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# Component Shortage Analysis for the Automotive Industry

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**“COMPONENT SHORTAGE ANALYSIS FOR THE AUTOMOTIVE INDUSTRY”**

## THESIS PLAN

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**Proposed Title:**

"Components Shortage Analysis for the Automotive Industry"

**Motivation and purpose of the thesis:**

To research the causes of the component crisis in the automotive industry, the influence that the evolution of electric mobility has on it, to analyse the response of the main companies in the sector, the resulting effect on market supply and demand and to study the role that politics has in this context.

**Objectives**:

| **Obiettivi** | **Methods/Tools** |
|---|---|
| 1. Analysing the main causes of the crisis;<br>Analysis of the pre-covid and post-covid automotive market trends;<br>Differences in the situation of the various components;<br>Analysis of raw material prices;<br>Analysis of transportation costs | University publications, white papers from consultancy firms, automotive association reports |
| 2. Analysing the effect COVID-19 had on the industry in general, and specifically how it affected the component crisis | University publications, white papers from consultancy firms, automotive association reports |
| 3. Analysing the excess of market demand | University publications, white papers from consultancy firms, automotive association reports |
| 4. Analysing the impact on car sales | University publications, white papers from consultancy firms, automotive association reports |
| 5. Analysing the impact and consequences on the major brands in the market, describing how each of them has responded to the crisis | University publications, white papers from consultancy firms, automotive association reports |
| 6. Analysing the impact of the evolution of the electric car in this context | University publications, white papers from consultancy firms, automotive association reports |

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|---|---|
| 7. Analysing the evolution of the situation and possible future scenarios | University publications, white papers from consultancy firms, automotive association reports |

**PROPOSED STRUCTURE OF THE THESIS**

1. **Introduction**
2. **Literature analysis on the topic and/or in-depth study of the context**
3. **Chapters of analysis**
4. **Conclusions**
5. **Bibliographical and sitographical references**

## Introduction

Modern cars cannot be produced without semiconductors, which are used in entertainment, driver assistance and safety systems, among other applications. The industry is facing a serious shortage of these components that, along with the effects of Covid-19, is causing an economic crisis.

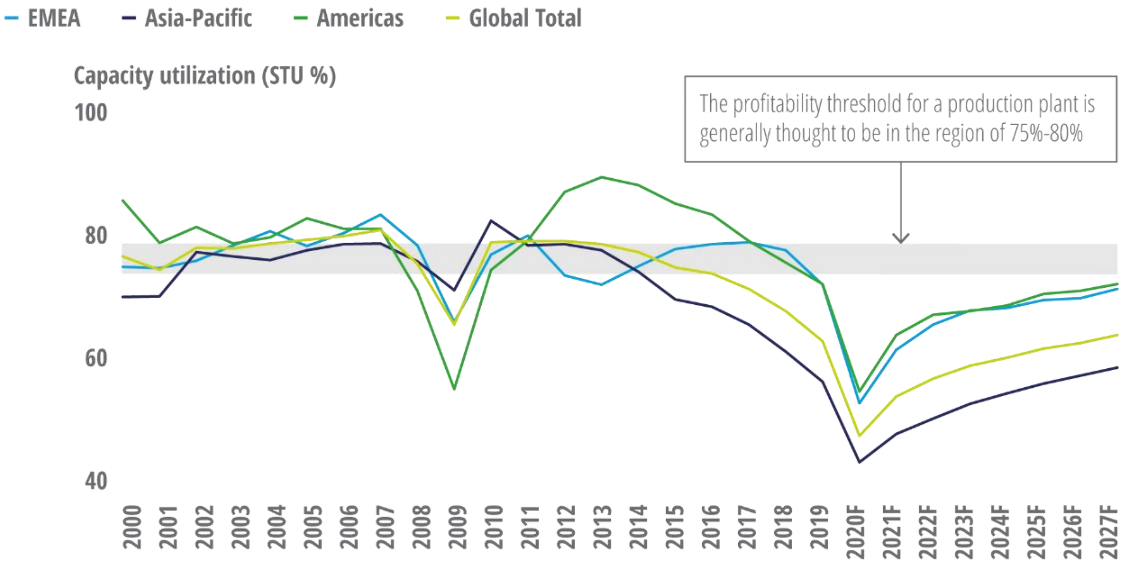
This crisis is accelerating already evident disruptive trends to the point that a radically different value chain is emerging faster than could have been anticipated. "Emerging disruptive forces present a spectrum of impacts for organisations from positive to negative, and from rapid revolutionary market changes to slower evolution over decades". An example is regional nuances in the adoption of electric vehicles (EVs), and broadly in the electric mobility, which is increasing worldwide, with a particular acceleration in Asia and Europe.

One of the visible impacts of the Covid-19 crisis was the closure of factories as measures to protect public health. The semiconductors shortage, combined with the depression of the demand, have pushed factory utilisation to historic lows with capacity utilisation falling below normal profitability thresholds (Figure 1).

Without reductions in capacity, utilisation is expected to recover gradually to return to pre-pandemic levels only in the long run.[1]

[1] Walton B., Hopkins-Burton R., Duncan S., "Value recovery in the automotive industry. Maximising value from non-core assets", Deloitte Insights (2021).

FIGURE 1 – Light vechicle capacity utilisation by region, 2000-2027 (forecasted)




Note: Straight-time capacity utilisation (STU) is calculated based on individual plant crew structure (i.e., number of shifts), excluding overtime.

Source: IHS Markit, 2020

The semiconductor shortage had a strong impact on the global automotive market. Russia's invasion of Ukraine introduced further uncertainties in the semiconductor supply chain and automotive demand. For example, Ukraine supplies 25-35% of the world's purified neon gas and Russia supplies 25-30% of palladium, a rare metal used for semiconductors.

Another problem: many semiconductors are transported by air, but transport costs have increased significantly, while the volume of available shipments has decreased. In addition, many car manufacturers have been unable to source critical vehicle components, such as wiring harnesses, and have reduced their production volumes in response, which has added even more uncertainty by decreasing demand for some semiconductor-based components.

More than three years after the start of the pandemic, the gap between chip supply and demand has widened across all semiconductor-enabled products. While sales of all consumer goods plummeted in the first half of 2020 and automotive sales dropped precipitously - by up to 80%

in some locations - demand rebounded more than expected during the year, continued to grow in 2021 and remains strong today. The high-tech sector, in particular, saw sales volumes increase, partly due to the changes brought about by the COVID-19 pandemic in our life. The growth of working from home, for example, has contributed to increased demand for wireless connectivity and PCs.

These market shifts have had an impact on demand for semiconductors and other components. In almost all sectors, demand for semiconductors in 2020 and 2021 exceeded anticipated forecasts. This means that automotive OEMs and Tier 1 suppliers (companies that are direct suppliers for an OEM) are increasingly competing with companies in other industries for chips.

Although chip shortage affects many industries, the automotive sector has some unique characteristics that amplify the problem. For example, many OEMs and Tier 1 suppliers follow a 'just-in-time' production strategy, in which they order semiconductors and other vehicle components close to production to optimize inventory costs. When vehicle sales dropped in the early 2020s, OEMs and Tier 1 suppliers decreased their chip orders, leaving them with little inventory when demand started to recover. Companies in industries that do not follow the just-in-time ordering approach were in a better position, especially since some secured additional capacity when carmakers cancelled or reduced orders.

The purpose of this paper is to analyze how the shortage of such components is affecting the automotive industry, to examine other factors influencing the market (such as the evolution of the electric car), to study how the system is reacting to the crisis and how state policies are responding to it.

# CHAPTER I: AUTOMOTIVE SECTOR: CHARACTERISTICS AND TRENDS

## 1.1 Sector characteristics

The automotive industry comprises a wide range of companies and organisations involved in the design, development, production, marketing and sale of motor vehicles. It is one of the largest industries in the world in terms of turnover (ranging from 16% in France to 40% in countries such as Slovakia). It is also the industry with the highest R&D expenditure per company.

The history of the automotive industry, even if it's short compared to that of many other industries, is of exceptional interest due to its effects on the history of the 20th century. Although the automobile originated in Europe at the end of the 19th century, the United States completely dominated the world industry for the first half of the 20th century thanks to the invention of mass production techniques. In the second half of the century, the situation changed dramatically, as Western European countries and Japan became the main producers and exporters.[2]

After the Second World War, there was an impressive expansion of motor vehicle production. In a 35-year period, total world production increased almost 10-fold. The most significant feature of this increase is that most of it occurred outside the United States. Although US production has continued to grow, its share of global automotive production has dropped from about 80% of the total to 20%. Among individual countries, the US was the largest producer until the recession of the early 1980s. In 1980, Japan, which had limited automobile production before the war, became the leading producer, while the European Economic Community (EEC) took second place. The United States regained the lead in vehicle production in 1994, as by then Japanese manufacturers were building more products in factories in their major

[2] Eckermann E. (2001). "World history of the automobile". SAE International.

foreign markets, such as the United States, in response to economic and political pressures in those markets. However, at the beginning of the 21st century, China became the leading producer of automobiles.

In 2008, the US automobile industry seemed close to collapse due to the global financial crisis. Through the Troubled Assets Relief Program (TARP), billions in loans were made available to GM, Chrysler and Ford; only the last of these automakers did not accept government assistance. Despite the assistance, GM filed for Chapter 11 bankruptcy protection in June 2009, emerged from bankruptcy reorganisation the following month, and went through a period of downsizing that helped its recovery. Chrysler also filed for bankruptcy in 2009 and shortly thereafter Italian carmaker Fiat bought a stake in it, eventually becoming a majority shareholder in 2011.

From a technical point of view, the first decades after the Second World War were characterised by improvements and refinements rather than major innovations. Diesel engines were increasingly used in trucks and buses. Automatic transmissions became practically standard equipment for passenger cars, and brakes and power steering were widely accepted, as were luxury features such as air conditioning. In the early 1960s, Chrysler experimented with a gas turbine engine for passenger cars, but it presented too many technical problems for widespread use. At the beginning of the 21st century, car manufacturers faced new design problems, as growing concerns about climate change led to a push for more fuel-efficient cars, including electric vehicles.[3]

The modern automotive industry is huge. In the United States, it is the largest manufacturing enterprise in terms of total value of products, value added from production, and number of workers employed. One in six American companies depends on the production, distribution, servicing or use of motor vehicles; sales and receipts of automotive companies account for more than one-fifth of the country's wholesale trade and more than one-quarter of retail trade.

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[3] Sachs W. (1992). "For love of the automobile: Looking back into the history of our desires". Univ. of California Press.

In other countries these proportions are slightly lower, but Japan, South Korea and Western European countries have rapidly approached the level of the United States.

