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Final Thesis

Do Electric Vehicles Really Represent the Solution for Sustainability in the Automotive Industry?

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Introduction

This paper explores the recent trends involving the automotive industry, one of the sectors that has become at the center of sustainability discussions. The purpose of the paper is to discover whether electric vehicles, arguably being the solution for the sustainability of this industry, can really constitute a feasible alternative to traditional combustion engine vehicles or the benefits they are associated to can considered to be only temporal and superficial. The automotive industry is currently under a wave of disruptive technological changes, driven by the electrification of powertrains, connectivity, autonomous driving, and development of alternative mobility solutions through mobility shared online platforms. Complexity of competitive dynamics has increased because of the entrance of mobility providers, tech giants, and specialty OEMs, putting pressures on those traditional carmakers which have now to deal with competition on multiple fronts and subsequent increased uncertainty in the market.

The regulatory political framework then demands for stringent sustainability requirements to be fully respected, bringing companies to consider sustainability strategies as one of the main prerequisites for the survival in the industry, especially given the internationalization of their supply chains. Climate change issues have been widely recognized worldwide and is up to any company to adopt climate change mitigation strategies to cope with government policies aiming at reducing, if not eliminating at all, the cumulative level of greenhouse gas (GHGs) emissions, which have risen to record levels. The automotive industry is among the most polluting industries in terms of carbon emissions, therefore arguments to achieve sustainability goals acquire relevance. This implies that all the business processes of the company need to be involved, and its entire supply chain must work towards the same sustainability goals if a sustainable business is to be achieved.

This paper analyses several dynamics concerning the managerial and supply chain business processes of companies and integrates the theme of sustainability in order to study the interconnections that exist between them, with a focus on automotive firms. Extensive literature studies have been used in conjunction with up-to-date automotive market data and trajectories, merging managerial and supply chain dynamics with green supply chain dynamics and sustainable practices of automotive firms.

The final object of the paper is directed towards electric vehicles (EVs) and their feasibility within the automotive industry framework. The size of the global electric vehicles market is currently in expansion, and it is forecasted to growth a lot in the upcoming years, eventually ending with the displacement of internal combustion engine vehicles within a relatively short period of time. Electric vehicles are forecasted to take the lead in the automotive market in the following years and carmakers, even historical ones, are considering strategies to face this vehicle electrification transition. The feasibility of electric vehicles is based on positive factors related to the multitude of advantages they provide in terms of emissions and pollution reduction, which make them one of the best solutions for sustainability in the automotive industry. Nevertheless, their real sustainability depends upon uncertain factors that seem to constraint worldwide acceptance and adoption. Availability of charging infrastructures, driving range, prices, disposal and recycling of large battery packs, supply chain issues, and emissions caused by energy intensive manufacturing processes are the main concerns putting at risk the feasibility of electric vehicles. The research goes in-depth into the debates involving the automotive industry and concerning worldwide adoption of electric vehicles, supported by evidence from academic and scientific literatures. A qualitative research has also been carried out to study whether concerns about feasibility of electric vehicles in the automotive industry are currently considered by companies in the sector or they merely lie in the background of companies' strategic approaches.

The reminder of this dissertation is structured as follows.
Chapter 1 introduces the automotive industry and gives a brief review of its history. It analyses the industry characteristics and attractiveness, and the market trajectories in terms of production and sales. It also illustrates managerial and supply chain dynamics, integrating them within the automotive context.
Chapter 2 discusses about sustainability pressures and the environmental impact of the automotive industry. It puts emphasis on those green supply chain dynamics and

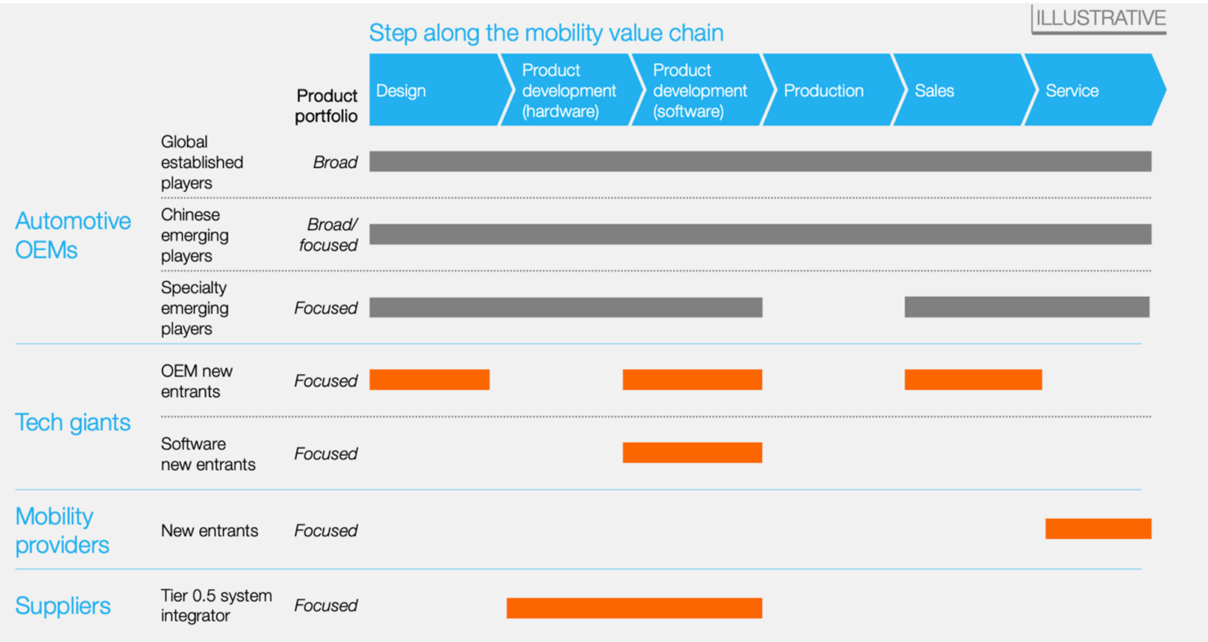
sustainable practices of automotive firms that can better be effective in coping with sustainability requirements.
Chapter 3 defines electric vehicles according to three categories – BEV, PHEV, HEV – and illustrates their market trajectory. Based on the latter, it goes in-depth into the debates concerning feasibility of electric vehicles in the automotive industry by discussing the main concerns that might prevent their worldwide adoption.
Finally, Chapter 4 argues about whether concerns about feasibility of electric vehicles are currently considered by companies in the sector, relying on a qualitative research that highlights the perspective of one of the top three automotive companies by market capitalization.

Chapter 1. The Automotive Industry

1.1. Defining the industry

The automotive industry, being one of the world's largest industries by revenue, involves several business areas across the board. Driven by the production and sale of self-powered vehicles, the industry has been favored by economic and technological developments during the years, especially related to the diffusion of increasingly advanced infrastructures, better standard of living, and the rise of south-east market. The demand for passenger cars in turn has been driven by increasing population and its purchasing power, sustainability pressures from the government and other stakeholders, and the growing economies of developing regions. Companies specialized in designing, developing, and manufacturing motor vehicles (OEM – "Original Equipment Manufacturers") as well as those that focus on marketing and sales, are all part of the automotive industry. Aftersales services such as the repair and maintenance of automobiles might be included, together with automotive suppliers, distributor, dealers, and importers. In addition, new competitive players are entering the mobility value chain, pushed by the latest trends in the automotive industry. Tech giants, software new entrants, and mobility providers are becoming part of the competitive landscape and are acquiring more and more centrality nowadays.

Figure 1. Mobility value chain.

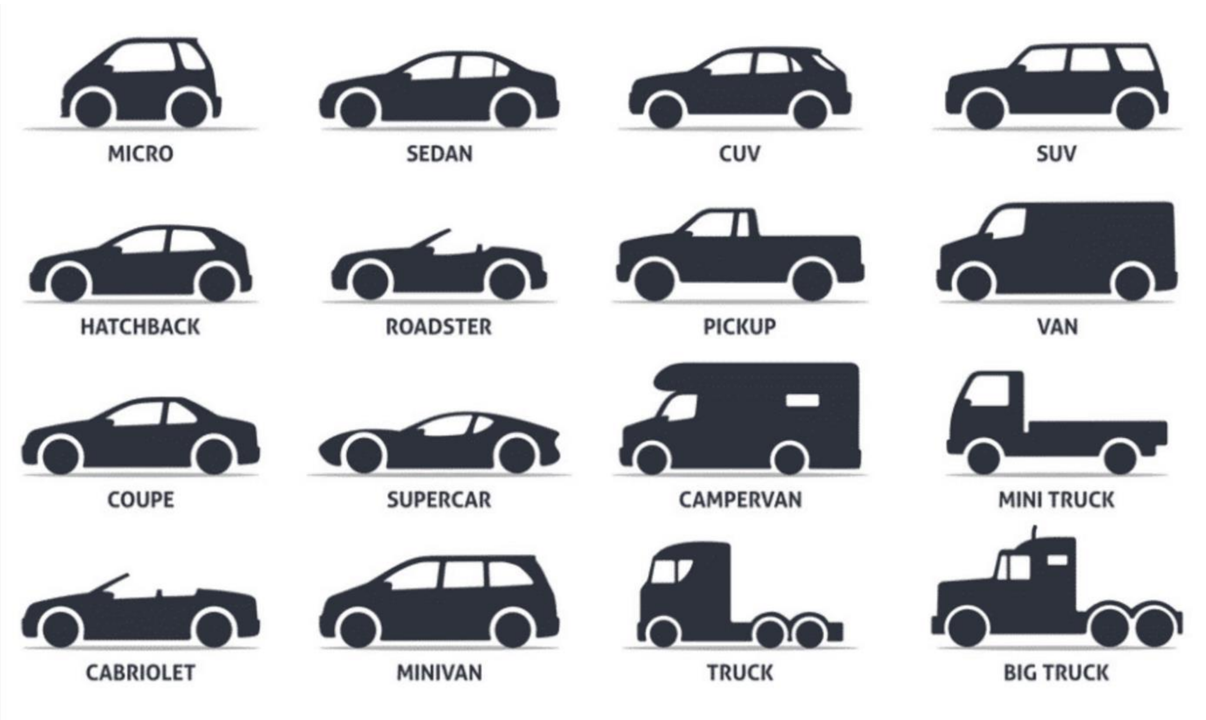


<u>Source</u>: Retrieved from Gao et al (2016)

The market can be segmented into passenger cars, trucks, buses, and other commercial vehicles, although its complexity allows segmentation based on other factors, such as economic value (e.g., luxury cars), type of fuel used, or horsepower. Challawala (2020) suggests there are different types of segmentation concerning the automotive sector. Carmakers can segment the market according to demographic factors, namely age, income level, and family life cycle. Family is more likely to prefer larger cars that have enough space for all the family components, while youngsters usually focus on affordable and small-size cars given their low purchasing power. Psychographic factors also play a role for those companies that segment the market by producing more than one product variants. Among the product variants, consumers usually choose the middle most segment of the car. Finally, geographic segmentation is another type of market segmentation that is important for automotive companies to consider. Consumers living in metropolitan areas more often choose commercial and luxury cars over SUV or vans, which are more likely to be chosen by consumers living in the countryside.

Segmentation by type of vehicle is also made possible given the large number of vehicle variants available in the automotive market. Vehicle size and aesthetic characteristics are two variables that can define different vehicle types. Challawala (2020) classifies passenger cars according to these two variables, finding seven categories: Micro-cars (e.g., Tata Nano), A-segment cars (e.g., Hyundai i10), B-segment cars (e.g., Volkswagen Polo), C-segment cars (e.g., Honda Civic), D-segment cars (e.g., Ford Kuga), E-segment cars (e.g., Volkswagen Tiguan), and F-segment cars (e.g., Porsche Panamera). This distinction mainly depends on passenger car size, ranging from the smallest-size category of micro-cars, going through family cars suitable for a nuclear family in D-segment, and ending with the last F-segment cars referring to luxury and high-performance cars quite large in size. Figure 2 illustrates the different categories of vehicles according to their size and aesthetic characteristics, including in addition SUV, trucks, and other commercial vehicles.

Figure 2. Car classification.



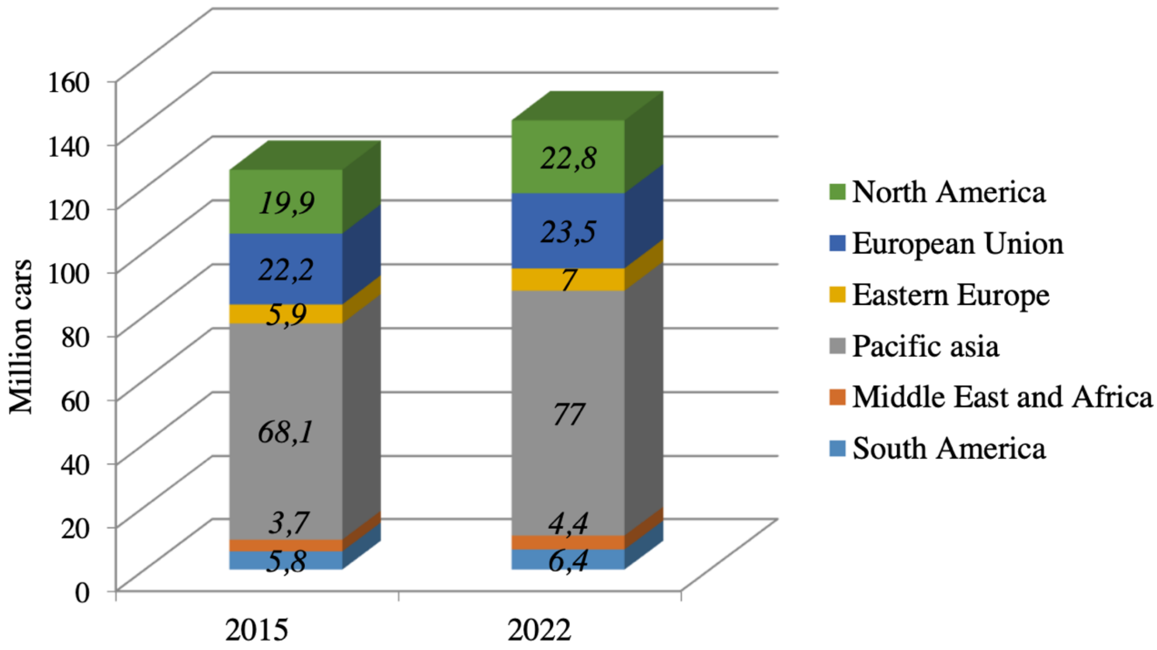
<u>Source</u>*: Retrieved from Felix (2022)*

Companies in this sector not only concern car manufactures, but also car parts manufacturers. The complexity of modern vehicles has indeed increased the necessity to outsource the production of parts and components to external partners. This necessity seems to be justified by the concept of modularity in manufacturing that is frequently associated to car makers. According to a study conducted by Sako and Warburton (1999), most of the car manufactures interviewed defines the concept of modularity as "A group of components, physically close to each other that are both assembled and tested outside the facilities and can be assembled very simply onto the car". This definition implicitly incorporates the outsourcing trend. Pandremenos et al (2009) argue that the platform concept and the modularization of both design (MID) and production (MIP) have been used to cope with the increased complexity of the car components required in the market. These activities go hand to hand with the outsourcing strategies and are becoming common practices for most of the automotive OEMs. Hierarchical organizational structures are losing their effectiveness due to shorter technological life cycle and globalization pressures in the automotive industry context. Modular structures expand the boundaries of the firm as production outcome is not limited to a single firm competence but instead is the result of a nexus of relationships between many parties. Seyoum (2020) explores the effect of modularity by looking at its linkages with production and firm relative positional advantage, focusing on the Chinese automobile industry, one of the biggest automotive markets. Dynamics in the automotive industry demand for efficiency in terms of cost, speed to market, and quality. Seyoum (2020) explains that modularity, supported by mediators such as knowledge sharing tools and physical proximity, has a positive impact on these three variables and can constitute a competitive advantage for companies in this industry. Modularity in production is achieved through collaboration with other firms, where resources are shared to develop synergies that would not be exploited if working alone. To gain full benefits from specialized supplier capabilities, carmakers need to engage in complementary alliances, which are facilitated when knowledge sharing tools are available. Pooling resources creates cost advantages thanks to achieving lower input costs and better utilization of capacity. At the same time, the knowledge base and the innovation capability of the supplier network increases speed-to-market, which is a fundamental attribute if considering the rapid technological pace in the automotive industry. Indeed, speed of new product development is a major advantage of Japanese companies in this sector.

This scenario creates a supplier-buyer interdependence that leads to inter-firm learning, potentially constituting a very important source of innovation for the companies involved and a wider range of innovative solutions for the consumers (Mikkola, 2003). Most companies worldwide rely on this “open innovation strategy” also thanks to the exponential globalization of markets experienced in the last decade. Wilhelm and Dolfsma (2018) explain the importance that open innovation strategies have in the current scenario where automotive companies operate. Recent technological developments and the rising need to innovate broaden the search for new ideas and more distant knowledge outside the company domain. Traditionally, most of the innovations in the automotive industry has been developed within R&D departments of a few large firms. However, the electrification transition, driving assistance, infotainment equipment, and autonomous driving features have created a market where creating and financing all innovations internally is not viable, especially because of the wide range of distant and specific knowledge needed. The pattern of innovation and knowledge development in the automotive industry is changing and those historical incumbents seem to be the ones most disrupted. To be innovative and cope with current competitive pressures, carmakers must focus on building relationships with actors who lie outside the traditional automotive supply chain, such as engineering firms, service providers, software developers, and research institutes. According to Wilhelm and Dolfsma (2018), this process is still in its infancy and is particularly challenging if considering firms from mature and asset-intensive industries like automotive. But given the huge costs of pursuing innovation alone across all technologies, efforts are expected on behalf of carmakers to follow this change and obtain innovations from outside their traditional firm and supply chain boundaries.

The automotive industry is currently based on an international value chain as companies began carrying out a wide range of value activities abroad. This is encouraged by the expansion of companies into foreign markets, especially promising ones. Schmid and Grosche (2008) suggest that several factors contributed to the internationalization of value creation in the automotive industry. Among these factors, they recognize the role of emerging countries – i.e., BRIC countries - and macroeconomic variables – such as exchange rates or oil prices – in shaping the decisions about where to locate. Consequently, increased competition from these emerging countries and cost pressures derived from it are additional factors that influence the dynamics in the automotive industry. Characterized by high levels of production internationalization, the development of automotive manufacturing in developing countries is indirectly related to their economic growth. According to Krasova (2018), in industries like the automotive one, focusing only on the national and domestic dimension undermines the efficiency and functioning of the industry itself, and is simply impossible. The development of global automotive industry is the result of a change in the structure of global demand, which has caused structural disruptions in the geography of global market. While economic growth in developing countries has made demand rise, sales stagnation in developed countries has underlined the saturation of the historical market. All of this creates the premises that led multinational automotive corporations to adjust their organizational and spatial architecture to adapt to these structural shifts. Krasova (2018) highlights this structural shift showing how the engine of global automotive sector growth is now represented specifically by China, and generally throughout Pacific Asia (see Figure 3).

Figure 3. The distribution of production capacity in automotive industry among the regions of the world.



<u>Source</u>: *Retrieved from Krasova (2018)*

The leading role of China partially explains the trend of rise in demand for motor vehicles in developing countries, particularly those located in Pacific Asia. This structural shift seems to be one of the main determinants of internationalization of the automotive industry.

1.2. The historical evolution of the industry

The history of the automotive industry finds its origin with the so-called Model T in 1908, introduced by Henry Ford and his mass-production model of manufacturing. The main function of his automobile was to be durable, easy to maintain and repair, and economical to operate. This complete assembly-line mass production of motor vehicles had proven successful in the market, despite the limitation regarding customization. Until the mid-1920s, the primacy of the Ford's mass production model remained unchallenged, but the inability to recognize that the model would soon become outdated brought about the replacement of the non-customized cars in favor of more luxurious and better-styled ones. Alongside with this trend, large-scale business organizations started spreading in the industry, making it difficult for small companies to compete in the sector. Heavy investments in plant and tooling constituted a barrier to entry that was difficult to cross. Moreover, cost-advantages derived from large scale operations were not easy to replicate for those smaller companies that needed to survive in the market. By the end of the World War I, the automotive market was dominated by the so-called "Big Three", namely Ford, General Motors, and Chrysler. While part of the market was divided among large independent companies, the Big Three supplied three-fourths of the American market for motor vehicles in 1929 (Rae & Binder, 2020).

1.2.1. The years between WW I and WW II

The years between the two World Wars have been economically difficult for all the companies in the sector, but this did not undermine the diffusion of significant developments withing the industry, such as the emphasis on style in passenger-car design, the introduction of the V-8 engine, the three-point engine suspension, and the automatic transmission. The war revealed the main functions of motor vehicles: transport and supply. It pushed the productive capacity of the automotive industry, demonstrating its military value. In addition, this period brought a significant growth of car manufacturing in Europe, where the living standards were lower than the American ones and the dimension of the national markets smaller. According to Rae and Binder (2020), the British automotive production rose from 73,000 in 1922 to 239,000 in 1929, outlining the concentration trend widely adopted in the American automotive industry. Peugeot, Renault, and Citroën were parallelly emerging in France, Daimler and Benz in Germany, as well as Volkswagen during the Nazi regime. On the other hand, during this period the automobile industry in Italy was still limited due to small-scale production at that time.

1.2.2. The period following WW II

An important increased in car production occurred after the end of World War II, where the total world output increased almost 10-fold (Rae & Binder, 2020). However, the US lost its predominance in the automotive market in the early 1980s as Japan and China started gaining the capabilities necessary to produce vehicles on a large-scale capable of competing with those manufactured by the leading companies in Europe and the US. The US market share was jeopardized by the increasing competition coming from imported cars and new manufacturing operations established by European and Japanese firms in the US, which restricted the power of the four major firms that were controlling the US automotive industry – namely GM, Ford, Chrysler, and AMC. This occurred also because of the limitations imposed on exports of cars to the United States, thereby encouraging the establishment of Japanese and European manufacturing plants in the American territory. The entrance of Japan in the automotive manufacturing sector was favored by the need to ease trade tensions that resulted in the establishment of manufacturing plants in markets outside Japan, consequently increasing the competitiveness of those major Japanese players that acquired an important position in the automotive market, those being Toyota, Nissan, Honda, Mitsubishi, Suzuki, and later Mazda. These Japan's carmakers put in place production models completely different from the ones adopted by the US and most of European carmakers. The famous "just-in-time" method of delivering components to the assembly plants, together with the use of statistical process controls for enhancing vehicle quality, quickly became emulated by other non-Japanese carmakers. In particular, the Toyota Production System proved to be a paramount for yielding high productivity and high quality at the same time. The lean production paradigm became consequentially exported into the Western world based on the superiority of the manufacturing model in the global comparison, thereby posing the Japanese exports as the greatest threat to their Western counterparts (Holweg, 2008).

The consolidation trend also went hand in hand with the new requirements in the market. Luxury features such as the air-conditioning system, styling, and well cared for aesthetic, all became positively valued by the customer. Sport utility vehicles and commercial trucks were diffusing all over the world, sponsored for example by the Rover Group, which focused on building Jaguar, Mini, and Rover cars.

1.2.3. The modern industry of the 21st century

Despite the market for automobiles was moving towards a more variegate scenario thanks to the presence of several different carmakers, the modern industry of the 21st century still shows that only few very large firms in each of the major producing countries predominate the output of motor vehicles, while small independent producers struggle to acquire the resources necessary to expand in the industry. Given the heavy investments in equipment and tooling required upfront and the subsequent investments in developing marketing and sales capabilities, it seems extremely difficult to compete at the same level of those companies that are already firmly consolidated in the industry. Furthermore, even if the bulk of the world's new cars come from the moving assembly line introduced by Ford, the process is much more refined and elaborated today. The flow of materials into the assembly plants must be accurately controlled and this gives the incentive to integrate production and manufacture its own components, either directly or through subsidiaries. At the same time, cars are becoming more and more technological, including extremely complex technologies and software that make complete integration difficult sometimes. Outsourcing has acquired particular importance, especially for components such as tires, batteries, and dashboard instruments. Not only does outsourcing is economically convenient, but it can result in higher flexibility and higher quality of components derived from the fact that supplier firms may have special equipments and capabilities than those possessed in-house. The effectiveness of outsourcing strategies is obviously subject to the compliance with several prerequisites essential for the application of this model. For instance, a study conducted by Ulewicz (2018) shows that outsourcing strategies benefit from quality control conducted by external parties, which can mitigate the potential risks of loss of information, asymmetry of information, and lack of knowledge. Considering the popular concepts of digital transformation and Industry 4.0 of the latest years, as well as the current megatrends concerning changes in connectivity, autonomous driving, and electric vehicles, Felser and Wynn (2020) also argue about the pressure for many companies in the automotive sector to review their IT sourcing strategies accordingly. They focus on the German automotive industry and show the potential of digitization in creating new, disruptive business and value models. According to their study, given the future relance of software and ownership of operating systems to network the vehicles, companies should move from a traditional make-or-buy strategy towards a make-or-buy-share decision for IT sourcing, where critical resources, capabilities, and competences are shared in partnership to create common platforms and ecosystems (Felser & Wynn, 2020). All of this in turn changes the competitive dynamics in the industry, shifting from a traditional classification of craft, mass (e.g., Ford), and lean (e.g., Toyota Production System) producers into a varied mix of manufacturing processes derived from both mass and lean production paradigms. Across manufacturers it is possible to capture elements of the different production models adopted along each historical period by carmakers, as the Ford's assembly line, the product and brand portfolio of GM, and the lean production techniques of Toyota are common at most manufacturers nowadays, even at those luxury carmakers that traditionally were seen to be craft producers. The adoption of diverse ownership structures, the wave of mergers and acquisitions, and the exponential establishment of international collaborations further increase the complexity of the industry competition (Holweg, 2008). From a consumer perspective, the image of the car takes intrinsic connotations in the modern times, seen from being a rich man's good into a collector's item, functional vehicle, status symbol, but also as a product of political power. Over the past century, the complexity of the organizational environment and the evolution of the dynamics in the automotive industry imply that today's management is confronted with far more issues and complexities than 50 years ago. The results of this process are a wider range of vehicles, short development times, increased productivity, increased outsourcing, and strong international competition, coupled with new government regulations for improving fuel efficiency and safety in order to cope with the increasing social concerns about auto pollution, traffic congestion, and auto safety (Papadopoulos, 2013).

1.3. Industry characteristics and attractiveness

The multitude of factors affecting the automotive sector makes it complicate to clearly identify the characteristics of the industry and the direction it is likely to take in the following years. The economy is in a continuous state of flux, sustainability concerns have become extremely important, and the strict government policies are changing the way business used to operate. The faster pace of innovation and emergence of new technologies, together with digitization and the use of new unconventional business models are further fueling the general consensus that the industry is ripe for disruption. The future of car sales seems to be shaped by the recent megatrends and the massive transformation the global automotive industry is experiencing. A study conducted by Schiller et al (2020) identifies four main disruptive drivers that perhaps will shape the future of car sales and the automotive aftermarket until 2035: connectivity, autonomous driving, shared mobility, and alternative drivetrains.

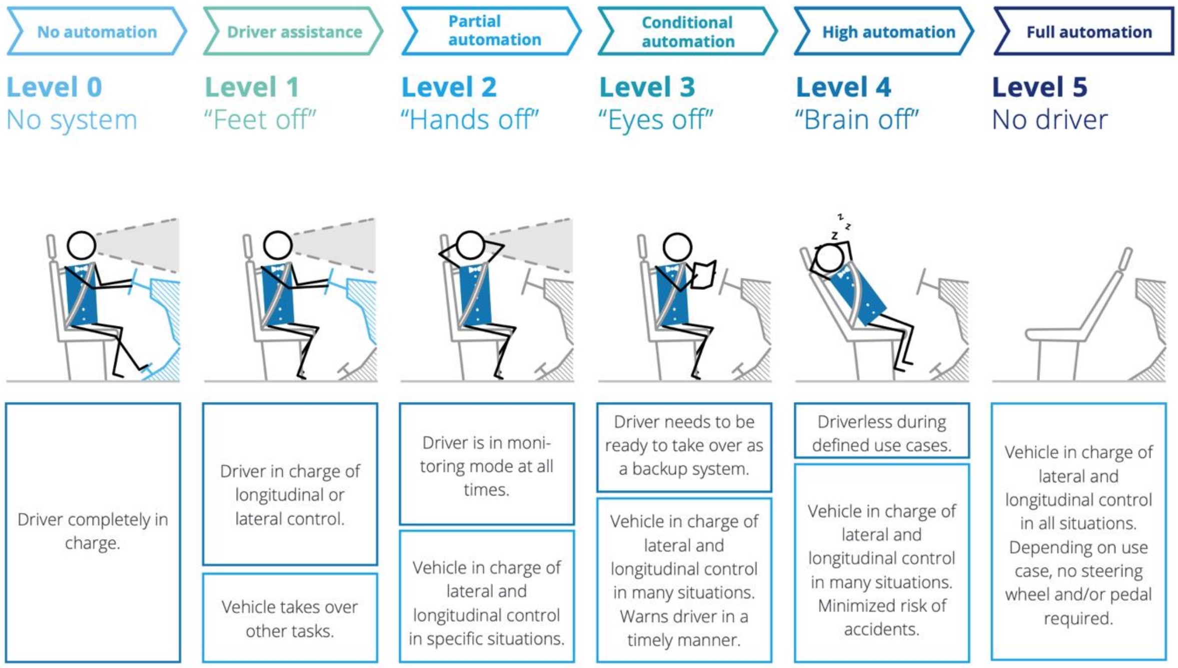
- *Connectivity*

Connectivity is a wide concept that involves both the cars and the customers. A connected vehicle communicates through a wireless network with the Internet, road infrastructure, or even other vehicles or pedestrians. In this product architecture, data are continuously exchanged to monitor external hazards and internal responses of the vehicle to hazards, thereby increasing driver and passenger safety. In addition, vehicle fuel consumption and tire wear can be optimized thanks to data acquired by the vehicle regarding real-time traffic and weather conditions, which calculates the best routes and driving behaviors the driver should follow. The rise of 4G LTE and emerging 5G networks enable new scenarios for the connected vehicles and forecasts show that almost all the cars sold by 2035 will be connected (Schiller et al, 2020). This makes customers happy given the huge amount of digital content available through in-car entertainment and a variety of infotainment options. Parallelly, connected vehicles seem to be one of the main drivers for the transition towards zero-emission vehicle due to fuel efficiency they can guarantee.

