the end of this year. Key drivers will be the development of local production of vehicles and upscaling of the value chain, particularly in lithium production, processing and battery production. Potential barriers could be a lack of financing for incentives and tax relief, the rhythm of industrial planning and supportive legislation.

9. Conclusions

The objective of this study was to describe and understand the advance in the adoption of private electric mobility and determine whether globally or in certain leading markets a tipping point is being reached. With an understanding of the key drivers and obstacles facing EV adoption in leading markets this knowledge could then be applied to the case in Argentina to estimate the implications for adoption in this country and provide policy recommendations to accelerate diffusion.

The study begins with a thorough review of the theoretical framework applied to the diffusion of technology and more specifically theories that are applicable to the adoption of Electric Vehicles, such as how learning curves have rapidly accelerated a reduction in battery costs over the last 10 years. It is also important to understand the diffusion of electric mobility within the context of trends in modern urbanism and sustainable transportation, which forms and integral part of this theoretical framework. Diffusion of technology does not happen in isolation but is dependent upon and influenced by the environment in which diffusion occurs.

The study goes on to develop an understanding of the global market for private vehicles, defining what electric mobility is and how it has developed, identifying key markets for both electric mobility and conventional vehicle production. The response of the auto industry and disruptive new entrants are analysed to identify the key trends and the rate at which new investments are being deployed.

Based on an online survey[186] of 150 respondents, the author is guided towards the key motivating factors and concerns of consumers towards a switch to electric mobility. Investigation of broader consumer surveys by professional third parties serve to define the core enablers and barriers into four main categories: Consumer Behaviour & Preferences, Economic & Industry, Technology and Infrastructure and Regulatory Framework & Public Policy. The study undertakes a descriptive analysis of key developments in each category for

[186] As detailed in the body of the study, the breadth and depth of the study only serves to be exploratory and not representative of the motivations and concerns of consumers towards electric mobility.

leading EV markets and attempts to determine whether these trends are supportive of or detract from EV adoption.

A quantitative and qualitative analysis of the development of the global EV market and a focus on the leading markets, particularly in the last few years, intends to confirm the key drivers that have accelerated the market and a consideration of the consensus for future development of the market and its implications. Other technological trends in mobility and their potential impact upon electrification are considered and discussed.

The study considers the case for Argentina, how the market has developed, what challenges or opportunities the region faces, the state of public policy and particular tensions in the local market that need to be overcome. The study culminates in a proprietary model to estimate the point of purchase price parity or TCO[187] parity between a medium sized EV and its equivalent conventional gasoline-powered vehicle, with comparisons in Colombia and Chile. The output of this model and through interviews with a panel of experts, the key challenges and an estimate of Argentina's state of advancement is determined. Finally, recommendations and key areas of focus for public policy are made.

The hypothesis or guiding statement of this study proposed, pre-pandemic in 2019, that a tipping point for adoption of electric vehicles had not yet been reached. In China, Europe and North America a tipping point would occur within the next 5 to 10 years but elsewhere particularly in Latin America the tipping point was at least 20 years away. In addition, new models of mobility would develop in the medium to long term but would not have any immediate impact upon the private ownership of vehicles globally.

The author believes that the balance of evidence and consensus from experts partially proves this hypothesis or statement to be true. In Europe and China, the tipping point already appears to have been reached and should be sustained through strong public policy support and the buy-in of the whole ecosystem from energy companies, supply chains, auto manufacturers, auto manufacturers, technology companies and of course consumers. Europe's policy development is concerned predominantly with emissions reductions and environmental impact and whilst

[187] 5-year Total Cost of Operation.

China's concern for air quality in its cities is a strong driver, the strategic objective to create a globally competitive new energy auto industry has been at the forefront of the latter's thinking. Both regions have boosted EV adoption through strong supply-side and demand-side incentives, penalties and looming bans of conventional ICE vehicles.

Elsewhere, including in North America, the situation is bleaker. Third placed market, the US, is far behind Europe and China along the adoption curve. California, arguably the birthplace of this modern electric revolution and home to the largest EV manufacturer and most valuable auto manufacturer, is not far behind China and close to a tipping point but other than a few west and east coast states that have followed California's lead, the US has yet to embrace electric mobility. Elsewhere, apart from parts of Asia, notably South Korea and to some extent Japan, the journey has yet to begin.

Nevertheless, the signs are encouraging in the US and elsewhere that governments are starting to recognise the inevitability of electric mobility, developing public policy and planning for an electric future. The importance of China and Europe's lead in accelerating the transformation cannot be understated. Together they represent 50% of the global auto market and approximately 90% of the EV market. Continued acceleration in these markets will continue to drive down battery costs and other economies of scale, which will be of benefit to countries who start their electrification journey further into the future. If the US are to get serious about the adoption of EVs, as the current administration indicate, they have the capacity to effect rapid change and catch up with the two leaders.

As EVs have improved, not only reduced in price, but with better performance, greater range and charging speed, they have become more ubiquitous, this in turn has provided the consumer with much more confidence in this technology. It is notable that environmental concern, undoubtedly enhanced by the pandemic and notable air quality changes, appears now to be one of the primary motivators for switching to an EV, whereas previously price, range and availability of infrastructure would have been of primary concern.

Direct purchase subsidies, tax relief or penalties on conventional vehicles have reduce the price differential, and consensus believes that purchase price parity without support is only a few years away. Advancements in battery technology have improved range and cost. Investments in publicly available infrastructure have largely kept pace with EV adoption. Innovative consumers in the two leading markets have now given way to the early majority and the rational consumer, as running costs for EVs are already better than conventional vehicles.

Nevertheless, major challenges and obstacles still exist. That China and Europe are already breaching a 20% market share is a significant achievement in just 10 years, still 80% of vehicles sold are conventional ICEs. Even once sales reach 100% in the next 10 years, it will likely take a further 10 to 15 years to convert the entire fleet of vehicles. To sustain the transformation, substantial investments will need to continue to develop the "whole product" from charging infrastructure or battery swaps to service, maintenance, vehicle choice, connectivity and ultimately autonomous vehicles. Employment of smart chargers, V2G technology and distributed generation will eventually be needed to manage peak loads on the electricity grid. Will a looming bottleneck for mining resources slow the accelerated ramp up of battery production capacity or create global asymmetries, as a shortage of semiconductors has done, as cars and mobile technology compete for resources?

The required increases in production capacity across the supply chain from mining to charging equipment appears to be staggering and is leading to more collaboration and vertical integration than we have seen before in and across the auto industry. Industry lines and business models are becoming more blurred as companies in Mining, Oil & Gas, Electricity Generation, Auto Manufacture, Technology and new ventures all compete in the same space.

Modern urbanism and new models for sustainable mobility also potentially threaten the private car and could slow the transformation. Consensus is that smart cities will reclaim themselves from the dominance of cars and give them back to their residents by redesignating space for cycling, pedestrians and public transport. Creation of local, lively diverse urban areas that reduce the need for mobility for work or leisure is a popular concept and is being adopted in several European cities but in the mass urban sprawl of Latin American cities this is more challenging. Public transport is not always an efficient alternative to the private car, and it is not always possible to live close to work. The pandemic has of course significantly reduced the need for mobility, but also increased preference for private vehicles. Whether teleworking becomes a permanent or semi-permanent change remains to be seen.