The trend towards industry consolidation has already been traced. In each of the major producing countries, vehicle production is in the hands of a few very large companies, while small independent manufacturers have practically disappeared. The fundamental cause of this trend is mass production, which requires heavy investment in equipment and tools and is therefore only feasible by a large organisation. Once the technique has been introduced, the resulting economies of scale give the large company a commanding advantage, provided that the market can absorb the number of vehicles that need to be built to justify the investment. Although it is difficult to determine the precise numbers needed, the best calculations, taking into account both the assembly operation and the moulding of the body panels, place the optimum production between 200,000 and 400,000 cars per year for a single plant. Increasingly stringent and costly regulations aimed at correcting the environmental damage caused by the growing number of vehicles on the road have also been a consolidating factor.[4]

The structural organisation of these giants, despite individual variations, resembles the model first adopted by General Motors in the 1920s. There is a central organisation with an executive committee responsible for general policy and planning. The operating divisions are semi-autonomous, each reporting directly to the central authority but responsible for its own internal management. In some situations, the operating divisions are even in competition with each other. The Ford Motor Company was consciously reorganised along the lines of GM after the Second World War; other American automobile companies have similar structures.

In addition, larger manufacturers decentralise production operations through regional assembly plants. These allow the central factory to ship chassis and components, rather than

[4] Høyer K. G. (2008). “The history of alternative fuels in transportation: The case of electric and hybrid cars”. *Utilities Policy*, *16*(2), 63-71.

complete cars, to the areas served by the assembly plants, which saves considerable transport costs. This system was developed for the Ford company in 1911.

The automotive industry's immense resources in terms of production facilities and technical and managerial expertise have been devoted mainly to the construction of motor vehicles, but there has been a strong and constant incentive to extend into related products and, occasionally, into operations whose relationship with cars is remote. The Ford Motor Company (once a tractor manufacturer), for example, made the famous all-metal Ford Trimotor transport aircraft in the late 1920s and early 1930s. GM, on the other hand, produced refrigerators and diesel-powered railway locomotives. By the end of the 20th century, however, Ford and GM had divested most of their non-automotive businesses and spun off most of their automotive component manufacturing divisions into separate joint stock companies: Delphi Automotive Systems in the case of General Motors and Visteon Automotive in the case of Ford.[5]

Also in Europe, but to a lesser extent, car manufacturers divested non-core businesses over the years, while in Japan, depressed economic conditions forced companies to start separating from the non-automotive and component companies in which they had long held stakes. By the end of the 1990s, the trend was towards greater international consolidation of core automotive businesses.

The process of bringing a new car into the market has become largely standardised. If a completely new model is planned, the first step is a market survey. Since a five-year interval can elapse between this survey and the appearance of the new car in dealer showrooms, there is a distinct element of risk, as illustrated by Ford Motor Company's Edsel in the late 1950s. (Market research had indicated demand for a car in a relatively high price range, but by the time the Edsel made its appearance, both public tastes and economic conditions had changed). This is followed by conferences for engineers, stylists and managers to agree on the basic

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[5] Talay M. B., Cavusgil S. T. (2009). "Choice of ownership mode in joint ventures: An event history analysis from the automotive industry". *Industrial Marketing Management*, *38*(1), 71-82.

design. The next stage is the production of a model of the car, on which revisions and refinements can be worked out.

Due to the increasingly competitive and international nature of the industry, manufacturers have employed various means to shorten the time from conception to production, which in recent cases has been reduced to a time frame of less than three years. This has been done at GM, for example, by incorporating vehicle engineers, designers, production engineers and marketing managers into a single team responsible for the design, engineering and market launch of the new model. Car manufacturers also involve component manufacturers in the design process to avoid costly redesigns at a later stage. The component manufacturer is often given full responsibility for the design and engineering of a component as well as its production.

The need for an accurate material flow control is an incentive for automotive companies to produce their own components, sometimes directly but more often through subsidiaries. However, complete integration does not exist, nor is it desirable. Tyres, batteries and dashboard instruments are generally purchased from external sources. In addition, and for the same reasons, larger companies also rely on external suppliers for their own products. Firstly, it may be cheaper to buy externally than to acquire additional in-house facilities. Secondly, the supplier company may have special and/or specific equipment and capabilities. Thirdly, the external supplier makes it possible to better control the costs of in-house activity. American companies, in particular, rely more than others on independent suppliers.

The production of a new model also requires elaborate equipment, and the larger the production run, the more specialised the tools the manufacturer is willing to invest in. For example, it is expensive to install a stamping press exclusively to produce a single body panel for a single model, but if the model run reaches several hundred thousand, the cost is amply justified.

The assembly process has a fairly uniform pattern throughout the world. As a rule, there are two main assembly lines: bodywork and chassis. On the first, the body panels are welded, the doors and windows are installed, the body is painted and finished (with upholstery, interior hardware and wiring). On the second line, the chassis is fitted with springs, wheels, steering and transmission (engine, gearbox, drive shaft and differential), as well as brakes and exhaust system. The two lines come together when the car is finished, except for minor elements and the necessary testing and inspection. A variant of this process is 'unified' construction, in which the body and chassis are assembled as a unit. In this system, the underbody still runs down the chassis line for the powertrain, front suspension and rear axle, which are supported on pedestals until they are joined to the unified body structure. Today, most passenger vehicles are produced using the unified method, while most trucks and commercial vehicles still use a separate chassis.

Assembly lines have been developed with automatic control systems, transfer machines, computer-guided welding robots and other automated equipment, which have replaced many manual operations when the volume is high. Austin Motors in Great Britain pioneered its automated transfer machines in 1950. The first large-scale automated plant in the United States was an engine plant of the Ford Motor Company, which went into production in 1951. A universal form of automated control used computers to programme a variety of styles along the same assembly line. Customers could be offered wide choices of body styles, wheel models and colour combinations.

Mass production implies mass consumption, which in turn requires an elaborate distribution organisation to sell cars and develop customer confidence in the availability of adequate service. In the early days of the industry, cars were sold directly from the factory or through independent dealers, who could deal in different makes. Many bicycle manufacturers, when they added horseless carriages to their line-up, simply used their existing outlets. When bulk sales became the goal, however, more elaborate and better organised distribution techniques became essential.

In the US, the restricted franchise became the uniform and almost exclusive method of selling new cars. Under this system, dealers may only sell the particular brand of new car specified in their franchise, must accept a car quota specified by the manufacturer, and must pay cash on delivery. In return, dealers receive a certain guarantee in the sales territory and may be assisted in various ways by the manufacturer, e.g. with financing or advertising support. The contracts also specify that dealers must maintain service facilities according to standards approved by the manufacturer.

The system, apparently a seemingly manufacturer-friendly one, has been the subject of periodic complaints by dealers, leading to state laws and a federal statute in 1956 to protect dealers from arbitrary actions by manufacturers. However, dealers have never been united in taking this kind of political stance and an effective substitute for the restricted franchise has yet to be found. In contrast, it is becoming the general practice in other parts of the world where large-scale car markets have developed.

Most of the world's new cars come from the moving assembly line introduced by Ford, but today the process is much more refined and elaborate. The first requirement of this process is a carefully controlled flow of materials in the assembly plants. No company can afford either the money or the space to stockpile the parts and components needed for an extended production period. Interruption or confusion in the flow of materials quickly brings production to a halt. In his vision, Ford depicted an organisation in which no element ever stood still from the moment the raw material was extracted until the vehicle was completed: a dream that has yet to be realised.

In the 1990s, attempts by car manufacturers to move away from the traditional franchised dealer network to direct sales via the Internet met with strong resistance in the US. American dealers enlisted the help of state governments to ban this practice (and to block attempts by car manufacturers to own dealerships through subsidiaries). In markets outside the US, mainly in Europe and South America, manufacturers can sell directly to consumers via the Internet, even if in limited quantities.[6]

The used-car market is an important part of the motor vehicle distribution system in all countries with a substantial automobile industry, because it influences the sale and styling of new cars. The institution of the model year was adopted in the United States in the 1920s to promote new car sales in the face of competition from used cars. The new model must have stylistic or technical changes that convince potential buyers that it is an improvement. At the same time, it must not be so radically different from its predecessors that the buyer doubts its resale potential.

Like all machinery, motor vehicles wear out. Some become scrap metal to fuel steel furnaces; others end up in scrapyards where usable parts are recovered. All over the world, however, the disposal of decommissioned motor vehicles has become a problem without a completely satisfactory solution. In many areas, landscapes are disfigured by abandoned wrecks or unsightly car graveyards. Driven by European legislation requiring car manufacturers to take back all end-of-life vehicles as of 2007, manufacturers all over the world have started to design new products with complete component recycling in mind. At the same time, they used more and more recycled material in new vehicles. For example, old bumper covers have been recycled into wing liners or battery trays for new cars.

Although the automotive industry has long been multinational in its organisation and operations, starting in the 1980s and accelerating sharply in the late 1990s, a trend towards international consolidation took hold. Larger and more financially secure companies bought controlling stakes in financially troubled companies, usually because the weaker company produced a highly valued product, had access to markets that the larger company did not, or both. However, the results were mixed. For example, Chrysler, as mentioned above, acquired

[6] Sturgeon T. J., Memedovic O., Van Biesebroeck J., Gereffi G. (2009). "Globalisation of the automotive industry: main features and trends". *International Journal of Technological learning, innovation and development*, *2*(1-2), 7-24.

AMC in 1987 to gain access to AMC's Jeep vehicles and in 1998 was in turn merged with Daimler-Benz, which sought Chrysler's expertise in high-volume production and design techniques. Recognising the need to penetrate the closed markets of Japan and South Korea, DaimlerChrysler acquired a 34% controlling stake in Mitsubishi Motors Corporation in 2000 and entered into a cooperative truck venture with Hyundai Motor Company. These deals did not help the ailing DaimlerChrysler and in 2007 Chrysler was sold to an American private equity firm. Seven years later Chrysler became a subsidiary of Fiat.

In 1989, General Motors bought a 50% stake in Sweden's Saab and acquired the rest 10 years later; in 2000, it took a 20% stake in Japan's Fuji Heavy Industries (renamed Subaru in 2017) to gain access to the all-wheel-drive technology used in Fuji's Subaru vehicles. However, due to financial problems, Saab was sold in 2010 and went bankrupt the following year. Furthermore, Toyota reached an agreement to acquire Subaru in 2020. In 1999, Ford bought the passenger car business of Swedish AB Volvo and in 2000, it bought the British Land Rover business from BMW. However, the latter was sold to the Indian Tata group in 2008 and two years later Ford sold Volvo to a Chinese company.