- *Autonomous driving*

Autonomous driving represents the technology that enables vehicles to drive autonomously without the need of human intervention. Despite government regulations, customer acceptance, and safety concerns still represent obstacles for the widespread adoption of autonomous vehicles, Gao et al (2016) suggest that by 2030, almost 15% of the vehicles in the market will be fully autonomous. The technology upon which autonomous driving relies is the ADAS ("Advance Driver-Assistance Systems"), which uses sensors in the vehicle such as radar and cameras to perceive the world around it. These sensors gather real-time information during driving, elaborate it, and permit the vehicle system to take automatic action based on what it perceives. ADAS can evolve in different versions, ranging from fully manual to fully automated systems (see Figure 4).

Figure 4. ADAS levels.



<u>Source</u>: Retrieved from Gao et al (2016)

ADAS Level 5 is of course the most challenging level, both for the current government regulations limiting its adoption and for customer concerns about safety and security. Transitioning from ADAS Level 2 to ADAS Level 4 will be the most important step for the adoption of the last level, and carmakers are now introducing into the market vehicles with these levels of autonomous driving. Features such as lane departure warning system, parking assist, automated braking, and adaptive cruise control have already become standard in many new vehicles. Tesla's Autopilot, for instance, provides a suite of driver assistance features that are standard in any new vehicle delivered by the American carmaker, starting with Model 3 and Model Y. Traffic-aware cruise control and autosteer are some of the functionalities available to Tesla's owners, and the driver assistant package can be integrated with additional features just by purchasing the Enhanced Autopilot version or the Full Self-Driving Capability package. Tesla's autonomous driving features are among the most developed technologies available in the market, but they only refer to ADAS Level 2. Recent rumors see Elon Musk, CEO of Tesla Motors, saying that by 2023, Tesla vehicles will achieve ADAS Level 4 autonomy (Mitrache, 2022). It seems to be a challenging path and further developments are necessary to make it possible, but this statement underlines the efforts carmakers will take in the upcoming years to make progress in autonomous driving.

- *Shared mobility*

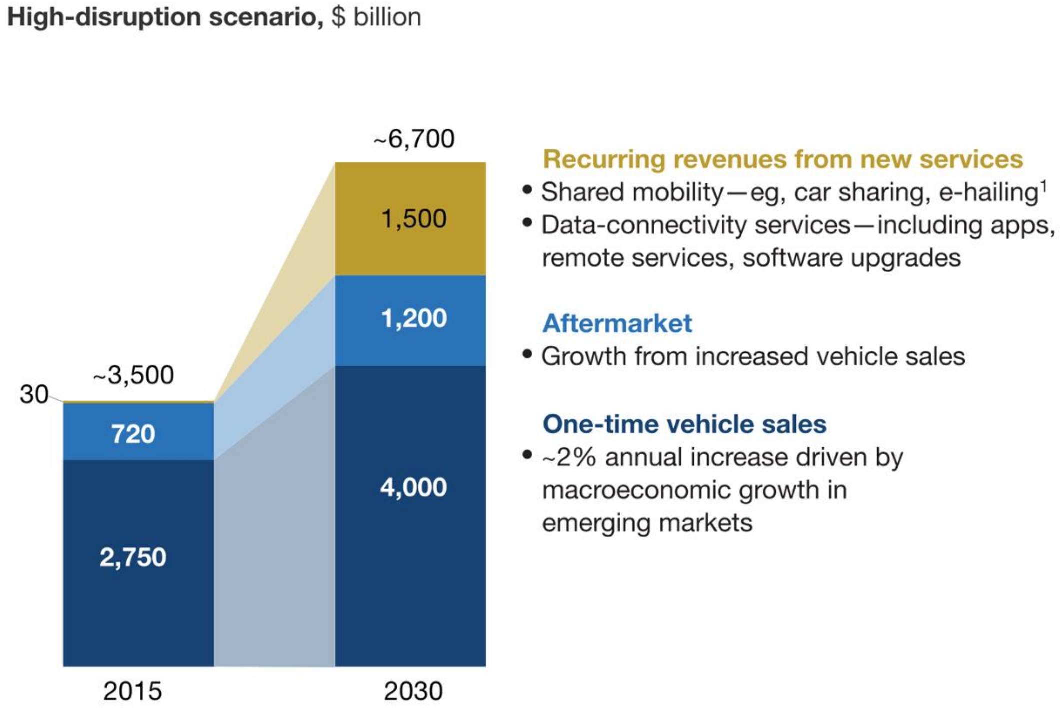
Encouraged by autonomous driving and consumer connectivity, shared mobility will change consumer preferences and purchasing choice, reducing private ownership, and increasing the number of fleet operators. Coordination of information is made possible thanks to connectivity between cars, consumers, and fleet service providers. This coordination allows multiple drivers to drive the same car one by one during the day, reaching the maximum efficiency of the vehicle and increasing its utilization. The spread of new payment processing infrastructures and the advent of pay-per-use mobility enhance the preferences of consumers to choose usage-based mobility services over private ownership. Apart for the overall perceived higher economic benefit from asset-sharing, consumers demand for flexibility, especially in metropolitan and highly urbanized areas, has led to this shift. Considering the number of different transportation solutions available to consumers nowadays, it becomes clear that focusing only on traditional business models of car sales is no longer feasible due to the presence of complementary on-demand mobility solutions. To complete their journeys, consumers will increasingly choose the best solution for each specific purpose, on demand and via their smartphones. Mobility shared platforms like BlaBlacar, ShareNow, and Enjoy have already become famous in many metropolitan areas, on a par with less recent platforms such as Uber. According to Schiller et al (2020), fleet operators vehicle ownership will be the new and future frontier for automotive companies, representing the largest customer share for most OEMs. This means that many carmakers might start designing vehicles specifically for shared mobility purposes, with a focus on high utilization, robustness, fuel efficiency, and passenger comfort.

- *Alternative drivetrains*

Conventional combustion engine vehicles are being displaced in favor of alternative drivetrains, battery-electric vehicles among all. A mix of different varieties of drivetrains coexists with the electrification trend so that hybrid-electric vehicles and fuel cell vehicles still take an important position in the market. The spread of these new alternatives is contingent upon the development of suitable charging infrastructures and regulations and depends also on solutions to decrease production costs and increase vehicle performance. The majority of OEMs is investing lots of resources in R&D to integrate these alternative drivetrains within their traditional business model, partially induced by the stringent environmental regulations affecting the automotive industry in the last years.

Given the huge incidence of these drivers in leading the massive transformation of the industry, the study reveals that many OEMs will struggle to remain as profitable as today in the next future if they do not considerably transform themselves to cope with the changing business environment. Alternative fuel solutions like electricity may have a strong negative impact on those highly profitable aftersales businesses that rely on their consolidated position in the market without taking into consideration this transformational process. Indeed, recent emerging automotive markets are thought to play an important role in the years to come. For instance, the Chinese market is expected to generate more than 80% of total growth, compared to a slower and moderate growth in Europe, United States, and Japan (Schiller et al, 2020). Gao et al (2016) also study the wave of disruptive technologies-driven trends that hit the industry, trying to make sense of the consequences that they will have on traditional vehicle manufacturers and suppliers, potential new players, regulators, consumers, markets, and the automotive value chain. According to the study, despite the annual growth rate is projected to growth at a lower rate of about 2% per year, there are still vast opportunities to keep growth in global car sales at more than a satisfactory level. Positive macroeconomic development, especially in emerging economies, is forecasted to drive global growth. The consumer mobility behavior is likely to affect his purchasing choices, shifting from the traditional business model of car sales to a range of diverse, on-demand mobility solutions, especially in dense urban environments that proactively discourage private-car use. Consequently, these new business models - which rely on shared mobility, connectivity services, and feature upgrades - have the potential to increase the automotive revenue by 30%, adding up to $1.5 trillion by 2030 (see Figure 5).

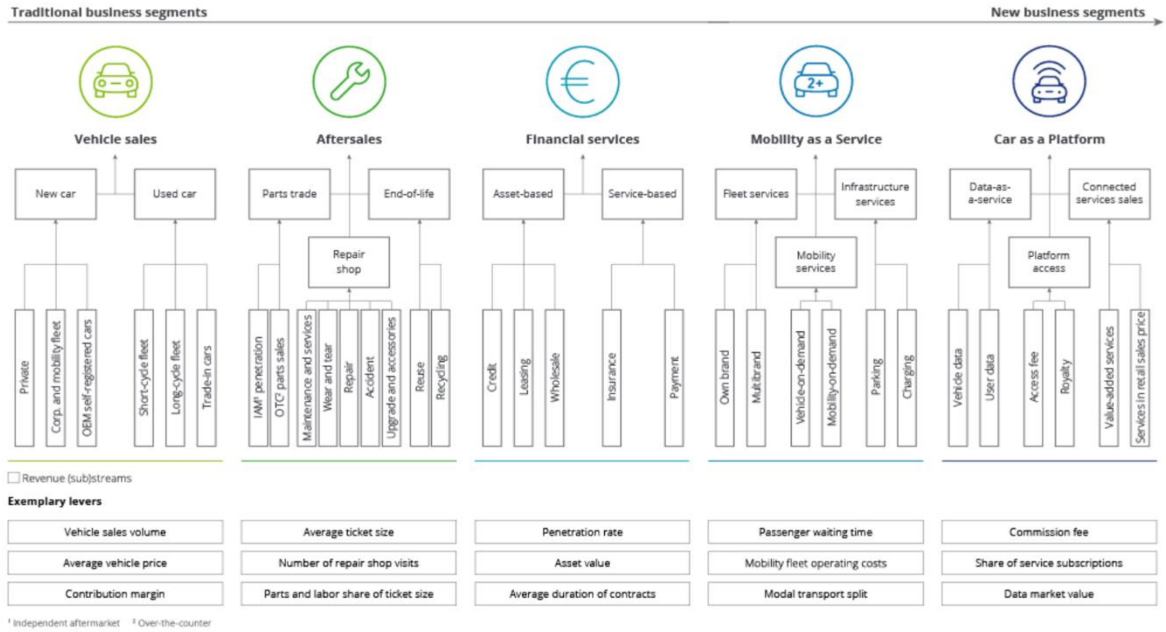
Figure 5. The automotive revenue pool.



<u>Source</u>: Retrieved from Gao et al (2016)

Figure 6 illustrates the sources of revenues of OEMs, which remain valid from here to years to come.

Figure 6. OEMs' sources of revenue.



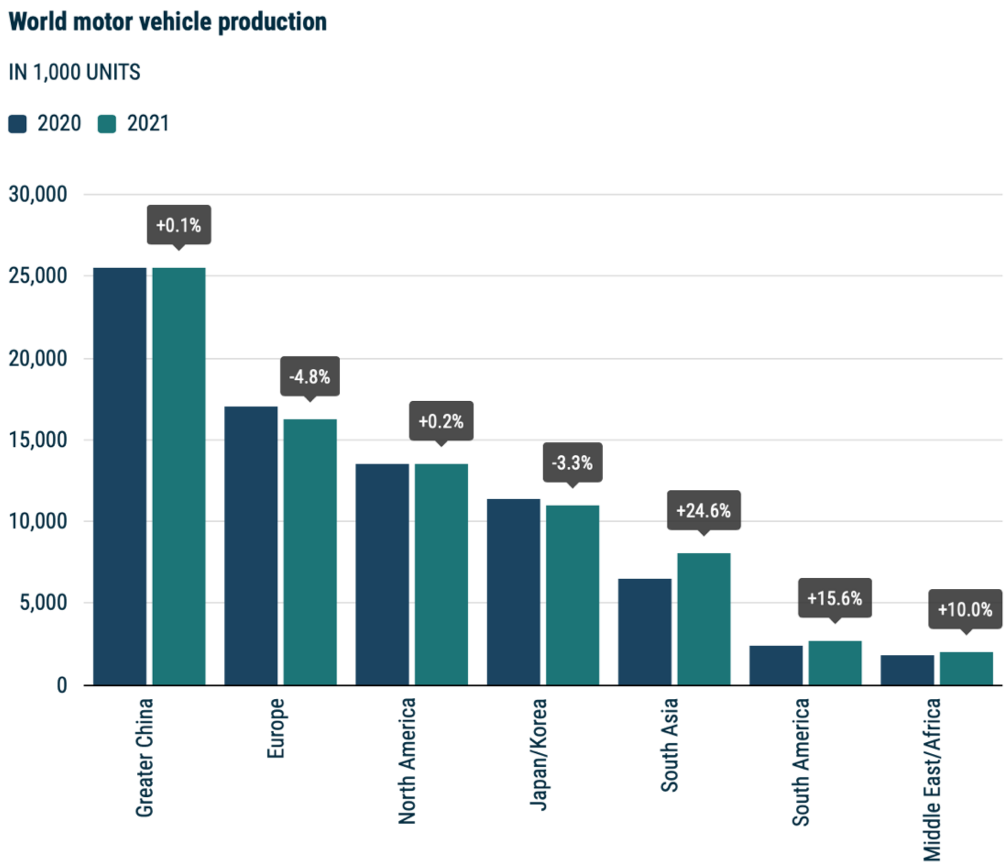
Source: Retrieved from Schiller et al (2020)

Considering the validity of these five business segments, competition in the automotive industry clearly depends on multiple fronts and new complex dynamics that are likely to emerge. The abovementioned dynamics put pressure on traditional companies, which need to find ways to cope with the increased uncertainty brought about the entrance of mobility providers (e.g., Uber), tech giants (e.g., Apple, Google), and specialty OEMs (e.g., Tesla) into the competitive landscape. Therefore, it is essential to take into consideration the variables of change, investing resources to support production and increase revenues during this transformational process the industry is experiencing, especially considering the relevance of the sector in the global scenario. Indeed, the number of people employed in the automotive industry in EU accounts for 6.1% of total EU employment (European Commission, 2022) and the country is among the world's biggest producers of motor vehicles. The competitive forces affecting the industry may represent a threat for EU carmakers, but the European Commission constantly provides funding for R&D to strengthen the competitiveness of the EU automotive industry, which constitutes the largest private investor in research and development.

1.3.1. Production trajectories

In the four quarters of 2021, the motor vehicle production accounted for 16,3 million units in Europe, compared to 16,1 million in America and 46,7 million in Asia/Oceania. The world motor vehicle production in the four quarters of 2021 decreased by -13% compared to 2019, from 92,1 million units to 80,1 million ("Production statistics", 2021). The major drop in production has been experienced in Europe, where the variation reached -24%. The pandemic situation is surely one of the major causes of this drop, considering that the period considered is between 2019 and 2021. Indeed, the drop was only -4% during the period from 2020 to 2021. Other countries performed better in term of production statistics, such as America and Greater China, which experienced a slight increase from 2020 to 2021, despite still being behind the level of 2019. The European Automobile Manufacturers Association ("World motor vehicle production", 2022) shows the trend of production covering the period from 2020 to 2021 (see Figure 7).

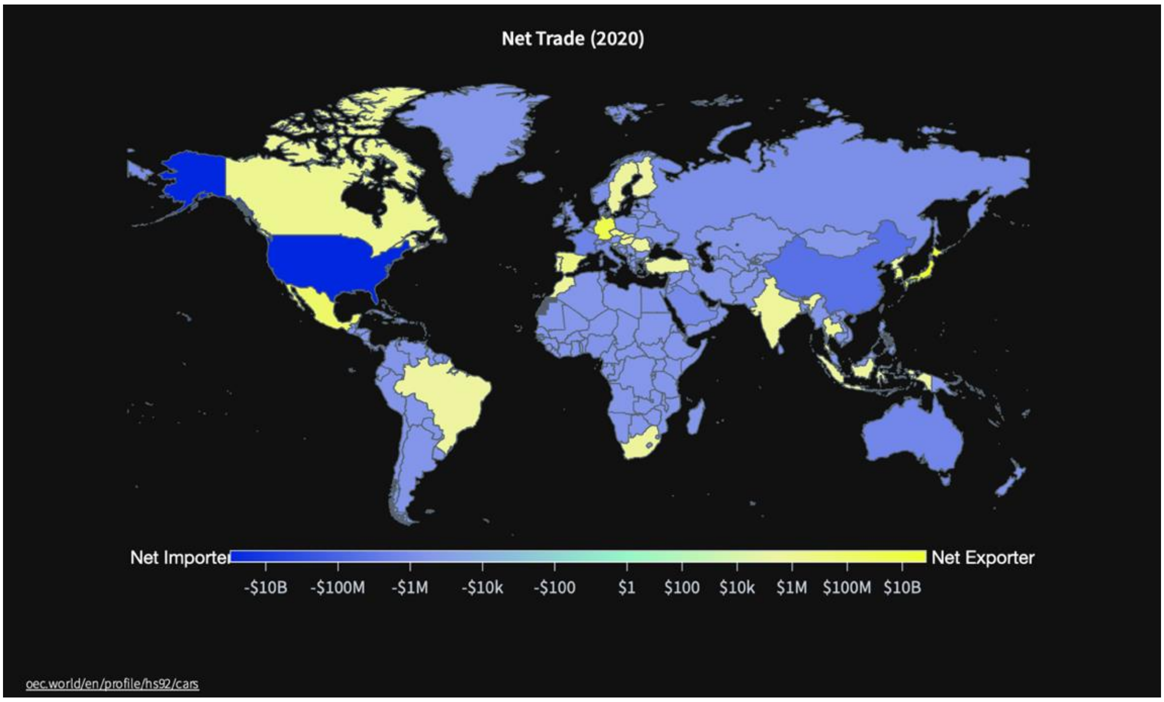
Figure 7. World motor vehicle production 2020 – 2021.



<u>Source</u>: Retrieved from "World motor vehicle production" (2022)

Overall, there has been an increase of production from 2020 to 2021 that may imply a recovery of the industry in economic terms. The Greater China seems to play a very important role in the following years, and many car manufacturers have already opened manufacturing plants in this region, for example Tesla Motors in Shanghai. The role of China in the global automotive industry is enhanced also by the effective efforts of the Chinese government to support the production of new-energy vehicles such as electric or hybrid cars (Noël, 2020). Despite China being the world's largest light vehicle manufacturer, export levels of the country still fall behind as only around 3% of passenger cars produced in China were exported in 2019. Chinese export has been mainly constrained by the saturated market and the shift in foreign trade policies. At the same time, given the increasing demand for luxury cars, import has seen a growth in the country, especially from Germany and the US (Ma, 2022). The increasing electric vehicles production in China seems to be fundamental and potentially poses the basis for its expansion in foreign markets. Equally important is the export of Chinese-made parts and accessories, a subsector where the country positions itself as one of the top exporters. Worldwide, the top exporters of motor vehicles in 2020 were Germany, Japan, the US, Mexico, and South Korea, while the main importers were the US, China, France, and the UK. According to Observatory of Economic Complexity (OEC World, n.d.) map, the top net exporter in 2020 was Japan ($72,8 billion). Parallelly, the top net importer in the same year resulted to be the US ($96,6 billion).

Figure 8. Net trade 2020.



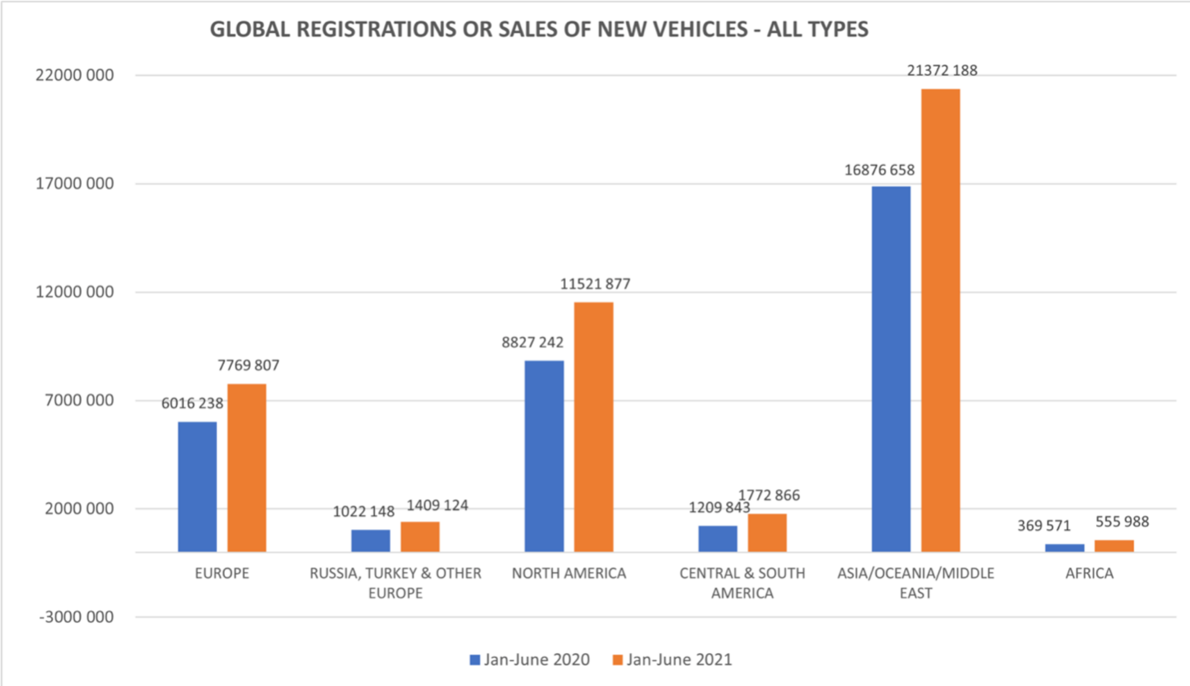
Source: Retrieved from OEC World (n.d.)

Dividing the production of vehicles by category, 82% of European motor vehicle production involves passenger cars, while the remaining part of the shares – 3.9%, 13.8%, and 0.2% respectively - includes commercial vehicles likes trucks, vans, and buses ("EU motor vehicle production by type", 2022). In this sense, the trajectory of production according to each category seems to justify the recent trends concerning the use of public infrastructures, together with the diffusion of alternative mobility solutions, especially in big cities. In fact, there has been a drop of 7.7% in the number of passenger cars produced in Europe in 2021, compared to 2020 ("EU passenger car production", 2022). On the other hand, the production of commercial vehicles in Europe increased by 1% during the same period ("EU commercial vehicle production", 2022). What is particularly interesting is the increasing diffusion of electrically chargeable buses, whose production experienced a strong growth in 2021 (+78.7%). Focusing on the Italian automotive industry, in 2019 the country ranked 6th in Europe and 19th in the world in terms of motor vehicles and related components production. There are three main automotive industry districts engaged in the manufacturing of motor vehicles, located in Piedmont, Emilia Romagna, and Abruzzo, whereas many SMEs operate in the component sector all over the Italian territory. The main portion of production output is attributable to companies belonging to the FIAT-Chrysler group. Given the importance of partnerships and cooperation between companies along the value chain, there is also a strong presence of foreign multinational group subsidiaries in the territory. High capital intensity, inflexible automated production lines, and substantial economies of scale are among the elements that characterized the structure of production ("Automotive industry report", 2020).

1.3.2. Sales trajectories

The International Organization of Motor Vehicle Manufacturers ("Global sales statistics 2019 – 2021", 2022) reports registrations and sales of new vehicles covering the period from 2019 to 2021. Compared to the production trajectory abovementioned, sales of new vehicles show a similar trend. There has been a considerable drop of -9% relating to the worldwide sales of new vehicles in 2021, compared to 2019. The total worldwide sales of new vehicles in 2019 amounted to 91,2 million and drop to 82,6 million in 2021. America and Europe are those countries that have been the most affected ones with a -13% and -19% figure respectively, while Asia/Oceania experienced a minor contraction of -2%. Indeed, as shown in the graph retrieved from the International Organization of Motor Vehicle Manufacturers ("Global sales Q1-Q2", 2022), Asia/Oceania has been the number one region in terms of sales and registrations of new vehicles, with North America and Europe falling behind it.

Figure 9. Global registrations/sales of new vehicles.



<u>Source</u>: Retrieved from "Global sales Q1-Q2" (2022)

Similarly to the production trajectory, there is evidence of a recovery in worldwide sales from 2020 to 2021, which increased by +5%. The growth involves both the sales of passenger cars and commercial vehicles. According to IBISWorld ("Global Car & Automobile Sales", 2021), the projected global automobile sales market size is expected to growth further by 5.3% in 2022, now accounting for $3,8 trillion. Significant growth is expected to interest developing countries like India and main markets as the Chinese one. According to Hecker et al (2018), the increasing environmental awareness of Chinese consumers has brought them to look for lower vehicle emissions, moving most Asian markets towards electrified vehicles. There are spaces in the Chinese market for new entrants specialized in fully autonomous technologies, potentially shifting even more the sphere of influence of the region in the automotive scenario. Indeed, the strong negative impact that electrification may cause to consolidated highly profitable businesses implies that without a major transformation in the industry, it is difficult to survive and generate revenues. Considering the propensity of Chinese car manufacturers to invest in technological and alterative car-related solutions, more than 80% of total growth is forecasted to be generated in the Chinese market, while Europe, the US, and Japan are expected to show only moderate growth. Used car business and shared usage are two additional drivers affecting growth of motor vehicles sales, hand in hand with macroeconomic trends such as wealth, demography, and urbanization (Schiller et al, 2020). Drury (2021) argues about the economic impact of the Coronavirus pandemic on the values of vehicles, mainly used ones. He suggests that there are external factors that are very important for the valuation of a vehicle, and in turn this valuation potentially affects the number of new vehicles sold in the market. For instance, supply chain constraints are currently impacting the final delivery of new vehicles, which sometimes exceeds a year of waiting for some car makers. This situation has increased the valuation and price of used vehicles because consumers' requirement for lower waiting time boosted demand for used vehicles that can be delivered within a range of time extremely lower compared to new vehicles. Car manufacturers that are able to deliver cars within a suitable range of time despite supply chain disruptions are expected to gather most of the benefits now and during the following years. For example, Tesla Motors has been able to hit another record delivering 308,600 vehicles in the fourth quarter of 2021, riding out global chip shortages and major supply chain disruptions. During the first quarter of 2022 the company performed even better, delivering 310,048. This number is surprising if compared with the number of vehicles delivered in the previous year same period, being 184,800 (Kolodny, 2022, April 02). As highlighted in Figure 10, Tesla Motors is currently the largest automaker by market capitalization, ahead of giants such as Toyota, Volkswagen, General Motors, and Ford ("Largest automakers by market capitalization", 2022).

Figure 10. Top ten automakers by market capitalization.

Rank	Name	Market Cap	Price	Today	Price (30 days)	Country
1	Tesla TSLA	$779.66 B	$752.29	▲ 2.54%		USA
2	Toyota TM	$215.11 B	$156.76	▼ 0.25%		Japan
3	BYD 002594.SZ	$135.69 B	$50.49	▼ 3.26%		China
4	Volkswagen VOW3.DE	$94.64 B	$136.91	▲ 5.91%		Germany
5	Mercedes-Benz MBG.DE	$60.86 B	$56.89	▲ 3.75%		Germany
6	BMW BMW.DE	$48.45 B	$77.43	▲ 1.68%		Germany
7	General Motors GM	$47.11 B	$32.31	▼ 1.07%		USA
8	Ford F	$45.88 B	$11.62	▼ 0.26%		USA
9	Honda HMC	$41.32 B	$24.16	▲ 0.33%		Japan
▲2 10	Stellantis STLA	$39.50 B	$12.61	▲ 2.60%		Netherlands

<u>Source</u>: Retrieved from "Largest automakers by market capitalization" (2022)

Contrarily, the ranking of the biggest car manufacturers by revenue shows Volkswagen placed at the top, with Toyota and Daimler sitting in the remaining positions of the podium (Handan, 2021).

1.3.3. Exploring opportunities and threats

The revolution the automotive industry is going through is likely to affect the competitive dynamics in the market, creating opportunities and threats for new potential competitors and for those already consolidated within it. The latest trends concerning among others diverse mobility, autonomous driving, electrification, and connectivity constitute a threat for those car makers that are rooted in the automotive industry since the beginning of its birth. At the same time, companies that want to embrace and have been able to exploit the technological revolution of the last years seem to be in a better position to take a large slice of the market in the years to come. A clear example is Tesla Motors, which have been able to reach the first place in terms of market value and a good portion of the market thanks to its culture based on innovation capabilities and cutting-edge technologies, putting out of the EVs market many big car makers with years and years of experience in the automotive industry. In any case, this disruptive phenomenon makes it difficult to forecast the shape the industry will take in the next years, also considering its intrinsic characteristics.

Threat of new entry in the automotive industry is known to be low because companies need a large amount of capital upfront to reach economies of scale needed to strive in the market. Despite the high differentiation of products by design and engineering quality, reputation and brand image still play a fundamental role in driving the purchase choice of consumers. There are several companies that have historically established a well-known reputation for the quality of their cars and new entrants would need to invest a lot in their image to be recognized as trustable and high-quality. Indeed, it seems to be extremely important in the future, for both incumbents and new entries, to remove any skepticism costumers may have regarding the new disruptive technologies delivered in the market. A study conducted by Hecker et al (2018) involving the Chinese consumers' evolving automotive expectations shows that while interest in traditional powertrain technologies is declining in favor of full EVs and hybrids, there are still concerns about the quality and functionality of these new vehicles (e.g., EV range anxiety and safety of full self-driving vehicles). The study argues about the role the brand trust will have in affecting consumer opinions, highlighting that opinions regarding the safety of fully autonomous vehicles (AVs) has improved significantly in this period. This creates an important competitive advantage in the market for those new emerging AV technology players that invest enough resources for developing brand trust and customer loyalty. According to Cretu and Brodie (2007), brand image and company's reputation have a positive influence on perceived quality, customer value and customer loyalty. They argue that by investing resources in these dimensions, companies can affect the costumer's trade-off between the perceptions of product and service quality and the price to pay for the product and service. This is especially relevant for brand-owners of consumer goods as they are more vulnerable to negative publicity about social or environmental conditions in their supply chain for instance.