New models of mobility, including ridesharing, ride hailing and carsharing prior to the pandemic were swiftly gaining traction in cities across the globe. Truly sustainable transportation will integrate existing public transport with new mobility services, including autonomous, shared and connected vehicles, seamlessly integrated. The benefits of autonomous and shared (pooled) vehicles are numerous: fewer accidents, greater road capacity, reduction in land use designated for parking, more efficient asset use. Electrification adds more efficient energy use, lower running costs and of course significant reductions in emissions and noise pollution, particularly when paired with renewable energy sources.

It seems broad adoption of fully autonomous (level 5) vehicles is likely decades away, although we are already seeing significant advances, notably in China. The full benefits of autonomous mobility will only be realised once all or most vehicles are autonomous. Autonomous vehicles will necessarily be connected (V2X) and inevitably electric, not only for electronic architecture and design but because these vehicles, if shared, their much higher use vastly improves the economics (TCO).

Shared mobility, both in the sense of a shared asset and a shared ride, suffered a setback during the pandemic (except shared micromobility) as safety and hygiene became of paramount importance. It is expected that shared mobility will recover and whilst still niche has the potential, particularly in Latin America, to accelerate much more quickly than electrification. As the offer increases and seamlessly integrates into mobility as a service platforms and costs reduce, the balance between private vehicles and fleet vehicles may shift, further enabling electrification, which will be much more efficient for fleet vehicles. The challenge of a cultural shift away from private vehicle ownership cannot be underestimated, particularly in countries where car ownership acts as a store if value. A transitional period where individuals use MaaS applications in urban centres but still own a private vehicle (electric or hybrid) for leisure would be a significant step forward.

The consensus of the panel of experts and the literature review is that Argentina is still at the beginning of its electric mobility transformation and most likely 10 years away from any significant advance. The author's own contention is that without further incentives, the tipping point for Argentina will not come before 2034, particularly if there is a failure to attract investment for local production. Geopolitics may still have a significant role to play particularly in oil producing countries such as Brazil and Argentina.

Whilst restrictions on foreign currency reserves, and fiscal constraints may limit the speed of transformation in Argentina it is not without weapons in its armoury. Finance and investment are important in initiating the adoption of electric mobility, but the journey must start with a strong policy that actively encourages collaboration of all the stakeholders in the transformation. Increasing tax relief, for example eliminating VAT, on vehicles, in addition to the continued reduction of import duties in the short term, could bring the tipping point forward by up to 5 years. A focus on fleet owned vehicles, companies and governments, mobility services and last mile deliveries, could bring the tipping point to just a few years away.

Argentina will likely compete with Brazil to become a regional hub for electric vehicles with the disadvantage that its domestic market is significantly smaller by comparison, barely large enough to justify a single battery production facility. Argentina has achieved specialisation in the manufacture of higher value utility vehicles and pick-ups, with significant exports to its neighbours.

Argentina will need to find a similar niche in electric mobility. Fleet vehicle owners will see the economic benefits of electrification sooner than private individuals and tend to be more rational consumers. Direct incentives and tax relief on new energy vehicles can be paid for by incremental taxes on conventional diesel and gasoline-powered vehicles, to limit the impact on the public purse, as has occurred in Norway and France. These incremental penalties will have an insignificant impact on the consumer in the early days of EV adoption. Limited currency reserves mean Argentina will be unable to or would be unwise to drive this transformation through imports alone. Stimulation of local production is paramount both through collaboration with incumbent OEMs, implementing a system of gradually increasing quotas for local production of EVs but also stimulating new companies such as Volt, Sero Electric and

Tito[188] that are already pioneering the production of small, economical citicars and utility vehicles for deliveries and commercial use, very similar to the development of EVs in China.

Argentina, by creatively using the experience and lessons from China and Europe, can embrace the electric mobility transformation even with the limited resources at its disposal. If it delays or hesitates, however, it may run the risk of presiding over an obsolete industry that slowly declines over time. It is of paramount importance that Argentina begins its journey now and that starts with public policy.

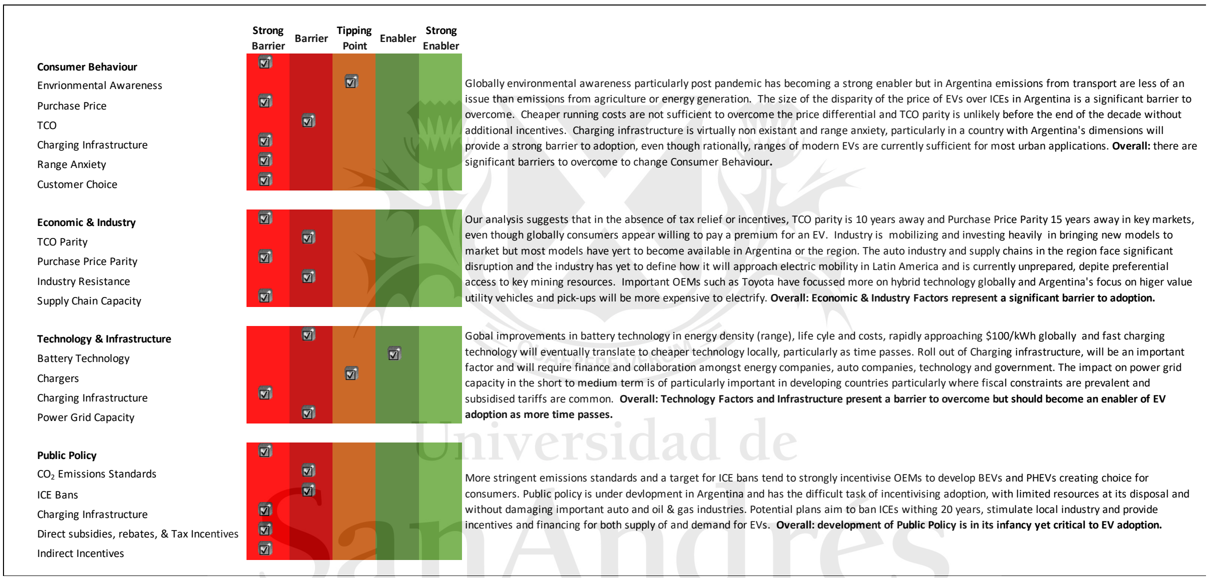


Figure 85: Summary of Barriers & Enablers for EV Adoption Argentina (Source: own development)

Figure 85 demonstrates the scale of the challenge for the diffusion of electric mobility in Argentina with an assessment that most factors still present strong barriers to be overcome. The author contends that even with limited resources, Argentina can advance electric mobility in the country but that perhaps rather than trying to achieve national scale transformation should focus on key urban centres where the benefits of transformation will be more keenly felt. In particular:

188 The Tito and Tita its commercial utility have reportedly presold 200 units for delivery in early 2022. At a cost of only USD 15,000 (at the official Argentina dollar rate) it comes with an in-built charger allowing it to be plugged directly into the mains electricity.