The most promising markets for motor vehicles have traditionally been developed countries with sufficient purchasing power to create demand for cars; these include North American and European countries, as well as Australia, New Zealand, South Africa and Japan. Since 1950, however, there has been a significant change in the market outlook, as less developed countries have shown greater growth in vehicle registrations than highly developed countries. As a result, there has been an intensification of assembly and distribution in parts of the world previously unimportant to the automotive industry.

Most of this production is assembly, carried out in affiliated plants and usually operated by Chinese, American, European, Japanese or South Korean car companies. To stimulate their car industries, most developing countries apply tariff policies that make imported cars prohibitively expensive and, in addition, require that a substantial part of the components used in local assembly plants be of domestic origin. A certain percentage of local ownership, public or private, is also a normal requirement. The rest of the financing and most of the initial managerial and technical expertise comes from the parent company.

The automotive industry has become a vital element in the economy of industrialised countries: motor vehicle production and sales are one of the main indicators of the state of the economy in those countries. For countries such as the UK, Japan, France, Italy, Sweden, Germany and South Korea, motor vehicle exports are essential for maintaining international trade balances.

The effect of automotive production on other industries is very strong. Almost one-fifth of US steel production and almost three-fifths of rubber production go to the automotive industry, which is also the largest consumer of machine tools. In addition, the special requirements of automotive mass production have profoundly influenced the design and development of highly specialised machine tools and stimulated technological advances in oil refining, steelmaking, paint and glass production, and other industrial processes. Indirect effects are also considerable due to the numerous automotive-related enterprises, such as freight operators and motorway construction companies. In addition, truck transport has grown steadily throughout the world.[7]

The mass use of motor vehicles was bound to have some unintended and undesirable consequences, three of which can be identified: traffic congestion, air pollution and road accidents. The approach to each of these problems illustrates the common propensity to blame the technology, rather than the way it was used.

City streets were already congested long before the automobile existed, but the problem has been greatly exacerbated by the masses of motor vehicles entering or leaving cities during peak traffic hours. The ever-increasing number of cars around the world adds to the difficulty

[7] Beaume R., Maniak R., Midler C. (2009). "Crossing innovation and product projects management: A comparative analysis in the automotive industry". *International Journal of Project Management*, *27*(2), 166-174.

of finding remedies for congestion. At the heart of the problem is that few city street systems are designed for car traffic. According to reliable estimates, about two-thirds of the vehicles in central business districts are only passing through and should have been directed onto circumferential highways. Finding a solution for this situation is difficult and expensive. Modern highways need to provide both immediate access to central areas and a way to avoid them. Plans to do this meet with strong opposition, often justified, on the grounds that building motorways in cities disturbs neighbourhoods and destroys scenic or historic areas.

The widespread use of the car for business travel has also led to a decline in public transport systems in many cities, and the need to develop and use mass transport has been much discussed. Given the trend towards dispersal of people and companies in urban areas, it seems doubtful that mass transport can significantly reduce car traffic. However, in most cities, bus/metro systems can provide the necessary capacity for public transport and are the cheapest way to do so.

Air pollution is older than the automobile, but the concentration of many thousands of motor vehicles in large cities has given the problem a new dimension. Car exhausts commonly contribute half of all air pollutants in large cities, and even more so in cities where atmospheric and topographical conditions are particularly conducive to smog formation. In the 1960s, US federal and state legislation mandated the installation of controls on motor vehicles to limit the emission of pollutants (see Emission Control Systems). By the end of the 20th century, most scientists believed that emissions from motor vehicles, industrial processes and power plants led to a build-up of carbon dioxide in the atmosphere, thus trapping additional heat and increasing the earth's temperature with potentially disastrous long-term results (see Greenhouse Effect). This has led governments in many major automotive countries to enact laws requiring significant increases in vehicle fuel economy, thereby reducing carbon dioxide production. Many car manufacturers have also embarked on the development of alternative and less polluting energy sources, such as fuel cells that convert hydrogen (derived from petrol, natural gas, methanol or other sources) and oxygen into electricity to power an electric engine, in order to improve their competitive position even in countries where there are no strong requirements in this regard.

Every year there are hundreds of thousands of victims of motor vehicle accidents worldwide, and about 40,000 in the United States alone. The social and economic cost of these accidents is incalculable. Efforts to improve highway safety have been successful in most countries, but the reduction in the ratio of fatalities to injuries per distance travelled is often offset by an increase in the number of accidents due to the increasing use of motor vehicles.

Safety devices, such as seat belts and airbags that inflate in the event of an impact, have become standard in cars and trucks since the 1960s (see vehicle safety devices). Today, many vehicles are equipped with multiple airbags to protect occupants in side impacts, rollovers and frontal crashes.

The desire to reduce fatal accidents and save fuel has led policy makers to focus on speed limits. Most countries in the world have set speed limits ranging from around 65 km (40 miles) per hour in some island nations to 120-130 km (75-80 miles) per hour in many European countries. In some parts of the world, such as parts of Germany, India and the Philippines, speed limits are traditionally not prescribed. In the early 21st century, the United Kingdom and the European Union supported a controversial proposal to equip new cars with a speed monitoring device that would use global positioning satellites to track the vehicle's position and, together with an on-board digital road map, would cut off the car's power supply if local speed limits were exceeded.[8]

Cumulative global production of automotive vehicles, including passenger cars, commercial vehicles and buses, reached 95 million units in 2016. The value of this industry is over USD 1 trillion, tax revenues exceeded USD 8 billion, and the annual investment of car manufacturers and their suppliers in research and development projects amounts to over USD 100 billion. Approximately 9.5 million people are employed in the automotive industry, which

[8] Rrell, G. F., Roman J. (2006). "Crime as pollution: Proposal for market-based incentives to reduce crime externalities". In *Crime reduction and the law* (pp. 151-171). Routledge.

accounts for 5% of the number of employees in the manufacturing sectors. The share of passenger cars by value amounts to 10% of the total exports of industrialised countries and 17% of machinery and equipment exports (OICA, 2017). The level of relative globalisation of the sector (value of the trans-nationalisation index) increased from 0.41 in 2000 to 0.55 in 2016, which means that more than half of the production and marketing activities of automotive multinationals have been relocated outside their home countries. Furthermore, the volume of multinationals' external activities and sales approaches USD 1.5 trillion and automotive production in foreign subsidiaries reaches 42 million units (OICA, 2017).

However, rather than the absolute figures of the sector, the most important thing is the institutional multiplier effect that its development exterts on economic growth at national and global level. The automotive industry, being the largest consumer of products from a wide range of industries, is a powerful development factor: one job in the automotive sector creates 8-10 job opportunities in the supporting industries: metallurgy, petrochemicals, electrical engineering, textiles, machine tools and others. For example, in the US, the automotive industry consumes up to 15% of steel, 46% of malleable iron, 70% of natural and synthetic rubber, and a third of machine tool production. Notably, over 55% of industrial robots and manipulators are employed in this sector (OICA, 2017).

Historically, the automotive industry was the locomotive that pulled the US economy out of the Great Depression, 'participated' fully in the Second World War and then 'pulled' the economy of post-war Europe and, in particular, Germany. Shortly afterwards, the automotive industry became the basis for the development of the Japanese and South Korean economies, resulting in the so-called "economic miracle". Today, the economic growth of many developing countries - China, India, Brazil and others - depends to a large extent on the development of automotive production, especially in the context of the activities of multinationals in the sector.

In describing the current state of the global automotive industry, the following main features can be specified:

- *The industry's main product is the passenger car.* Up to 90% of the world's motor vehicle production is passenger cars (UNECE, 2016), which is not surprising considering the crucial role the car plays in modern society, which is becoming increasingly mobile and dynamic.

- *Global form of competition.* The major regional and national automotive markets are largely integrated into the global automotive market, where the largest multinationals operate. Moreover, competition today is becoming transnational.

- *Industry life cycle - maturity.* The global automotive industry currently operates under conditions of oversupply and overcapacity, which increases the intensity of competition and causes a gradual decrease in companies' profit rates (OICA, 2017).

- *The stakeholders in the industry are large multi-brand multinationals.* Today, there are about 30 car manufacturing companies, the largest and most strategically important of which are American multinationals - General Motors, Ford, Chrysler; European - Volkswagen, PSA Peugeot-Citroen, Renault-Nissan, Fiat Group, BMW; Japanese - Toyota, Honda, Suzuki, Mitsubishi, Mazda, Fuji Heavy Industries (Subaru); and Korean - Hyundai, KIA, Daewoo (Hertenstein, Williamson, 2018; OICA, 2017).

- *The level of consolidation of industry players is high*. More than 70% of production is concentrated in the 7 largest companies (Toyota, GM, Ford, Renault-Nissan, Volkswagen, Hyundai, Honda) (Liu, 2018; OICA, 2017).

The main critical determinants of industry competitiveness are: resource intensity, primarily, in terms of component-related expenditures (up to 40% in the cumulative expenditure structure for production and merchandising), labour (up to 20%), marketing (up to 20%); technological leadership (R&D expenditure reaches 8% of sales); product quality and brand reputation (Hertenstein, Williamson, 2018; OICA, 2017).

Dependence on external factors and general economic conditions is high. The reason is a branched structure of intra- and inter-sectoral links in the automotive industry and the deep integration of production and marketing into one interdependent system. In addition, a motor vehicle is not a basic necessity item and therefore the demand for cars depends to a large extent on the income level of consumers and the general socio-economic situation in consumer countries.

The close correlation between the production and marketing sectors is mainly due to the specificities of the distribution channels: their minimum length together with a rather wide width is an important characteristic of the sector. All major automobile manufacturers directly control the marketing process of their products to the end consumer through an extensive network of dealers, which are either directly integrated into the corporate structure or are bound by strict dealer agreements with the parent companies. As a consequence, the automotive industry is not influenced by intermediary institutions and this, on the one hand, allows direct price regulation and, consequently, direct sales management. On the other hand, this situation leads to hard feedback, without a buffer intermediary, from the market, where in fact "the seller is equal to the manufacturer". Considering this circumstance, the development of the market is the most important factor for the development of production. The reverse is also correct: the functioning of the automotive sector is only possible in combination with its production and marketing sectors, which act as one.

The main factors in the development of the automotive industry are as follows:

1) world population needs for motor vehicles continue to grow steadily, despite unstable global market conditions;

2) Industry is high-tech and knowledge-intensive. Firstly, this fact contributes to the growth of related industries. Secondly, the application of innovations in the automotive sector stimulates the innovative development of related industries; therefore, due to the large number of such industries, the automotive sector is able to boost the growth not only of the industrial product but also of the economy in general;

3) The automotive sector in developed countries is one of the most profitable industries;

4) Car production is a strategically important industry, the development of which demonstrates that a country has achieved a high level of economic security.