Brand image and reputation are also drivers for long-lasting relationships with component producers and after-market distribution networks, which contribute to high entry barriers in the industry. New entrants like cash-rich high-tech companies and startups are for these reasons expected to target initially only specific, economically attractive segments and activities along the value chain before expanding into further fields, creating opportunities in diverging markets also for those companies outside the automotive industry that are generating interest around new mobility forms. On a parallel road, incumbents are forced to compete simultaneously on multiple fronts to face these new disruptive trajectories the industry is taking. The consequence of the shift in the paradigm to mobility as a service is an increased complex competitive landscape where mobility providers such as Uber, tech giants as Apple or Google, and specialty OEMs like Tesla Motors put under constant pressures those traditional automotive players already operating in the industry for years. Furthermore, considerable relevance has to be attributed to the increasing need for software competences, which are becoming important differentiating factors for the industry, especially for domains covering ADAS/active safety, connectivity, and infotainment. All of this creates the conditions for a future scenario where market positions shift in favor of those companies that can embrace the transformation by leveraging partnerships and open, scalable ecosystems, by addressing new challenges like cybersecurity or data privacy, and by developing new integrated mobility-business models with an omnichannel strategy (Gao et al, 2016).

Of course, while this implies that there can be several opportunities coming from these new mobility-business models, it also assumes that competition from substitutes can be a threat, perhaps because they always cost less and sometimes are more environment friendly. Indeed, rivalry among existing firms in the automotive industry mainly focuses on aggressive pricing strategies, which often include trades in used vehicles or interest-free financing. Pressure for lowering prices also comes from competing suppliers based in emerging countries that offer cheap components with low value added. According to the study conducted by the Italian Trade Agency ("Automotive industry report", 2020), one of the critical success factors will be the ability to cooperate simultaneously with the entire production chain, including both cooperation between carmakers and between component producers. There are several advantages that can be gained from cooperative strategies. Among these advantages, relevant for the automotive industry is the opportunity to reduce the burden of high R&D costs and to acquire learning capabilities and technical skills by pooling knowledge and know-how of several different companies.

In addition, the study argues about the important role of the brand image and international partnerships previously discussed, as well as about the opportunities that carmakers might encounter in areas such as development of innovation capabilities, green mobility – defined as the biggest growth opportunity for the sector – and shared mobility services.

If the quality of life continues to improve, availability of data and information reaches even the remote areas, and new markets like Asian and BRIC nations further acquire economic importance, demand for new vehicles will increase accordingly, expanding the opportunities in the automobile market. Stringent regulatory requirements for safety and for reducing the CO_2 emissions are expected to increase the demand for fuel efficient vehicles. High intensity and capacity of R&D places established carmakers in a favorable position to exploit the plethora of opportunities associated to the optimization of fuel-driven combustion engines. R&D expenditure drives the next phase of growth brough about the advent of EVs and alternative fuel, coupled with governmental tax subsidies to encourage their adoption.

Despite the negative impact of the Covid-19 pandemic, recent developments see in addition an increasing request for luxury vehicles, also in those developing countries where the standard of living is rising exponentially. More spending power and consumer preferences for products that incorporate safety and cutting-edge innovations led to the growth of the luxury and premium car segments ("Automotive Motors Market - Global Forecast to 2025", 2020). Automobili Lamborghini for example recorded its best sales results ever, with 8,405 cars delivered worldwide in 2021, thanks to the solidity of its strategic plan and the brand's outstanding international reputation ("New sales record in 2021 for Lamborghini", 2022). Gokhale et al (2021) reveal that among the most critical predictors of purchase intention of luxury cars are style, social parameters, fuel economy, performance, safety, and brand.

On the contrary, because of the shift from demand to supply market, bargaining power of buyers cannot be considered low. The presence of a wide variety of options available and a differentiated range of products reduce switching costs for the consumer who can choose between alternative transportation methods or alternative car brands with low efforts. Price sensitivity is a related matter that cannot be left behind.

Hence, the automotive industry is subject to threats concerning macroeconomic uncertainty, recession, and unemployment, which affect the growth of the industry because they can cause volatility in the fuel prices and in the prices/availability of raw materials and components. Two of the major constraints in the automotive industry are indeed the availability of materials and cost competitiveness in manufacturing process. This will be even more evident in the next years because estimates show the demand of EV batteries to increase dramatically. These batteries are built with rare materials such as nickel, cobalt, and lithium. Only few suppliers provide these materials, most of them located in China, the country accounting for 75% of all battery production globally. The rare minerals shortage problem is expected to have a long-term impact on electric transportation and fleet strategies. Estimates show that while the number of EVs will reach 56 million units by 2050, 2,000 million tons will be the amount of total material required for lithium-ion batteries (LIBs), 35 times the amount needed in 2015 (Gökmen, 2021). This threat is pushing carmakers to think about alternative and innovative supply and production policies to cope with dramatic delays in production lines and delivery times of new cars. Consequently, prices of new cars for most brands have increased remarkably in the last period. According to Kaneva ("Driving into 2025: The Future of Electric Vehicles", 2018), head of metals research and strategy at J.P. Morgan, "Auto producers and battery makers are very sensitive to raw material costs. Proportionally, the cost of raw materials will increase over time relative to the total cost of the battery pack. In fact, if total battery pack prices drop from $209/kWh to $100/kWh, but raw material costs stay the same, the raw materials cost would account for 56% of the price, substantially higher than today's 27%.".

Apart from materials used in production of EVs batteries, the ongoing chips and semiconductors shortage, Covid-related plant shutdowns, logistical problems involving shipping containers and truck drivers, and employment related matters also contribute to raise the cost of the current supply chain crisis. For instance, the stringent local rules in Shanghai blocked production at Tesla Giga Shanghai, probably the top production source of Tesla Motors in 2021. This closure may have resulted in a possible loss of $2 billion of revenue, represented by a production loss of about 45,000 vehicles (Ohnsman, 2022). Supply chain disruptions have had a major impact on the automotive sector during the Covid-19 pandemic, and if coupled with the current and future threats abovementioned, they make it clear the need for carmakers to rethink their supply chain strategies for the longer term.

1.4. Managerial and supply chain dynamics

Globalization of markets and the spread of information through the Internet have pushed companies to engage in relationships outside of their domestic boundaries. Outsourcing and international partnerships are commonly in use across companies in the automotive industry. The capacity to establish a network of trustable relationships with agents along the entire value chain is particularly relevant when innovation capabilities and development of cutting-edge technologies are valuable. Mattsson (2003) sees the global market as "networks of multidimensional, dynamic exchange relationships between economic actors who control resources and carry out activities". He thereby argues that this interconnectivity between agents and between markets cannot work without considering the reorganization of the firm's distribution activities and organizational structures. If this is to be true, the transformational process the automotive industry is currently going through might imply that new business models and supply chain strategies must be adopted to remain in a profitable position in the market. Enyinda et al (2008) say that to survive competition at a global level, increase customer value, sustain competitive advantage, and enhance the operational efficiency and profitability of the firm, one of the most effective strategies is the establishment of a global supply chain. Given the importance of having a well-coordinated flow of materials along the chain, one of the consequences of global sourcing, time and quality become fundamental dimensions to drive competition. Companies therefore tend to focus on getting closer relationships to achieve flexibility both in the individual companies and in the supply chain relationships, thereby favoring coordination. This seems to be the right strategy during turbulent times, when the changing technology conditions and the increasing market uncertainty make it difficult to manage performance at global level (Mentzer et al, 2011).

1.4.1. Supply chain resiliency and responsiveness

If considerations are to be made concerning the fast-changing environment in which automotive companies operate, the concept of resiliency is likely to acquire relevance. Defined by Kamalahmadi and Parast (2016) as the capability of a supply chain to restructure quickly in case of disruptions, it allows companies to recover effectively and preserve performance under challenging and emergent circumstances. There are several positive aspects related to building supply chain resiliency. Companies must address the risks coming through both external sources (e.g., natural disasters) and internal issues (e.g., failure to integrate supply chain operations). Tiwari et al (2015) also argue that building responsive supply chain is particularly beneficial for performing well in uncertain and volatile environments. They study the role of flexibility to cope with disruptions and describe it as a multi-dimensional construct composed by three distinct components: adaptability, alignment, and agility. All these components render the supply chain responsive in meeting structural changes in markets and modifying supply network designs and strategies, creating incentives among supply chain partners, and responding to short-term changes in demand or supply quickly. Then, supply chain and end customer needs can be achieved both at once if agility and flexibility are combined, through a dynamic configuration of several parameters, including product, partner, and relationships, as well as priorities such as time, cost, quality, and risk (Fayezi & Zomorrodi, 2015). Supply chain resiliency and responsiveness hence ensure operational continuity and enable the system to face unpredictable events avoiding the negative impacts usually associated to them.

The negative effects many companies are bearing after Covid-19 pandemic hit the world are a clear example of how disrupting and unpredictable events can jeopardize the profitability of a company and pose serious risks to its survival. Sugiura and Tanaka (2021) explain the limits of some supply chain management strategies in coping with the recent disruptive events. The Covid-19 pandemic first, followed by shortages of car components like semiconductors, chips, and wire harnesses, have resulted in an exponential rise of costs and prices and a nonstop chain reaction of disorder. "Just-in-time" practices, become famous with the Toyota production system, have been under extreme pressure in this period. Adopted by most carmakers in the automotive industry, “just-in-time” practices revealed vulnerabilities throughout the entire supply chain. While their essence translates in concepts as no waste in stockpiles or no overproduction, carmakers like Toyota and Nissan are currently changing their view in favor of increase in stockpiles of chips as a contingency measure. Because many car companies have not been able to deal with shortages in semiconductors, $210 billion revenue is estimated to be lost in the automotive industry in 2021 (Sugiura & Tanaka, 2021). In virtue of this, a shift from “just-in-time” to “just-in-case” seems extremely important, that is explained through the urgent need for companies in the automotive industry to rethink the supply chain network and make it more resilient. It is likely to come with a tremendous cost upfront, but the gains will be accrued from years to come.

Pettit et al (2011) developed a model that takes into consideration the combination of possible vulnerabilities and capabilities of the supply chain. These are described respectively as potential causes of disruptions within or among supply chain members and the ability of each supply chain actor to handle the unforeseen situations by integrating, reconfiguring, and adapting strategies according to the disruption. Among the vulnerabilities identified, external pressures, resource limits, and connectivity seem to be strictly connected to the disruptions the automotive industry is currently facing. By contrast, they also emphasize those supply chain capabilities that might counteract these vulnerabilities, among which there are flexibility in sourcing, visibility, adaptability, and collaboration. The level of resiliency is nothing more than the balance between these factors, but what is worth mentioning is that both risks and capabilities need to be assessed as they have an impact on the performance and efficiency of the supply chain. Indeed, according to a study conducted by Jüttner and Maklan (2011), supply chain risk knowledge is positively associated to supply chain resiliency. Companies should engage in practices that mitigate risks across the various stages since these practices can enhance flexibility, visibility, and collaboration in the supply chain.

This is particularly important when speaking about global supply chains, where operations are spread across many developing countries around the world. Vulnerability of supply chains in these areas is more prominent and requires far more attention. Consequently, greater levels of visibility need to be achieved to better predict and manage risk. Kaviani et al (2020) carried out an analysis involving companies in the automotive industry that builds upon the model above mentioned to measure resiliency of their supply chains located in developing countries. Cultural, geographic, and economic distance is likely to impact operations of companies that have a wide geographical scope. Evidence shows that these companies need to focus more on collaboration and flexibility in sourcing to achieve the desired level of resiliency.

1.4.2. Risk management and supply chain complexity

Risk management practices work especially well in companies that have a wide geographical scope, because the increased complexity of the environment makes these practices fundamental to anticipate the risks that may occur in different areas of the supply chain and mitigate their negative impacts. A correct analysis of the relevant market can be useful to define the boundaries within which disruptions might have an impact, however the analysis must be accompanied by both an extensive risk identification/prioritization and the preventive development of contingency and risk mitigation plans ("Top 4 Automotive Supply Chain Challenges and Solutions", n.d). In the automotive industry, for example, relocating some operations to different countries or including vehicle parts backup manufacturing can help avoiding the negative effects of a disruption that results in shortages of raw materials and components.

Risks involve every activity in the supply chain and what is worst is that issues at one stage affect the entire system, causing a chain reaction that affects the whole performance. Hence, effective supply chain management should consider how to anticipate these risks and how to recover quickly from the subsequent negative impacts after their occurrence. As Ritchie and Brindley (2007) argue, the implementation of supplier management tools and control systems yields to performance maximization and risk mitigation, thus this demonstrates how risk and performance are related with each other. Given the relationships between risk and performance, the use of appropriate risk management strategies might generate a competitive advantage and sustain long-term competitiveness.

Moreover, what is important to denote is that although performance maximization is clearly important, assuring supply chain resilience and robustness it is equally so, especially in the current turbulent business environment in which most of the companies in the automotive industry operates. El Baz and Ruel (2021) investigate how the effects of disruptions on supply chain resilience and robustness can be mitigated by supply chain risk management. They consider events with low frequency and high impacts, like the Covid-19 pandemic, because these events are extremely difficult to forecast and therefore show the effectiveness of preventive and recovering practices in mitigating their effects. Indeed, if not handled appropriately, they can threaten supply chain resilience and robustness. During the pandemic, 94% of the top 1000 biggest companies by revenue has experienced disruptions in its supply chain, perhaps because the very low probability of the occurrence of such event has constrained companies from developing effective mechanisms to guarantee their resilience and resistiveness (Sherman, 2020).

Vulnerabilities have been also exacerbated by the global and lean trend of the last years, a trend that seems not to work well in conjunction with rare disruptive events. Thus, the aim of supply management risk practices is to ensure continuity of material and information flows within the supply chain, by limiting the effects of disruptions. There exist different frameworks used in the risk management process. Manuj and Mentzer (2011), for example, propose a model where a set of suitable risk management strategies is selected after a five-step process in which risks are identified, assessed, and evaluated according to certain criteria. Fan and Stevenson (2018) also include the identification, assessment, treatment, and monitoring of supply chain risks in a four-step comprehensive framework. According to El Baz and Ruel (2021), supply chain resilience is positively affected by all these dimensions of risk management practices. These practices also serve as mediator for restoring supply chain operations and quickly recovering the planned performance. Although their positive effect, the first step concerning risk identification results to be the most beneficial and should be a priority for companies engaging in risk management practices, as it can affect all the other risk management processes. One of the goals of supply chain risk management is indeed to reduce the information gap caused by ambiguity in disruption situations. Information gathering helps avoiding the lack of suitable data necessary to deal with this ambiguity, thus enhancing supply chain resilience and robustness. Because of the wider availability of resources and capabilities, while SMEs usually have to face shortages in resources when they want to deploy strategic initiatives, big firms can instead increase their ability to initiate supply chain risk identification and mitigation.

As mentioned before, the more the complexity of the supply chain, the more risk management practices have a positive impact on the performance of a company. Given the dynamic trend of the structured system characterizing supply chains, difficulties arise when lots of components interact between each other. And if looking at an international context, complexity amplifies, also due to the greater impact on speed time and delivery performance. Therefore, the more the complexity, the more risk management practices are likely to be beneficial.

Milgate (2001) describes supply chain complexity using three primary dimensions: uncertainty, technological intricacy, and organizational system. Uncertainty is described as the reliability of a series of sequential and parallel tasks. For example, late deliveries by suppliers hurts manufacturing performance of the entire chain, not only a single stage. Technological intricacy relates to the product design and process structure, meaning how many and which kind of interconnections do exist between different components, and how much integrated are the various process operations. Finally, organizational systems concern the number of layers and departmental interactions within the internal and external organizational systems of the firm.

Serdarasan (2013) uses a different definition to represent supply chain complexity that involves three interrelated variables: static, dynamic, and decision-making complexity. Dynamic complexity represents the uncertainty in time and randomness, whereas decision-making complexity takes into consideration the type and volume of information that are necessary to make a supply chain related decision. These two variables and their interrelation create a complex environment that is difficult to manage when uncertainty and ambiguity levels become high. As discussed before, supply chain risk management practices might constitute a solution to ease the flow of information and mitigate the negative effects during uncertain situations, then resilience increases accordingly and so does the capability to recover from a disruption.

Dehdar et al (2018) specifically discuss about the types of risks that threaten automotive supply chains and the relative mitigation strategies that companies should adopt to avoid these risks. Considering the complexity and vulnerability of automotive supply chains, and their high sensitivity, risk management practices acquire further relevance in this context. They divide supply chain risk mitigation strategies into proactive approach and reactive approach. The first approach consists of executing strategies before risk events occur, while the latest's goal is to react after their occurrence. Avoiding certain suppliers because of unreliability, investing resources to build closer relationships with them, or integrating supply chain activities are some strategies attributable to the proactive approach. Flexibility or use of safety stock are instead reactive strategies that can reduce the effects of changes in demand. Supply chain collaboration and risk-sharing-contracts are two additional mitigation strategies that can be really useful in uncertain and complex industry environments like the automotive one. Among the risks identified in the automotive industry, the most important ones include supply risk (e.g., poor quality of raw materials), demand uncertainty, and shortage of materials. Focusing on the mitigation strategies to cope with these risks, a proactive approach can be used for the supply risk, which is based on avoiding potentially unreliable suppliers by accurately assessing their competences before stipulating any contract with them. The same approach can be also used to mitigate the impact of demand uncertainty and shortage of materials, by signing risk-sharing-contracts with suppliers and keeping additional inventory, respectively (Dehdar et al, 2018).

Sakuramoto et al (2019) try instead to study the cause of supply chain inefficiencies and how to overcome them through a comparison between the structure and management of the supply chain of companies in the Brazilian automotive industry and those from countries such as South Korea and China. In Brazil, traditional and historical automakers tend to have an overreliance on outsourcing in manufacturing, leading to a complete dominance of multinational suppliers in Tier 1. In addition, the lack of competitiveness of the Brazilian auto parts industry and the inefficiency of national Tier 2 suppliers have generated many supply problems, increasing costs and reducing innovation capabilities. All this results to be not sustainable anymore in a country characterized by frequent economic and political instability and represents a weakness of the traditional automotive supply chain in Brazil. On the contrary, automakers born later in countries such as China and South Korea have adopted different structural and managerial configurations, more suitable in environments where complexity and ambiguity coexist. For instance, Japanese automakers are famous for their consolidated structure of close relationships with suppliers and the use of extensive vertical integration and control over them. As Sakuramoto et al (2019) suggest, strategies like the vertical integration of the upstream supply chain can improve the level of quality of the supply chain and help companies better managing uncertainty in case of macroeconomic instabilities.

When macroeconomic instabilities make the business environment dynamic, and firms focus on identifying customer needs, another possible solution to mitigate risks can be the pursuance of supply chain ambidexterity. Defined as the firm's capability to exploit existing skills and resources while exploring new solutions at the same time, ambidexterity helps supply chains better adapting to sudden changes and maintaining resiliency, consequently enhancing business performance (Ojha et al, 2018).

1.4.3. The role of digital technologies and innovation capabilities

Mitigating risks and correctly applying strategies consistent along the entire supply chain not only is a matter related to risk management practices, but it works in conjunction with the structure and interconnections that exist between and within the many layers of the organizational system of a company. The integration of information is therefore hugely important because for taking decisions the company must know what is going on at every point in time and in any organizational area. If a continuous flow for two-way communication exists, processes in any supply chain stage can be improved, and so does customer relation, forecasting accuracy, and production efficiency. At the internal level, the use of ERP, an information system integration technology, can help sharing real-time data across intra-organizational functions for example. At the external level, electronic linkages can connect suppliers all around the world, so information and real-time data can be shared instantaneously (Yu et al, 2018). When the supply chain is complex and the industry dynamics are in continuous state of change, real-time reliable data and fast communication might make the difference, especially when sudden disruptions occur.

The automotive industry is undergoing massive technological and social change, and this requires innovation capabilities that cannot be exploited if automotive companies and their suppliers do not understand, assess, and incorporate the new technologies that arise into their long-term business and product strategy. According to Isgro (2018), the automotive industry is the top industry in Germany in terms of innovation capability in manufacturing. Critical to the success of the industry, innovation expenditure is supposed to increase in the following years, remarking how important is to invest in R&D, particularly now that trends like "digitalization" and "Industry 4.0" have become common in any sector. Hence, the integration of cutting-edge technologies into the vehicle, the optimization of manufacturing techniques, and the restructuring of the supply chain are approaches that major carmakers currently take to remain competitive in the market. Now that concepts like autonomous cars, connectivity, shared mobility, and blockchain technologies take over, it becomes clear the primary role of digital technologies in driving competition and growth, and so does the capability to generate and manage innovation.

Brown (2021) illustrates the new innovations in automobile industry, innovative solutions that will be sources of revenue in the upcoming years. This technological revolution in the automotive industry is exacerbated by the pressures for sustainable mobility and the changing customer preferences, which impact design, manufacturing, marketing, and after sales. He argues that innovation in this industry is in a continuous state of flux and technological advances are always around the corner. The demand for electric and self-driving vehicles is indeed boosted by AI-based automated technologies, big data analytics, human-machine interfaces, and IoT, while blockchain technologies can enhance supply chain efficiency and improve vehicle information and usage data.

The role of IT is specifically predominant in the context of supply chain management, above all in industries such as the automotive industry, where thousands of individual suppliers of different component complexity interact with each other. Supplier performance is essential for the efficiency of the supply chain and the functionality of the processes. To have a clear view in mind about whether the flow of activities is working well, IT integrated infrastructures constitute the right solution to ensure flows of information and coordination activities across all business divisions and supply chain partners, even for companies with activities spread worldwide. The fact that common ERP systems can share relevant information directly and in a timely manner explains why technology is an indisputable enabler of information sharing.

Fuchs et al (2018) say that there is a strong positive relationship between IT capabilities, supply chain capabilities, and supplier performance. Tier-1 suppliers adopting adequate IT systems have more efficient internal processes and more fluent communication channels with supply chain partners. Indeed, if supplier chain tiers do not correctly manage the flow of communication, the lack of relevant information that derives from can result in significant disruptions and delays to recover the operations capacity. In disruptive situations like the Covid-19 pandemic, this is likely to threat the firm's survival. Therefore, effective information integration lowers the barrier to information sharing between stages of the chain. Real-time, relevant, reliable data are so available at the right time and the right place, thereby enhancing the decision-making process because of higher quality information at disposal. Consequently, because IT capabilities significantly influence both internal process excellence and information sharing in a positive way, then also supplier performance increases accordingly. Benefits accounting to the achievement of internal process excellent result in a better ability to fill customer orders and more reliability, quality, and flexibility to order changes. Reliability and flexibility are in turn supported by the degree of information sharing between automotive suppliers. The higher the openness to external communication, the more they are able to exchange high quality information with suppliers and customers.

Globalization and the exponential diffusion of the internet, networks, social media, and mobile devices have increased the amount of data companies deal with, thus the ways this data is acquired, processed, exchanged, and stored have put pressure on supply chains with high level of complexity, like those involving companies in the automotive industry, rendering digital technologies a core platform for conducting the business.
According to a study conducted by Balakrishnan and Ramanathan (2021), apart from improving the performance, digital supply chain technologies are in addition beneficial for the supply chain resilience. In situations like the Covid-19 pandemic, when human interaction is limited, technology plays a greater role in improving supply chain

performance. But benefits are not limited to business performance. They suggest that to recover quickly and to provide quicker response to market during these disruptive events, the development of the right set of digital supply chain technologies competency and practices in automotive firms as well as in their supplying firms influences resilience practices positively. Among the benefits recognized, Balakrishnan and Ramanathan (2021) point out to increased business agility, swifter responses to supply chain risks, increased flexibility, visibility, better tracking and transportation management, inventory optimization, and better planning capacity.

Spieske and Birkel (2021) also argue about the effects of industry 4.0 on supply chain resilience, focusing on the effects of Covid-19 pandemic on the automotive industry. As already discussed, the vulnerability of automotive supply chains, given their complexity and geography, makes supply chain resilience an important factor to avoid the multitude of negative outcomes usually associated to sudden disruptions. Companies frequently underestimate low-probability, high-impact events like the Covid-19 pandemic and therefore lack preparedness when it comes to deal with these extremely uncertain risks. Taleb (2007) describes Covid-19 as a "Black Swan" due to its extremely low probability of occurrence, but high impact. He suggests that although "Black Swans" are unpredictable and human beings tend to rationalize them after the fact, companies need to adjust to their existence rather than naively try to predict them. If not, repercussions can happen at any business level, from sales and market share losses to firm's reputation damages. Nevertheless, the effectiveness of supply chain risk mitigation seems to be supported by the recent technological progresses, Industry 4.0-related technologies above all. According to the framework developed by Spieske and Birkel (2021), Industry 4.0 enabler technologies enhance both supply chain resilience and supply chain antecedents. The latter involve supply chain resilience enablers as agility, visibility, supply chain engineering capabilities, collaboration, and a supporting culture. They argue that among the Industry 4.0 enabler technologies, the one that has the major influence on supply chain resilience is Big Data Analytics, which in turn also supports supply chain resilience antecedents like visibility and velocity. Indeed, the more reliable data are available during a crisis, the more it is possible to evaluate the situation and derive proactive measures to cope with it. For instance, in case of supply shortages as those currently faced by carmakers, having a clear visibility on safety stocks or production capacities can enable better decision-making and countermeasures.

Furthermore, the effects of velocity and collaboration antecedents on supply chain resilience must not be overlooked. Supply chain collaboration is particularly important for risk mitigation as well as for innovation capability development. Storer and Hyland (2009) explain that a collaborative approach toward innovation generation can create a competitive advantage since unique value-added solutions can be developed at any supply chain stage, improving the overall efficiency of the system. Intra-organizational cooperation reflects the willingness of the various actors to act in conjunction to improve or change current activities according to the dynamics of the market, thereby employing a supply chain's innovation capacity that can enhance resilience in turbulent environments. Swink (2015) suggests that this collaborative approach needs to be complemented by new organizational structures and communication technologies. Benefits account for reduced time in new product introduction, reduced scrap, improved development cycle, wider sources of new ideas, and greater potential for recognition of possible technology applications.

Considering the rapid pace of technological evolution in the automotive industry, having a collaborative approach in building innovation capability seems to be extremely important to cut out competition and strive during uncertain times. To complement and reduce any lack of capacity or deficiency, Lii and Kuo (2016) say that the establishment of internal and external relationships can potentially help generating unique abilities and value-added activities. Integrated innovation-oriented firms that are able to exploit supply chain partners collaboration are more efficient in terms of cost, quality, speed, and flexibility.

Aalbers and Whelan (2021) add that to facilitate the emergence of innovation ecosystems, a combination of online and offline channels is the best solution to access external sources of ideation. Digitally enabled infrastructures have indeed expanded firm's activities over its organizational boundaries. Open innovation concept has become famous in many industries, especially in the automotive sector, where companies now openly collaborate also thanks to new available technologies and digital platforms. In a continuously changing environment, where companies and carmakers are currently experiencing pressures of various nature, being able to collaborate and exploit external sources of knowledge seems to be fundamental.

Finally, sustainability requirements have increased the amount of innovative capability that automotive firms should possess to survive the upcoming competition, eventually supporting the usefulness of open innovation practices. Social and environmental dimensions are now equally important for a firm as economic and financial performance are. Companies should find strategies and adopt structural configurations to merge the concepts described above with sustainability practices, and this requires a huge dose of flexibility as well as innovation capability.

Chapter 2. Sustainability concerns in the Automotive sector

2.1. The environmental impact of the Automotive Industry

One of the most debated arguments of the last years is the reduction of the environmental footprint caused by the automotive and transport industry. Climate change issues have been widely recognized worldwide and climate change mitigation actions are now considered to be of outmost importance in almost any country. Consequences like shifting weather patterns and rising sea levels have become global in scope and unprecedented in scale, while many changes in the Earth's climate are unprecedented in thousands, if not hundreds of thousands of years.

What is notable are the changes the environment went through after more than a century and a half of industrialization, deforestation, and large-scale agriculture. Technological advances and industrial revolutions have resulted in growing populations, economies, and standards of living, and although increasing quality of life and social welfare, they also contribute to increase the cumulative level of greenhouse gas (GHG) emissions, which have risen to record levels not seen in three million years. CO_2, the most abundant GHG, is largely the product of burning fossil fuels, which have been widely used across the whole industrial history.

The United Nations ("Global Issues: Climate Change", n.d.) analyze the main effects related to climate change and show that there is alarming evidence some changes in major ecosystems and the planetary climate system might have already reached the breaking point, becoming irreversible. In particular, they show that the average global temperature increased by 0.85°C from 1880 to 2012, whereas the global average sea level rose by 19 cm due to the warmer temperatures. Estimates see that as world's oceans will warm and ice melt will continue, average sea level rise will probably reach 24–30 cm by 2065, highlighting the fact that even if emissions are stopped, climate change effects are likely to persist for many centuries. The effect of warming and drying is more pronounced if thinking about the diversity of ecosystems in different areas of the world. Amazon rainforest, Arti tundra, or mountain glaciers are all at risk and may be approaching thresholds of dramatic change.

NASA (NASA, 2022) also points out that the effects of global warming will worsen in the decades to come if urgent actions are not taken, depending on the amount of GHG emissions emitted globally and how sensitive the Earth's climate will be to those emissions. Apart from the continue increasing temperatures and sea levels, among the long-term effects of global climate change it highlights the lengthening of the frost-free season, changes in precipitation patterns, more droughts and heat waves, more intense hurricanes, and the most worrying consequence of ice-free Artic Ocean.

The environmental situation people currently must deal with is perhaps the consequence of biases human beings live by, which inherently affect the decisions they take. Most of the people tends to be myope in front of some events. People indeed tend to overestimate the costs in the short-term and underestimate the potential benefits in the long-term, therefore they are susceptible to different types of myopia when deciding not to invest in prevention and mitigation. Moreover, the Covid-19 pandemic underlines how people are generally unprepared for rare events because they have the tendency to focus only on the next period when determining the likelihood of an event occurrence. But now more than ever is fundamental to recognize that drastic and immediate actions are needed to tackle the already advanced irreversible negative consequences, otherwise future generations will have to bear huge costs and risks. The predictions of the past have not been considered as they should have been, and the predicted effects of climate change are now occurring.

Despite the negative role of human influence on the climate system is undisputable, luckily human actions aimed at reducing emissions of carbon dioxide and other greenhouse gases still have the potential to determine the future course of climate change and to limit its effects. There are several associations like the WWF that are actively engaging in activities to address this crisis, either through advance policies to fight climate change, business collaborations to reduce carbon emissions, or by helping people and nature adapting to a changing climate (WWF, 2022). The benchmark limit of 1.5°C discussed by the Intergovernmental Panel of Climate Change in 2018 regarding global warming requires rapid, far-reaching, and unprecedented changes in all aspects of society, starting from transitions in land and energy and going towards industry, cities, and transport changes in order not to be exceeded. From now to 2030, global GHG emissions must be reduced by 45% to limit global warming to 1.5°C, whereas global net human-caused CO_2 emissions should reach "net zero" by 2050 ("Global Issues: Climate Change", n.d.). United Nations efforts to address the climate change problem include legal instruments such as the Kyoto Protocol, the Paris Agreement, and the 2019 Climate Action Summit. These instruments aim at incentivizing investments and actions for a sustainable low carbon future, especially in the business and industrial dimensions.