1. Local production with a regional outlook: Harness the expertise of the existing ecosystem and collaboration with OEMs present in Brazil and Argentina and incentivise the production of electrified vehicles. Negotiate a plan that increases emissions targets and production targets over time. Transformation through reduction of import duties is not sustainable.
2. Hybrid vehicles as transitional solution for private mobility: Hybrid vehicles can have an important role in a country with Argentina's geographical dimensions. Toyota is an important industry participant and is one of the most advanced in hybrid technology. Greater adoption of hybrids does not require equivalent investments in charging infrastructure and generation capacity and could be a more attractive alternative for incumbents
3. BEV focus on commercial utilities and micro-mobility: Fleet vehicles, for last mile delivery or other commercial purposes, will achieve TCO parity much sooner than private vehicles because of their average higher use. Tax relief for commercial electric utility vehicles can be subsidised by incremental taxes on conventional vehicles with only a limited impact on the latter in the early stages of adoption. Indirect incentives such as favourable parking tariffs or use of bus lanes could be provided for fully electric micro citicars. Required charging infrastructure can be much more localised for commercial applications or home charging is prevalent in the case of citicars.
4. Accelerate adoption of new mobility models: Collaboration rather than confrontation with the development of new mobility models, particularly when pandemic fears subside, pooled or shared rides. Stimulate use of alternatives to the private vehicle through redesign of urban centres, limiting access, and incentivising healthier forms of mobility.

This study is by no means an exhaustive study of the adoption of electric mobility at a global level or as applied to Argentina and the region. There are several additional areas of study that would benefit the formulation of a comprehensive sustainable mobility study in Argentina, amongst which the author would highlight the following investigative questions:

1. How can collaboration enable acceleration and integration of new models of mobility into a heavily subsidised public transport system and a politically sensitive private taxi industry?

2. What role can other technologies such as compressed natural gas and hydrogen fuel cells play in the transformation of mobility in Argentina to more efficient sources of energy?
3. What is the best way to build an adequate national charging network that serves the needs of users but also provides a sustainable business model for operators?
4. What are the consequences of an electrified vehicle fleet on grid capacity in Argentina and how important is the development of smart chargers, distributed generation and V2G technology to managing peak load capacity?
5. How feasible is the development of an electric vehicle supply chain in Argentina, considering skill sets, market volumes and competitive considerations and how quickly can it be developed?

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11. Appendices

11.1. Appendix 1- OEM EV Models, Investments & Infrastructure

	Models: HEV	Models: PHEV	Models: BEV	Models: FCEV	Battery Supply	All-Electric Target	EV Investments	Charging network
Toyota	Prius	Prius Prime	Toyota Bz4x (2022)	Mirai	Panasonic	Not stated	$13.5bn Battery Tech. 15 BEVs by 2025.	Third Party Public Chargers
	Corolla	RAV4 Prime	Lexus UX 300e					
	Camry	Lexus NX						
	Avalon							
	Sienna							
	Venza							
	RAV4							
	Highlander							
	Lexus Models							
VW		Golf	VWID.3		LGChem, Samsung, SKI (Europe), CATL (China)	70% in Europe by 2030: 100% by 2035. US & China to take longer.	$50bn by 2024	Electrify America 800 stations by 2021. 18.000 fast charging stations in Europe by 2025 (BP, Enel, Iberdrola). Access to 150.000 public charging service through WeCharge, IONITY network (Europe). 17.000 fast public chargers planned for China
		Passat	Porsche Taycan					
			VW e-up!					
			VW e-Golf					
			VW ID.4					
			VW ID.6 (China Only)					
			Audi Q4 e-tron					
Daimler		A-Class	EQC		CATL, SKI, LGChem, Farasis	By 2030 in major markets	$47 bn to 2030	Collaboration VW, BMW & Ford in Europe to set up Europe charging network: IONITY
		B-Class	EQA					
		C-Class	EQV					
		E-Clas	EQS					
		S-Class	EQE					
		CLA Coupe	EQB					
		GLC SUV						
		GLA SUV						
		GLE SUV						
Ford	Mondeo	Escape			SK Innovation, LG Chem	40% by 2030: 100% in Europe.	$22 billion to 2025	FordPass: 16.000 fast charging stations (40,000 plugs) Electrify America & Chargepoint. Europe part of IONITY
	Maverick	Kuga	Mustang Mach E					
	Escape		Lightning					
	Explorer							
	F150							
	Kuga							
	SMAx							
	Galaxy							
GM		Chevy Volt (discontinued)	Baojun E100 (China Only)		LG Energy Solution	By 2035 if economics allow.	$27 bn 2025 - 30 New Models	GM & Evgo: 2700 fast chargers US 2025. Ultima brand level 2 chargers 40.000 planned for US and Canada.
			Cadillac Lyriq					
			Chevrolet Bolt					
			Chevrolet Bolt EUV					
			Buick Velite 7 (China Only)					
Honda	SH-AWD	Clarity (discontinued)	Honda e (Europe)	Clarity (discontinued)	GM Ultium in US, CATL in China	By 2030 China incl. hybrids. By 2040 major markets	$46 bn over 6 years	Third Party Public Chargers
	Acura RLX							
	Acura MDX							
	Accord							
	Odyssey							
	CRV							
	Step WGN Spada							
	Fit							
	Freed							
	Grace							
	Jade							
	Shuttle							
	Vezel							
BMW		BMW 7 Series	Mini Electric		CATL, Samsung SDI, Northvolt	Undeclared but expects 50% of all new cars are EVs by 2030	$35bn EV & Hydrogen 2025	BMW Charging: EVGo (US). IONITY (Europe)
		BMW 5 Series	i3					
		BMW 3 Series	i4					
		BMW X1 xDrive25e	iX					
		BMW X2 xDrive25e						
		BMW X5 xDrive 45e						
Stellantis		Peugeot 508	Fiat 500e		LG Energy Solutions, CATL, Samsung SDI	70% Europe, 40% US. BEVs & PHEVs by 2030	$35bn 2025 - 55 models, 21 models by 2023	Creating network of 15,000 locations in Europe by 2025 with TheF Charging a charging start-up
		Peugeot 508 SW	Peugeot E-208					
		Peugeot 3008	Peugeot E-2008					
		Jeep 4xe	Citroen e-C4					
		Chrysler Pacifica	Citroen Ami					
		Citroen C5 Aircross	Citroen Berlingo					
		Citroen C5X	Citroen E- Spacetourer					
		Opel Grandland	Opel Corsa					
			Opel Mokka					
			Opel Vivaro					
			Opel Combo					
Hyundai	Hyundai Santa Fe	Hyundai Kona	Hyundai Kona	Hyundai Nexo	SK Innovation, CATL	By 2040 in major markets	$87 billion in 5 years. $7bn in US EV transition by 2025. 44 models by 2025	IONITY (Europe), Electrify America (USA), SP Group Singapore + BaaS
	Hyundai Elantra	Hyudai Tuscon	Hyundai IONIQ 5					
	Hyundai Tuscon	Hyundai Santa Fe	Hyundai IONIQ					
	Hyundai Sonata	Hyundai IONIQ	Kia e-Niro					
	Hyundai IONIQ	Kia Niro	Kia Soul EV					
	Kia Sorento		Kia EV6					
Tesla			Model S		Panasonic, LG Energy Solution (China), CATL (China)	Born Electric	No investment transformation required. Invests 5% of revenues in line with other OEMs.	2,500+ Supercharger stations with 25000+ superchargers
			Model X					
			Model Y					
			Model 3					
			Cybertruck					
			Roadster					