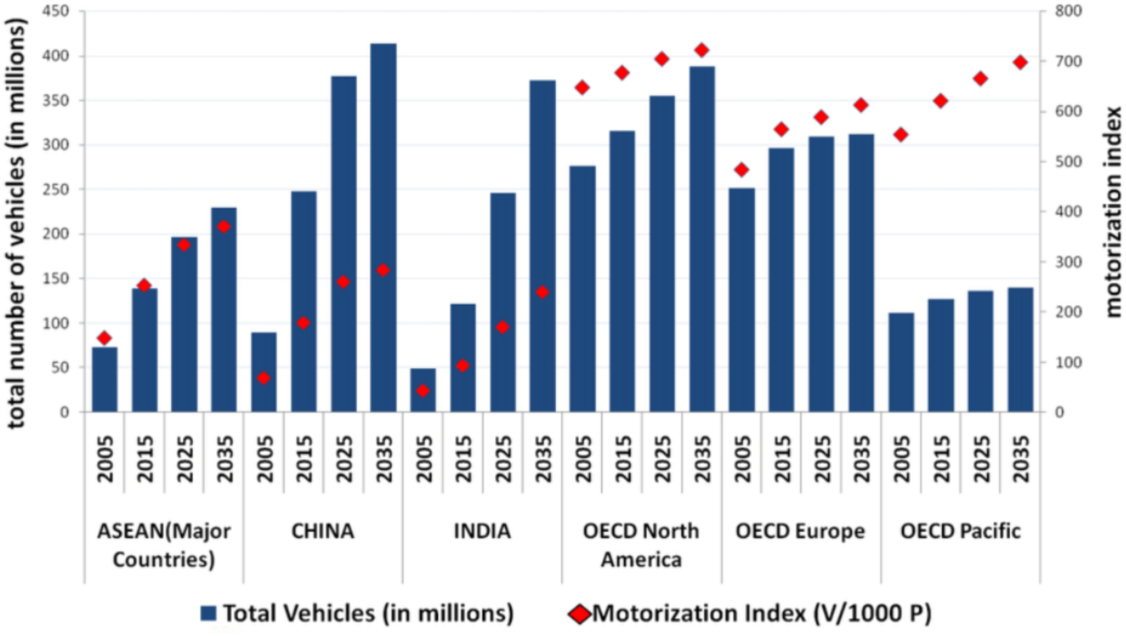
The transformation of the structure of the global economy in favour of high-tech industries is a decisive factor for the development of the automotive industry. It is reflected in the reduction of costs and expansion of the range of product models and allows the production of goods to be designed for densely populated developing countries with rather modest living standards.

The changes in demand for motor vehicles are caused, firstly, by the transition of the industry's life cycle in developed countries towards the saturation phase, when supply begins to exceed demand; secondly, by the economic success of developing countries, where the huge unmet need for cars is transformed into actual demand as national economies grow and incomes rise (Bansal and Kockelman, 2017). In fact, in the last 10 years, GDP per capita in developing countries, particularly in China, has more than doubled. Comparing the development dynamics of the major car markets and the number of cars in the respective countries and regions, we can see that the less saturated areas show a greater increase in sales (Figure 2 – Figure 3).

Additionally, culture variations, travel patterns and mobility needs do not allow developing countries to adopt model specifics and parameters established in developed countries. For example, contrary to many western countries, India has a very high share (around 75%) of two-wheelers. [9]

[9] Bansal P., Kockelman K., "Indian Vechicle Ownership: Insights from Literature Rewiev, Expert Interviews, and Stae-Level Model". Journal of the Transportation Research Forum (2017).

FIGURE 2 – Number of vehicles and motorization rates by region, 2005-2035 (forecast)




Source: ResearchGate

FIGURE 3 – Sales dynamics of new passenger and commercial vehicles, 2005-2016 (thousands of units)

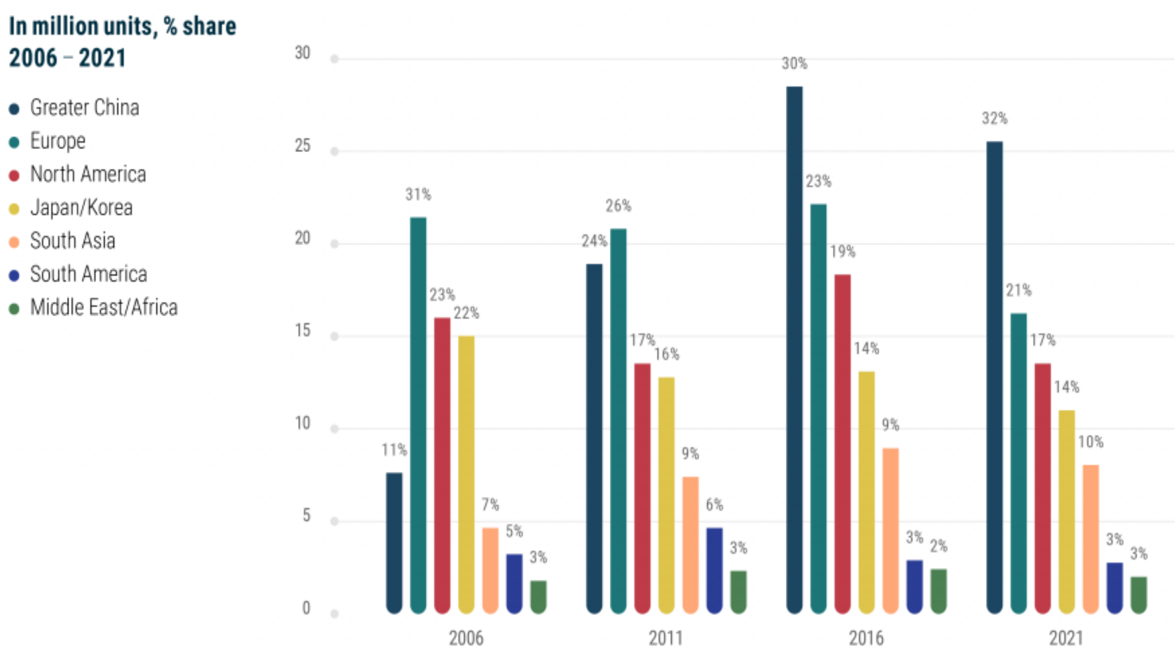
| *Countries* | *2005* | *2010* | *2012* | *2014* | *2015* | *2016* | *Structure in 2016* |
|---|---|---|---|---|---|---|---|
| *World* | 67 688 | 76 865 | 84 865 | 90 212 | 90 718 | 95 108 | - |
| *Europe* | 21 063 | 18 809 | 18 663 | 18 588 | 19 036 | 20 135 | 21.2% |
| *Russia, Turkey* | 2 877 | 3 144 | 4 305 | 3 592 | 2 582 | 2 566 | 2.7% |
| *North America* | 20 243 | 14 204 | 17 527 | 19 910 | 21 175 | 21 497 | 22.6% |
| *(USA)* | 17 444 | 11 772 | 14 786 | 16 843 | 17 846 | 17 866 | 18.8% |
| *Central e south America* | 3 096 | 5 516 | 6 144 | 5 565 | 4 514 | 4 052 | 4.3% |
| *Asia, Oceania and Middle East* | 20 409 | 35 192 | 38 226 | 42 557 | 43 411 | 46 858 | 49.2% |
| *(China)* | 5 758 | 18 062 | 19 306 | 23 499 | 24 662 | 28 028 | 29.5% |

Source: OICA

The best dynamics in recent years were demonstrated by Russia and China, where the vehicle fleet and motorisation were not as developed as in Western countries. This gap can serve as a particular indicator of further market growth potential, given the quick-start effect. It is clear that in China and India, densely populated and rapidly developing countries, the number of citizens willing to purchase a motor vehicle will be much higher than in the US or India.

Currently, there is a trend towards greater concentration of automotive production in Asia Pacific and a slight weakening of the positions of North America and Europe in percentage terms. The figure below (Figure 4) shows the distribution of global automotive production across regions in 2006, 2011, 2016 and 2021.

FIGURE 4 – World vehicle production share by region, 2006-2021




Source: European Automobile Manufacturers's Association

The following tables (Figure 5 – Figure 6) show the cumulative global automotive production figures (passenger cars + commercial vehicles) worldwide and for the main producer countries from 2000 to 2018.

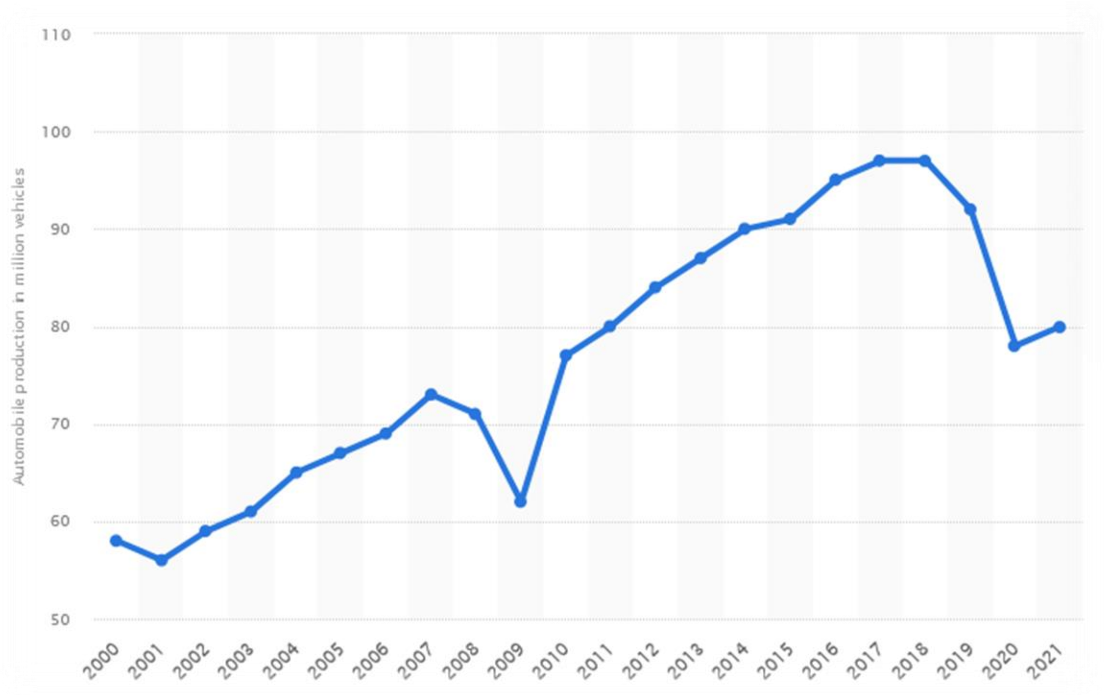
FIGURE 5 – World car production (million vehicles), 2000-2018

| PRODUCING COUNTRIES | 2000 | 2005 | 2010 | 2014 | 2018 | CHANGE 2000/2018 |
|---|---|---|---|---|---|---|
| **WORLD** | 58,37 | 66,48 | 77,63 | 89,75 | 95,63 | **+64%** |
| **CHINA** | 2,07 | 5,72 | 18,26 | 23,72 | 27,81 | **+1243%** |
| **USA** | 12,80 | 11,95 | 7,74 | 11,66 | 11,31 | **-12%** |
| **JAPAN** | 10,14 | 10,80 | 9,63 | 9,77 | 9,73 | **-4%** |
| **GERMANY** | 5,53 | 5,76 | 5,91 | 5,91 | 5,12 | **-7%** |
| **INDIA** | 0,80 | 1,64 | 3,56 | 3,84 | 5,17 | **+546%** |
| **SOUTH KOREA** | 3,11 | 3,70 | 4,27 | 4,52 | 4,03 | **+30%** |