According to the 2019 Greenpeace report (Stephan et al, 2019), the impact of the car industry on the environment in terms of carbon emissions is extremely negative, positioning the automotive industry among the most polluting business sectors. Comparing the combined footprint of the twelve car manufacturers analyzed in the report with the total annual GHG emissions of the entire EU, data show a shocking fact: car industry has larger carbon footprint than the entire EU, accounting for 9% of total annual GHG emissions in 2018. More than half of the emissions come from the top five car makers, namely Volkswagen, Renault Nissan, Toyota, General Motors, and Hyundai-Kia. In 2018, the total annual GHG emissions of Volkswagen have exceeded those of the Australian continent, while the combine carbon footprint of the latter, Daimler, and BMW has exceeded that of the entire Germany. Carbon emissions not only are a matter of fuel efficiency, but they are the sum of the GHG emissions caused through the production of the car, the tailpipe emissions caused by fuel consumption during its life, the emissions caused through supplying this fuel, and the emissions caused through recycling at the end of its life. The table below (see Figure 11) shows the GHG emissions over the lifetime of an average VW Group car and provides an example of the contribution that each phase gives in terms of GHG emissions.

Figure 11. GHG emissions over the lifetime of an average VW Group car.

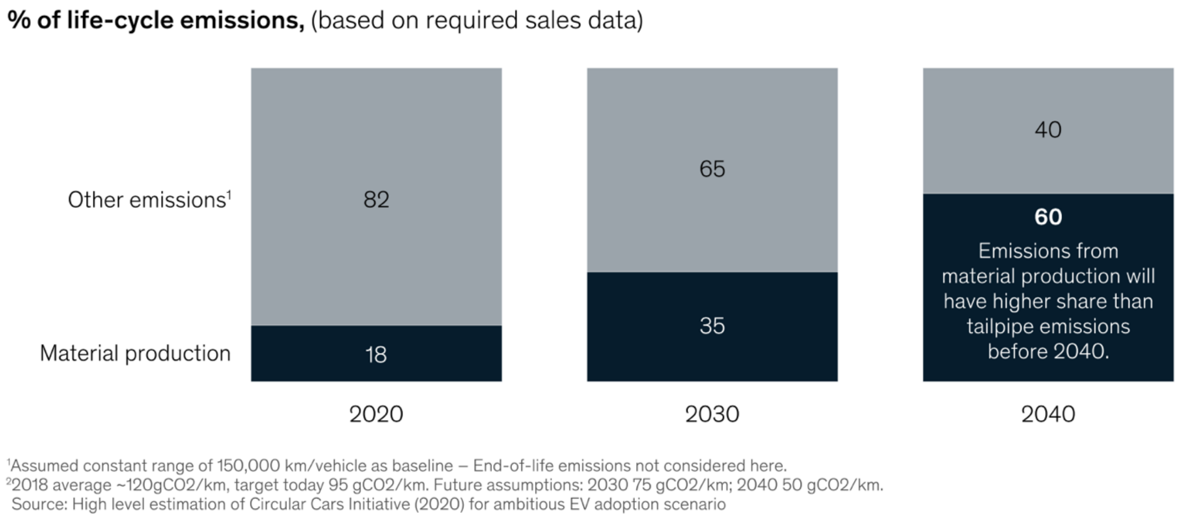
PRODUCTION		USE PHASE		END OF LIFE	OVERALL
Supply chain	Production	Fuel supply	Fuel consumption	Recycling	
5.7t CO_2e	0.8t CO_2e	5.5t CO_2e	29.0t CO_2e	2.7t CO_2e	43.7t CO_2e[41]

<u>Source</u>: *Retrieved from Stephan et al (2019)*

The carbon footprint of producing a new vehicle is usually overshadowed given that most of the emissions during its lifecycle are due to usage, also because it is more complex to determine exactly the quantity of emissions generated in the production phase. Different styles and energy-types have varying levels of carbon footprint and require different kind of raw materials to be used in the manufacturing process. In general, the peculiarities of the materials used for producing a car (e.g., steel, aluminum, plastic, rubber) make the raw materials extraction process extremely energy intensive, therefore it consumes a huge amount of energy with consequential high greenhouse gas emissions. Focusing solely on the usage phase seems to be not effective since the positive effect of green policies on the transportation industry will be damaged by the negative impact of GHG emissions of manufacturing new cars.

Recent trends see circular economy strategies in the automotive sector as promising, considering that many carmakers are getting benefits from the reduction of waste materials, the recycle of materials, and the use of renewable energy, which can cut energy costs in the manufacturing phase. Hannon et al (2020) suggest that large-scale decarbonization will be the result of long-term efforts. All the automotive industry participants are encouraged to work in conjunction to abate material emissions as soon as possible given that reducing material production emissions must be considered a priority, on a par with reducing tailpipe emissions. Considering that tailpipe emissions, mainly related to fuel consumption, currently constitute the main source of GHG emissions, they argue that as soon as these emissions decrease thanks to the transition towards EVs, emissions caused by the production phase will take a primary role both in absolute and relative terms, becoming a larger share of the vehicle life-cycle emissions. Figure 12 graphically represents the incidence of vehicles' materials on the total lifecycle vehicle emissions.

Figure 12. Percentage of life-cycle vehicle emissions.



<u>Source</u>: Retrieved from Hannon et al (2020)

By 2040, the share of battery electric vehicles is estimated to be the larger portion of the market, thus tailpipe emissions will be extremely reduced given that EVs do not generate any emission related to fuel consumption. On the contrary, EVs are assumed to have higher baseline material emissions, therefore the percentage of material emissions on the total lifecycle vehicle emissions will shift from 18% in 2020 to 60% by 2040. For this reason, companies in the automotive industry should exploit the latest trends by developing cost saving strategies associated to low-carbon energy sources, process electrification, and increasing use of recycled materials. Apart from cost saving benefits, recycled aluminum, new smelting technologies, and green electricity can for instance reduce emissions from aluminum production by about 73%, this being one of the main components used in production, while the use of plastic-related recycled materials such as polypropylene or polyethylene can cut emissions from plastic production by 34%. Overall, 66% of emissions from material production are estimated to be abated at no extra cost by 2030 if companies implement such strategies during the production phase and exploit new technologies and their associated processes (Hannon et al, 2020). Electrifying powertrains is not the only option available to cut emissions, instead, huge importance must be given to reduce material emissions as it can be an opportunity to accelerate the global decarbonization transition.

What is relevant to denote is the fact that this opportunity requires cooperation of all the supply chain players, which must pursue the same goals and follow the same standards in order to avoid inefficiencies and to limit emissions abatement. According to the European Automobile Manufacturers Association ("CO2 emissions from car production in the EU", 2021), despite the growing number of cars produced if compared to ten years ago, European carmakers have been able to reduce CO_2 emissions from production by almost 49% since 2005. This data is clearly a demonstration of the transition towards sourcing energy from renewable and low-carbon sources, as well as of the use of new more efficient industrial processes and technological advances.

It becomes clear that to foster a sustainable society and improve environmental quality, all the business processes of a company need to be involved, and its entire supply chain must work towards the same sustainability goals if a sustainable business is to be achieved, considering that most of the emissions caused during production comes from the supply chain. Of course, the amount of production carbon emissions differs according to variables related to vehicle sizes, amount and type of materials used, and the share of renewable energy used for production. However, data also show that the market share of heavier models like SUVs has expanded a lot during the last decade - 69% of market share in the US refers to SUVs – and therefore vehicle design and customer preferences are perhaps slowing down, if not reversing, progress in CO_2 emissions reduction.

It is important to include production GHG emissions because, differently from the fuel consumption phase, these emissions affect those car makers fully engaged in the production of electric vehicles too, supposedly the most sustainable car frontier. Indeed, despite the production footprint of an EV is similar to that of a combustion engine vehicle, battery production is energy intensive and drives up production emissions significantly, with the result that this component alone doubles the production footprint compared to a combustion engine vehicle. On the other hand, EVs do not generate any carbon footprint related to the usage phase, which is the phase with the highest level of GHG emissions, thus the hot topic of transitioning from diesel and petrol cars to electric vehicles remains valid. According to a study conducted by Qiao et al (2017), which compares the life cycle CO_2 emissions from the production of EVs and combustion-engine vehicles in China, the carbon footprint related to the production phase of the first category results to be higher than more than a half compared to the latter category. Traction motor, electronic controller, and Li-ion batteries are those components driving up CO_2 emissions of EV production, but also most of the other major components included in the body and chassis that are commonly used in both the categories of vehicles generates higher footprint during EV production phase, mainly because of EVs larger weights. The diffusion of EVs is extremely important for the safety of the environment in China, however it has to be supported by greener manufacturing techniques and strategies in order to reduce the impact during the production phase.

At the same time, transport system needs to be reinvented to be climate friendly. CO_2 emissions from road transport were estimated to be increased by 71% between 1990 and 2016 and the path they are taking now evidences a trend to rise, despite already producing almost 20% of total global CO_2 emissions (Stephan et al, 2019). Being the biggest source of CO_2 emissions in the US, transport accounts for 29% of total country emissions, a huge number that exacerbates the pressure to move towards greener modes of travel, promote alternative business models that lead to reducing the individual use and ownership of cars, and provide services that complement public transport, such as car-sharing. The European Environment Agency (2020) has been working hard on policies to address the negative environmental impact of transport, as it consumes one third of all final energy in the EU and produces more than one quarter of the EU's total greenhouse gas emissions. Shipping and aviation are only a minor portion of GHG emitters; indeed, the main sources of pollution are associated to cars, vans, trucks, and buses.

To confirm this last point, data during the Covid-19 lockdown periods show that the social restrictions imposed have had a direct positive impact on the environment. Air quality level has increased thanks to a contraction of GHG emissions caused by international travel restrictions, the reduction of tourism and business travel, and the big decline in road transport. Lockdown measures resulted in less passenger cars, buses, and trucks driving on the road, which made concentrations of PM_{10} ("Particulate Matter") and NO_2 ("Nitrogen Dioxide") fall. These air quality improvements unfortunately have proved to be temporary and short-term as pollution increased again when stricter lockdown measures have been lifted (European Environment Agency, 2022).

Last years' environmental policies concerning fuel quality standards and the Euro vehicle emission standards, despite having slightly reduced air pollution, have not been enough to break down GHG emissions drastically. Air pollution and noise pollution levels still remain too high and amplify the need for the transition of the energy and mobility systems if climate neutrality is to be achieved by 2050. The main object of the European agenda is to decarbonize transport, meaning to reducing the adverse effects of transport. The "European Strategy for low-emission mobility" and the European Commission's 2018 strategy "A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" are two of the most significant EU efforts that aim at transitioning towards net-zero GHG emissions primarily through the electrification process and the use of renewable energy sources. Nevertheless, even if national governments and international bodies are actually taking care of these issues, not all the companies and carmakers that operate in the automotive industry seem to do the same.

Stephan et al (2019) argue that despite growing concerns about climate emergency and the urgent need to take effective and timely actions, many companies in the automotive industry are not supporting the cause as they should, thus negatively affecting those car makers that put efforts in the process to accelerate the transition towards sustainable energy. This transition must be a priority and as such it asks for real actions instead of green-washing initiatives that benefit only the image of the brand and the reputation of the company, while the environment continues to suffer. By 2028, new sales of diesel, petrol cars, and hybrids should end to stay within the 1.5°C target set by European Environmental Agency, but just few of the companies analyzed in the report have released public commitment to phase-out combustion engine vehicles in the upcoming years.

Lobbying and fighting against robust climate-related regulations is another problem that characterizes the way carmakers operate in the industry. An example can be provided by the Volkswagen Group scandal in 2015, known as "Dieselgate", where the company attempted to escape from the environmental regulations in the industry through the installation of a defeat device that falsified actual emissions. Its marketing campaign during that period put emphasis on its cars' low emissions, while facts stated the opposite (Hotten, 2015).

Transparency needs to acquire further relevance in the sector as the real impact of carmakers can be better assessed if reliable data are available. The gap between test cycle results and on-road emissions needs to be shortened as much as possible, otherwise the effectiveness of green initiatives and actions can be distorted, resulting in a reduction of emissions only on paper.

Interesting is also the approach that many companies have undertaken regarding marketing and advertising of EVs. Stephan et al (2019) sustain many carmakers have not done enough to this extent, although they argue back not to have sufficient charging infrastructure and incentives. Instead of investing resources to develop new models and encourage the diffusion of EVs, many of them focus on SUV sales and then advertisement spending for SUVs is skyrocketing. Problem here is that the bigger the car, the less the vehicle fuel efficiency, with a consequential increase of emissions during the whole vehicle life cycle. This reasoning works for both combustion-engine and electric SUVs. Moreover, hybrids are equally discussed for their efficiency. It seems that updates to hybrid vehicles, together with improvements in fuel efficiency which have stalled or even reversed, are no longer adequate solutions to the climate crisis. Hybrid vehicles are incompatible with the 1.5°C limit because despite the partial use of electricity, they still consume petrol or diesel, which makes the rate of emission reduction too slow to stay within the abovementioned limit. As long as cars include a combustion-engine of any kind, reaching the point of zero tailpipe emissions seems unlikely and this blocks the rapid adoption of real alternatives not powered by oil.

The car industry needs the backing of both companies and policymakers to speed up the transition and completely change the dynamics and directions of the industry. Carmakers must focus their efforts on phasing-out internal combustion engines and hybrids by 2028, producing EVs in a sustainable manner, and reinventing themselves as a transport provider either through car-sharing initiatives or ride-pooling services. Policymakers must put their attention on clear and effective policies and regulations to accelerate the decarbonization of the transport system and on developing alternative mobility modes to reduce mass car ownership.

2.2. Sustainability and the pressures for sustainable development

The topic of sustainability has acquired enormous relevance in the daily life of people in the last years. Climate change, high level of pollution, scarcity of resources, rising sea levels, and extreme unhealthy conditions in poor countries are matters that currently raise concerns among all the sectors of the economy. Social inequalities are present worldwide with catastrophic repercussions on the stability of the societies, which most of the times translate in wars, high levels of criminality, unemployment, and lack of education. Starting from 1988 up to the present day, the richest people, so called top 1% global elite, experienced around a 60% increase in income, whereas the income of the poorest population has remained around the same level (Ghemawat, 2018). A sharp increase in income has been experienced only by the emerging economies such as China, while the rest of the developed world middle-class has experienced a decline in income instead. This trend has been depicted by Branko Milanovic's curve, also known as the "Elephant curve", and underlines the huge gap on the social side between the 1% booming global elite and the rest of the world. Companies are asked to address these concerns because as they are part of the society and interact continuously with it, they are responsible for the society's welfare and need to fully understand corporate governance and social responsibility.

Global initiatives have become a requirement to follow rather than an option, and most of the actors of the economy has started to follow them accurately. Corporate strategy more and more includes areas addressing initiatives such as the 2021 Sustainable Development Goals Report, an annual report that is part of the Agenda 2030's plan of action to eradicate poverty and achieve sustainable development by 2030 worldwide (United Nations, 2021; United Nations, n.d.). In 2020, some of the hottest trends explaining how to achieve a sustainable business included climate mitigation, plastics management, circular solutions, sustainable consumption, green supply chain management, and sustainable finance (Brackley et al, 2020).

Hereby described as the conscious use of resources to preserve the ability of future generations to use in turn the resources they need, sustainability has become particularly important for companies. Companies operate at any level of the society, and they impact the environment where people live. Therefore, they must work towards balancing economic, social, and environmental goals at the same time. Customers and governments have become aware of sustainability concerns and demand companies to operate accordingly, whether by driving demand for sustainable products or by issuing sustainability policies and regulations that aim to guarantee a healthy and safe work environment for the employees and the minimum impact on the environment. Competitive advantage not only does arise from cost strategies, but competition focuses also on reaching efficiency in implementing sustainable practices across the entire supply chain. Given the large influence of companies on the economy and life in general and the increasing environmental and social awareness, addressing internal and external stakeholders pressure must be a priority for any of them. Sustainability can be seen both as a challenge and a trend for companies in this period. It was a hot topic even before the global pandemic, but the latter seems to have boosted this inevitable process.

A survey carried out by the Italian foundation Symbola ("GreenItaly", 2020) on a sample of 1,000 manufacturing companies finds green companies to be more resilient and more reactive in facing the pandemic effects on the economy. In 2020, these green companies reported lower turnover losses than the others and believe they will go back to their pre-crisis levels of activity within 1-2 years. Of the companies surveyed, 16% of them managed to increase its turnover, compared to 9% of non-green companies. Eco-investing companies show higher level of investment in areas related to R&D, innovation capability, and implementation of 4.0 technologies. The competitive advantage that can be derived from is likely to sustain their competitiveness even in the following years. The survey indicates that the direction the economy is taking is characterized by a green transition many companies have already embarked. Indeed, a quarter of them, despite the adversities of this period, intends to invest in sustainability also in the following three years ("GreenItaly", 2020).

Pirelli & C. S.p.A., the multinational tyre manufacturer based in Milan, provides a clear example of how sustainability practices can be integrated within the corporate strategy to the extent that they become a source of competitive advantage for the company. The purpose of its business management model is to add value to the group and its brands through the complete integration of socio-environmental practices into the whole corporate strategy. These actions of corporate social responsibility become a real distinctive character of the organization compared to most of the other companies in the sector. By 2030, Pirelli & C. S.p.A. has planned to use more than 60% of renewable raw materials in manufacturing while reaching carbon neutrality ("Sustainability target at 2025-2030", 2021). According to the CEO Marco Tronchetti Provera ("Pirelli's model", 2019) "Sustainability is a fundamental choice for Pirelli, it is fully integrated into the Group's Vision and Strategies for growth, in all business areas and in all management decisions, everywhere in the world". This vision is an integral part of the Group's strategy and value chain and combines value creation with long-term sustainable growth.

Supply chain and business strategy must align towards the same sustainability goals to enact a complete integration. Considering the global context in which companies in the automotive industry operate, the integration of sustainable practices is necessary at every stage of the chain to align business operations worldwide with current legislation, public interest, and competitive opportunities. This can help avoiding any repercussion of a negative chain reaction, favoring the transition of conventional supply chains towards sustainable ones. Of course, pressures from government legislations, consumer changing habits, or from other stakeholders are not the only driver fueling the growth of sustainability practices within a company's strategy. There is a positive impact of sustainability integration on the economic and financial dimensions too, apart from the benefits that can accrue to the brand image and reputation.

According to Tay et al (2015), the presence of multiple drivers supporting the economic dimension has a positive impact on the effectiveness of sustainable supply chain management in increasing the overall business performance. Energy savings, waste and pollution reduction, and lower health and safety costs all have a positive impact in terms of cost reduction. Moreover, the search for ever new technological and sustainable solutions helps developing innovation capabilities, which in turn increase the possibility to beat competitors in the field of relevance and acquire a dominant position in the market. Finally, a supportive culture and shared corporate social responsibility act as tools for mitigating political, societal, market, and environmental risks.

Despite benefits can be acknowledged, the adoption of a sustainable supply chain is not exempted from the presence of challenges and barriers to its effective implementation. Its intrinsic definition implies that both internal and external variables can have an impact on the performance of a sustainable supply chain. Government regulations in foreign countries or poor supplier commitment can seriously affect the overall effectiveness of the chain, which for most of the big companies has a global perspective, also due to the consumer's desire for ever lower prices. Tay et al (2015) illustrate some internal and external barriers that can put at risk the efficiency of a sustainable supply chain. Among the internal barriers they find lack of management commitment, cost of green purchasing, lack of training and understanding, lack of corporate structures and processes, organizational size, and financial constraints. They also position green washing and operations in less regulated industries as external barriers capable of jeopardizing supply chain management strategies.

Mathiyazhagan et al (2013) also argue that organizational size is one of the main barriers in the adoption of sustainable business practices. The larger the size of a firm is, the more it tends to participate in green supply chain initiatives. Smaller firms have less resources to invest out of their operational activities and they fail to recognize the benefits accruing from the implementation of green practices. Moreover, according to their study about auto component manufacturers in India, maintaining environmental awareness of suppliers constitutes a barrier that is difficult to eradicate, especially in countries like this where less stringent government regulations are put in place. Indeed, suppliers located in developing countries are more likely to lack corporate social responsibility. For this reason, it is important to select suppliers according to their level of commitment to green concepts, as well as to stress existing suppliers to focus on eco-friendly materials. Removing these barriers can increase the possibility that green strategies are integrated across the whole company's activities and benefits that accrue from sustainable supply chain management are fully exploited.

Howells (2021) argues that pressures from both the government and the customer in the automotive industry are currently creating a business environment where internal departments within an organization and external partners such as Tier-1 and Tier-2 suppliers are asked to provide sustainability information about both the products and the processes that they make and deliver. However, having visibility at each stage of the supply chain, especially if this is globally spread like that of carmakers, is not an easy task and may constitute another barrier to overcome. Of those thousands of supply chain decision makers present in the 2021 Oxford Economics survey, almost 90% of them has designed a corporate strategy around sustainability. On the contrary, only 52% has translated strategy into action, while few than half of these respondents has actually clear visibility into their own sourcing of sustainable products. Moreover, the survey outcomes also highlight that only 21% of them has complete visibility concerning supplier operations and supplier sourcing of sustainable products (Howells, 2021).

The transition towards a sustainable future requires companies, consumers, and governments to work in conjunction to help each other in understanding the best possible solutions to encourage social and environmental responsible behaviors while at the same time generating positive financial gains. Indeed, as Gimenez et al (2012) suggest, both internal and external sustainability initiatives can potentially enhance the overall business performance, because the positive effects on the social and environmental dimensions reflect on the financial dimension at the end. Explanations can be provided through examples like the introduction of a new less-polluting production system. This enhances the environmental performance and in the meanwhile employees and people working in the production line benefit from better working conditions and community's quality of life. In turn, less absenteeism and fewer industrial accidents decrease industrial costs and at the same time increase both manufacturing efficiency and the value of the firm's social reputation. The same happens through external programs like supply chain collaboration initiatives or open innovation philosophy, where suppliers and customers are encouraged to share knowledge and resources to develop new manufacturing processes that generate less waste and use fewer resources or new eco-environmentally products.

Open innovation strategy seems to be particularly important considering the power of customers in driving the strategic decisions of the company about sustainability related products and processes. The open innovation construct is part of the United Nations Sustainable Development Goals for 2030 and places collaboration between customers, universities, consultants, or even competitors at the center of its functioning. According to Obradović et al (2021), there is a positive correlation between openness to external knowledge and firms' performance in the manufacturing industry, to the extent that improvements related to innovation capability and sustainability integration can be exploited, resulting in new products availability, better performance, and more sustainable business. During the Covid-19 pandemic this strategic approach has been adopted by many companies given the benefits that can accrue from. The rapid pace of the technology cycle and the ongoing globalization have thus boosted the tendency for companies to search for new ideas and knowledge outside of their organizational boundaries to improve productivity and meet customer demand, with an effort to address sustainability concerns by developing sustainable solutions jointly with external partners. Despite the open innovation tendency is more prominent in high-tech and medium-high tech manufacturing, the competitive advantage that can derive from is pushing low and medium-low manufacturers to collaborate with bigger firms so as to acquire valuable knowledge and competences without investing too many resources.

Collaborative innovation in the automotive industry is currently becoming popular thanks to the latest trends involving autonomous vehicles, electrification, 5G, artificial intelligence, big data, and IoT. One single carmaker is unlikely to possess all the knowledge, technology, and capabilities to master these new technological innovations and integrate them within the structural configuration of its vehicles. Indeed, considering the complexity and interdisciplinarity of the intelligent connected vehicles technology, companies in this sector are embracing the open innovation approach to integrate the technology, knowledge, and other resources outside their organizational boundaries, with the goal of achieving internal innovation. Pressures coming from the transformation of the traditional automobile industry are changing the dynamics governing the operations of traditional carmakers and at the same time influence the way small and medium companies in the automotive industry conduct business. The latter need to be able to create an ecosystem where innovation platforms facilitate the establishment of clusters and alliances for information, technology, and knowledge sharing purposes. Because EVs and intelligent connected vehicles have cross-industry and interdisciplinary crossover characteristics, synergies must be created between automobile, communication, Internet, and big data industries, together with market and political actors like the government, consumers, universities, and research institutions.

Zhou et al (2021) argue about the role of collaborative innovation in the emerging intelligent connected vehicles industry in China. They emphasize that although there is still place for improvements, the development of this industry in the country is contingent upon openness and cross-border synergy initiatives. Methods identified as drivers for the development of a collaborative innovation approach in this industry concern building an innovation cooperation platform, promoting R&D cooperation, building industrial clusters, and promoting cross-regional linkage. The current sustainability trend in the automotive industry renders this approach as one of the most effective since the achievement of a sustainable business involves many different actors in the context of a global supply chain. By making industrial alliances and establishing a collaborative network for ideas diffusion, companies can create a cultural environment where new green processes and solutions are able to flourish, and the pace of technological innovation accelerates substantially. And the effects of an open innovation strategy are even more remarked when speaking about complex technologies as those integrated in the latest automobiles, which require existing knowledge structure and system to be complemented with external resources to allow the growth of enterprises, industrial progress, and the creation of social and economic benefits.

Companies like Pirelli & C. S.p.A. and Toyota provide clear examples of how this strategic approach can be beneficial to all the dimensions of business performance discussed so far.

Looking at Pirelli's business model, the company's attitude to collaborative innovation is easily recognizable. The culture based on inside and outside dialogue not only does concern the product but also the qualitative and constructive approach with all the stakeholders, therefore this creates synergies that allow the supply chain to add solutions that create unique value at every stage, providing a market competitive advantage. The company firmly believes in the concept of open innovation and sees as the main open innovation projects those related to virtualization and to sustainability. Through the establishment of long-lasting relationships with the major prestige and premium car manufacturers, Pirelli & C. S.p.A. has been able to develop and produce tires that match the dynamic characteristics and electronics of the vehicles. In accordance with these manufactures, the company can create customized tires – what it calls the "perfect fit" - that are specifically designed for electric cars or plug-in hybrids ("The Pirelli Open Innovation model in support of Research and Development", 2021; "Electrifying breakthroughs", 2019). These tires offer multiple advantages for eco-friendly cars. Moreover, university agreements have resulted to be beneficial as they helped developing innovative materials and solutions which are fundamental for the design and production of tires with reduced environmental impact and high performance. Toyota uses the same approach through the Toyota NEXT Open Innovation Program, aiming at the joint development of services that make daily travel more convenient and comfortable and help achieving a safer and more reliable mobility society ("Toyota Announces Partners Selected for Joint Development of Services for the TOYOTA NEXT Open Innovation Program", 2017).

2.3. Green practices and supply chain dynamics of automotive firms

The great negative impact of the automotive industry on the environment has brought people to question whether the dynamics of this kind of sector open spaces for sustainability practices across the supply chain, particularly considering the technological intricacy and complexity that characterize modern vehicles. The previous discussion about the necessity to integrate green practices in new vehicle manufacturing, especially as far as EVs are concerned, implicitly assumes that all the areas where a company operates are aligned towards the same environmental standards and goals. Pursuing environmental sustainability involves both the firm's internal processes and supply chain management practices, thus a collaborative approach is needed to establish a set of cultural rules that anyone inside the organizational framework must follow. Given the state of transition the automotive industry is currently experiencing, turbulency in the supply chain of both new entrants and incumbents' carmakers poses serious threats to the stability and status quo of the supply chain. Autonomous driving, connectivity, electrification, and new forms of mobility are some of the latest trends in the automotive industry, but their development must coexist with the increasing environmental concerns of internal and external stakeholders, who have become extremely sensible to sustainability matters and demand carmakers to deliver products and design processes less aggressive to the environment.

In general, there are several benefits associated to green supply chain management practices on all the three dimensions of the triple bottom line – environmental, social, and financial dimension. Internal and external green supply chain management practices act as a tool to minimize the impact on the environment of both the forward and the reverse flows, creating an indirect effect on the economic and financial performance thanks to ecological, operational, and cost efficiencies. The integration of these practices requires efforts not only at the internal level of the organization, but also from downstream consumers and upstream suppliers. Cross-functional and cross-company processes must work in a cohesive manner and involve intra- and interfirm management of the upstream and downstream supply chain; thus, a cooperative approach is always necessary to reap benefits from environmental management and be sure that every player behaves the same way and follows the same direction. The dynamics involving each different industry are of course not the same and the complexity of the automotive industry makes it difficult to assess the real effect of such practices in terms of increasing performance of all the three dimensions.

Feng et al (2018) argue about the indirect effect of environmental and operational performance on financial performance focusing on Chinese carmakers. Using China as the country of reference seems to be useful given the dramatic air pollution level in urban areas mainly caused by cars' emissions. The Chinese government's plan of action is to accelerate the green revolution of the automotive industry by focusing on electric and hybrid cars and battery production, making them more competitive and sustainable. Government initiatives are not effective without the efforts of Chinese carmakers, who are more and more recognizing that benefits can be reaped from the application of green management practices. Feng et al (2018) indeed, explain the argument such that financial performance can be indirectly increased if companies focus on increasing both environmental and operational performance directly. Financial performance depends on many variables, most of them resides outside the scope of analysis and is not related to resource efficiency, therefore pretending to focus primarily on this dimension would discourage the effective implementation of strategies to improve environmental and operational performance. Managers need to learn that green supply chain management practices are of outmost importance for achieving superior performance on these last two dimensions, while profitability and market share can indirectly benefit but do not have to be the primary goal of the decision to go green. It is by focusing on the linkage between these three performance dimensions, and not on one or two of them separately, that complementarity effects between different internal and external green practices arise. An integrated green supply chain strategy then serves as a glue between internal processes and external supply chain partners.