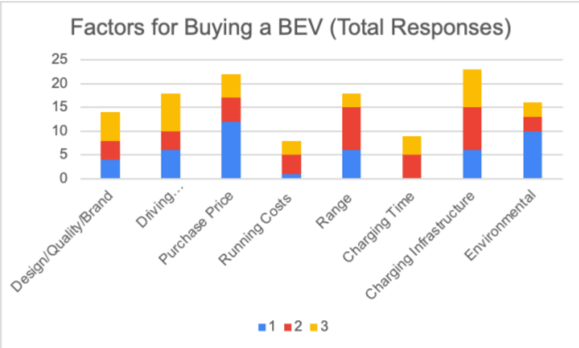
- Cars & Mini Vans
- Crossover/SUV/Trucks
- Coming Soon

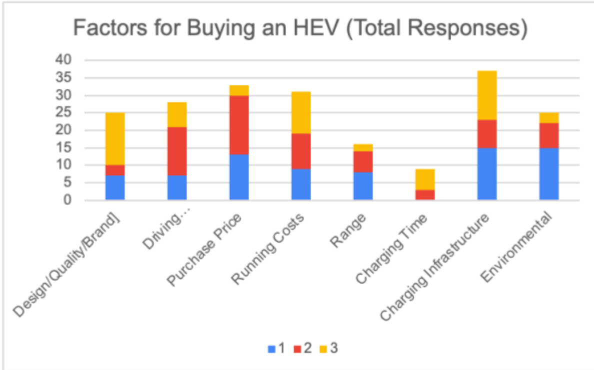
11.2. Appendix 2 – OEM Gross Revenues, Gross Profit Margins and R&D Expenditure

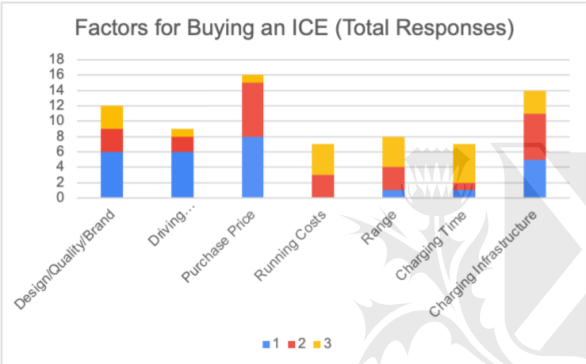
Gross Revenues (millions)	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Tesla	**15**	**112**	**117**	**204**	**413**	**2,014**	**3,198**	**4,046**	**7,000**	**11,759**	**21,461**	**24,578**	**31,536**
VW Group	167,040	146,680	168,170	222,170	247,710	261,640	269,240	236,690	240,460	259,970	278,490	282,948	254,600
Toyota	206,470	204,350	220,590	235,450	266,980	256,510	249,050	236,690	255,190	265,160	272,640	274,562	254,914
General Motors	148,980	104,590	135,590	150,280	152,260	155,430	155,930	135,720	149,180	145,590	147,050	137,237	122,485
Ford	145,110	116,280	128,950	135,600	133,560	146,920	144,080	149,560	151,800	156,780	160,340	155,900	127,144
BMW	78,080	70,670	80,160	95,960	98,800	101,010	106,920	102,290	104,220	111,310	115,110	116,715	113,076
Daimler	144,530	110,060	129,580	148,550	146,940	156,690	172,710	165,860	169,620	185,910	197,620	193,474	176,267
Honda								121,185	130,192	138,250	142,998	137,365	123,803
Gross Profit (millions)	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Tesla	**(1)**	**10**	**31**	**62**	**30**	**456**	**882**	**924**	**1,599**	**2,222**	**4,042**	**4,069**	**6,630**
VW Group	25,240	18,940	28,420	38,990	45,200	47,280	48,570	37,630	45,370	49,320	54,730	55,039	44,489
Toyota	20,860	24,430	27,620	27,810	41,420	48,830	49,320	48,310	44,970	49,550	49,100	49,607	45,180
General Motors	(278)	(7,606)	16,820	19,890	12,020	20,500	17,850	17,400	19,031	18,231	14,095	13,972	13,672
Ford	18,010	17,420	20,160	18,380	17,400	23,870	19,050	25,110	25,600	25,460	24,070	21,207	14,392
BMW	8,878	7,426	14,490	20,280	19,920	20,280	22,610	20,120	20,720	22,600	21,910	20,230	15,516
Daimler	31,640	18,630	30,190	35,580	32,750	33,370	37,480	34,900	35,380	39,100	39,050	32,665	29,229
Honda								27,130	29,140	30,245	29,769	28,330	25,670
Gross Profit Margin (%)	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Tesla	**-7.7%**	**8.5%**	**26.3%**	**30.2%**	**7.3%**	**22.7%**	**27.6%**	**22.8%**	**22.8%**	**18.9%**	**18.8%**	**16.6%**	**21.0%**
VW Group	15.1%	12.9%	16.9%	17.5%	18.2%	18.1%	18.0%	15.9%	18.9%	19.0%	19.7%	19.5%	17.5%
Toyota	10.1%	12.0%	12.5%	11.8%	15.5%	19.0%	19.8%	20.4%	17.6%	18.7%	18.0%	18.1%	17.7%
General Motors	-0.2%	-7.3%	12.4%	13.2%	7.9%	13.2%	11.4%	12.8%	12.8%	12.5%	9.6%	10.2%	11.2%
Ford	12.4%	15.0%	15.6%	13.6%	13.0%	16.2%	13.2%	16.8%	16.9%	16.2%	15.0%	13.6%	11.3%
BMW	11.4%	10.5%	18.1%	21.1%	20.2%	20.1%	21.1%	19.7%	19.9%	20.3%	19.0%	17.3%	13.7%
Daimler	21.9%	16.9%	23.3%	24.0%	22.3%	21.3%	21.7%	21.0%	20.9%	21.0%	19.8%	16.9%	16.6%
Honda								22.4%	22.4%	21.9%	20.8%	20.6%	20.7%
R&D (millions)	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Tesla	**53.71**	**19.28**	**93**	**209**	**274**	**232**	**465**	**718**	**834**	**1,378**	**1,460**	**1,343**	**1,491**
VW Group				10,030	12,235	15,601	17,427	15,104	15,134	14,842	16,107	15,965	16,849
Toyota	9,650	8,263	9,164	9,770	8,273	8,611	8,299	9,712	9,251	9,645	9,875	9,621	10,400
General Motors	8000	6000	6,900	8,100	7,400	7,200	7,400	6,000	6,600	7,300	7,800	6,800	6,200
Ford	5000	4700	5,000	5,300	5,500	6,200	6,700	6,700	7,300	8,000	8,200	7,400	7,100
BMW	4,213	3,414	3,677	4,697	5,082	6,368	6,065	5,735	5,716	6,902	8,136	6,642	6,904
Daimler	4484	4038	4,607	5,820	5,373	5,585	6,027	5,282	5,818	6,725	7,771	7,376	6,986
Honda								5,449	6,430	6,767	7,262	7,398	6,946
R&D % Revenues	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Tesla			**79.7%**	**102.3%**	**66.3%**	**11.5%**	**14.5%**	**17.7%**	**11.9%**	**11.7%**	**6.8%**	**5.5%**	**4.7%**
VW Group	0.0%	0.0%	0.0%	4.5%	4.9%	6.0%	6.5%	6.4%	6.3%	5.7%	5.8%	5.6%	6.6%
Toyota	4.7%	4.0%	4.2%	4.1%	3.1%	3.4%	3.3%	4.1%	3.6%	3.6%	3.6%	3.5%	4.1%
General Motors	5.4%	5.7%	5.1%	5.4%	4.9%	4.6%	4.7%	4.4%	4.4%	5.0%	5.3%	5.0%	5.1%
Ford	3.4%	4.0%	3.9%	3.9%	4.1%	4.2%	4.7%	4.5%	4.8%	5.1%	5.1%	4.7%	5.6%
BMW	5.4%	4.8%	4.6%	4.9%	5.1%	6.3%	5.7%	5.6%	5.5%	6.2%	7.1%	5.7%	6.1%
Daimler	3.1%	3.7%	3.6%	3.9%	3.7%	3.6%	3.5%	3.2%	3.4%	3.6%	3.9%	3.8%	4.0%
Honda									4.9%	4.9%	5.1%	5.4%	5.6%