Source: OICA

As we can see from the data in the table, the last twenty years have seen a steady growth in car production. However, this increase is very uneven between countries: while the USA, Japan and Germany (leaders in 2000) have experienced a slight to moderate decline, developing countries have experienced exponential growth. In particular, China has seen a very substantial surge from 2 million units produced in 2000 to almost 28 million in 2018. Over the last decade**,** China has emerged as one of the most important growth markets for all players in the world automotive industry to establish itself in the recent years as the world leader in the production of cars.

FIGURE 6 – Cumulative worldwide car production, 2000-2021




Source: Statista

The growth rate of automotive production worldwide was very uneven during the years. During the economic crisis of 2008-2009, production declined in many countries, while the sharpest decline was recorded in the US and Japan. At the same time, China reported a record growth of 48.4%. After 2009, China's automotive industry began to decline, reaching its lowest value in 2011 - 0.8%. Finally, 2016 was the year of the recovery of growth to 14.5%.

Despite the uneven dynamics of production and the lack of a clear trend, the Chinese automotive industry is demonstrating deliberately higher growth rates than the world as a whole. China's significant progress in this sector has been made possible by a large and fast-growing domestic market and low-cost resources that have attracted the largest automotive multinationals to the country. It is important to remark China's sensible industrial policy to stimulate multinationals within a framework of administrative and economic regulation. China's current national policy is designed not only to facilitate manufacturing activities throughout the country, but also to integrate them into the national economic system.

Increasing the localisation level of automotive manufacturing, expanding cooperation, creating joint ventures and attracting foreign capital are the main elements of integration.

China has managed to perfectly integrate its automotive industry into a modern global automotive production and marketing system, fully appreciating the advantages of the global market in the form of access to technology, resources and world-class automotive industry management experience. As a result, the country is not only gradually meeting the needs of its citizens for modern passenger transport but is also laying another important brick in the foundation of the national economy: the high-tech automotive industry, which is a powerful generator of economic growth. Brazil, India and other developing countries in Asia and Central and Eastern Europe have embarked on a similar path. These countries are seeking to expand their presence in the global automotive sector and are employing both passive (as consumers) and active (as producers and players in the global economy) ways to do so.

## 1.2 Key players and market trends

In 2021, the ranking of the world's largest car brands was led by Toyota with a market share of around 10.5%. The Toyota brand is owned by the Japanese Toyota Motor Corporation, the world's largest car manufacturer, which overtook in 2020 the previous leader, the Volkswagen Group, owner of the 6.4% of the global market share in 2021.[10]

Considering a growing environmental awareness and increasing efforts to connect vehicles, car manufacturers are facing a variety of new challenges. Market trends such as the shift to lighter materials and the trend towards electric and autonomous vehicles are set to revolutionize the industry. Tesla Motors, based in Palo Alto, is currently at the forefront of the electrification trend, while other Californian companies such as Google and Apple may follow

[10] Carlier M., "Car brand market share worldwide 2021". Statista (2022).

its lead. Tesla delivered approximately 936,000 vehicles in 2021, which is more than nine times lower than the sales of the Volkswagen Group. Tesla is believed to have a US car market share of around 2%.

Starting in 2020, the global automotive industry faced a drop in demand and production disruptions due to the COVID-19 pandemic and a shortage of automotive semiconductors. This chip shortage led to the elimination of about 11.3 million vehicles from global production in 2021, and analysts estimate that these disruptions in the automotive supply chain contributed to the elimination of another seven million units from production in 2022. Global car sales have begun to recover from the decline experienced during the pandemic, reaching 66.7 million units sold in 2021. However, this sales volume declined again in 2022, with a forecast for 2023 still lower than 2019.

In 2021, almost 80 million motor vehicles were produced worldwide. This figure translates into an increase of around 3% over the previous year. China, Japan and Germany were the largest producers of cars and commercial vehicles in 2020.

Understanding the state of the global automotive supplier market and the underlying trends will help define ways to improve competitiveness. Below is a snapshot of the five most important trends or what we are witnessing:

- *Regulations*. Governments have introduced regulations and incentives on CO2 emissions to accelerate the shift to sustainable mobility. Regulatory authorities around the world have set stricter emission targets by 2030 and beyond. Under pressure from OEMs (Original Equipment Manufacturers), the public and capital markets, most automotive suppliers have set their own sustainability targets. There is no doubt that industrial suppliers with a more sustainable footprint will develop a price and margin advantage.

- *Consumer behaviour*. Consumer behaviour and awareness are changing in the light of the ‘software-defined vehicle’ and the fact that more and more people are accepting alternative and sustainable forms of mobility. Whereas in the past the customer experience with a car was mainly defined by the hardware, software is taking on a much more important role. The sharing economy is disrupting conventional notions of car ownership, moving away from traditional individual transport towards completely new forms of mobility, such as self-driving taxi-robots (with an automation level of SAE 4 or 5). This affects car suppliers, as the next generation of cars will need different components as well as completely different chassis, systems or interiors. This evolution not only affects the development and operations of suppliers, but also makes possible new business models and types of collaboration, e.g. using model-based systems engineering (MBSE), virtual simulation and digital twins.

- *Technology*. The industry's focus on connected cars, autonomous driving, shared mobility and electrification (CASE) is causing a shift in business models and product mix. As the automotive industry evolves from ICEs to hybrid, plug-in, battery electric vehicles (BEV) and fuel cell vehicles (FCEV), industry suppliers are reshaping their portfolios to emphasise electric motor technologies, advanced driver assistance systems (ADAS) and battery-related innovations, while reducing the importance of external body systems, tyres and combustion engines. As a result, most of the technical content of the car of the future is expected to come from software, a change accelerated by increasing customer demand for 'experiences' while driving.

- *Sales decline and diversification*. Light vehicle sales have been hit hard by the pandemic. In 2020, global sales of light vehicles dropped by 14%. Mainly due to supply chain pressures and semiconductor shortages, experts believe that light vehicle sales will not reach pre-COVID volumes before 2024. Therefore, industrial suppliers are increasingly looking for new growth in sectors other than automotive. Those looking to diversify their business portfolios are exploring areas such as everyday household products or agricultural and industrial machinery.

- *Quick transformation and forced agility*. The need to execute bold programmes in accelerated timeframes, often extending to several parts of the company simultaneously, continues. This requires new digital solutions and adaptability for long-term business success. Industrial suppliers must embrace the cloud and digitise their infrastructure and offerings with foresight and vision. Becoming structurally agile with these core capabilities and assets is critical for future growth.

In this context, we are witnessing consolidations, divestments and changes in product portfolios among global suppliers. For instance, investment pressure on electric and autonomous vehicles and software will further accelerate M&A activities and industry consolidation. In fact, the entire automotive supplier market is expected to be dominated by a handful of players within the next few years.

Evidence of this is the fact that already in 2020 and 2021, the top 10 suppliers accounted for 40% of the total global turnover, with the top 5 achieving a turnover of more than USD 30 billion each. A prime example is the merger of Faurecia and HELLA to create the 7th largest global automotive supplier with a highly advanced technology portfolio. The combined group, Forvia, has publicly stated its ambition to achieve a turnover of more than EUR 30 billion, with an operating margin of more than 8.5% by 2025, focusing on six business groups and areas such as electric mobility (including hydrogen solutions), ADAS and autonomous driving, the cockpit of the future and life-cycle value management.

We are also seeing the entry of new players, many of them digital natives, bringing technical innovations and agility to meet the needs of emerging markets. For example, US chipmaker Nvidia expects its automotive sales to increase by more than a third to $11 billion this year, thanks to booming demand for more automation in cars. The company is increasingly focusing on software and chips that underpin sophisticated driver assistance systems.

Overall, the automotive industry is recovering from the effects of the pandemic. Growing savings and the maintenance of relatively low interest rates have driven demand for all types of goods, including cars.

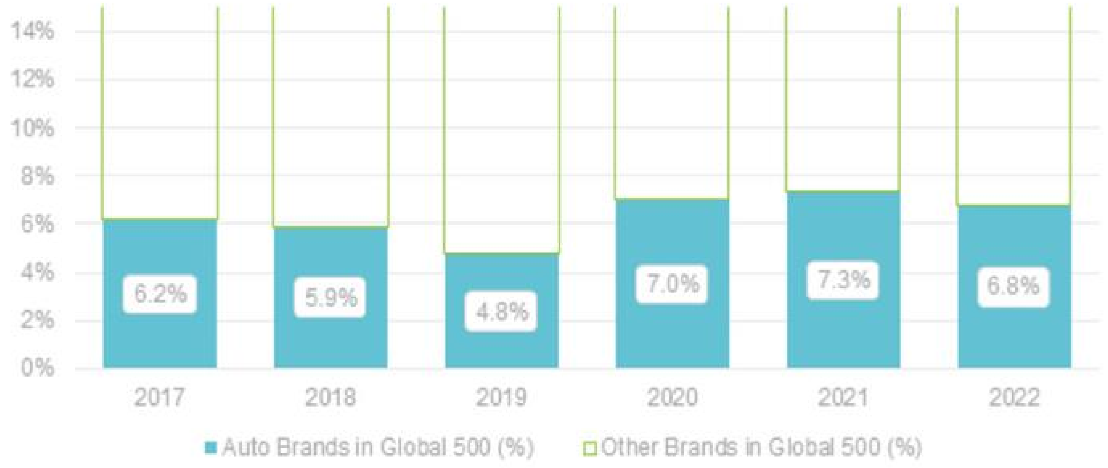
SUVs and crossover SUVs remain the most popular models and their popularity continues to grow in all regions. In a way, this is eroding large differences in model popularity between regions, such as the European trend for small cars and the US trend for larger models.