2.3.1. Environmental collaboration

Gaining a competitive advantage through the implementation of an integrated green supply chain strategy is the result of the merger between the implementation of environmental management practices on internal operations and the establishment of environmental collaborative relationships with upstream suppliers and downstream customers across the entire supply chain. To reduce the overall environmental impact is not enough to focus entirely on making internal processes greener, because as previously discussed, most of the GHG emissions in the life cycle of a vehicle comes from the supply chain, thus involving external suppliers and customers. Consequently, cross-functional cooperation for environmental improvements enables carmakers to achieve superior environmental and operational performance that indirectly leads to improved financial performance.

Lopes and Pires (2020) study green supply chain management to recognize those practices mostly able to positively affect the automotive industry performance. Among the practices considered are green design, green purchasing, green production, reverse logistics, internal environmental management, and collaboration within the supply chain. They argue that automotive companies analyzed in the study mostly adopt internal green management practices and green production. Establishing a culture of open communication, cooperation, and commitment can indeed favor the adoption of green practices within the company and help employees and managers learning and recognizing the usefulness of such practices. A suitable set of measuring and monitoring systems for environmental performance, coupled with IT systems integration, environmental management systems such as ISO 14001, and environmental audit programs, can then help multifunctional integration of green practices. On the other hand, green production can reduce production cost, pollution, and waste while increasing both economic and environmental performance as companies start using environmentally friendly materials and technology in the production process. These two practices perhaps are easier to implement because companies have direct control and supervision over them since they can determine their environmental policy internally, hence companies maximize the effectiveness of internal management practices to increase environmental performance. Lopes and Pires (2020) also show that supplier collaboration is the practice that generates the most positive effect on environmental performance. One of the main challenges for companies in the automotive industry is indeed the management and governance of global supply chains. Suppliers of raw materials, auto parts, tires, distributors, logistics service providers, and after-sales services are asked to cooperate in order to achieve the overall purpose of the company, otherwise environmental performance is unlikely to increase, and the positive effects can even reverse.

According to Gimenez et al (2012), supply chain collaboration is potentially performance enhancing because of its impact on all the three dimensions of the triple bottom line. To this extent, they individuate benefits related to resource efficiency that reduces manufacturing costs thanks to the use of less polluted supply materials, less waste generation, and less resources processed. Knowledge integration and cooperation allows the firm to develop organizational and environmental management capabilities, which in turn can improve environmental performance, cost efficiency and quality. More than other practices, environmental supply chain collaboration seems to be extremely important in the long term as trustable relationships take time to establish. Time is a variable that needs to be taken into consideration and this supports the idea that rapid actions to fight climate change issues and strategies to address environmental concerns must be implemented as soon as possible. Changing how suppliers and customers are managed and how they used to behave before collaborating with the company is a long-term process, more complex if compared with internal management changes.

To reduce this complexity, Yu et al (2020) investigate how green human resource management can be beneficial to ease environmental cooperation with customers and suppliers and how internal green supply chain management serves as mediator, with a focus on the conceptual framework in the Chinese automotive industry. Selecting the right employees is not an easy task because many people put the economic retribution as the main motivational factor of the job. Encouraging employees to look outside of this economic dimension is a matter of finding the combination between explicit and implicit motivational drivers. The first step is of course determining the sensibility of the employee to sustainability issues and his potential ability to enjoy green initiatives execution, all of this during the selection phase. Green training and development follow the first step and are necessary to grow high-performing employees and enhance them. Green training allows employees to develop green abilities and raises awareness of alternative greener perspectives. The more they learn and know about the positive effects of green initiatives, the more they are encouraged to execute them, especially for those who are reluctant to change and consider the financial retribution as the only personal goal. What managers must understand is that green training is not enough, though. Green employee motivation and involvement play a relevant role in driving employees' behavior. They fuel commitment in adopting green initiatives. Employees that are part of the corporate strategy and feel to be at the center of the project are more motivated to acquire and develop new skills and therefore are likely to be proactive in practicing new values and methods at work, and to further learn by engaging in green initiatives. In turn, green employees are then oriented towards expanding their skills externally, for example by introducing new ideas to customers and suppliers on how to reduce their environmental impacts, which consequentially eases the process of building environmental collaboration with them. As Yu et al (2020) show, green human resource management is positively related to environmental cooperation with customers and suppliers, and green supply chain management indirectly moderates this relationship in a positive way.

The selection criteria for suppliers are equally relevant in the process of building trustable relationships. Supplier sustainable development depends on the current capabilities and willingness of suppliers to integrate corporate social responsibility standards and sustainable activities within their sourcing and management processes. Selecting and evaluating suppliers according to green and social criteria, as well as cost and quality criteria, are considered capabilities that may facilitate the implementation of green supply chain management practices. Moreover, sustainable supply chain dynamic capabilities can be created through the integration of external resources with developed supply chain processes. When synergies exist, the company is more responsive in adapting to changing stakeholders' demands. In turbulent contexts like that where the automotive industry operates, having dynamic capabilities can constitute a source to sustain superior competitive advantage given that these capabilities are extremely difficult to imitate (Reuter et al, 2010).

Long-term sustainable development leads to programs of collaborative waste reduction, environmental innovation, cost-effective environmental solutions, and implementation of innovative environmental technologies, which produce a positive effect on the environmental, social, and economic performance. Green innovative solutions can arise through the exploitation of resources and knowledge of suppliers and customers. This will help the company reducing costs because resources are joined together and technologies are shared, while it will also favor compliance of environmental management standards in the supply chain. According to Yang and Lin (2020), who study the Chinese automotive industry, long-term and trustable relationships with supply chain partners are crucial for the company's green innovation strategy. They argue that supply chain collaborative drivers should be gradually integrated within the innovation strategy of the company given their huge influence on green innovation performance. External partners usually possess knowledge that cannot be acquired alone internally, especially in the global context where the automotive industry operates. Cultural diversity either demands for global integration or differentiation, hence exploiting different set of resources, technology, and knowledge of external partners and trying to integrate them within the internal organizational boundaries is essential to develop new innovative and green solutions that support growth and competitiveness.

2.3.2. Green innovation through R&D investment

Supply chain environmental collaboration proves to be a very important driver for the green innovation strategy, as discussed earlier. Resource sharing decreases R&D costs and diversifies the risks to implement green innovation. Considering the utility of green innovation strategy in achieving both environmental protection and economic growth, not only are external drivers important for the effectiveness of green innovation, but the willingness of the company to invest in R&D seems to be a big part of the picture. Investing resources in R&D represents the attitude of the company to growth internally and build innovative capabilities, which in a technological complex sector like that of the automotive industry, is necessary for competitive and economic reasons.

The current environmental issues and the transition towards greener processes have put into the game new ways of thinking related to supply chain practices, which are now driven by green standards. The greening process is a potential source of competitive advantage since it stimulates ideas generation and search for innovative green solutions. Investing resources to convert these new ideas into practice can be extremely useful to speed up the green transition and build new processes and products that use less resources, generate less waste, and reduce environmental impact. According to the European Automobile Manufacturers Association ("R&D investment by top 10 industrial sectors in the EU", 2022), the automotive industry was the number one sector for investment in R&D in 2020, with €59 million spent, ahead of pharmaceutical, biotechnology, software, and computer services industries. Europe remains the world's largest investor in innovation in the auto industry, while other countries such as the US, Japan, and China are currently accelerating to keep pace with it.

Latest trends in the industry and the focus on electrification are fueling investment in R&D as all carmakers are rethinking their business model to cope with the innovation disruptions. The technology plan of Mercedes-Benz, for instance, foresees a sharp increase in R&D spending, justified by the willingness of the company to accelerate and advance the shift from electric-first to electric-only by the end of this decade ("Mercedes-Benz Strategy Update: electric drive", 2021). Tesla Motors provides another example on how R&D is now, more than ever, becoming a necessity rather than an option. The company is the first carmaker in terms of resources invested in R&D, which partly explains why it maintains its EV technology lead. While the industry average is roughly $1,000 per car, Tesla Motors spends $2,984 on R&D per car produced, which is almost three times the money spent by most of the other carmakers (Lambert, 2022).

Wu et al (2020) analyze the drivers of R&D looking at the automotive industry, in light of the development of the new energy vehicle industry. Eco-innovation, despite being already discussed in the previous years, is still difficult to deal with when novel innovation is introduced. The requirements to deal with the novel innovation are directly related to technological capability the company possesses, and its ability to manage new innovations largely depends on knowledge and skills developed throughout the years. Eco-innovation, indeed, is characterized by high innovation intensity. The more the firm's technological capacity is, the more the firm is encouraged to follow eco-innovation strategies. Wu et al (2020) suggest that R&D input considerably contributes to the new energy vehicles output, together with the support of government through subsidies. This means that as long as the company builds and exploits technological capability, investing in R&D for eco-innovations has great chances of success and is likely to generate a higher payoff, particularly when technological complex innovations are involved.

Moreover, investment in R&D allows the company to learn thanks to continue experimentation, which increases creativity, an important skill in turbulent environments. Experience favors technological capability accumulation, creating a positive cycle that benefits the learning process. Through continuously learning, not only are technological capabilities enhanced, but also eco-innovation chances of success increase. In the process of the R&D, innovative firms are more likely to generate innovations because their experience enable them to make the best of knowledge spillover and exert their absorptive capacities to acquire and integrate new knowledge. Effective knowledge integration is made possible thanks to the ability of innovative firms to reap the best from external partners, since their higher technological capacity helps them in selecting skilled partners and resisting technology leakage and opportunistic behaviors. Therefore, the motivation for cooperation increases consequently.

Government support is then a driver for R&D spending propension due to the fact that firms with low technological capabilities can reduce technological hurdles and financial risks thanks to government subsidies. Without government support, these firms would not participate heavily in the R&D activity, perhaps because they are more concerned about uncertainties and risks related to investing resources in an activity that generates uncertain outcomes. Government support may mitigate this concern and increase the likelihood that these technological-lagging firms pursue inventive ideas and join in the R&D proactively, leading to higher R&D output in turn. If sustainability issues want to be solved, all companies must engage in the green transition, both technological-leading firms and technological-lagging firms. The latter are supposedly less efficient in managing resources because they remain anchored inside their old technological paradigms, which block them from growing and being green in the eyes of external partners. Despite innovation being expensive from several points of view, companies must avoid concerns by recognizing that long-term benefits be generated through the design of a green innovation strategy. Persistent innovation seems to be crucial in the automotive industry given the strong pressures from consumers, rivals, and regulators, which have changed the competitive landscape and patterns of firms, rising costs of traditional and conventional processes.

According to Lin et al (2021), investing in a green innovation strategy increases the company's brand value through the mediating roles of R&D and marketing capability investment. They conducted an analysis based on the top automotive organizations in the world, considering the increasing attention of customers in environmentally friendly cars. Customer requirements have become stricter, and a green innovation strategy can potentially sway consumers' mentality as the company and its products are perceived to be sustainable. Firms with high R&D intensity and high marketing capability investment are perceived as more sustainable, therefore their brand value is enhanced thanks to their green innovation strategy. To this extent, it is important to acknowledge the role of company's internal resources, together with the fact that investment in R&D do not yield to uncertain outcomes, but can engender new market prospects, increase revenues, stabilize stakeholder relationships, and create a financial advantage.

2.3.3. The importance of circular economy

The concept of circularity is widely being discussed in almost any business scenario. Recycling, reusing, and remanufacturing are not just abstract words, but ask for many efforts on behalf of the companies since they must entirely change their processes to integrate these strategies effectively. A circular economy is a system where economic production is based on restoration and regeneration, with the purpose of improving the productivity of the resources while eliminating waste and their continual use, so that economic activity builds and rebuilds overall system health (Ellen MacArthur Foundation, 2020). Apart from improving environmental and social performance, this system can provide economic opportunities, together with the possibility to build long-term resilience.

The European Union has set in the list of its priorities the willingness to abate emissions created by the automotive industry and is issuing several strict policies to regulate this industry. At the same time, carmakers must cope with stakeholders' pressures and are asked to cooperate with them to embrace sustainability requirements. Circular economy positions itself at the center of the green transition involving the automotive landscape and seems to be the right strategy to address stakeholders' demand, although its feasibility is still under discussion given how challenging is to create business value from circularity (Holst et al, 2021). Further industry alignment and joint development of standards are only two of the challenges carmakers have to deal with. What they must focus on in the upcoming years not only is to reduce vehicle emissions, but to reduce emissions embedded in vehicle materials, especially now that these emissions will increase due to increasing materials' share of automotive life-cycle emissions in the production of battery-electric vehicles. Circular economy measures can lower lifecycle environmental footprints and costs, increasing both environmental and financial performance through activities such as vehicle sharing, smart charging, refurbishing, repurposing, and recycling.

To implement these activities, cross-value chain partnerships and collaboration are essential and the joint effort of all the partners involved is required. Initiatives to encourage circular economy measures have already begun to take hold. The "Circular Car Initiative" for instance has been launched at Davos 2020 and involve more than 100 global organizations and 250 executives in the automotive and mobility industry. Led by the World Economic Forum, it consists of a partnership between industry, policymakers, and fleet purchasers from the automobility ecosystem. The aim is to dramatically reduce total lifecycle emissions, particularly those related to the manufacturing phase, to produce the so-called "circular car", meaning a car that produces zero materials waste and zero pollution during manufacturing, utilization and disposal (World Economic Forum, n.d.).

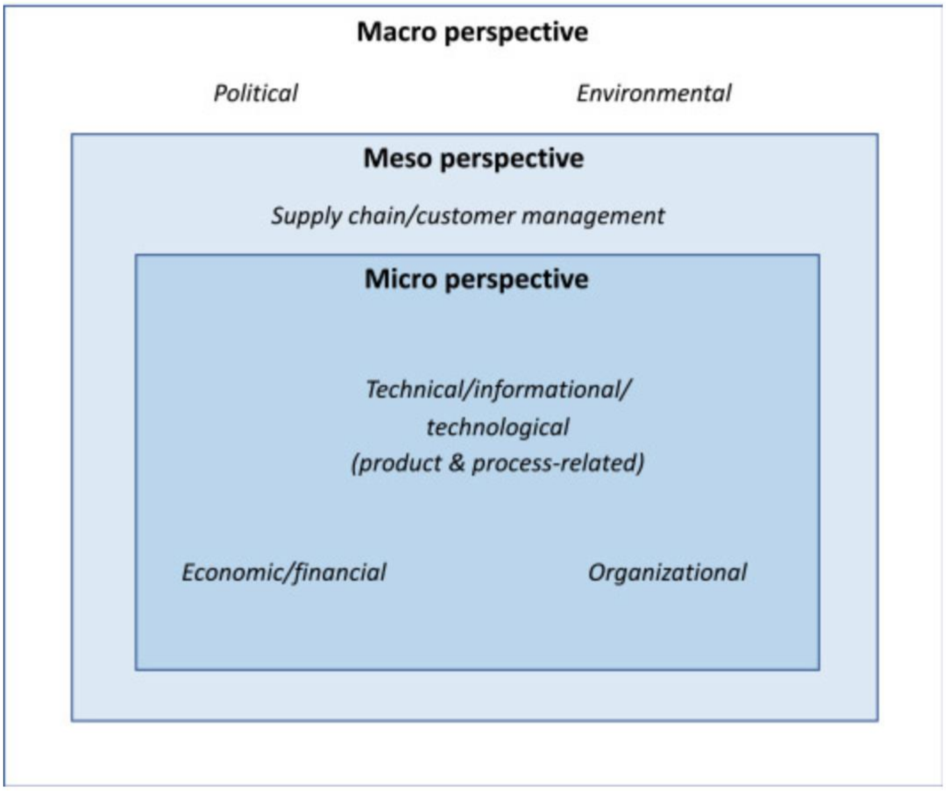
The huge number of resources invested in R&D by companies in the automotive industry explains the willingness of carmakers to integrate circularity measures within all their processes, from reducing the carbon footprint of the production phase to improving the design of motor vehicles. Producing vehicles that are sustainable over their entire lifecycle is not an easy task and is a matter of being efficient during both manufacturing phase (i.e., by remanufacturing components or reducing waste) and usage phase (i.e., by prolonging the service life of the vehicles to conserve natural resources and energy). According to the European Automobile Manufacturers Association ("Circular economy", 2018), 70% of overall waste can be reduced by having a circular approach during manufacturing, resulting from the use of remanufactured components, which leads to 80% less energy consumption, 88% less water, and 90% less chemicals.

The automotive industry seems to have already made the circular economy an integral part of its operations. Groupe Renault introduced the first European circular economy factory for vehicles in 2020, with the ultimate goal of extending the life of vehicles and components, keeping materials in use, and reducing raw materials usage (Ellen MacArthur Foundation, 2021). The French carmaker labelled it the "Re-Factory" because its ecosystem is based on four pillars: life extension of vehicles ("Re-trofit"), production, storage and management of green energies ("Re-energy"), efficient management of resources to support the ecosystem ("Re-cycle"), and innovation and knowledge sharing ("Re-start"). Tesla Motors also seems to have caught the point with its Tesla Cybertruck, which can potentially be one of the first circular vehicles. Indeed, the design upon which it is built makes remanufacturing many components easier, so that these components can be recycled and processed into automotive components again without being reworked excessively. The material used to produce the Tesla Cybertruck is the same the company uses in the production of its SpaceX Starship. This unconventional material is not generally used to manufacture cars, but Tesla Motors justified its use because it found the material to be extremely efficient in terms of costs, thermal properties, and recyclability.

To make lifetime vehicle optimization, components recycling, and electrification transition effective, circular economy measures demand companies to profoundly transform their business models accordingly, the key levers for rapid decarbonization of automobility. Focusing only on product costs is not enough and the benefits from investments in circular economy strategies must be fully recognized and integrated within the business model, instead of being disregarded. Moreover, looking at its own organizational boundaries is not enough as well, because the shift towards the circular economy requires a collaborative approach across the entire ecosystem.

Urbinati et al (2021) argue about the main enablers and barriers for the design of circular business models, with a focus on the Italian automotive industry. Using the automotive industry as the industry of reference is meaningful for the purpose of their analysis because latest trends about electrification and the distinctive characteristics of electric batteries have put pressures on carmakers' business models, which are most of them being redefined according to circular economy criteria. The automotive industry has long been based on linear economic paradigms that result to be inefficient in any business area, causing high fixed costs, overcapacity, and high environmental impacts. Circular economy business models have increased stimuli for green innovation and have encouraged carmakers to invest in R&D and cutting-edge technologies to escape from their technological locks-in. Figure 13 shows the comprehensive framework that identifies the main enablers and barriers for the design of circular business models.

Figure 13. The reference framework.



Source: Retrieved from Urbinati et al (2021)

The conducted analysis emphasizes the relevance of product-related and supply chain-related variables in affecting the degree of adoption of circular business models. Among the enablers, the presence of suitable resources and technologies to support the three Rs (i.e., reuse, reduce, recycle), together with availability of technical solutions like IT technologies and technologies that facilitate remanufacturing and product regeneration, are of outmost importance. The top management environmental awareness helps transitioning from a linear to a circular business model as its decisional power involves all the operations of the company and top management can therefore drives the transition at all organizational levels. Reverse flow of supply chain works best if there are well-structured and available partners to implement such approach, whose effectiveness depends upon many variables related to product features and processes flow. Among the barriers for the design of circular business models, product-related variables play a major role, as well as company-related ones. High investment costs and the time to recover these costs make it difficult for some companies, especially SMEs, to see the benefits from the transition towards greener models. Companies that approach a circular business model must deal with their organizational hierarchy and its inertia, which prevents them from adopting such model because locks-in are usually difficult to overcome if benefits are not clearly visible. Moreover, high products' complexity and high returned products' flow variability generate product-related issues that can be avoided only if the company possesses suitable technical solutions to manage the three Rs processes. Then, extended lifecycle of a car and the existence of a well-established second-hand market do not help having control over the customer and the product, increasing challenges in adopting circular business models because reverse flow, for instance, risks not to be efficiently managed.

2.3.4. Supply chain visibility and transparency

The availability of reliable and timely data increases transparency along the entire supply chain and constitutes both a barrier and an enabler to the implementation of a sustainable supply chain business model. Having traceability and visibility into upstream and downstream supply chain operations is important to monitor supply chain partners' behaviors and to have a clear view of business operations at any point in time.

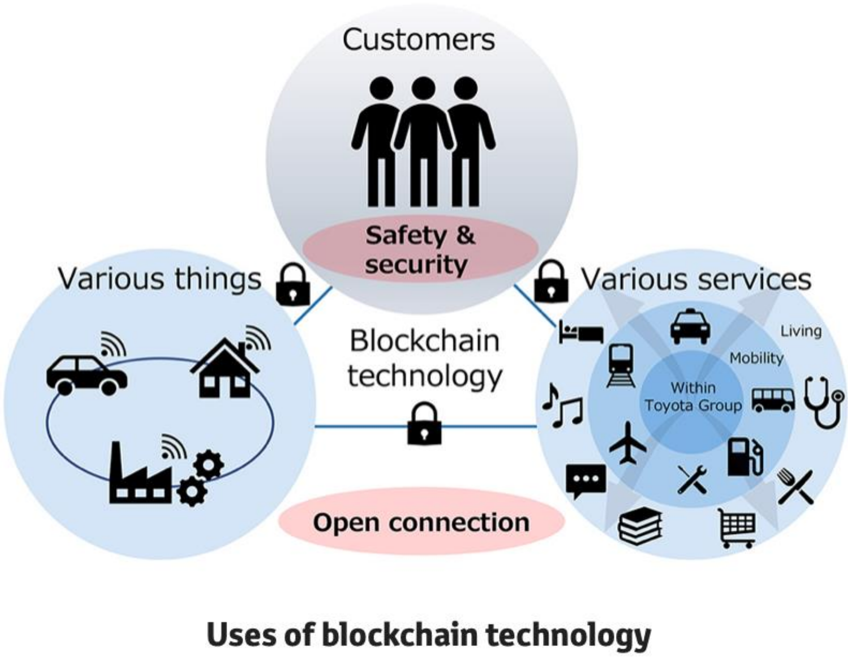
Heubach and Flohr (2022) explain why transparency of data helps companies in the automotive industry handling circular processes better and keeping track of any inefficiency along the value chain. Real-time data improves decision making and enhances visibility of the materials from the source to the final step. Green processes are optimized when the company has access to carbon footprint data because potential underperforming areas along the supply chain can be identified and corrected according to the environmental standards in use. The same can be said when speaking about quality issues during manufacturing. The more real-time data are available, the more the company is able to identify quality issues instantly and correct the deficiencies. Product information, compliance certificates, and CO_2 emission data enable supply chain partners to have visibility into the sustainability performance and to increase opportunities to identify carbon reduction potentials. Moreover, remanufacturing, reuse, and recycling benefit from availability of additional information on material composition or dismantling, thus improving the circularity of materials and processes. Indirectly, traceability of products, parts and raw materials contributes to better collaboration throughout the supply chain and improves supply chain governance.

Ahmed and Omar (2019) argue about the correlation between supply chain transparency and performance, highlighting those factors that positively affect transparency throughout the entire chain. The best indicator for transparency is the level of formalization of the company, meaning how standardized operations are and how consistent buyer-supplier operational information, material, and monetary flows are. Standardized policies and KPIs make it easier to monitor and evaluate partners and to design operations oriented towards the achievement of the same goal. At the same time, common strategies adaptable and acceptable to all supply chain partners help with system integration and increase trust. Trust and system integration prove to be positive factors for making transactions and information flow more reliable and clearer. According to Urbinati et al (2021), high levels of transparency, achieved by designing a trustworthy, visible, and timely information flow, positively impact supply chain performance as far as operational and relationship performances are concerned. Transparency among supply chain partners increases the quality of innovative joint project/product development and the effectiveness of R&D because standards are clear to everyone and evaluation criteria as well, which in turn increase stability, efficiency, and satisfaction.

Regarding carmakers' operations, recent issues about supply of raw materials used in car production are putting pressures on manufacturing efficiency, which consequently puts at risk the efficiency of the whole company. To gain transparency on supply chain issues such as CO_2 emissions and the source of materials, carmakers are using technologies like blockchain that dramatically increase supply chain visibility. Technologies like blockchain support risk mitigation and facilitate the identification of strengths and weaknesses along the chain. BMW Group, for instance, is able to keep traceability of parts and critical raw materials thanks to this technological solution, although the complexity of its international supply chain. In this way, the German carmaker optimizes processes as data are continuously shared within its multi-stage international supply chain during purchasing, keeping track of each component's origin or supply route (Graser, 2020).

Toyota is taking the same approach through its "Toyota Blockchain Lab", an initiative to foster the use of blockchain technology to connect people and businesses more openly, eventually fostering collaboration with various partner companies (see Figure 14).

Figure 14. Uses of blockchain technology.



<u>Source</u>: Retrieved from "Toyota Blockchain Lab" (2020)

Toyota's ambitious goal is to become a "mobility company" proving a wide array of services related to transportation, which implies the fact that inside and outside company's nodes must be linked to each other to create an environment where reliable data can be shared between various parties under safety and security ("Toyota Blockchain Lab", 2020). By creating a continuous flow for two-way communication, the firm may be able to improve processes at every supply chain stage: customer relation, product and services, forecasting accuracy, and stipulation of alliances that can develop innovative and greener products, which in turn, will enable firms to stay more competitive in market.

Chapter 3. Electric Vehicles and the current debate about their sustainability

3.1. What are EVs?

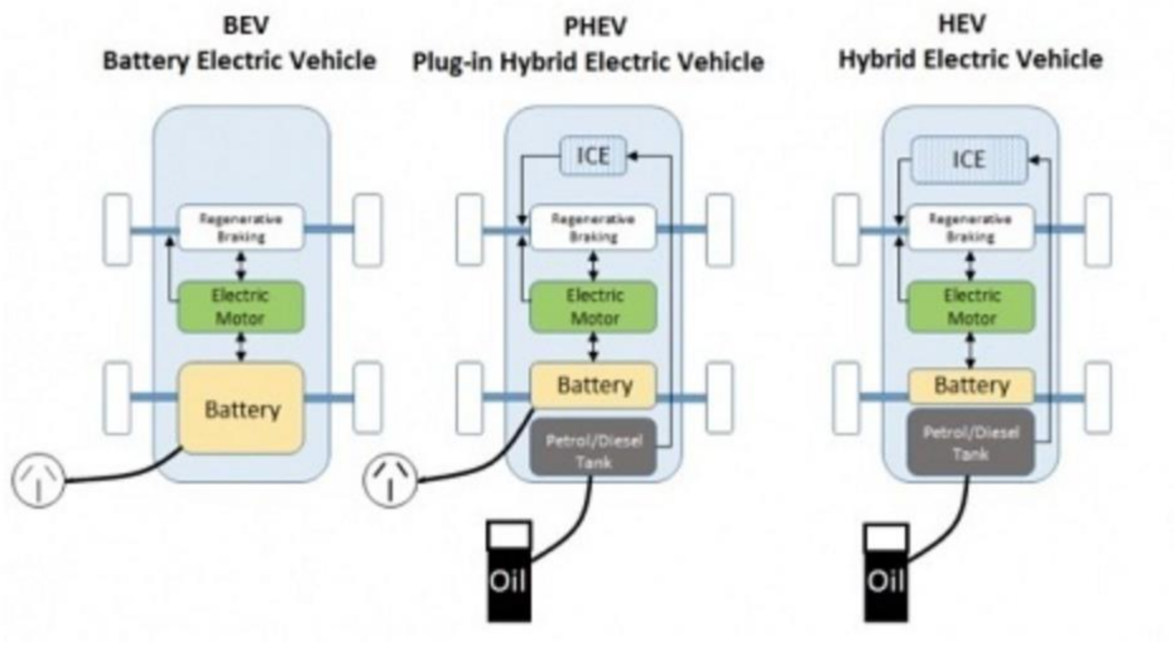
The advent of electric powered vehicles has generated rumors about their functioning and how they can compete with traditional combustion engine vehicles. EVs, acronym of "Electric Vehicles", involve the category of vehicles that uses one or more electric motors for propulsion, which are fueled by a collector system or by a battery pack. The internal combustion engine is displaced in favor of these electric motors, although there are hybrid versions that still include them into their structure. Indeed, EVs can be either partially or fully powered on electric power, which is, among others, the reason why debates arise related to their sustainability.

Generally, EV's battery pack is made of lithium-ion batteries, given their greater longevity and capability to store energy if compared with lead acid or nickel metal hydride batteries. The function of the large traction battery pack is to power the electric motors; therefore, no tailpipe emissions are generated in the usage phase. The battery pack is charged through a wall outlet or charging equipment, but energy is created also thanks to an energy recovery mechanism that permits to generate energy during braking. This regenerative braking mechanism is particularly efficient because the energy can be used immediately or stored until needed. This increases the driving range of the vehicles, one of the points of debate regarding feasibility of EVs in the market.

According to Simpson and Van Barlingen (2021), driving range is one of the major concerns for potential EVs drivers. Roughly 40% of them has concerns related to battery consumption, especially for long trip, where it is not taken for granted there are electric charging stations available in case of need. This was true in the past, where electric charging stations were not as diffused as today, and when EV range barely reached 180 km. Nowadays, EV range reaches 637 km and the number of electric charging stations is exponentially increasing, which enormously reduces the gap with traditional internal combustion engine vehicles. Tesla Motors currently owns the largest fast charging network of superchargers in the world – i.e., its electric charging stations – and is planning to triple the number within 2023. The efforts of the company are centered on increasing the possibility for customers to charge their vehicles wherever they go, at the same time decreasing their concerns about battery consumption. Tesla Motors has also started opening the charge to not-Tesla vehicles, which seems to be a great foot ahead to follow its ambition to accelerate the world's transition to sustainable energy. On the other hand, the presence of hybrid versions of EVs renders the scenario multicolored, meaning that not all electric powered vehicles will access these electric charging station network.

The most adopted forms of EVs that have lately acquired relevance among users are BEV ("Battery Electric Vehicle"), PHEV ("Plug-in Hybrid Electric Vehicle"), and HEV ("Hybrid Electric Vehicle"). Figure 15 briefly distinguishes the system architecture each kind of EV version is built on.

Figure 15. The system architecture of the three types of electric cars.



<u>Source</u>: Retrieved from "Types of Electric Cars and Working Principles" (2022)

Despite being quite limited, tailpipe emissions are completely eliminated only in the BEV system architecture, while the other two variants generate some emissions during the usage phase when the internal combustion engine is in use. Moreover, driving range, efficiency, and maintenance needs differ across the variants. Current debates usually focus on the real sustainability of BEVs. The implications covering EV range and the number of electric charging stations available seem not to concern PHEV and HEV directly as these system architectures still include traditional gasoline as fuel source.