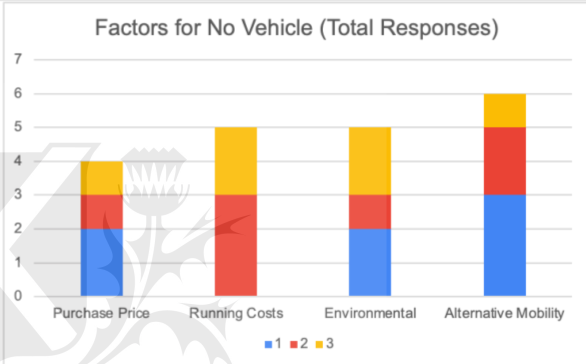
Source: own development from regulatory filings.

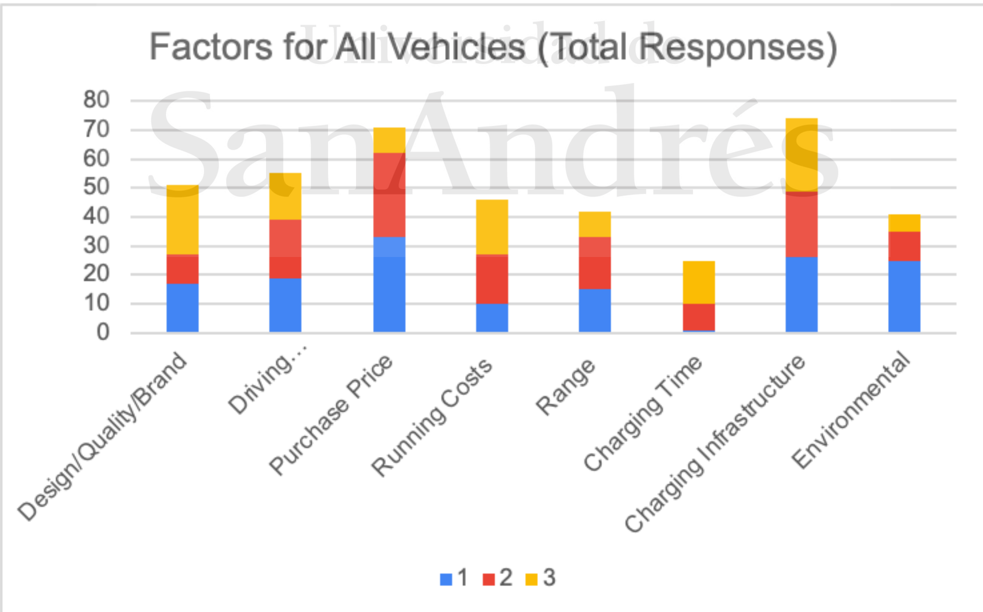
11.3. Appendix 3 – Consumer Survey Results (key graphs)