Although demand is positive across the industry, electric vehicles are by far the best performing transmission type in terms of relative growth. Approximately 6.4 million plug-in electric vehicles were sold in 2021, an increase of more than 100%. This represents an increase from 4.5% of all vehicles sold in 2020 to 9% in 2021.

The main obstacle holding back OEMs is access to microchips, which is expected to remain an issue for some time. In addition, another major obstacle to value growth is the effect on investor sentiment of the major changes that are taking place in the industry. In recent years, there has been a reasonable increase in risk sentiment for the sector, which increases financing costs and reduces values in general.

Partly due to this additional risk, the percentage of the value of automotive brands in the Brand Finance Global 500 ranking decreased for the first time in three years, from 7.3% to 6.8% of the total (Figure 7). The absolute value of automotive brands in the Brand Finance Global 500 ranking increased by 5%, but larger growth increases in the retail, tech, media and travel sectors drove down the share of cars.

FIGURE 7 – Auto brand value as % of Top 500 brand's value, 2017-2022




Source: Reasearchmarkets

Looking at the Brand Finance Automobiles 100 ranking, the brands on the list recorded a respectable overall increase of 4.3%, with the total brand value rising from $5.9 billion in 2021 to $6.1 billion in 2022 (Figure 8).

FIGURA 8 – Brand finance's top 100 automobile brands, 2017-2022


Source: Reasearchmarkets

This growth has been widespread, but special attention must be paid to China, which is home to eight of the 10 fastest growing brands and 7% of the total brand value in the ranking, up from 5% in 2021. Chinese brands have successfully exploited the push towards electric vehicles within the country and are now moving around the world.

These results show an industry that is adapting to a period of great strategic challenges and high investment requirements, shaking up old players and introducing new ones with some success.

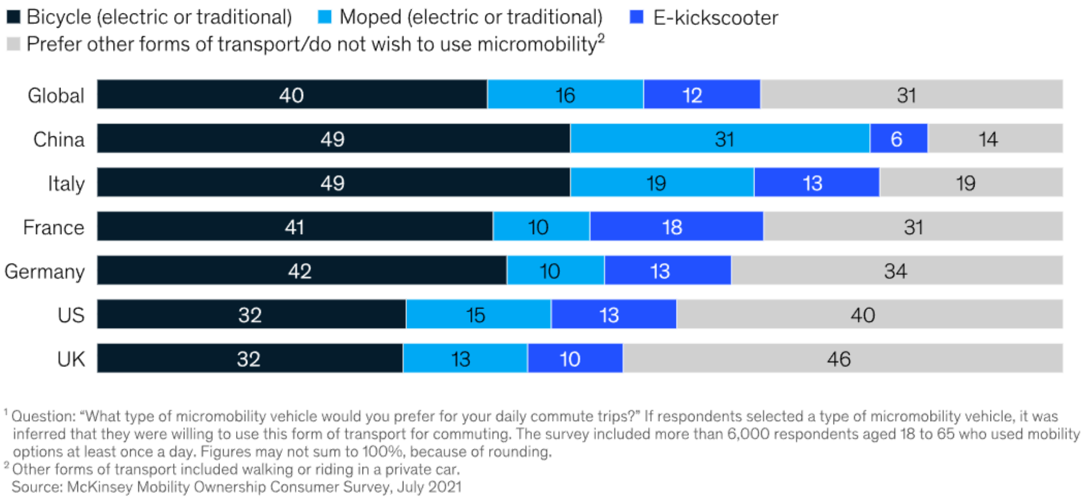
Looking ahead, there are significant threats to the continued strength of the industry, in particular the rise of multi-medium and micro-mobility and the related backlash against cars by many cities, especially in wealthier parts of the world.

A recent study by Mckinsey shows that up to four fifths of people are willing to use bicycles, mopeds or scooters to get to work (Figure 9). These results suggests that a growing number of workers is going toward smaller, more environmentally friendly forms of transport as pandemic restrictions lift and offices reopen. [11]

Lime, Voi and many other scooter companies are reaching significant size, filing IPOs and achieving relatively strong commercial success as providers of alternative mobility services.

[11] Heineke K., "Why micromobility is here to stay". McKinsey (December 2, 2021).

FIGURE 9 – Preferred micromobility vehicle for commuting, by country




Source: McKinsey Mobility Ownership Consumer Survey

Paris, Berlin, Barcelona and many other cities are making life more difficult for cars, especially those with internal combustion engines (ICE). At last count, more than 150 cities in Europe had introduced regulations to favour low-emission cars over traditional ICE models, and the same trend is being seen, to a lesser extent, around the world.

These close-range mobility trends are not the only way in which our modes of mobility could change in the near future. Although a little further back in time, personal air mobility has also seen a huge increase in investment in the last two years.

According to S&P Global Intelligence, the total value of venture capital investments, together with associated R&D spending and announced SPAC mergers in customised air mobility, was almost four times higher in 2020 and 2021 (at about $9.8 billion) than in all years up to 2019 combined.

British start-up Urban-Air Port has announced plans to build 200 'vertiports' for the vertical take-off and landing of cargo drones, as well as the launch of passenger drones, in 65 cities around the world, in partnership with Hyundai. The first of these, in Coventry, will be operational as early as April this year.

According to some estimates, these advanced air mobility options could account for more than 50% of long-distance travel over the next 20 years, especially in cities and regions with high levels of road congestion. The combined effect of micro-mobility (short-distance) and customised air mobility (long-distance) options is likely to cause significant pressure on traditional car manufacturers in the future.

# CHAPTER II: OPEN ISSUES FOR THE SUPPLY CHAIN

## 2.1 The evolution of the electric car

The first electric vehicle was presented at an industry conference in 1835 by a British inventor named Robert Anderson. At that time, Robert Anderson's vehicle used a disposable battery powered by crude oil to turn the wheels.[12]

Anderson was not the only one pursuing electric mobility. At the same time, Hungarian scientist Ányos Jedlik and Dutch professor Sibrandus Stratingh both invented electric vehicle models. On the other side of the Atlantic, Thomas Davenport, an American blacksmith turned inventor, would invent integral electric motor components that produced the first electric car.

However, all of them were little more than prototype electrified wagons, travelling at a maximum speed of 12 km/h, with cumbersome steering and a short range. In the 1860s, a French physicist named Gaston Plante invented the first rechargeable lead-acid battery, a huge step forward for electric mobility. However, it was not until the late 1880s that batteries and electric motors were put together by electric mobility pioneer William Morrison to create the first 'practical' electric vehicle. Since then, much progress has been made and today there are many electric car models on the market.[13]

While the electrification of rail transport is now fully established and consolidated in much of the world, the electrification of road transport, although with difficulty, has been accelerating in recent years. The technologies used for electric cars can now be considered to have reached

[12] Sachs, W. (1992). "For love of the automobile: Looking back into the history of our desires". Univ of California Press.
[13] Fitzgerald A. E., Kinsley C. Jr., Kusko A., "Macchine elettriche" (FrancoAngeli, 1991).

a sufficient level of maturity. Today, there are many recent developments that focus on the improvement of electric vehicles and their components, particularly with regard to advances in batteries, energy management systems, autonomous functionality and charging infrastructure. This plays an important role in the development of the next generation of electric vehicles and encourages a more efficient and sustainable ecosystem.

The electric vehicle landscape is changing rapidly, both due to evolving technology and interest, and many more electric vehicles will be on the roads, seas and skies in the coming years. In the US, sales of electric vehicles have increased by more than 40% per year since 2016. By 2035, the largest car markets will be fully electric. The transition from petrol to electric drive obviously means new models, often with improved performance and new features.

The transition to electricity has also opened the door to new car manufacturers, as complex engines with proprietary technologies are replaced by electric motors and relatively simpler batteries. Although the progress we are seeing in the availability of EV models is still important, policies such as zero-emission vehicle regulations are increasingly relevant and significant to the industry.

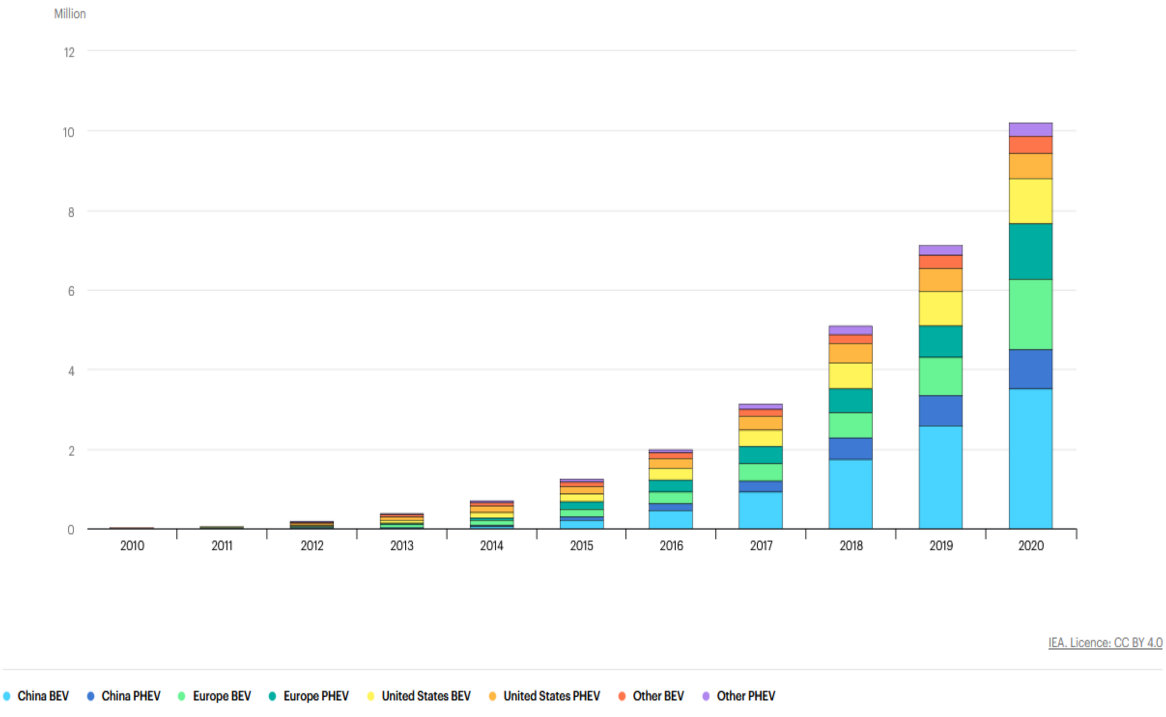
While many automakers are offering EV options to buyers, some are lagging behind. For example, Honda (among the world's largest manufacturer brands) does not currently have an electric vehicle offering. To ensure the reduction of climate-changing emissions, we will need to see progress from all car manufacturers. More and more states around the world are adopting policies in anticipation of an increasingly electric-oriented future for the industry. In California, for example, 35% of all new cars by the year 2026 will have to be zero-emission models (battery electrics, plug-in hybrids or fuel cell electrics), rising to 100% by 2035.[14]

[14] Fitzgerald A. E., Kinsley C. Jr., Kusko A., "Macchine elettriche" (FrancoAngeli, 1991).