3.1.1. BEV – Battery Electric Vehicle

Battery electric vehicles, also known as all-electric vehicles, use electric motors that are entirely powered by the large traction battery pack. This system architecture does not include any internal combustion engine and it relies only on electricity stored to drive. The main components of a BEV are the traction battery pack, the thermal system, the onboard charger, the inverter, and the electric traction motors. The traction battery pack is alimented by DC power, so the main function of the onboard charger is to convert AC power usually supplied by the home generator into DC power to charge the battery pack. At the same time, the inverter converts DC power stored in the traction battery pack into AC power for the electric traction motors. During this process it is fundamental to maintain the proper temperature of the battery pack. This is made possible thanks to the thermal (cooling) system. The battery pack is charged by plugging into the electricity grid.

Depending on the configuration of the power generator, charging time can range from 30 minutes up to more than 12 hours. Tesla Supercharger, for instance, allows users to charge up to 275 km in 15 minutes ("Supercharger", 2022). Enel X charging stations work the same way and offer solutions at all levels: private, public, and business level. Enel X charging stations are made of recycled plastics, contributing to circular economy advantages, thus not only are they encouraging e-Mobility, but show how sustainability looks at the whole process and not at some steps of it. Of course, charging time also depends on the size of the battery pack. Some BEVs like Tesla Model S come with different configurations and can have a total battery capacity of 75 kWh or 100 kWh for example. The more the total battery capacity, the longer the driving range and the time required to fully charge the vehicle. As discussed above, driving range has increased a lot during the years thanks to new technologies and innovations, together with less raw materials expenditure, in particular as far as battery production is concerned. The gap between driving range of an internal combustion engine vehicle and a BEV is slowly leveling out and the latest BEVs introduced in the automotive market are the proof.

Elfalan (2021) estimates the average range and consumption of BEVs looking at different automotive companies. Data show that most of the vehicles has an autonomy of 240 miles, more than enough for the average user. 2022 Lucid Air Dream Range, 2022 Mercedes-Benz EQS 450+, and 2021 Tesla Model 3 Long Range are those BEVs showing the best results, reaching 505, 422, and 345 miles respectively. Despite there are several factors affecting driving range of BEVs, such as driving speed, driver habits, or external temperatures, average distance covered by BEVs is arguably more than sufficient to satisfy customers' need.

Driving experience seems to be particularly important in this context because driving range consumption can be reduced when using the right approach during the drive. For example, the positive effect of regenerative braking is vain if the driver frequently uses only the brake pedal. In this case, energy cannot be recovered, and brake pads wear out faster, increasing cost of maintenance and waste for disposal. According to Rauh et al (2017), training potential BEV drivers to adopt driving habits suitable to the vehicle of reference can be extremely important to eliminate range anxiety and range overestimation. Drivers' range interaction competence increases usage efficiency of BEV range, which means that the more the user experience, the more the ability to understand range dynamics and better predict actual available range. This favors widespread adoption of BEVs because, at least in part, lightens the barriers related to limited driving range of BEVs.

3.1.2. PHEV – Plug-in Hybrid Electric Vehicle

This category of vehicles works similarly to all-electric vehicles as it uses a battery pack to power the electric traction motor. But differently from BEV, PHEV includes an additional internal combustion engine that can be used alone to drive or that can recharge the batteries while driving using the electric traction motor to enable longer driving range, together with the regenerative braking typical of the first category. Indeed, PHEV usually runs on electric power as long as the energy stored in the battery pack permits, then it automatically switches over to use the internal combustion engine when the energy needed from the battery pack is not sufficient. There are thus two sources to fuel this kind of vehicle: gasoline or petrol and electricity. The charge port connects to the onboard charger to supply the traction battery pack with DC power, while the fuel filler directly connects to the fuel tank to supply the internal combustion engine. The main components of PHEV are the electric traction motor, the traction battery pack, the thermal system, the onboard charger, the internal combustion engine, and the transmission. The last two components are what differentiate BEV from PHEV because they are mainly used in traditional internal combustion engine vehicles.

The peculiarity of PHEV relies on the fact that the vehicle can work extremely well on short journeys because it runs only on electricity stored in the battery pack, while long journeys are made possible thanks to the internal combustion engine or through the combination of both electricity and gasoline. This erases any concern related to driving range that is subject of discussion when speaking about BEVs. On the other hand, despite quite reducing emissions if compared to a traditional vehicle, especially if daily driving distance is short, the use of an internal combustion engine still raises questions about the sustainability of this category of vehicles. To reach the 1.5 °C target of the Paris Agreement, emissions must be dramatically reduced, if not eliminated at all. PHEV needs more maintenance and generates more engine noise if compared to an all-electric vehicle. It weighs more because of the presence of the dual drive system, which consequentially seems to reduce its efficiency. The limited electric driving range also implies that the vehicle must be plugged in more often to recharge the battery.

According to a study conducted by the Electric Power Research Institute (2007), PHEVs instead are potentially emission-reduction alternatives to conventional vehicles because of their greater fuel efficiency, but quantifying their true benefits seems to be challenging. Estimates show that by the year 2030 air quality improvements will be made possible thanks to the diffusion of PHEVs, although not as significant as one might think. Wolfram and Hertwich (2020) argue about the role of PHEVs in the US market by studying the climate impact variations depending on the fueling behaviors of plug-in owners. Long-range PHEVs electrify as many annual miles driven as BEVs, differently from what someone might think. The price of a PHEV is favored by the smaller battery pack assembled into the vehicle, resulting in smaller price increments if compared with a BEV, where traction batter pack is bigger.

However, the role of PHEVs in the future largely depends on the fueling behavior of their owners. To mitigate GHG emissions in a significant way, Wolfram and Hertwich (2020) find to be fundamental encouraging people to use electricity as much as possible during the drive. For instance, the presence of an EV charger not only at home, but also at work, highways, or in commercial areas sharply increases the efficiency of PHEVs. Frequent charging is necessary due to their smaller driving range while using electricity as the source to run the vehicle, therefore the more the sources to plug-in the vehicle, the less the need of switching over the internal combustion engine. Consumers must be properly educated about the right approach related to fueling their plug-in hybrid electric vehicle, taking into consideration the price benefits of electricity against gasoline or petrol.

3.1.3. HEV – Hybrid Electric Vehicle

Hybrid electric vehicles are very similar to plug-in hybrids as far as their design is concerned. What makes the difference is the function of the battery pack. The internal combustion engine and the electric motor coexist and work together to run the vehicle, but there is no charge port to plug-in the vehicle to charge the battery directly. The only source of energy to let in is gasoline. The battery pack is usually smaller than that assembled in PHEVs and BEVs and is charged via the internal combustion engine and through the regenerative breaking. Essentially, the role of the battery pack and electric motor is to support the internal combustion engine in rotating the transmission, which drives the wheels. This helps reducing idling when stopped and favors the use of smaller combustion engines. When the internal combustion engine is inefficient, here comes into play the electric motor to assist it during certain conditions. For instance, when accelerating from a stop or cruising at highway speeds, HEVs result to be more efficient than conventional vehicles. Braking energy usually lost as heat in the brake pads and rotors can be recouped thanks to the regenerative braking, thereby being reused to assist the internal combustion engine during acceleration.

Although HEVs are similar to drive to conventional vehicles, they are considered to be more sustainable thanks to better fuel economy and lower emissions. On the other hand, the same questions raised regarding sustainability of PHEVs are even more pronounced in this context, given that gasoline is nearly the only source of energy in HEVs. Pielecha and Gis (2020) study the potential positive impact of HEVs by comparing emissions of a conventional passenger car equipped with a spark-ignition engine and a mild hybrid vehicle. Findings demonstrate that in all the frameworks considered, HEVs bring a decrease in the average road exhaust emissions. With a mild hybrid system, carbon monoxide emissions are reduced by 41% (comfort mode), 58% (eco mode), and 44% (sport mode), while emissions of nitrogen oxides are reduced by 51% (comfort mode), 85% (eco mode), and 89% (sport mode). Interesting to note is that a mild hybrid system actually increases carbon dioxide emissions in comfort and eco driving modes by 24% and 1%. This opens spaces for discussion about the sustainability over the long term of this category of vehicles.

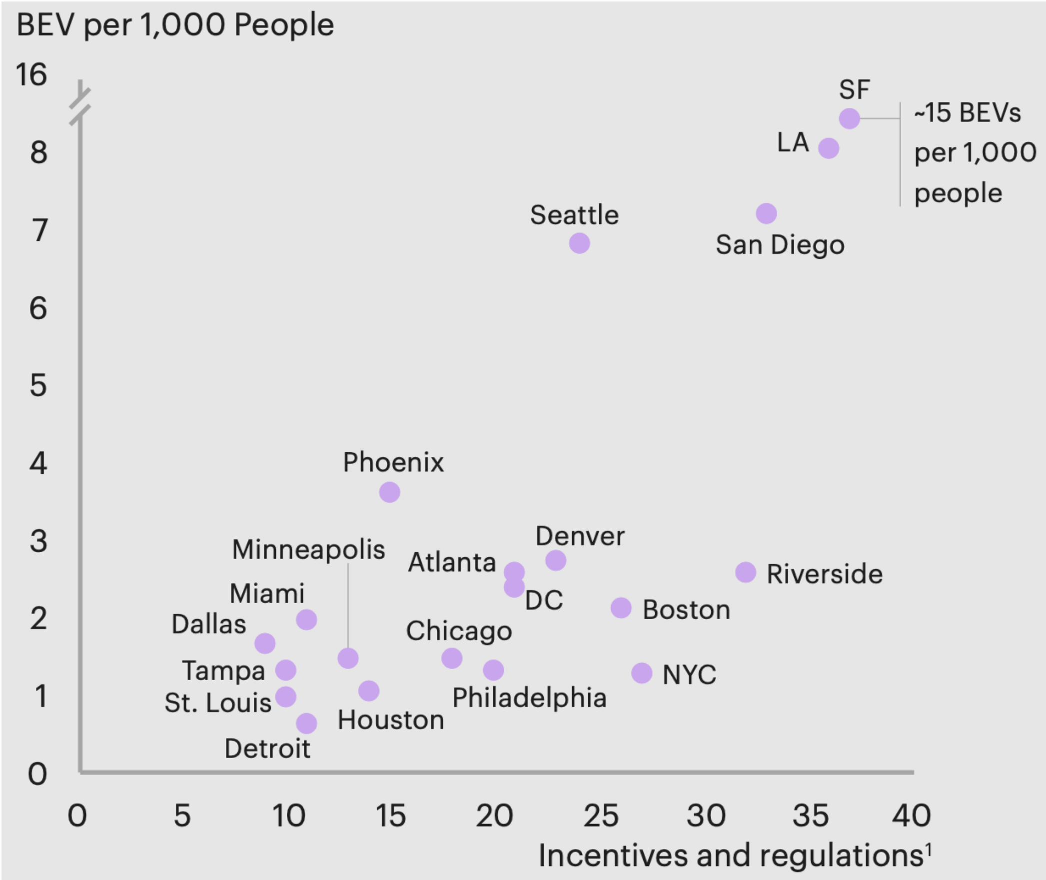
Bhusal (2021) also studies the impact of HEVs by focusing on their effectiveness in reducing the annual fuel cost and in improving environmental safety. He uses a sample of 1248 hybrid and 25 non-hybrid vehicles and considers data about the annual fuel cost, CO_2 emissions, city average milage, highway average milage, and spent cost over 5 years. Results confirm that HEVs have indeed a positive impact on annual fuel consumption and CO_2 emissions, if compared with conventional internal combustion engine vehicles.

Having clear in mind that HEVs provide fuel savings and low emissions output, which make them a real alternative option to BEVs, Last et al (2021) argue about the long-term feasibility of HEVs. The urgency to take actions to meet the zero-emissions target by 2050 puts pressures on governments all around the world. The electrification trend currently involving the automotive industry gives a central role to BEVs, the category of vehicles that generates no tailpipe emissions. To this extent, PHEVs and HEVs seem to be not compatible with the zero-emissions target because having an internal combustion engine generates tailpipe emissions, even if significantly smaller compared to a conventional vehicle. If the idea that most of all vehicle trips can be completed without an internal combustion engine takes place, PHEVs and HEVs are likely to be phased out in the upcoming years. This is still a topic of discussion and depends on the government legislations to meet stringent emission targets in the years to come. What is sure is that HEVs seem to be the first category to leave the market given they do not have any plug-in option, differently from PHEVs and BEVs. For now, HEVs are an excellent short to medium term solution for making travels more sustainable and they can be considered, together with PHEVs, a transitional technology to mitigate BEVs' driving range concerns, at least as long as more infrastructures for BEVs will be diffused worldwide.

3.2. The market of EVs

The global electric vehicle market has experienced a sharp positive trend in the last three years, despite Covid-19 pandemic slowing it between 2019 and 2020. The exponential development of the market is mainly driven by political and environmental factors, among all the strict government regulations to abate vehicle emissions and the subsequent government subsidies to favor the adoption of battery-electric vehicles. According to Walker et al (2020), availability of government policies and incentives for EVs in a given country is strictly related to their adoption and drives sales of EVs. Despite responsibilities to cut final product prices lies in part on manufacturers, governments can play a very important role to encourage the electrification transition. Tax and purchase incentives, regulations around clean emissions, promotion of infrastructure development through local aids and utilities, and public initiatives such as convenient parking spaces for EVs owners are some policies governments can deliver to increase adoption of EVs. Many municipalities have already put in place public initiatives for EVs drivers, who can have access to preferential EV rates, public charging infrastructures, and incentives for multifamily dwellings. Figure 16 shows the positive correlation between number of pro-EV incentives and regulations available in a country, and per-capita number of BEVs, focusing on the US market.

Figure 16. Correlation between number of BEVs and policy adoption in the US.



<u>Source</u>: *Retrieved from Walker et al (2020)*

The more the number of incentives and regulations in a country, the more the per-capita number of BEVs circulating on the road. Walker et al (2020) stress this point by analyzing the controversial effect that is created when government subsidy programs end. For instance, they saw that the cancellation of the Electric Vehicle Incentive Program in 2018 in Ontario (Canada), a government incentive program that gave up to $14,000 to potential drivers to buy an EV, resulted in a drop of -50% of EV sales in the first subsequent quarter of 2019. The same effect has occurred in China after the country reduced subsidies on BEVs by half in March 2019. The following month, sales of one of the country's largest EV manufacturers have decreased by 38%, and by 12% over the same period a year earlier (Walker et al, 2020). Government role seems to be extremely important for the continued growth of EV market in the future, but of course EV manufacturers will have a slice of responsibility too as far as manufacturing costs and final product prices are concerned.

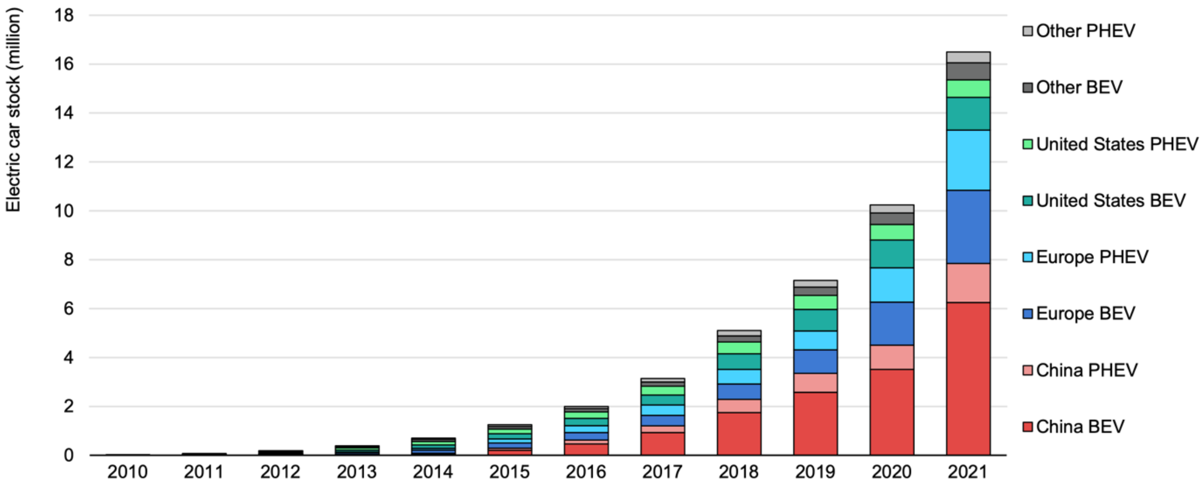
Prices to purchase a BEV are higher if compared to those necessary to purchase a conventional combustion engine vehicle, yet the tremendous growth of global electric vehicle market seems to signify that consumers' purchasing choice not only is related to end prices, but puts emphasis on factors related to environmental safety, fuel consumption cost, and social responsibility awareness. Fortunately, the gap in purchase prices between an EV and an internal combustion engine vehicle has reduced a lot compared to three to four years ago, eventually mitigating customers' concerns about pricing which made transitioning towards electric vehicles difficult at the beginning of their diffusion. EV battery costs, the major portion of the manufacturing cost of a BEV, are rapidly decreasing thanks to economies of scale and new manufacturing technologies and techniques, thereby supporting demand for cost-effective EVs. The price of an EV battery was around $120 per kWh in 2021 and estimates see the price dropping at approximately $60 per kWh by 2030 (MarketsandMarkets, 2022). Compared to 2010, where the price was $1,100 per kWh, great steps forward have been made in this context and future estimates actually play in favor of high price-sensitive customers, who will see prices for EVs far lower than those seen today.

The size of the global electric market is currently in expansion, and it is forecasted to grow a lot in the upcoming years. Accounting for $287 billion in 2021, 41 billion more if compared to 2020, it is anticipated to grow to $1318 billion by 2038 (Fortune Business Insights, 2021). One of the major contributors of the electric vehicle market growth is the growing investment in the electric mobility space, which puts in the foreground the efforts of carmakers in terms of resources invested in new technologies and business models. Coupled with government support and declining EV battery prices, these factors are expected to keep the market growth constant and to boom sales of new EVs in the following three years. Mercedes-Benz has planned to invest €40 billion to pursue its technology plan, with the aim to shift towards electric-only vehicle architectures by 2025 (Bureau, 2021). Starting from that year, any new vehicle delivered by the German carmaker will be full-electric. Mercedes-Benz has indeed already full capacity to mass produce BEVs, and investment planned underlines its efforts to join the electrification transition. Moreover, the company is also planning to install a new battery recycling factory in Germany, in collaboration with a German global leader in battery production.

Jaguar Land Rover is moving towards the same direction with its ambitious plan to be all-electric by 2025. This costs the company £2,5 billion annually in R&D for new technologies, and the resources invested are not likely to be paid off in the near future (Winton, 2021). Despite uncertainty about feasibility of this plan, the efforts of Jaguar Land Rover clearly show the awareness of companies in the automotive industry about future competitive dynamics, implying the need to organize themself for the electrification transition as soon as possible to stay competitive in the market. The same approach is taken by Ford, which has planned to invest $2 billion for EV battery production at one of its main European plants in Cologne in order to accelerate its global plan to reach more than 2 million in EV sales (Eckl-Dorna, 2022). Indeed, Ford ambition, like that of its main competitors, is to go all-electric in Europe by 2030, not only focusing on the passenger car segment, but also delivering a range of purely electric light-duty commercial vehicles by 2035.

Looking at these examples, even if plans seem ambitious and profitability uncertain, effects in the automotive market are perhaps likely to translate in a decline of internal combustion engine vehicle sales and an increase in EV sales, contributing to keep the global electric market in expansion. Recent data show the resiliency of the global electric vehicle market even during the Covid-19 pandemic. Despite global car sales decreased by 16% at the turn of 2019 and 2020, EV registrations contrarily increased by 41% in 2020, with over 3 million new EVs sold globally (International Energy Agency, 2021). Approximately more than 10 million EVs accounts for the global electric car stock in 2020, an achievement that seems incredible if compared to the number of EVs on the world's roads in 2010. Important is the number of full-electric vehicles among the total global electric car stock, amounting to two-thirds of the stock in 2020, most of them related to China – 4,5 million electric cars – and Europe – 3,2 million electric cars. To see how rapidly the global electric vehicle market is growing, it is enough to look at data related to 2021. If compared to 2020, the number of new EVs sold globally more than doubles, reaching 6,6 million new EV registrations, and data about the first half of 2022 seem to confirm the exponential increasing trend of the last two years, with 2 million new EVs sold only in the first quarter of the year (International Energy Agency, 2022). Considering that almost 10% of global car sales has been electric in 2021, with respect to 2018 the number of the global electric car stock in 2021 nearly tripled, achieving the record of 16,5 million electric cars on the world's roads. Of these cars, most of them is related to China and Europe, confirming the trend appeared in 2020 (see Figure 17).

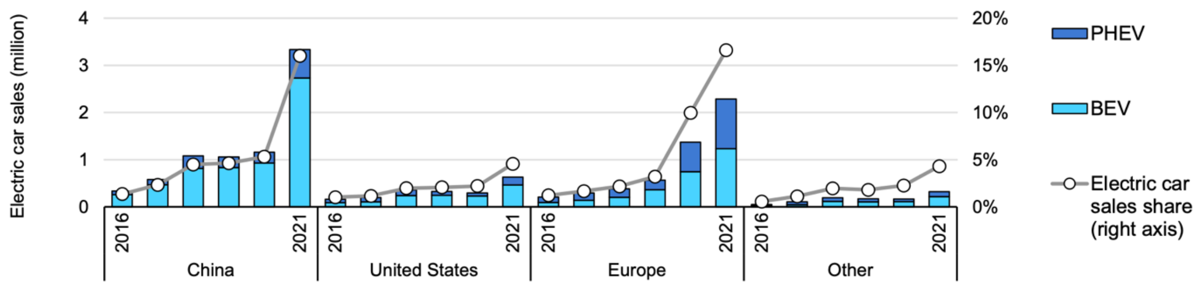
Figure 17. Global electric car stock, 2010-2021.



<u>Source</u>: *Retrieved from International Energy Agency (2022)*

China and Europe are the two main contributors for the expansion of the global electric market and seem to play a primary role from now to years to come, as together accounted for more than 85% of global electric car sales in 2021. China is currently leading the EV market thanks to the economic growth of the country in the last ten years, which has pushed investment in R&D, new technological solutions, and charging infrastructure developments to keep pace with the competitive forces in the other continents. This is also the result of actions taken by China during the pandemic, which allowed the country to recoup earlier than the others and therefore to gain advantages in the market in the second half of 2020. Nevertheless, the 1,2 million new EV registrations in China have been less than new EV registrations in Europe in 2020, where for the first time Europe has taken the lead with 1,4 million new EV registrations. This path actually raises questions about which continent will take the lead in the future, but at the same time it creates new competitive dynamics that can be beneficial to increase the widespread adoption of EVs in their countries. In 2021, China still represented the main contributor for the growth of the electric vehicle market. Only in the Chinese countries, 3,3 million new EVs have been sold in 2021, more than the entire world in 2020. Europe and the US have followed, with 2,3 million and 630 thousand new EV registrations respectively (see Figure 18).

Figure 18. Electric car registrations and sales share, 2016-2021.



<u>Source</u>: *Retrieved from International Energy Agency (2022)*

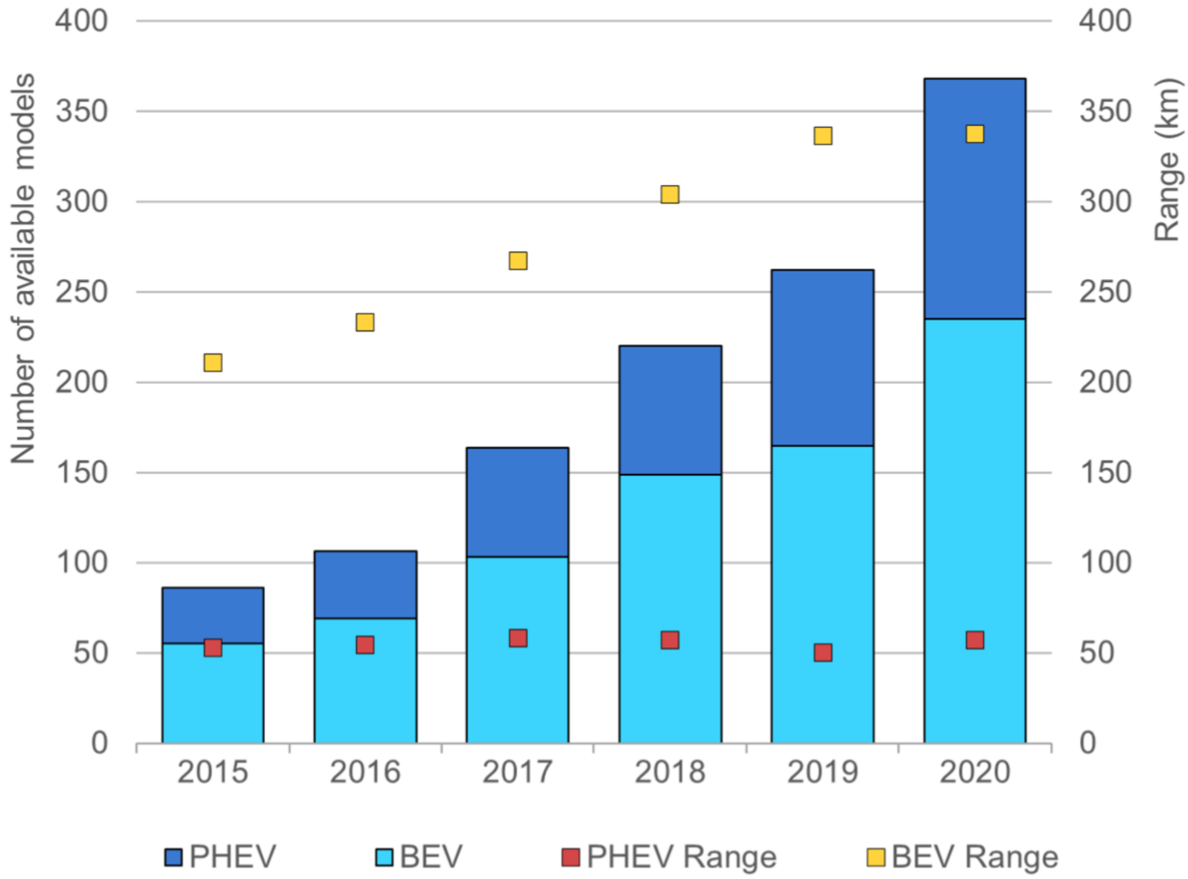
Chinese government efforts aimed at increasing investments in the electric automotive sector arguably imply that given the positive effects these investments are likely to have on production capacity, China's electric market is expected to further expand in 2022 and beyond. In addition, the new 14th Five-Year Plan (2021-2025) involving decarbonization and relative policy support for the EV market, all together have contributed to the sharp growth of the electric vehicle market in China, which detains the largest world's electric car stock with 7,8 million EVs in 2021, more than double of the number of EVs circulating in the country in 2019. EV new registrations account for 16% of total domestic car sales in 2021 and most of them concerns BEVs (International Energy Agency, 2022).

The same positive trend interests Europe, which confirms the 2020 boom and trespasses new records in 2021, with electric car sales increasing by 65% compared to the previous year. Europe EV sales exhibit a sharpen trend than Chinese ones, reflecting the willingness of each country to stay ahead in the competitive race for global electric market lead. With more than 5,5 million electric cars on European roads, the share of electric cars over Europe's total auto sales in 2021 amounts to 17% (International Energy Agency, 2022). Prompted by the European Union's CO_2 emissions standards and European government subsidy and tax benefit schemes, the EVs market has experienced growth in almost any major European country, particularly Germany, the largest market in terms of number of EVs sold. European countries with the highest sales share of electric cars have instead been Norway, Iceland, Sweden, and Netherlands, with 86%, 72%, 43% and 35% respectively (International Energy Agency, 2022). The percentage share of BEVs over PHEVs in these countries has been slightly higher for the first category, even if differently from China there is not a clear lead, perhaps because of the CO_2 regulation structure in Europe and the lack of experience in new electric powertrains of historical European carmakers. Still, the fact that Europe's stock of electric cars was about 55% BEVs supports the argument many European carmakers are taking huge efforts to follow the full-electrification transition.

Previous discussions explain the positive correlation between EVs adoption and availability of supportive regulatory frameworks and incentives. Overall, worldwide governments spending on electric cars indeed has increased year-by-year, reaching about $30 billion in 2021, 10% of governments total spending. Europe, in particular, has seen an increase from $3 billion in 2019 to $12,5 billion in 2021, supposedly encouraging EVs adoption as recent trends about EVs sales confirm (International Energy Agency, 2022). At the same time, despite the relative share of government incentives in total spending on electric cars has decreased over the past five years, consumer spending has increased yearly, reaching the threshold of $250 billion in 2021, eight times what was spent five years ago. This suggests that even if government spending slightly decreases, consumers' willingness to purchase an electric vehicle is likely to remain unvaried to some extents, perhaps because EVs are becoming increasingly attractive to consumers. Considering that prices of EVs are expected to drop sooner or later, attractiveness of EVs will increase accordingly. In China, for instance, average prices for an EV are lower than any other major country and might be one of the reasons of its leading position in the global electric vehicle market. A stronger market position for small and medium models, lower production costs, and integrated domestic battery value chains are some of the factors keeping final prices of EVs low.

A stimulus to consumer spending has also been the wider range of EV options introduced in the market along the years. The number of electric car models available has increased a lot during the last five years, together with their average driving range (see Figure 19).

Figure 19. Electric car models available globally and average range.



<u>Source</u>: Retrieved from International Energy Agency (2021)

The plethora of electric car options now available to customers includes many small to medium cars, crossovers, large cars, and SUVs. Year 2020 has registered 40% more electric car models compared to 2019, while average driving range of new BEVs is able to reach more than 350 km. Unsurprisingly, China takes the lead as far as number of different electric car models is concerned, especially concerning the SUV segment, one of the segments that shows the biggest expansion in 2020. The International Energy Agency (2021) argues that the number of electric car models is estimated to increase even further in the next years, according to the commitments of many large OEMs to increase the offer and sale of EVs. Previously mentioned Ford's ambition to go all-electric in Europe by 2030, as well as Mercedes-Benz's technology plan to shift towards electric-only vehicle architectures by 2025, implicitly mean that these two carmakers will probably deliver to the market new EV models, increasing the options of electric vehicle models available to potential customers. As a result, the more the offer of different electrical models in the market, the more the likelihood that customers choose an EV over an internal combustion engine vehicle, also given the fact that price-sensitivity customers will have access to a wider range of prices according to their preferences.