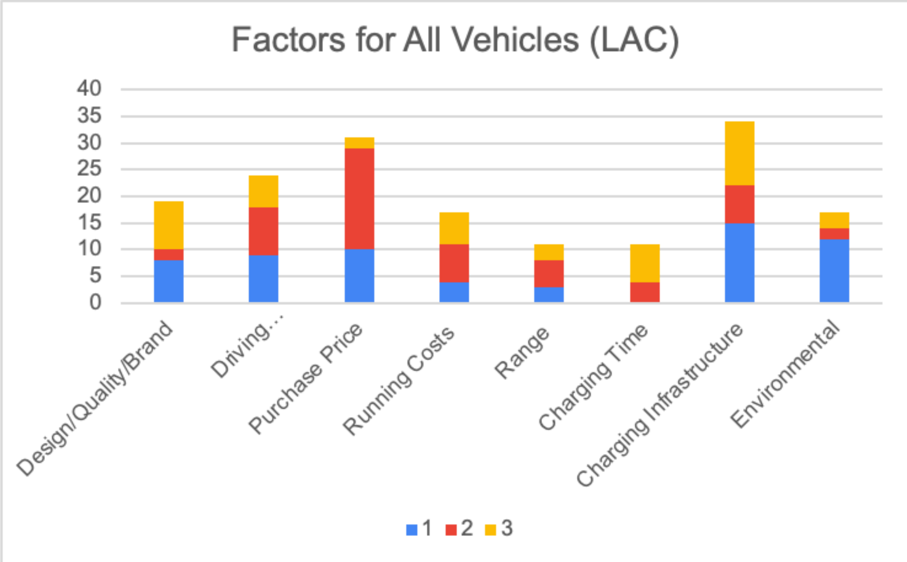


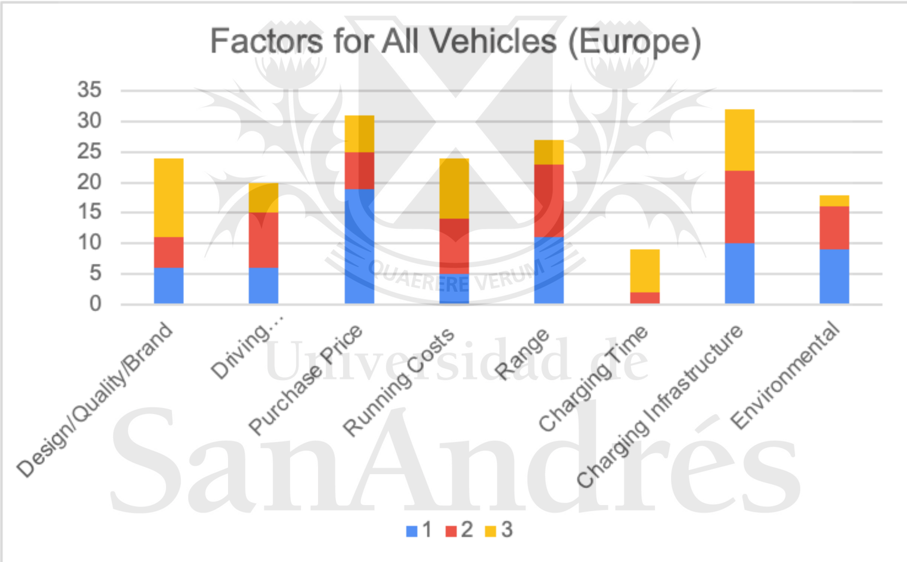


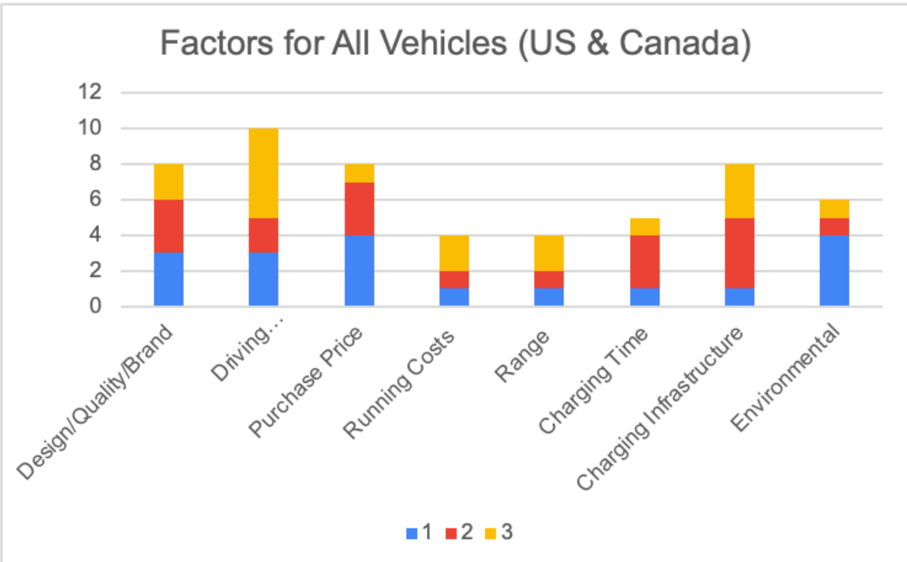


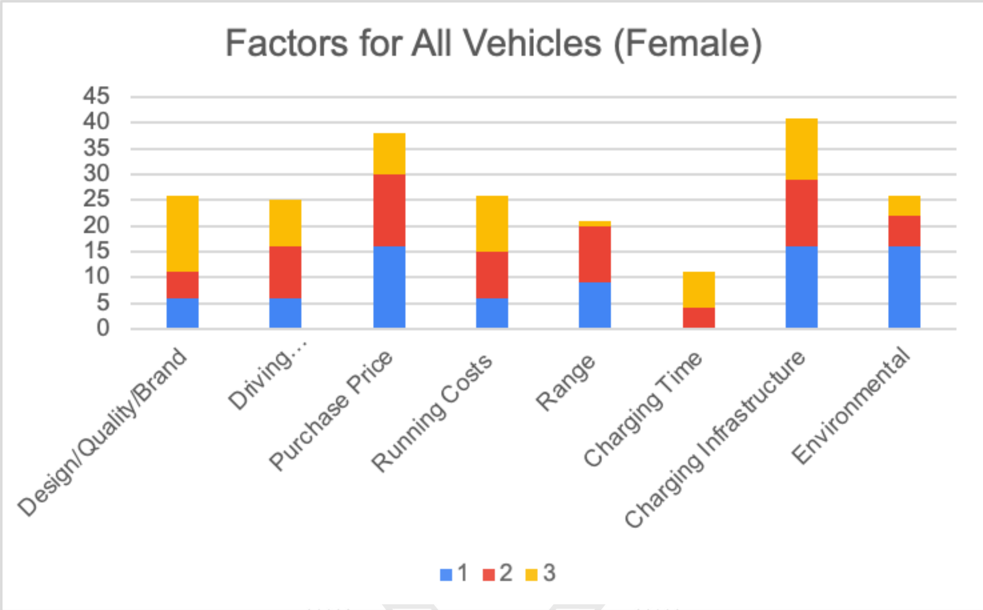


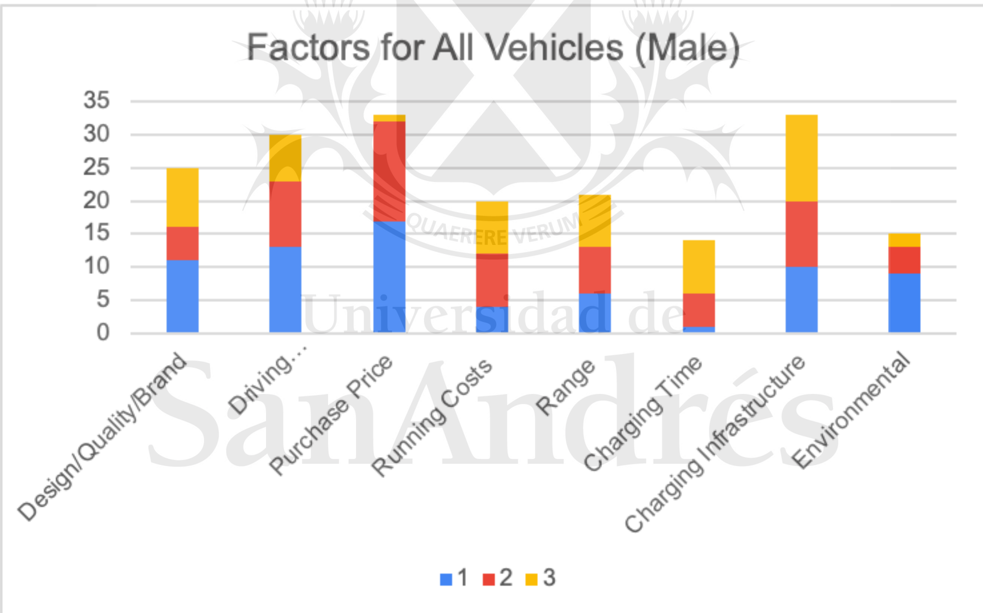



Factors for All Vehicles (LAC)
40
35
30
25
20
15
10
5
0
Design/Quality/Brand
Driving...
Purchase Price
Running Costs
Range
Charging Time
Charging Infrastructure
Environmental
1 2 3


Factors for All Vehicles (Europe)
35
30
25
20
15
10
5
0
Design/Quality/Brand
Driving...
Purchase Price
Running Costs
Range
Charging Time
Charging Infrastructure
Environmental
1 2 3


Factors for All Vehicles (US & Canada)
12
10
8
6
4
2
0
Design/Quality/Brand
Driving...
Purchase Price
Running Costs
Range
Charging Time
Charging Infrastructure
Environmental
1 2 3


Factors for All Vehicles (Female)
45
40
35
30
25
20
15
10
5
0
Design/Quality/Brand
Driving...
Purchase Price
Running Costs
Range
Charging Time
Charging Infrastructure
Environmental
1
2
3