Some car manufacturers (such as Tesla and Rivian) have already achieved 100% sales of electric vehicles and others, such as Volvo, have committed to going fully electric before 2035. However, the ZEV (Zero Emission Vehicle) regulation means that all car manufacturers will soon have to accelerate the transition to electric vehicles.

After a decade of rapid growth, the global stock of electric cars reached the 10 million mark in 2020, an increase of 43% over 2019 and a share of 1% (Figure 10). Battery electric vehicles (BEVs) accounted for two-thirds of new electric car registrations and two-thirds of the stock in 2020. China, with 4.5 million electric cars, has the largest fleet, although Europe had the largest annual increase in 2020, reaching 3.2 million.[15]

FIGURE 10 – Global electric passenger car stock, 2010-2020




Source: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2021); EAFO (2021); EV Volumes; Marklines (2021)

[15] Sachs, W. (1992). "For love of the automobile: Looking back into the history of our desires". Univ of California Press.

Overall, the global market for all types of cars was significantly affected by the economic repercussions of the Covid-19 pandemic. In the first half of 2020, new car registrations decreased by about one third compared to the previous year. This was partially offset by higher activity in the second half of the year, which led to an overall decrease of 16 % year-on-year. Notably, while conventional and overall car registrations declined, the overall sales quota of electric cars increased by 70%, reaching a record 4.6% in 2020.

Around 3 million new electric cars were registered in 2020. For the first time, Europe led the way with 1.4 million new registrations. China followed with 1.2 million registrations and the US registered 295,000 new electric cars.

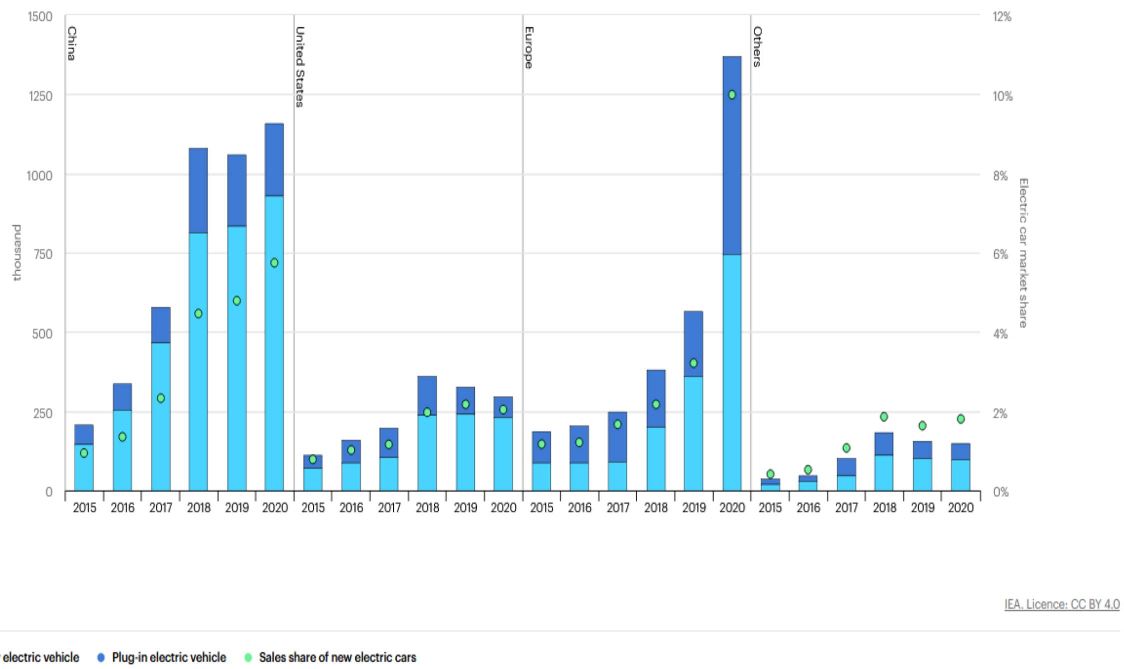
Several factors have contributed to the increase in electric car registrations in 2020. In particular, electric cars are gradually becoming more competitive in terms of total cost of ownership in some countries. Several governments have provided or extended tax incentives that have protected electric car purchases from the downturn in car markets.[16]

Overall, the European car market contracted by 22% in 2020. However, registrations of new electric cars more than doubled to 1.4 million, representing a 10% sales share (Figure 11). In the large markets, Germany registered 395,000 new electric cars and France 185,000.

The UK more than doubled its registrations to 176,000 units. In Norway, electric cars reached a record sales share of 75%, an increase of about one third compared to 2019. Electric car sales shares exceeded 50% in Iceland, 30% in Sweden and reached 25% in the Netherlands.

[16] Fitzgerald A. E., Kinsley C. Jr., Kusko A., “Macchine elettriche” (FrancoAngeli, 1991).

FIGURE 11 – Global electric car registrations and market share, 2015-2020



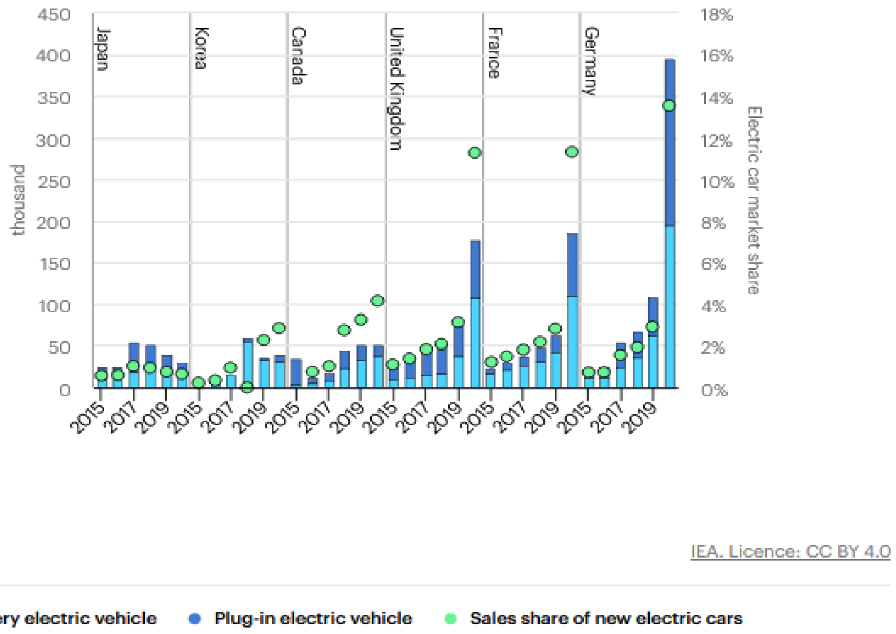

Source: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2020); EAFO (2021); EV Volumes (2021) and Marklines (2021)

This soaring registration of electric cars in Europe, despite the economic crisis, reflects two policy measures. First, 2020 was the target year for the European Union's CO2 emission standards, which limit the average carbon dioxide (CO2) emissions per kilometre driven by new cars. Second, many European governments increased subsidy programmes for electric vehicles as part of stimulus packages to counter the effects of the pandemic.

In European countries, BEV registrations accounted for 54% of electric car registrations in 2020, continuing to exceed those of plug-in hybrid electric vehicles (PHEV). However, the registration level of BEVs doubled from the previous year, while that of PHEVs tripled (Figure 12a/12b). The share of BEVs was particularly high in the Netherlands (82% of all electric car registrations), Norway (73%), the UK (62%) and France (60%).[17]

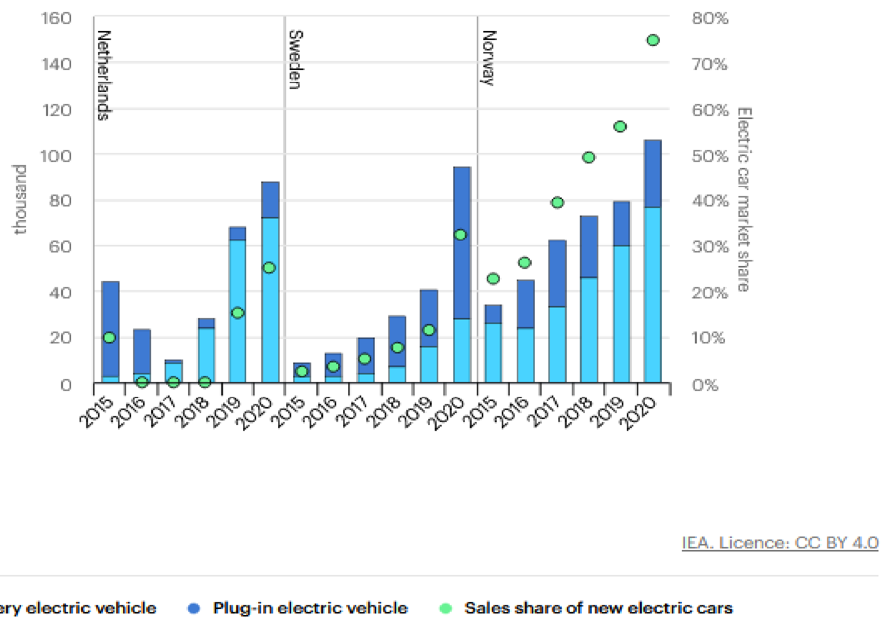
[17] IEA (2021), Global EV Outlook 2021, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021, License: CC BY 4.0.

FIGURE 12a – Electric car registration and market share in selected countries, 2015-2020




Source: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2020); EAFO (2021); EV Volumes (2021) and Marklines (2021)

FIGURE 12b – Electric car registration and market share in north-western europen region, 2015-2020




Source: IEA analysis based on country submissions, complemented by ACEA (2021); CAAM (2020); EAFO (2021); EV Volumes (2021) and Marklines (2021)

The Chinese car market was less affected by the crisis than other regions. Total new car registrations decreased by about 9 %. In the first half of the year, new car registrations were lower than those of the entire car market. This trend was reversed in the second half of the year, when China limited the pandemic impact. The result was a 5.7% sales share, up from 4.8% in 2019. BEVs accounted for around 80% of new electric cars registered.