Finally, interesting is the role many private companies have in driving demand for zero-emission commercial vehicles, especially those operating in the transport sector. The transition to electric mobility is already taking place in major companies around the world, whose commitments address the shift of their fleets to electric vehicles and investments for charging stations installation. The Climate Group's EV100 Initiative is one of the international initiatives that touches this point and currently involves 122 companies committed to accelerating the transition to EVs, aiming at making electric transport the new normal by 2030. More than 169,000 zero-emission vehicles have already been deployed, whereas the number of commercial electric vehicles rose 23% in 2020, these including commercial vans, heavy-duty vehicles, and electric trucks. Goals are to reach 4,8 million vehicles switched to EVs and to install charging stations in more than 6,500 locations worldwide (The Climate Group, 2022). Businesses have a major role in the society and as such they are socially and environmentally responsible for their actions. Corporate social responsibility must address the electrification transition. Companies should recognize their role in driving this transition, eventually by increasing demand for EVs and displacing conventional vehicle assets, thereby sending a powerful demand signal to OEMs and governments to accelerate the market scale up worldwide. Amazon, the American multinational famous e-commerce company, has for instance issued its sustainability plan to reach carbon neutrality by 2040. Starting from huge investments in carbon reduction technologies, the sustainability plan of Amazon covers any business operation of the company, and its supply chain partners. Indeed, both Amazon's buildings and its supply chain activities run on renewable energy, utilize sustainable materials, and optimize energy efficiency. Considering the logistic impact of Amazon's operations, the company aims at adding 100,000 fully electric vehicles to its global delivery fleet (Amazon, 2021). FedEx, one of the largest American transportation companies, publicly announced the same commitment to carbon-neutral operations by 2040. The company has invested lots of resources in using alternative sustainable fuels and modernizing the existing assets, which include aircrafts and conventional vehicles. As regards to the latter, FedEx has already started carrying out phased programs to replace existing vehicles and by 2040 it aims at converting the entire FedEx parcel pickup and delivery fleet into zero–emission electric vehicles. In addition, by 2030 all the new parcel pickup and delivery vehicles will concern only fully electric vehicles (FedEx, 2021). These are some of the examples that can be provided, and there are many other cases involving big private companies' commitment towards carbon neutrality. Consequently, this demonstrates that companies can actually give their contribute to the cause and increase EV sales even further, with positive effects on the global electric vehicle market.

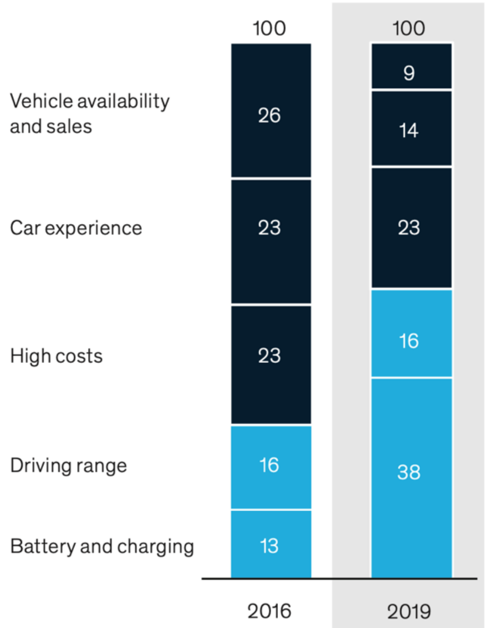
3.3. The current debate on their sustainability

The vehicle electrification transition currently in place in the automotive industry bodes well for the world's environmental health and seems a paramount to be reached as soon as possible to limit the already visible negative climate change effects. There are several benefits associated to EVs adoption, as discussed in so far, and most of the discussions points to them when arguing about the sustainability of the automotive industry. Yet, current debates argue about whether electric vehicles can be considered as a real option for the future of our society and if some additional measures are required to before giving the go-ahead to the electrification transition. Ortar and Ryghaug (2019) study the debates occurring across Europe that create uncertainty as far as the electrification transition is concerned. Benefits of the transition seem to be mostly recognized, but concerns among people are still present and cover areas from energy security issues to questions about the sustainability and ecological effects of the transition. Increased electricity demand may for example be a challenge companies and policymakers must deal with, especially because renewable energy sources alone are perhaps not sufficient, therefore the fact that demand might not be met by renewable energy sources raises concerns about whether nuclear and carbon fossil energy will increase consequently, putting at risk the real sustainability of EVs. Shifting to EVs may also create inequality and distributional effects related to the diversity of access within countries between rural and urban areas, as well as the diversity of energy production and access to the grid across Europe. Though, prices of EVs, challenges concerning the recycling of the batteries, carbon emissions generated during battery and EV manufacturing phase, the ecological footprint of batteries, the social and ecological consequences of mineral exploitation, and the limited availability of mineral resources are among the most frequent concerns raised by people (Ortar & Ryghaug, 2019). Taking into consideration these concerns seems to be extremely important to accelerate the transition towards sustainable energy and transport systems and to overcome challenges related to.

3.3.1. Customers' concerns: vehicle prices, driving range, and charging infrastructure

From the customer point of view, final product prices, charging costs, driving range anxiety, and availability of sufficient charging infrastructures are concerns that still limit widespread adoption of EVs, especially in remote areas where charging stations are not enough to satisfy customers' driving needs. Mass-market readiness is not as clear as it should be and its current level for EVs adoption needs to be redefined to address customer concerns once for all, given their purchasing force. According to Gersdorf et al (2020), significant EV-specific concerns about batteries, charging, and driving range continue to persist despite consumers are more and more recognizing the benefits of EVs. Their consideration of EVs has increased a lot over the past years, but these concerns seem to prevent a large-scale consumer pull for EVs. Latest EVs delivered in the market contain complex technology and work in ways that general customers perhaps might not understand until experiencing with them. The survey conducted by Gersdorf et al (2020) in 2019 has revealed that while consumer consideration rates and user satisfaction of early adopters increased with respect to years earlier, lack of information of most vehicle consumers persisted instead. To improve the consumer experience and increase EV sales, carmakers must fully understand consumers' perspective on EVs and create a marketing strategy that puts at the center this perspective. Evidence shows an increasing purchase intention of consumers for EVs, therefore converting this purchase intention into a completed purchase must be a priority for the evolution of the electric vehicle market into mass-market. Among the benefits perceived by consumers, driving experience and cost advantages related to availability of monetary subsidies and mobility benefits are those gaining major consideration. Few considerations are given to environmental conscience and battery and charging convenience, which arguably asks carmakers for more initiatives to familiarize customers with the wide range of benefits that can be derived from charging the EV battery at home, both in terms of time saving and convenience. On the other hand, consumers' concerns about battery charging and driving range have increased from 2016, concerns about costs remained constant, and questions about vehicle availability decreased (see Figure 20).

Figure 20. Consumers' concerns when considering purchase of EVs.



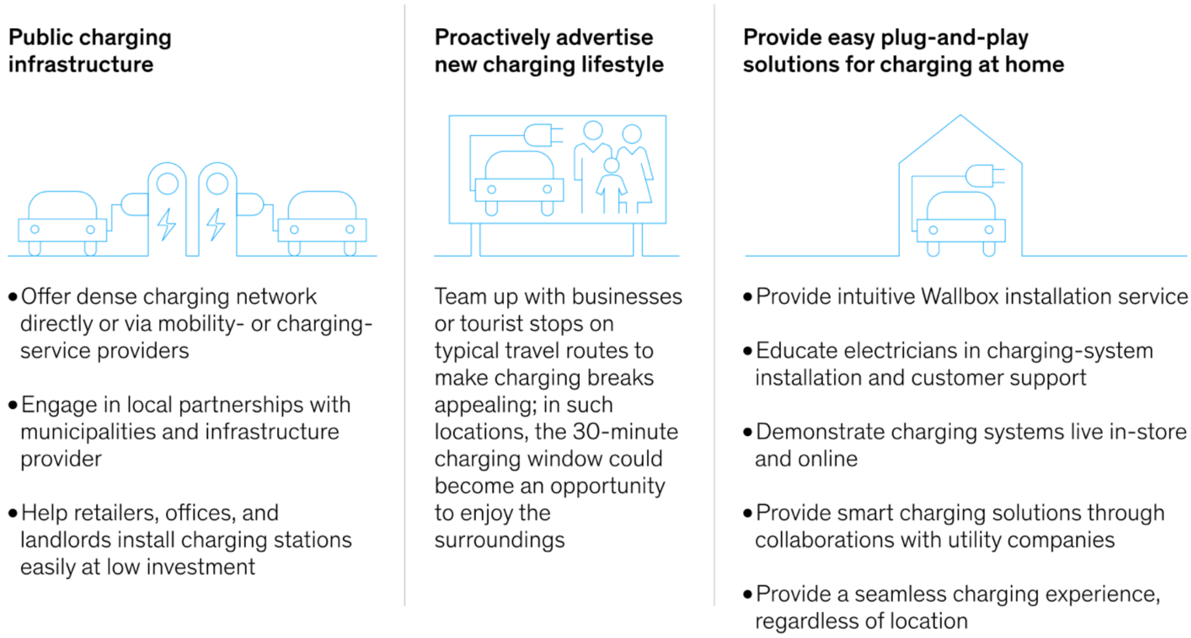
<u>Source</u>: Retrieved from Gersdorf et al (2020)

It is argued that most of the concerns expressed by customers is likely to decrease further in the years to come. In particular, concerns about battery and charging issues could be easily eliminated if consumers became aware of their true driving range needs. Driving range anxiety is present even for short distance trips, but current driving range of many EVs is more than enough to allow customers to drive for several days with fully charged battery, without the need to recharge the vehicle day-by-day. Advancements in battery technology, use of larger batteries, and huge progress in vehicle driving range are making EVs more than competitive against internal combustion engines, resulting in more customer acceptance and decreasing battery prices. Most of the carmakers is planning to go full-electric within ten years and it will deliver to the market a great number of new EV models, offering to customers a wide range of prices and driving range options among which they can choose. At the same time, governments and private/public companies are investing tons of resources to accelerate the electrification transition, with charging infrastructures expecting to increase exponentially, covering even remote areas of the world. Further analysis is needed to see whether the electrification transition will sooner or later interests also poorest countries around the world, where purchasing power of customers is extremely low. Government incentives and tax benefits, coupled with decreasing battery prices, might partially be a solution to give access to EVs to people in those countries, however whether adoption will occur within a relatively short period is still uncertain.

According to the recent analysis conducted by Batra et al (2022), consumers are becoming more comfortable with the EVs and their concerns over high initial costs and range anxiety have substantially faded. Charging infrastructures seem to remain the main barrier for most of them, but as suggested before, worldwide initiatives at all business and government levels are being carried out to accelerate the availability of charging stations worldwide. Survey data show that of those who intend to buy a new car in the upcoming months, 52% of them will choose to buy an EV or hybrid vehicle, 22% more with respect to customers who were willing to buy an EV in 2020 (Batra et al, 2022). Longer driving range, monetary incentives, lower cost of ownership, and rising penalties on internal combustion engine vehicles are what push customers' purchase intention over EVs. In any case, environmental concerns result to be what customers value the most, a great variable if one considers how powerful environmentally aware customers can be in taking care of sustainability actions.

Driving customers' considerations and purchase intention over EVs seems to be of outmost importance to boost EVs adoption ulteriorly. Gersdorf et al (2020) suggest OEMs to focus on creating a superior online experience, coupled with an in-store experience that meets customers' expectations, with specific options dedicated to increasing awareness about the real benefits of EVs adoption. Shared-mobility solutions, as well as dedicated driving experience via test drives help customers familiarizing with EVs. Indeed, customer experience is a great predictor of their knowledge about EVs, thus the more the customer knows the vehicle, the less the concerns over driving range and charging infrastructure availability are likely to be. Equally important is to offer a seamless charging experience in the public, semi-public, and private space to further alleviate the persistent concerns about charging infrastructures. EV charging advertising can help customers having a clear view on how much the charging network is articulated in any given area. If they easily find charging stations and access them without technical difficulties, then acceptance degree is likely to increase a lot. Good cost transparency and reasonable prices at public charging poles contribute to mitigate concerns, especially for consumers particularly sensible to change in prices. Kempf et al (2020) follow this direction and argue about how important will be for governments and companies to shape the charging ecosystem. Additional efforts are required on behalf of OEMs, which are asked to build partnerships and collaborative agreements with leading ecosystem players, creating a network for large-scale charging infrastructures (see Figure 21). This involves integration of different charging options – home, public, and dealer – into the existing system and app landscape, having clear in mind that concerns about charging infrastructure availability cannot coexist with the goal of transitioning to electric vehicle mass-market.

Figure 21. How to shape the charging ecosystem.



Source: Retrieved from Kempf et al (2020)

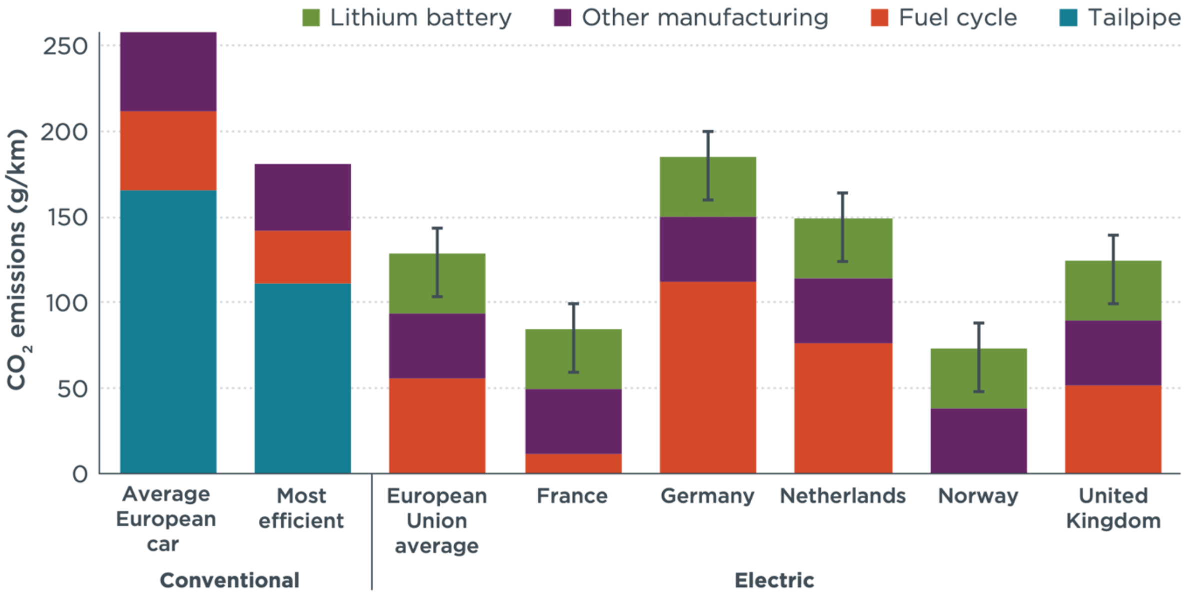
3.3.2. Carbon emissions during manufacturing phase

Choudhury (2021) argues about the sustainability of EVs and how environmentally friendly they are. It is true that their life cycle emissions are quite low compared to the emissions generated by internal combustion engine vehicles, but arguments against their predicted sustainability lie on the battery energy-intensive production and the energy source that powers the electricity grid, which involves fossil fuels in many areas of the world. Ellsmoor (2019) replicates that manufacturing concerns are present among skeptics, which doubt about emissions during battery production due to battery composition containing a range of rare earth metals, which generate emissions in extraction and manipulation activities, making the overall process highly energy intensive. As previously discussed, carbon emissions not only are a matter of fuel efficiency, but they are the sum of the GHG emissions caused throughout the production of the car, the tailpipe emissions caused by fuel consumption during its life, the emissions caused through supplying the fuel, and the emissions caused through recycling at the end of car life. Despite the production footprint of an EV is similar to a combustion engine vehicle, battery production is energy intensive and drives up production emissions significantly.

Consistent with Hannon et al (2020), if companies focus on developing cost saving strategies associated to low-carbon energy sources, process electrification, and increasing use of recycled materials in the manufacturing phase, estimates show that 66% of emissions from material production can be abated at no extra cost by 2030. Reducing material emissions can be an opportunity to accelerate the global decarbonization transition. Qiao et al (2017) confirm that emissions from the production of EVs are higher than more than a half compared to those from the production of combustion-engine vehicles, suggesting that manufacturing phase must be supported by greener manufacturing techniques and strategies in order to reduce its impact and make EVs even more sustainable. Braun and Rid (2017) point out to the advantages in energy consumption efficiency related to BEVs in the usage phase, by comparing it with a conventional internal combustion engine vehicle. The relative consumption advantages are more marked while driving in urban areas, perhaps the places when more emissions are generated given the daily large flux of vehicles on the road. No tailpipe emissions and higher energy efficiency are more than enough to confirm the benefits associated to EVs adoption, but it seems necessary to refine battery manufacturing techniques and technologies to reduce the overall CO_2 life-cycle emissions. This is because, as suggested at the beginning, the share of battery electric vehicles is estimated to be the larger portion of the market by 2040, therefore tailpipe emissions will be extremely reduced. On the contrary, the percentage share of production emissions will increase a lot and its incidence could put at risk arguments in favor of EVs real sustainability.

The International Council of Clean Transportation (2018) analyses the effects of battery manufacturing on electric vehicle life cycle GHG emissions, comparing them with those of conventional internal combustion engine vehicles and trying to identify primary drivers of battery manufacturing emissions and how these emissions could be mitigated. Several variables can affect the efficiency and sustainability of the manufacturing phase, meaning that the assessment of the impacts of battery production on electric vehicles' overall emissions is not an easy task. If the global electric vehicle market expands, as it is estimated, battery production intensifies because of larger demand for batteries, and progress in lithium-ion battery technologies will need to be balanced with progress in manufacturing techniques and technologies. Gathering the overall life cycle GHG emissions of each category, Figure 22 compares the different impacts of electric and conventional vehicles, taking into consideration an average new European passenger car.

Figure 22. Comparison of life cycle GHG emissions of electric and conventional vehicles.

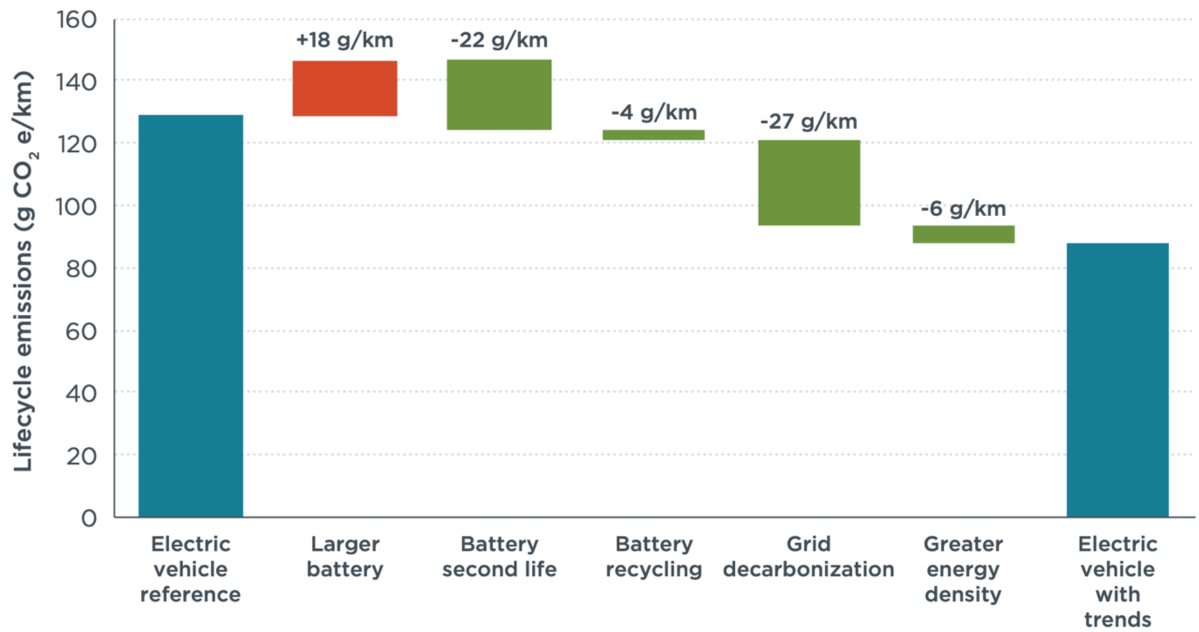


Source: *Retrieved from International Council of Clean Transportation (2018)*

Data highlight higher emissions concerning lithium-ion battery production because of the peculiarities of raw materials required and the energy needed to extract and refine these rare earth metals. Adding the fact that in 2016 most of the lithium-ion batteries produced in China and Japan used up to 40% of electricity generated from coal during manufacturing, this increases even more the potential negative impact in terms of emissions (International Council of Clean Transportation, 2018). Despite the relatively high emissions during manufacturing phase of EVs, data clearly play in favor of sustainability of EVs and confirm their much lower overall life cycle GHG emissions compared to a conventional internal combustion engine vehicle. On average, 50% life cycle GHG emissions can be saved by using an electric vehicle and within 2 years of driving its higher manufacturing-phase emissions can be paid back compared to driving a conventional vehicle. Moreover, batteries are made to last for more than 150,000 km, which makes battery degradation not a big deal because replacement is not required within this time frame (International Council of Clean Transportation, 2018). More energy efficiency during usage phase and much lower emissions through the fuel production and vehicle usage phases are more than sufficient to counterbalance the negative high battery manufacturing emissions.

According to the International Council of Clean Transportation (2018), the future of the vehicle electrification transition will be even more pronounced when the positive effects of programs to reduce emissions from battery production will be gained (see Figure 23).

Figure 23. Potential changes in battery manufacturing GHG emissions.



<u>Source</u>: Retrieved from International Council of Clean Transportation (2018)

Longer driving range is frequently associated to larger batteries assembled into the vehicle, which results in increasing battery production emissions. At the same time, several trends can be exploited to cope with battery production emissions and substantially reduce their impact. Decarbonizing the electricity grid, i.e., reducing greenhouse gas emissions produced by burning fossil fuels, will be of outmost importance to cut down pollution as half of the emissions produced when manufacturing batteries comes from electricity used in the battery manufacturing process. The use of renewable energy and more efficient power plants can lead to 17% lower battery manufacturing emissions just by using 30% less carbon fossils to power the electricity grid (International Council of Clean Transportation, 2018). A cleaner electricity grid, of course, not only does affect companies engaged in vehicle manufacturing, but also companies in related sectors like aluminum production, creating a chain-benefit effect. In short, the cleaner the grid where electric vehicles are produced and charged, the largest the overall life cycle emissions reduction will be in the future. Northvolt, Swedish high-tech firm specialized in lithium-ion battery development and manufacturing, provides a very good example of how to exploit sustainability benefits and ultimately reduce emissions during manufacturing process. The company has recently opened a battery factory located close to the cleanest energy grid in Germany. The electricity grid is directly powered by wind power and the energy produced through this renewable green source is enough to power one million electric vehicles (Orth, 2022).

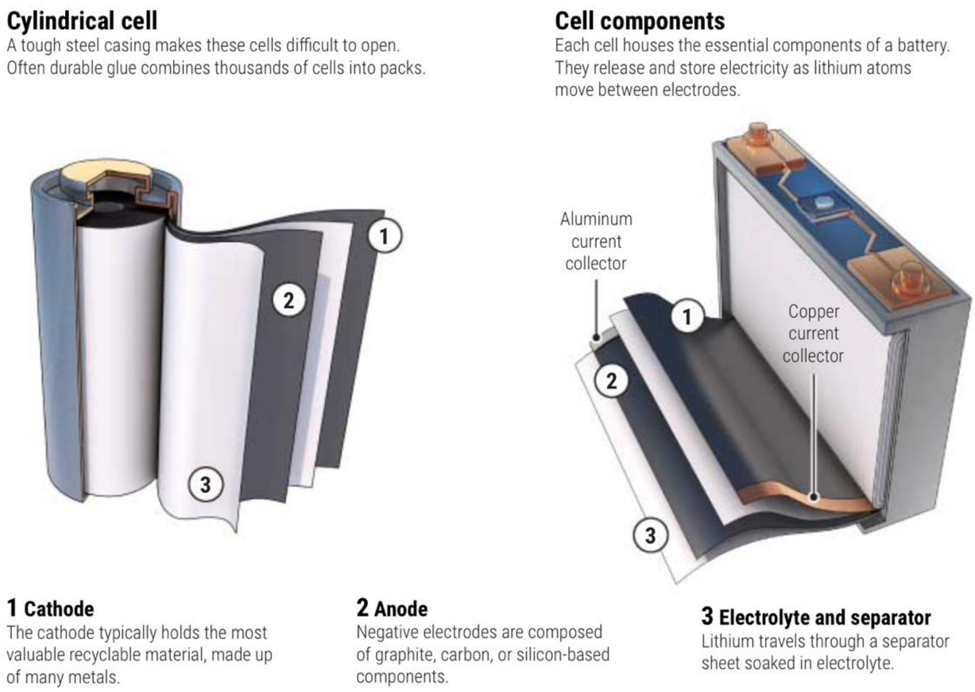
Battery reusage, and integration of recycled materials and lower-impact chemistries, two well-known concepts of circular economy, contribute to reduce emissions in the manufacturing phase. Economically and environmentally speaking, second life batteries can be an outstanding opportunity to spread the initial battery production footprint across more uses and to extend the period before battery disposal. Equivalently, the use of recycled materials in production can substantially decrease GHG emissions as well. Steel, aluminum, and copper are arguably feasible for recycling and indeed they constitute an opportunity that can be exploited to reduce greenhouse gas emissions significantly. As Hannon et al (2020) argue, the mix of recycled aluminum usage and new smelting technologies can reduce emissions from aluminum production by about 73%, while the use of plastic-related recycled materials such as polypropylene or polyethylene can cut emissions from plastic production by 34%. These reductions benefit the overall GHG emissions produced in the vehicle manufacturing phase. But greatest economic and environmental incentives for recycling are accounted for rare metals such as cobalt and nickel, for which it seems there is not a clear standardized procedure for recycling, preventing them from being commercially viable for recycling. One of the reasons is the relatively low number of batteries exiting vehicular use, which causes recycling of lithium-ion batteries to be still an undeveloped area. There is confidence, though, that as soon as the number of lithium-ion batteries suitable for recycling will be sufficiently high, recycling strategies will rise and become a standard in the industry. Choudhury (2021) suggests that there is no need at the moment of battery recycling infrastructures because of the limited number of batteries eligible, but as the time comes, both firms and governments will have to be prepared to deal with it. Lack of availability of raw materials for battery production can be a future driver to force investments in recycling initiatives, together with a new regulatory environment in which carmakers are asked to deal with battery disposal directly. According to Choudhury (2021), many carmakers have already started looking around to be prepared when EVs will approach the end of life, focusing efforts on building significant recycling capacity before the next decade.

3.3.3. Large battery disposal and recycling

Imagining a future where all the vehicles on the road will be electric vehicles seems not ambitious as some years ago and it will perhaps be the reality people will be used to. The rate of growth of the global electric vehicle market is astonishing and the stock number of electric vehicles is already quite big. If estimates are going to be respected, the number of electric vehicles delivered to the market by 2030 is likely to exceed 145 million. What happens to the EV large battery packs once their lifespan approaches the deadline is still an ongoing matter, considering that recycling of large batteries is still an undeveloped area because EVs in the market are relatively new and the number of batteries approaching the end of life is very limited. Yet, the situation will change from now up to 2030, when many EVs will surpass 10 years of life and the large batteries are likely to require disposal or replacement. Usually, even if designed to last longer, battery packs come with an eight-year warranty and battery degradation generally needs to be under 75% of the total capacity before the battery can be considered at the end-of-life stage (Pawar, 2022). Progresses are being made by many manufacturers and as new technological solutions will be developed, so will be battery efficiency and duration improved. For instance, Tesla Motors is studying the use of alternative materials to produce the standard batteries assembled into its vehicles, which are currently lithium-iron-phosphate (LFP) batteries. By using instead nickel-based batteries, their life-stage can be increased by more than 100 years in optimal conditions (Pawar, 2022).

The intricate engineering characteristics of EV battery composition make recycling a controversial topic. Direct disposal of batteries is not feasible because the rare metals and materials they are made of release problematic toxins. With the huge number of EVs estimated to be on the road in the following decade, this can create environmental disasters. At the same time, advancements in battery recycling seem to be of outmost importance given the lack of standardized infrastructures engaging in this process. Recycling the battery can be a hazardous business because of the way batteries are designed, which makes recycling not as easier as it should be. Chemistry and construction are not the same in all batteries, and manufacturers can use different configurations and materials to make batteries, consequently increasing difficulties in adopting standardized procedures for recycling. Plus, the use of recycled materials might be less convenient and more complex than buying freshly mined metals, therefore incentives to push efforts along this process seem to be necessary to accelerate its development. According to Morse (2021), EV battery disposal not only is a waste management issue but can be an opportunity to gain advantages in terms of producing a sustainable secondary stream of critical materials. The typical representation of the large battery pack describes it as a panel that holds several modules. Each module is then made of numerous smaller battery cells and thousands of cells can be assembled into just one battery pack. The most valuable recyclable materials reside within each single battery cell, specifically in the cathode, one of its components (see Figure 24).

Figure 24. Composition of a battery cell.



<u>Source</u>: Retrieved from Morse (2021)

What recyclers target are the materials inside the cathode, whose composition can differ in nickel-cobalt-aluminum, iron-phosphate, and nickel-manganese-cobalt. The difficulty lies on the fact that quantities of cobalt and nickel in each cathode, for instance, are very small, thus they cannot be found and recovered easily. Three different techniques are currently taken into consideration, namely pyrometallurgy, hydrometallurgy, and direct recycling (Morse, 2021). The first two techniques might be interchangeable and can be used together, but are the most energy intensive, producing extensive waste and emitting greenhouse gases. Pyrometallurgy is widely applicable because it does not require the recycler to know the exact composition or design of the battery pack. The metals are extracted from the charred mass of plastic, metals, and glues resulting from the burn of the battery cell once this is mechanically shredded. The process of hydrometallurgy is quite similar but does not involve burning the cell, instead it consists of dunking battery materials in pools of acid and then extracting the cathode metals from the metal-laden composite created by the acid. This method however involves the use of chemicals that pose health risks and extracting metals from the metal-laden composite is not easy. On the other hand, direct recycling is arguably the ideal recycling method because it allows the cathode to remain intact, thus avoiding any subsequent heavy processing that can generate further waste and emissions. This method is the closest to circular economy, but still shows several limitations, even if its scaling up might make it a viable solution in the future (Morse, 2021).