Factors for All Vehicles (Male)
35
30
25
20
15
10
5
0
Design/Quality/Brand
Driving...
Purchase Price
Running Costs
Range
Charging Time
Charging Infrastructure
Environmental
1
2
3

11.4. Appendix 4 – TCO & Purchase Price Parity Model Outputs

11.4.1. Key Model Inputs

	Vehicle Specifications		
	Nissan Leaf		Nissan Versa
Battery Capacity (kWh)	40		
Battery Cost % PC	20%		
Max. Autonomy (km)	250	Approx. WLTP/EPA	
Energy Consumption kWh/km or L/km	0.16		0.07
Service & Maintenance USD/km	0.038		0.101
Insurance Costs % PC	3.0%		3.0%
Battery Replacement % (half life)	Guarantee 8 years or 100.000 miles		
Expected Useful Life (years)	8		8
Home Charger CAPEX	2,000		

	Other Variables		
	Argentina	Chile	Colombia
Annual Finance Cost			
Principal	80%	80%	90%
Term	5	5	5
Initial Interest Rate	47%	20%	15%
Sistema	Frances	Frances	Frances
Average Annual km	10,000	18,000	
	15,000	25,000	
	12,500	22,000	20,000
USD Inflation	2.50%		

11.4.2. Comparative Price Evolution by Country

	USD		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Argentina	Nissan Leaf EV	59,342	59,342	51,652	46,123	41,550	39,459	37,614	36,734	35,916	35,153	34,443	33,755	33,079	32,418	31,770	31,134
	Nissan Versa	23,705	23,705	24,298	24,905	25,528	26,166	26,820	27,491	28,178	28,882	29,604	30,345	31,103	31,881	32,678	33,495
Chile	Nissan Leaf EV	35,732	35,732	31,102	27,773	25,020	23,760	22,649	22,119	21,627	21,168	20,740	20,325	19,919	19,520	19,130	18,747
	Nissan Versa	14,946	14,946	15,319	15,702	16,095	16,497	16,910	17,333	17,766	18,210	18,665	19,132	19,610	20,100	20,603	21,118
Colombia	Nissan Leaf EV	36,883	36,883	32,103	28,667	25,825	24,525	23,378	22,831	22,323	21,849	21,408	20,980	20,560	20,149	19,746	19,351
	Nissan Versa	17,415	17,415	17,851	18,297	18,755	19,223	19,704	20,197	20,702	21,219	21,750	22,293	22,851	23,422	24,007	24,608
											Price Parity			Price Parity		Price Parity	

11.4.3. Relative TCO by Country

Annual Km	TCO COMPARISON ARGENTINA											
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
2,500	2.2154	1.8928	1.6627	1.4764	1.3780	1.2910	1.2373	1.1873	1.1404	1.0965	1.0545	1.0141
5,000	2.1774	1.8594	1.6325	1.4494	1.3524	1.2671	1.2144	1.1656	1.1198	1.0768	1.0357	0.9961
7,500	2.1408	1.8272	1.6035	1.4234	1.3279	1.2440	1.1924	1.1447	1.0999	1.0578	1.0176	0.9789
10,000	2.1054	1.7962	1.5756	1.3983	1.3043	1.2218	1.1713	1.1246	1.0807	1.0396	1.0001	0.9622
12,500	2.0712	1.7662	1.5486	1.3742	1.2815	1.2005	1.1509	1.1052	1.0623	1.0220	0.9833	0.9462
15,000	2.0382	1.7373	1.5227	1.3509	1.2596	1.1799	1.1312	1.0865	1.0445	1.0050	0.9671	0.9307
17,500	2.0062	1.7093	1.4976	1.3285	1.2385	1.1601	1.1123	1.0685	1.0273	0.9887	0.9515	0.9158
20,000	1.9753	1.6823	1.4733	1.3068	1.2181	1.1410	1.0940	1.0511	1.0108	0.9728	0.9364	0.9014
22,500	1.9453	1.6562	1.4499	1.2859	1.1984	1.1225	1.0764	1.0344	0.9948	0.9576	0.9218	0.8874
25,000	1.9163	1.6309	1.4273	1.2657	1.1794	1.1047	1.0594	1.0181	0.9793	0.9428	0.9077	0.8740
27,500	1.8881	1.6064	1.4054	1.2461	1.1610	1.0874	1.0429	1.0025	0.9644	0.9286	0.8941	0.8609
30,000	1.8608	1.5826	1.3842	1.2272	1.1432	1.0708	1.0270	0.9873	0.9499	0.9148	0.8809	0.8483
	-16.00%	-16.39%	-16.75%	-16.88%	-17.04%	-17.06%	-17.00%	-16.85%	-16.71%	-16.58%	-16.46%	-16.35%

Annual Km	TCO COMPARISON CHILE											
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
2,500	1.7054	1.4910	1.3347	1.2034	1.1353	1.0736	1.0359	1.0007	0.9675	0.9363	0.9066	0.8779
5,000	1.6612	1.4533	1.3018	1.1744	1.1080	1.0475	1.0104	0.9756	0.9429	0.9122	0.8834	0.8555
7,500	1.6197	1.4180	1.2709	1.1471	1.0825	1.0231	0.9864	0.9522	0.9200	0.8897	0.8617	0.8345
10,000	1.5806	1.3848	1.2419	1.1214	1.0584	1.0001	0.9640	0.9302	0.8984	0.8687	0.8413	0.8148
12,500	1.5439	1.3535	1.2145	1.0973	1.0358	0.9785	0.9428	0.9095	0.8782	0.8489	0.8222	0.7963
15,000	1.5093	1.3240	1.1887	1.0745	1.0144	0.9581	0.9229	0.8900	0.8591	0.8302	0.8042	0.7790
17,500	1.4765	1.2961	1.1643	1.0529	0.9942	0.9389	0.9040	0.8716	0.8411	0.8127	0.7872	0.7626
20,000	1.4455	1.2697	1.1411	1.0325	0.9750	0.9207	0.8862	0.8542	0.8242	0.7961	0.7712	0.7471
22,500	1.4162	1.2447	1.1192	1.0131	0.9569	0.9034	0.8694	0.8378	0.8081	0.7804	0.7560	0.7324
25,000	1.3883	1.2210	1.0984	0.9947	0.9396	0.8870	0.8534	0.8222	0.7929	0.7656	0.7417	0.7186
27,500	1.3618	1.1984	1.0787	0.9773	0.9233	0.8714	0.8382	0.8074	0.7784	0.7515	0.7281	0.7054
30,000	1.3367	1.1769	1.0598	0.9606	0.9077	0.8566	0.8237	0.7933	0.7647	0.7381	0.7151	0.6929
	-21.62%	-21.07%	-20.59%	-20.18%	-20.05%	-20.21%	-20.48%	-20.73%	-20.96%	-21.16%	-21.12%	-21.08%