Disassembling EV batteries one after one takes a lot of time and effort, that is why infrastructures and technologies for large-scale recycling are so important. Stone (2021) shows the importance of scaling up the recycling industry by estimating the metric tons of battery waste in 2040. If considering only dead batteries of Tesla Model 3, the battery storage capacity needed by 2040 would be of nearly 8 million metric tons of battery waste. To give a better idea, this amount corresponds to 1,3 times the mass of the Great Pyramid of Giza. According to Stone (2021), 500,000 metric tons of battery waste will be generated by EVs stock in 2019, but the current worldwide recycling capacity accounts for only 180,000 metric tons of dead EV batteries a year. Put in other terms, if the recycling industry does not scale up, it would be a huge, missed opportunity, given that up to 12% of the EV industry's minerals demand could be met by 2040 thanks to recycling. Forecasts evidence that 25% and 35% of the EV industry's lithium demand and cobalt and nickel needs can be respectively met by 2040 as well thanks to large-volume battery recycling (Stone, 2021). Recycling must be considered among those strategies capable of offsetting demand for new mining, and although it is likely to be not enough to meet all battery metals demand, it can still reduce it at lot. Together with the development of new batteries that use less minerals and the implementation of robust government policies to support EV battery recycling, recycling can even play a much bigger role. Working on the battery design is indeed a related issue since batteries must be designed for circularity processes from the beginning to reduce the time and effort needed. Performance and durability are those two attributes EV battery makers traditionally consider, overshadowing reusability. Good for electrical connection is the fact that most components are welded together, but this is bad for efficient recycling. Arguably, battery producers should change the focus when designing EV batteries.

One concern for battery makers and recyclers is how cost competitive will recycling be compared to mined materials, and if it more convenient, for how long there will be a market for cathodes recycled materials given the rapidly changing battery market. This should not prevent them from focusing on design architectures and material composition to ease battery recycling, and more than anything else it should not deter large-scale recycling evolution, mainly because EV batteries can come in many designs, but generally share the same main components. Worth mentioning for economic purposes is also the use that recycled materials extracted from EV batteries has, and the function that used batteries can cover, which makes the business of battery recycling attractive even if changes in battery composition and design occur. Used EV batteries can be used to power factory robots, fishing boats or as mobile power units for remote locations ("Electric vehicles: Towards a circular battery economy", 2022).

Additional related limitations concern transportation and logistics management, which will suffer from large-scale recycling without a clear strategy to rely on. Large-scale recycling development is not enough, and its efficiency depends on the efficiency of the transportation and logistics system. According to Barber and Marshall (2021), a great percentage of the overall cost of recycling can be attributed to transportation. EV batteries usually weight between 300 to 600 kg and their size is around the same size of a general car. The nature of the EV batteries makes it particularly difficult to transport them to the facilities where they will be recycled or demised. Shipping a large quantity of batteries by airplane is not feasible, so they need to be shipped by truck, often across vast distances. Placing recycling centers at the right spot might be a partial solution, but transportation costs are likely to remain high, eventually discouraging recycling. This is why companies throughout the entire battery supply chain must start cooperating as soon as possible to create a network for cost efficient and sustainable transportation of dead batteries.

Lewis (2022) argues that the efficiency of the transportation system largely depends on how prepared the battery supply chain will be in coping with influx of batteries once they reach end-of-life. To this extent, planning, investment, and coordination efforts in advance are determinants of success to ensure that battery recycling capacity matches the future volume of batteries. The economics of the process must be ensured, otherwise incentives are likely to fade out as transportation costs will increase even further. Nonetheless, the sustainability of the transportation system must not be lost. Apart from the large incidence of transportation on the overall cost of recycling, shipping batteries overseas with large trucks generates huge GHG emissions and reducing these emissions is a matter that must not be overlooked. Furthermore, battery recyclers not only have them to deal with transportation for battery recycling procurement, but must comply with strict handling, storage, treatment, and disposal requirements, as well as government regulations of any given country. It becomes clear there are huge benefits that can be derived from collaborative agreements with manufacturers, auto dealers, governments, and any other actor within the supply chain. A well-organized transportation system that is both safe, cost, and environmental efficient requires the combined efforts of OEMs, recyclers, and all the supply chain partners. Actions to speed up battery recycling in large volumes are already being taken by companies worldwide and if continue investments along this direction are made, recycling plants capable to meet the future demand are likely to be a reality. According to Lewis (2022), as soon as the pioneers of this frontier gain experience to enhance their learning curve, and thanks to technology advancements, more regional and national recyclers are expected to enter the market for battery recycling, something that countries like the US is already seeing because of growth of some US-based recyclers. By focusing on extracting materials from batteries and reusing them into the battery supply chain, companies such as Redwood Materials, Li-Cycle, and Ascend Elements can reduce reliance on virgin mining materials. They are exploiting innovative domestic recycling technologies and processes. Lewis (2022) indeed says that while additional progress is absolutely needed, the development of the battery recycling industry is on its way and continue investments in education, innovation, safety, regulatory stability, and design will ultimately ensure its expansion to meet the recycling needs of the future.

Chapter 4. The feasibility of EVs within the Automotive framework: a qualitative research

4.1. Methodology

A qualitative research has been carried out to investigate further the debate involving the automotive industry and concerning worldwide adoption of EVs. The ultimate purpose of the research is to study whether concerns about feasibility of EVs in the automotive industry are currently considered by companies in the sector or they merely lie in the background of companies' strategic approaches. Considering the primary role carmakers will have in the electrification transition of the industry, it is of fundamental importance they address these concerns effectively. Large battery disposal and recycling, manufacturing emissions caused by energy-intensive processes, customers' concerns about prices and charging infrastructures, and supply chain-related issues are areas that still seem to be under considered by many automotive companies, especially those that are approaching to enter the EVs market later.

Data have been sought from five employees of one of the top three companies by market capitalization in the automotive industry. The company in question has been selected because of its relevance in the EVs market, which makes it fit perfectly with the purpose of the research. The growth prospects of this company imply that it will play an extremely important role in the electrification transition of the industry, therefore gathering relevant data from its employees is useful to confirm that leaders in the sector are currently taking into consideration concerns about feasibility of worldwide adoption of EVs. In addition, the experience the concerned company has in EVs manufacturing and sales contributes to help gathering valuable insights and perspectives. A sample of five employees has been selected and judged to be able to provide insights on key topics identified from a preceding literature review and current debates. The selected employees have different cultural backgrounds as they are located in different regions inside and outside Europe. They work in business areas directly related to the topics covered, and even if discussion has also touched arguments out of their work interest, the good deal of experience they have accumulated within the company has helped them providing useful insights. This is meaningful because their contribution is based on the experience they have gathered in the field and the specific knowledge they have acquired, having seen the changes that have occurred during the last years. Considering they are involved in various organizational divisions, the insights they can provide are based on different business perspectives that might help having a wider view of the company strategic approach. Cultural diversity is equally important to increase opportunities for creativity and problem-solving and to decrease likelihood of negative stereotypes and personal biases that similar groups may have. The list of selected employees is depicted in Table 1.

Table 1. Interviewees selected.

Interviewee	**Business role**
Interviewee 1	Senior Supply Chain Field Operations Manager, Material Planning
Interviewee 2	Senior Product Engineer
Interviewee 3	Cell Manufacturing Engineering Director
Interviewee 4	Supply Chain Analyst
Interviewee 5	Country Sales and Delivery Manager

The interviews have been carried out using a virtual face-to-face approach via Microsoft Teams, a proprietary business communication platform used as the primary communication channel within the concerned company. Differences in time zone might make difficult organize the interviews, but Microsoft Teams communication platform has resulted to be the most effective method to set a time by mutual agreement and to overcome geographic distance constraints. The virtual face-to-face approach has been chosen because of the effectiveness it has in having a conversational discussion that also provides insights regarding indirect topics not directly related to the specific questions delivered. Each interviewee was indeed asked about topics not always specific to his/her business area, therefore having the possibility to deal with the questions indirectly has proven effective for gathering insights and suggestions coming from employees with different skills and backgrounds. The number of interviewees selected has been affected by the interview method and might have been larger if using approaches such as online surveys but having the possibility for a virtual face-to-face discussion has been more meaningful for the purpose of the analysis and the number of selected interviewees has resulted to be in line with the forecast. The answers coming from people inside the concerned company are enriched by the knowledge and experience of these people in dealing with what is going on around EVs, especially considering their seniority level within the concerned company.

Respondents were asked to answer five questions divided according to three macro areas: (1) recycling/disposal issues and circular processes, (2) supply chain issues, and (3) market trajectories and customer attitude. The macro areas have been chosen because of their relevance in the current debate about feasibility of electric vehicles within the automotive industry. The number of questions delivered to the respondents has been enough to permit a discussion and has been appreciated by the respondents, who were available for a limited amount of time because of working reasons. Table 2 illustrates the questions delivered to the respondents.

Table 2. List of research questions.

Macro Area (1)	
Question 1	How are you dealing with concerns related to large EV battery, materials, and components disposal and recycling?
Question 2	Can circular economy strategies and technologies make the difference to mitigate emissions and pollution during EVs production?
Macro Area (2)	
Question 3	How do you manage to cope with disruptions in your supply chain, considering issues emerged due to Covid-19 pandemic for example?

Question 4	Do you find supply chain transparency and visibility to be a possible source of competitive advantage for your business?
Macro Area (3)	
Question 5	How do you expect the market for EVs to be in 10 years from today?

The nature of the interview has enabled to discuss questions with a wider view, gathering suggestions and insights concerning but not only strictly specific to the questions delivered. Each interviewee was more competent in one macro area rather than the others, but as previously suggested, the experience each of them has accumulated during the years has been determinant to allow them to provide useful insights in all the macro areas involved, despite these being pretty different from a business perspective. Therefore, findings have been collected, integrated, and reported based on these three macro areas.

4.2. Findings and discussion

Interviews drew out a broad range of insights and perspectives related to the key topic areas from prior literature, facilitating the deductive identification of initial themes. The first macro area - recycling/disposal issues and circular processes - was the most technical one and it has been difficult to go deeper into the topics of the questions delivered, also because of privacy and security matters. However, interviewees' responses have been particularly interesting to discover future developments regarding recycling and disposal issues, useful for the purposes of the research. The supply chain issues, and the market trajectories and customer attitude areas were instead more suitable for a multilateral discussion and interviewees' responses have indeed resulted in valuable insights and perspectives.

4.2.1. Recycling/disposal issues and circular processes

Of greatest interest to this study was interviewees' perceptions about development of the recycling industry, especially for large EV battery packs, and the need for constant efforts on behalf of the company concerned. As previously argued, recycling of large battery packs is still an undeveloped area and what happens to the EV large batteries once their lifespan approaches the deadline is an ongoing matter, considering that direct disposal of batteries seems not feasible at the moment. Because of the way batteries are designed and their intricate engineering characteristics, recycling assumes controversial connotations, putting pressures on advancements in battery recycling techniques and infrastructures. The majority of the interviewees agrees with the latter discussion and points out to the fact that infrastructures and technologies for large-scale recycling are going to be fundamental for the sustainability of EVs. They argue that EV large battery pack recycling processes are currently underdeveloped and are energy and time consuming, which make them not sustainable at all, especially to cope with future increase in the recycling demand.

Interviewee 2 suggests that designing batteries for circularity processes from the beginning is unlikely to be feasible because of the way battery packs work and for efficiency and performance reasons. Battery design is difficult to change because performance and efficiency are usually placed before sustainability to this extent, considering the features of the vehicles sold by the company concerned. On the other hand, despite working on battery pack design seems not feasible, all of them suggest that there are alternative solutions to smooth concerns about recycling and disposal of large EV battery packs. Even if recycling 100% of the EV battery pack on a large scale seems not to be feasible now, it is still possible to recycle a good percentage of it thanks to the fact that materials put inside each of the battery cell are recoverable and recyclable. Differently from fossil fuels, which are extracted and used only once, the chemical composition of battery materials allows them to be recycled to recover valuable materials for reuse, repeatedly. Each cell composing the EV battery pack can be removed singularly, enabling the recycling of the materials inside of it and their reuse in a brand-new battery. This structural design additionally enables the EV battery pack to be reused and remanufactured, extending its lifespan. Respondents have indeed underlined this option as a solution to recycling the whole large battery pack for both environmental and business reasons. When the EV battery pack comes to be faulty, it can be sent to one of the specialized facilities of the concerned company to be repaired by replacing some modules instead of the whole pack, enormously reducing the need for battery pack disposal – and consequentially the waste/pollution that might be generated from.

Additionally, Interviewee 3 argues about the role that internal recycling facilities will assume in making recycling a safe process with high recovery rates, low costs, and low environmental impact. Circular economy principles handled in-house are likely to be more effective and allow the company to gather experience and valuable skills. The aim of the concerned company is to establish an internal ecosystem to re-manufacture and recycle batteries in order to maximize key battery material recovery. This process has already started as the company successfully installed the first phase of cell recycling facilities in two of its main manufacturing plants. By closing the loop on materials generation thanks to on-site recycling, Interviewee 3 says that large scale battery recycling might be rendered possible because the experience the concerned company can make enables for innovation generation, which can result in more efficient and cost-effective recycling processes and solutions. Of course, the conveniency of large-scale recycling in economic terms must be visible and acknowledged, meaning that the costs of purchasing additional raw materials for cell manufacturing must be higher than the costs associated to large-scale battery material recovery and recycling to make the latter the best solution to adopt for carmakers and companies in the automotive sector.

The ultimate purpose of the concerned company is to avoid any scrapped large battery to go to landfilling, either by recycling it or extending its useful life. Despite most of the interviewees agrees with the necessity for advancements in technologies and growth of infrastructures for large-scale recycling, it also suggests that efforts on behalf of companies are already taking place towards these directions. It seems that companies are aware of these concerns and in search of solutions to handle them. According to Interviewee 2, companies will experience pressures related to recycling and disposal brought about new regulations and directives for large batteries recycling and related to end-of-life of these batteries that are likely to be adopted in the years to come. Carmakers then will have to deal directly with recycling and disposal according to these government regulations, therefore strategies to cope with recycling are going to be taken into consideration as a legal requirement apart from sustainability reasons. Interviewee 4 argues that the concerned company has implemented partnerships with some recycling companies in Europe as part of its battery recycling program, which support the already established internal cell recycling facilities. These recyclers can recover valuable metals from the battery packs that can be reused in the manufacturing process, thereby reducing carbon footprint. What is still unclear is the economic conveniency of this recycling program over the long term. If it wants to be adopted on a large-scale, it must be economically viable, otherwise any argument in favor of it risks losing appetite, as suggested by Interviewee 2. The outcome to this doubt is likely to be visible in the following years when the recycling industry will hopefully experience growth and be consolidated.

The efforts of the concerned company are more remarked at reducing the carbon footprint from the manufacturing process. Interviewee 3 points out to the fact that the latest manufacturing plant built by the concerned company has been described as extremely advanced, efficient, and sustainable. Structural changes have also occurred in the other manufacturing plants of the concerned company to be sure that sustainability targets are met. The aim of the concerned company is indeed to reduce energy use and material impact. Solar panels have been installed over any of the manufacturing plants, coupled with insulated windows to reduce building heating and cooling demand. Building well-designed and efficient factories that work on renewable energy is the first but important step towards reducing manufacturing emissions and it seems to be highly relevant for the financial performance as well. Localizing factories in the right spots is equally important to reduce logistics and packaging costs. Modern factories are better designed for material flow, therefore when distance is minimized, transport GHG emissions can be significantly reduced. Moreover, building localized factories eases the return process of faulty materials and components, reducing waste and favoring recycling initiatives as costs of material handling can be decreased.

Circular initiatives are facilitated by an efficient material flow. According to Interviewee 2 and Interviewee 4, many materials like paper, plastics, and metals are recyclable, and apart from minimizing shipment and packaging impacts, the concerned company is engaged in reducing non-recyclable materials in the manufacturing process. Materials like leather find application in other sectors after being recycled. The concerned company indeed sends scrapped seats made by leather to a recycling company, which then utilizes the recycled leather to produce phone covers, key cases, or small bags.

4.2.2. Supply chain issues

The correct functioning of the entire supply chain is a paramount for any manufacturer that aims at keeping costs low while increasing the speed of final product delivery. Covid-related issues have created a multitude of disruptions in the flow of the supply chain of many organizations, threatening the proper functioning and forcing them to think about strategies in order to counteract the negative consequences. The automotive industry is no exception and has been hit quite hard. Dramatic delays in production lines and delivery times of new cars, the ongoing chips and semiconductors shortage, raw materials scarcity, plant shutdowns, and logistics problems are just some of the consequences of the Covid-19 pandemic crisis. According to Interviewee 1, the effects of the Covid-19 pandemic, mainly on materials costs, are likely to last for 5-10 years from today, consequently the effects on the final vehicle prices will presumably be persistent. Looking at this scenario, for many carmakers it will be difficult to reduce final vehicle price, one of the main determinants of the customer purchasing choice, because the difficulties in reducing material costs eventually affect final delivery in the market.

One of the strategies adopted by the concerned company is to reduce commitments with specific suppliers and diversify the supplier portfolio. Interviewee 4 indeed suggests that overreliance on some suppliers, especially for key components, might result in very bad situations when unpredictable events occur, because it does not give any possibility of a backup strategy to avoid the negative repercussions. By searching for other suppliers in countries distant from where the main suppliers are located, the company seems to be able to reduce waiting time and accelerate final deliveries even in case of disruptions. For instance, the concerned company has managed to cope with electronic components shortages by searching for suppliers of electronics and infotainment hardware outside of China, one of its main providers, partially reducing delays. At the same time, the capability to evaluate production forecasts with suppliers is another strategy upon which the company concerned focuses. This has helped the company keeping a buffer stock for chips that has been used during the pandemic, when many other carmakers had to deal with shortages of this component.

As argued by Pettit et al (2011), flexibility in sourcing, visibility, and adaptability are among those supply chain capabilities that might counteract the possible vulnerabilities. The evidence from the concerned company shows that engaging in practices to mitigate risks across the various supply chain stages can be beneficial for the health of the business. For risk management strategies to work, Interviewee 1 says that there must be high levels of visibility across functions and stages. Having complete visibility of the supply chain is extremely important to keep track of the flow of materials and processes and to ease production and delivery forecasts. The concerned company uses an information system that connects different teams across different departments, where data are constantly exchanged to have everything under control at any point in time. This sort of supply chain digitization has been critical for the business strategy of the concerned company during the Covid-19 pandemic. One consideration has to be made regarding the organizational structure of the company concerned, this being a vertically integrated one. Information within vertical structure flows better during disruptive events when there is an efficient information system that support the flow. Interviewee 1 says that when most of the processes is kept in-house, there is less risk of losing information and data, which instead is more remarked when the company engages in frequent interactions with outside partners. Transparency and visibility are to this extent more likely to be reliable, eventually increasing the efficiency of the processes.

According to Interviewee 5, the wide pool of data gathered by each company's vehicle on the road is the first step to calculate accurately use of product emissions year on year. Primary data are more effective than estimates of emissions over the lifetime of the vehicle because they are real time data. Interviewee 4 adds that monitoring supply chain partners requires effective and reliable real time data as well, something that is accomplished by the concerned company through audits and delivering questionnaires on a regular way to direct supply chain partners. This method is particularly useful to map battery supply chain and collect environmental and social management systems information. Furthermore, rather than relying on intermediaries or third-party suppliers, the concerned company sources materials and components directly from its Tier 1 suppliers and mining companies. The closer the company is to its suppliers, the better it is to keep environmental and social requirements under control, which enables a more transparent and traceable supply chain.

4.2.3. Market trajectories and customer attitude

The perspectives of the interviewees respect the market trajectories concerning the exponential growth of EVs in the automotive industry. The rapid expansion of the EVs market has mainly been driven by political and environmental factors. Government's efforts play a central role in the vehicle electrification transition and are among the key elements to accelerate the adoption of EVs even in poorer countries, where infrastructures and incentives are still too low. In these countries there are several barriers to EVs adoption. Lack of charging infrastructures, driving range concerns, and high prices seem to constraint widespread adoption of EVs in countries that do not have a solid capital and financial structure.

Interviewee 1 argues about his country of origin – Norway - and agrees with the fact that the EVs market in his country has experienced a positive boom during the last years. Data as shown by Hill (2022) confirm that of all the new passenger cars sold in January 2022 in Norway, 83.7% were electric vehicles. What is particularly relevant is the approach of the country regarding not only passenger cars, but also commercial trucks and vans. Many companies in the Norwegian transport sector are building up EV fleets, that is why the number of electric vans and trucks on the road in this country is considerably high. The electrification transition benefits from the aggressive adoption of EVs from both consumers and companies, which is in line with the argument about the role of the latter for the widespread adoption of EVs. According to Bu (2022), despite the climatic conditions and the territorial characteristics of Norway, which are perhaps supposed to constrain the adoption of EVs for several reasons, government actions and policies have been fundamental for the vehicle electrification transition in the country. Apart from incentives like lower road tolls, partial access to bus lanes, and cheaper public parking for EV owners, climate change policies ask for more effective and dramatic solutions to convert all the sales of new vehicles and vans into zero emission vehicles by 2025. Indeed, strong demand-side policies, stringent emission restrictions for car manufacturers, and EV tax policies enacted by the Norwegian parliament made the difference for the radical shift towards EVs.

As explained by Walker et al (2020), there is a very positive correlation between number of pro-EV incentives and regulations available in a country and per-capita number of BEVs. Considering that the more the number of incentives and regulations in a country, the more the per-capita number of BEVs circulating on the road, it becomes clear that urgent actions must be implemented by governments of less advanced countries where public infrastructures are not well developed for the worldwide success of the vehicle electrification transition. Interviewee 5 says that prices for EVs are likely to remain fair high even in the upcoming years due to Covid-19 negative effects that protract. Supply chain issues are the main determinants for the increase in the prices of EVs, therefore even if solution strategies emerging are likely to reduce their impact, time is still needed before the negative effects of supply chain issues fade completely. The transition towards EVs must be fast and strong policies are urgently needed to counterbalance the low purchasing power of the population located in less developed countries, where the persistency of high prices blocks large-scale adoption of EVs. Investments to advance and increase availability of charging infrastructures are equally extremely important, both in urban and rural areas. Interviewee 2 suggests that the EVs market is not ready to cover global surface yet because there are still too many countries where investments to advance charging infrastructures have not been enough or have been focused only on urban areas with high population density. In some countries like Italy, where rural areas are predominant, a lack of charging infrastructures in areas outside the city center can seriously compromise the adoption of EVs. Luckily, governments in many countries seem to have recognize this point and are currently taking into consideration plans to expand further the presence of charging stations and services for EVs, with the help of companies and organizations located in their countries.

Most of the interviewees adds that the availability of charging infrastructures even in remote areas might increase the likelihood that companies and organizations convert their traditional fleets into EV fleets. Big trucks and vans that travel long distances will find several difficulties if the net of charging stations is not distributed uniformly, making the use of electric trucks not a viable option from an economic point of view. Globalization implies that many companies have international scope and operate in foreign countries such as India, Pakistan, or Turkey, which means logistics interactions are spread and distant from each other. The feasibility of electric trucks in the transport sector seems to be unclear now and the direction the sector will take in the upcoming years cannot be easily foreseen.

According to Interviewee 2, there will probably be a mix of sustainable solutions for each category of vehicles, depending on the function they cover. EVs will almost certainly be the preponderant category of vehicles in the automotive industry as internal combustion engine vehicles definitively cease to exist, at least for the passenger vehicle category. Alternative sustainable power sources to electricity for passenger cars are not likely to be adopted as intensively as electricity because the infrastructures for electric vehicles are already quite diffused and expected to expand exponentially. Nevertheless, alternative sustainable power sources like the hydrogen, another topic of discussion in the automotive industry, might find application in transportation means as trains, city buses, and even big trucks, because the use of this power source will be mainly restricted to these categories of vehicles and perhaps will not require as many infrastructures as those needed for EVs. Consumers' habits, needs, and preferences are changing as consumers become more environmentally conscious. A mixture of mobility solutions might be one of the most viable options for the sustainability and the future of the automotive and transport industry.

Conclusions

The feasibility of electric vehicles within the automotive industry framework is currently one of the most debated topics worldwide. The pressures from stakeholders, the need to safeguard the environment, and the public interest have pushed carmakers to consider the vehicle electrification transition as a core element to be competitive in the years to come. As the market trajectories suggest, the electric vehicles market is likely to become within 20 years the main market, if not the only one, for carmakers and automotive firms. Companies in the automotive industry are embracing the electrification of powertrains and employ strategies integrating the new technology trends that have emerged. The technology plan of Mercedes-Benz aimed at shifting towards electric-only vehicle architectures by 2025 reflects the necessity to join the electrification transition, which many other carmakers are considering for surviving and competing in the automotive market in the following years.

Sustainability pressures in this industry have taken a primary role in driving companies' strategies and efforts, demanding for integration of green practices into the organizational and managerial processes. Environmental collaboration and R&D investments can contribute to increase supply chain resiliency and responsiveness, as well as the capacity to generate innovation and exploit newel digital technologies. This is particularly important in the current turbulent business environment in which most of the companies in the automotive industry operates. Considering the impact of the Covid-19 pandemic, companies must be ready for any future challenge that might jeopardize their performance and put at risk the sustainability of their business, without letting behind environmental considerations. Equally, being able to predict and anticipate the risks that can arise from the management of global complex supply chains like those frequently associated to major carmakers is extremely important and benefits from supply chain visibility and transparency. The more a process is visible, the more it can be monitored to avoid any inefficiency that might exist. From a sustainability point of view, the more a company is transparent and its processes visible, the better its compliance to sustainability requirements.

The environmental impact of the automotive industry, being among the most polluting industries in terms of carbon emissions, places arguments on how to achieve sustainability goals at the top of the current discussions. The solution to these discussions finds the foundation with the electric vehicles and the benefits they provide in terms of emissions and pollution reduction. Literatures and studies illustrate the amount of GHG emissions that can be avoided when adopting electric vehicles instead of traditional combustion engine vehicles, especially involving the usage phase, i.e., the phase that generates the higher level of GHG emissions over the lifetime of the vehicle. Despite government regulations of the last years, air pollution and noise pollution levels remain too high, amplifying the need for the transition of the energy and mobility systems if climate neutrality is to be achieved by 2050. Decarbonizing transport is one of the main objects of the European Agenda and the transition towards net-zero GHG emissions primarily goes through the electrification process and the use of renewable energy sources. This can perhaps be accomplished thanks to a complete radical shift in the automotive industry with worldwide adoption of electric vehicles. The benefits attributed to electric vehicles seem to be largely recognized even among critics, however, there still subsist concerns that might prevent their worldwide adoption and that must be addressed by carmakers to enact the full transition towards the electrification of powertrains.

Current debates indeed focus on whether electric vehicles can be considered as a real option for the future of the automotive industry. The main talking points for potential customers involve their perceptions about price, availability of charging infrastructures, and driving range. Sustainability concerns are instead directed at the amount of carbon emissions generated during EVs manufacturing phase and the pollution that might come from large battery disposal. While customers' concerns about availability of charging infrastructures and driving range are being widely addressed by carmakers, at least as far as passenger cars are concerned, electric vehicles' price remains one of the major constraints for worldwide adoption, in particular for the large number of people with relatively low purchasing power. As suggested by findings of the qualitative research, prices are likely to remain high in the medium-to-short term period because of the persistency of supply chain issues, stressing carmakers to find ways to keep them as low as possible, also considering the decreasing cost of large battery packs, which should help reducing final prices of vehicles. At the same time, government incentives are fundamental for EVs adoption and should further increase to accelerate the vehicle electrification transition.

Reducing carbon emissions during EVs manufacturing is a related issue that carmakers must deal with. Because manufacturing processes of an EV are usually more energy-intensive compared to those of a traditional combustion engine vehicle, the amount of carbon emissions generated from them is seen as to counterbalance the benefits from the reduction of carbon emissions during the usage phase of the EV. Findings demonstrate that even if manufacturing emissions for the EV are higher, its overall lifetime carbon emissions are still significantly lower than those of the tradition combustion engine vehicle. Even so, as suggested by Hannon et al (2020), reducing material emissions can be an opportunity to accelerate the global decarbonization transition. Around 66% of emissions from material production can be abated by using circular economy cost saving strategies such as the use of renewable energy sources to decarbonize the electricity grid and the use of recycled materials in the manufacturing phase. Once positive effects of programs to reduce emissions from battery production will be gained, the future of the electrification transition will be clearer and companies will see benefits not only related to the environmental sustainability side of the business, but also to their financial and economic performance.

Finally, large battery disposal and recycling is arguably an uncertain area where automotive companies must focus their attention. The recycling industry for large battery packs is an undeveloped industry given the low availability of battery packs eligible for recycling. But starting from thirty years from now, the situation is going to be completely different. Large-scale recycling is a controversial topic because of the intricate engineering characteristics of EV battery composition. Yet, supply chain issues affecting availability of raw materials to build EV batteries might put at risk the feasibility of electric vehicles given the huge sales volume forecasted in the following years. By focusing on extracting materials from batteries and reusing them into the battery supply chain, carmakers and companies in the automotive sector might be able to offset demand for new mining through recycling processes. Findings from the qualitative research highlight how building internal recycling facilities can be a partial solution to address recycling concerns since the company directly deals with the recycling process, gathering experience and valuable skills that maximize its performance. Nevertheless, the lack of infrastructures and technologies for large-scale recycling remains a hot topic and their development seems to be fundamental for the future sustainability of EVs.

This paper confirms that additional measures are required to before giving the go-ahead to the vehicle electrification transition. Carmakers must deal with most of these concerns directly to accelerate worldwide adoption of electric vehicles. The benefits from worldwide adoption of EVs are recognized and the sustainability of the automotive industry lies on them. Fortunately, many automotive companies are working towards the same direction and their efforts are visible. The vehicle electrification transition has already started taking shape and although there is still space for improvements before the shift can be fully completed, the automotive industry will continue to go in the drawn direction, eventually making it possible for the future generations to live in a better and more ecological world.

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