Annual Km	TCO COMPARISON COLOMBIA											
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
2,500	1.6771	1.4591	1.2997	1.1665	1.0973	1.0355	0.9969	0.9608	0.9268	0.8949	0.8644	0.8350
5,000	1.6591	1.4443	1.2871	1.1557	1.0874	1.0261	0.9877	0.9517	0.9180	0.8863	0.8561	0.8271
7,500	1.6417	1.4299	1.2749	1.1452	1.0777	1.0170	0.9787	0.9430	0.9094	0.8779	0.8481	0.8194
10,000	1.6248	1.4160	1.2630	1.1351	1.0683	1.0081	0.9700	0.9345	0.9011	0.8698	0.8403	0.8119
12,500	1.6084	1.4025	1.2515	1.1252	1.0592	0.9995	0.9616	0.9262	0.8930	0.8619	0.8327	0.8046
15,000	1.5925	1.3893	1.2404	1.1156	1.0503	0.9911	0.9534	0.9182	0.8852	0.8542	0.8254	0.7976
17,500	1.5770	1.3766	1.2295	1.1062	1.0417	0.9830	0.9454	0.9104	0.8775	0.8468	0.8183	0.7908
20,000	1.5620	1.3642	1.2189	1.0972	1.0333	0.9750	0.9377	0.9028	0.8701	0.8396	0.8114	0.7841
22,500	1.5473	1.3521	1.2086	1.0883	1.0251	0.9673	0.9301	0.8955	0.8630	0.8326	0.8046	0.7777
25,000	1.5331	1.3403	1.1986	1.0797	1.0172	0.9598	0.9228	0.8883	0.8560	0.8257	0.7981	0.7714
27,500	1.5193	1.3289	1.1889	1.0714	1.0094	0.9525	0.9157	0.8814	0.8492	0.8191	0.7917	0.7653
30,000	1.5058	1.3178	1.1794	1.0632	1.0019	0.9454	0.9087	0.8746	0.8425	0.8127	0.7855	0.7593
	-10.21%	-9.68%	-9.25%	-8.85%	-8.70%	-8.70%	-8.85%	-8.97%	-9.09%	-9.19%	-9.13%	-9.07%

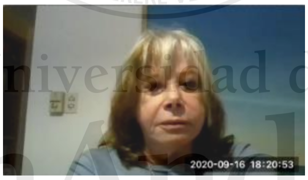
11.4.4. Sources

Battery Prices	BNEF IHS Markit	https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/ https://energymonitor.ai/tech/energy-storage/reducing-battery-cost-is-essential-for-a-clean-energy-future
Car Cost Structure & Price Parity	AutoVista24 UBS Evidence Lab ICCT Damodaran: Stern NYU	https://autovista24.autovistagroup.com/news/bev-vs-ice-race-price-parity/ https://neo.ubs.com/shared/d1wkuDlEbYPjF/ https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html
Car Specifications	Car & Driver US News Nissan Argentina INSIDEEVs Pod Point	https://www.caranddriver.com/nissan/leaf https://cars.usnews.com/cars-trucks/compare?trims=14622-413448_14593-413105 https://www.nissan.com.ar/vehiculos/nuevos/nissan-leaf/autonomia-recarga.html https://insideevs.com/news/414786/comparison-epa-wltp-range-ratings/ https://pod-point.com/guides/vehicles/nissan/2018/leaf
Ownership Costs	Nissan UK Argonne National Laboratory Edmunds INSIDEEVs	https://www.nissan.co.uk/vehicles/new-vehicles/leaf/prices-specifications.html#grade-LEAFZE1A-0|specs https://publications.anl.gov/anlpubs/2021/05/167399.pdf https://www.edmunds.com/nissan/leaf/2020/cost-to-own/ https://insideevs.com/features/341500/the-ultimate-buyers-guide-to-home-ev-chargers-plus-top-5-picks/
Gasoline & Electricity Costs	Global Petrol Prices & ABECEB	https://es.globalpetrolprices.com
Credit Terms		Various
Km Colombia Km Chile Km Argentina	Com Automotriz Autofact Telam	https://www.comautomotriz.com.co/noticias/consejos-para-comprar-usados/el-kilometraje-en-los-carros-usados https://www.autofact.cl/historial-vehiculo/kilometraje https://www.telam.com.ar/notas/201910/397647-los-argentinos-usan-cada-vez-menos-el-auto-con-una-caida-promedio-de-2500-kilometros-desde-2012.html
Economic Projections	ABECEB	

11.5. Appendix 5 – Panel of Experts & Key Questions

Smart Cities, Urbanism and Sociology

1. What key trends (social, economic, cultural, innovation, information, environment) in the development of smart cities will have the greatest impact on urban mobility and how will these new mobility paradigms manifest themselves? For example, is Moreno's "15-minute city" a realistic vision?
2. How important a role will electrification of mobility play and what is the future of privately owned vehicles are they compatible with smart cities (congestion, pollution, parking spaces etc.)?
3. Do you sense that cultural shifts, education /knowledge development and intergenerational differences will be a key driver towards more sustainable cities? How sticky, for example are the changes we are seeing in European cities in the post-COVID era with more spaces assigned to micro mobility (bikes and scooters), home working etc.?
4. How far behind the curve is a city such as Buenos Aires, and what are the key drivers for change?



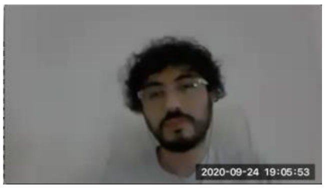
Dr Susana Finquelvich: Senior Researcher at CONICET and the University of Buenos Aires; Director of the Research Program on the Information Society, IIGG-FSOC- UBA.

Electromobility

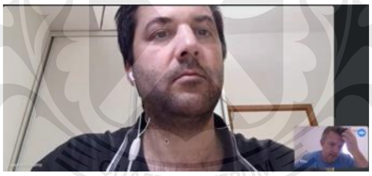
1. Do you think that electric vehicles have finally reached a turning point globally and what do you think are or have been the main barriers and facilitators in the adoption of electric mobility?
2. The proliferation of new mobility models, particularly in urban environments, has accelerated in recent years, in particular platform transport services ("Hailing"), shared transport ("sharing") and micro mobility (scooters, bicycles). To what extent do you think advances in autonomous vehicles, the sharing economy, mobility as a service and/or connectivity will impact private ownership of vehicles if not the electrification of transport?
3. Do you think that the electrification of transport (especially when combined with renewable energy sources) using battery-powered technology will be the dominant solution to reduce our

carbon footprint and pollution in cities or do you foresee that advances in other sources of clean energy (e.g., hydrogen fuel cells) can disrupt the current revolution in electric vehicles?

4. How far behind is Argentina in the mobility revolution and do you think electric mobility will develop in the short to medium term? What are the key obstacles and opportunities for moving forward and what are the key first steps for successful electrification of private transport?



Dr P. Sebastián Cortez Oviedo, Senior Researcher, Digital Technologies & Platforms INVIHAB-IDH CONICET | FAUD-UNC



Gastón Turturro, MSc. Energy Engineering; Business Development Manager, Genneia, leaders in green hydrogen; ex-Business Development Manager YPF Luz; Programme Coordinator in Electromobility at the University of Buenos Aires.

Maximiliano Scarlan, Senior Consultant, Content & Innovation, Smart Cities, Knowledge Economy & Mobility, ABECEB. Andrés Martín Civetta, Senior Consultant, Automotive Industry, ABECEB.