The main policy actions have eased incentives for the electric car market in China. Purchase subsidies were initially supposed to expire at the end of 2020, but after signalling that they would be phased out more gradually before the pandemic, in April 2020 and in the middle of the pandemic, they were cut by 10% and expired in 2022. Reflecting the economic concerns related to the pandemic, several cities relaxed policies on car licences, allowing more internal combustion engine vehicles to be registered to support local car industries.

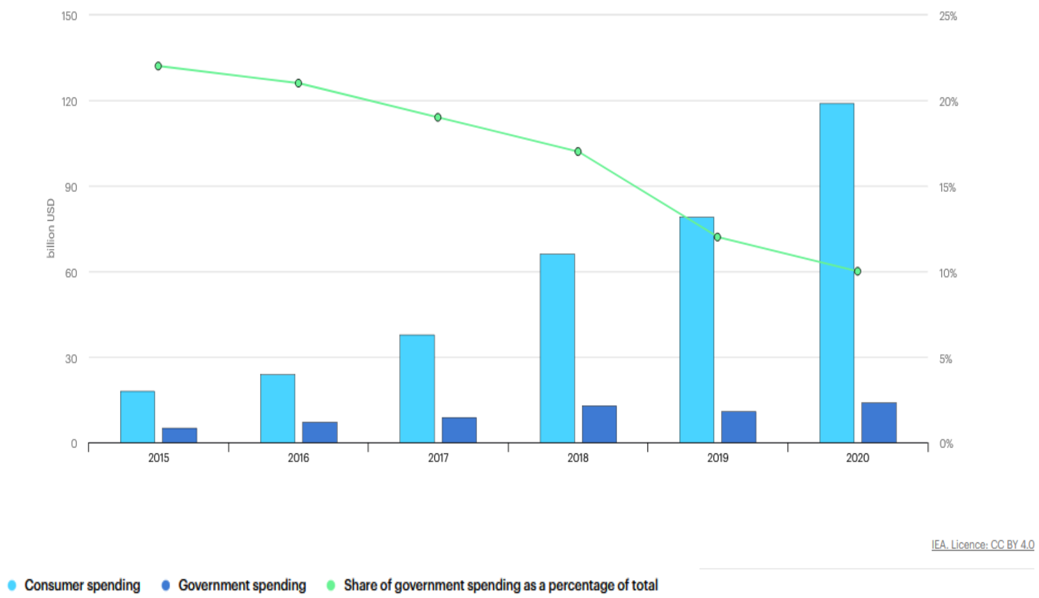
The US car market declined by 23% in 2020, although electric car registrations fell less than the overall market. In 2020, 295,000 new electric cars were registered, of which about 78% were BEVs, down from 327,000 in 2019. Their sales share rose to 2%. Federal incentives decreased in 2020 due to the federal tax credit limit being reached for Tesla and General Motors, which account for the majority of electric car registrations.

Electric car markets in other countries held up in 2020. In Canada, for example, the market for new cars shrank by 21%, while registrations of electric cars remained essentially unchanged from the previous year (51,000). New Zealand is a notable exception. Despite its strong response to the pandemic, it recorded a 22% drop in new electric car registrations in 2020, in line with a 21% drop in the car market. The decline appears to be largely related to exceptionally low EV registrations in April 2020, when New Zealand was in isolation. Another exception is Japan, where the overall new car market has shrunk 11% from its 2019 level, while electric car registrations are down 25% in 2020. The electric car market in Japan has declined in absolute and relative terms every year since 2017, when it peaked at 54,000 registrations and a sales share of 1%. In 2020, registrations were 29,000 and sales share 0.6%.

Consumers globally spent USD 120 billion on electric cars in 2020, a 50% increase over 2019, which translates into a 41% increase in sales and a 6% increase in average prices (Figure 13). The increase in average prices reflects the fact that Europe, where prices are on average higher than in Asia, accounted for a larger share of new electric car registrations. In 2020, the global average price for BEVs was around USD 40,000 and around USD 50,000 for PHEVs.

Governments around the world spent USD 14 billion on direct purchase incentives and tax deductions for electric cars in 2020, a 25% increase over the previous year. Nevertheless, the share of government incentives in total spending on electric vehicles is declining, from about 20% in 2015 to 10% in 2020. All of the increase in public spending occurred in Europe, where many countries responded to the economic recession caused by the pandemic with incentive programmes that favoured sales of electric cars. In China, public spending decreased due to the tightening of eligibility requirements for incentive programmes.

FIGURE 13 – Consumer and government spending on electric cars, 2015-2020




Source: IEA analysis based on EV Volumes (2021) and Climate Policy Initiative (2021)

An important change in the subsidy programmes was the introduction of price caps in Europe and China, i.e. no subsidies for vehicles priced above a certain threshold. This could be responsible for the drop in the average price of electric cars in these two markets: BEV cars sold in China were 3% cheaper in 2020 than in 2019, while PHEV cars in Europe were 8% cheaper.

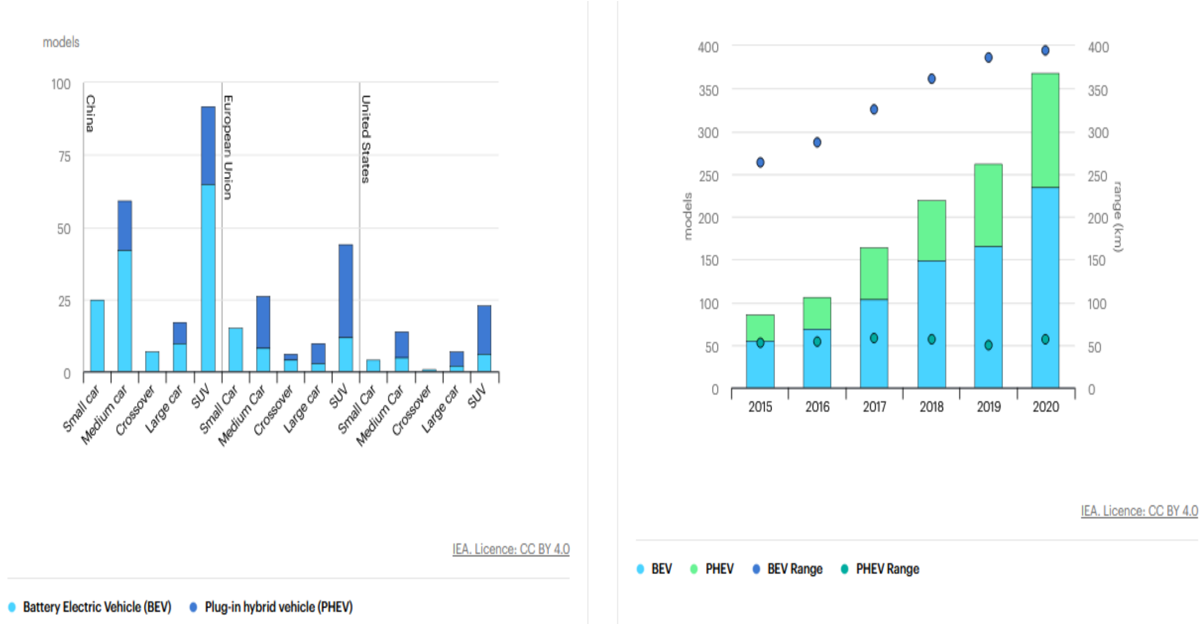
The average range of new BEVs is constantly increasing. In 2020, the weighted average range of a new battery electric car will be around 350 kilometres (km), up from 200 km in 2015. The weighted average range of electric cars in the US tends to be higher than in China, due to the higher share of small urban electric cars in the country. The average electric range of PHEVs has remained relatively constant, around 50 km, in recent years.

Worldwide, some 370 electric car models were available in 2020, a 40% increase over 2019. China has the largest supply, reflecting its less established automotive sector and the fact that it is the largest EV market in the world. But in 2020, the biggest increase in the number of models was in Europe, where it more than doubled (Figure 14).

BEV models are offered in most vehicle segments in all regions; PHEVs focus on the larger vehicle segments. Sport utility vehicle (SUV) models account for half of the available electric car models in all markets.

China has almost twice as many electric car models available as the European Union, which has more than twice as many electric models as the United States. This difference can be partially explained by the lower maturity of the US electric vehicle market, reflecting weaker regulations and incentives at the national level as well as a cultural legacy anchored in the use of internal combustion engines.

FIGURE 14 – Electric car models available, 2020 / 2015-2020




Source: IEA analysis based on Marklines (2021)

The widest variety of models and the greatest expansion in 2020 was recorded in the SUV segment. More than 55% of the models announced worldwide are SUVs and pick-ups. Original Equipment Manufacturers (OEMs) could move towards electrification of this segment for the following reasons:

- SUVs are the fastest growing market segment in Europe and China and by far the largest market share in the United States.
- SUVs have higher prices and generally offer higher profit margins than smaller vehicles. This means that it is easier for OEMs to bear the additional costs of electrification for SUVs, as the powertrain represents a smaller share of the total cost than for a small car.
- Electrification of the heaviest and most fuel-consuming vehicles allows more emission targets to be met than a small car.

- In Europe, the ZLEV credit system under the latest $CO_2$ emission standards offers strong incentives for the sale of electric SUVs from 2025, as it relaxes emission standards in proportion to their potential to reduce specific $CO_2$ emissions. In fact, in Europe, the share of electric SUV models is higher than that of the overall market.

The global stock of electric light commercial vehicles (LCVs) is about 435,000 units. About a third of these are in Europe, where registrations of new electric LCVs in 2020 were only 5% lower than in China, which is the world leader.

Electric car registrations in China in 2020 were 3,400 units lower than the previous year and just under half of the 2018 peak. The majority of electric LCV registrations are BEVs, while PHEvs account for less than 10%.

In Europe, electric LCV registrations in 2020 increased by almost 40% year-on-year to more than 37,000 units. However, this data is less impressive than the more than doubling of electric car registrations. New registrations of electric vehicles in Europe have been driven by economic stimulus packages and $CO_2$ standards limiting emissions per kilometre driven. However, the current standards for LCVs are not strict enough to justify large-scale electrification, as is the case for passenger cars. This also explains the lower growth, albeit good, of the LCV market segment.

Electric LCV registrations in 2020 in the rest of the world amounted to about 19,000 units. Most of these units were registered in Korea, thanks to the launch of two new BEV LCV models, but Canada also increased its stock of electric LCVs. Other markets around the world have not yet seen a large uptake of electric LCVs.

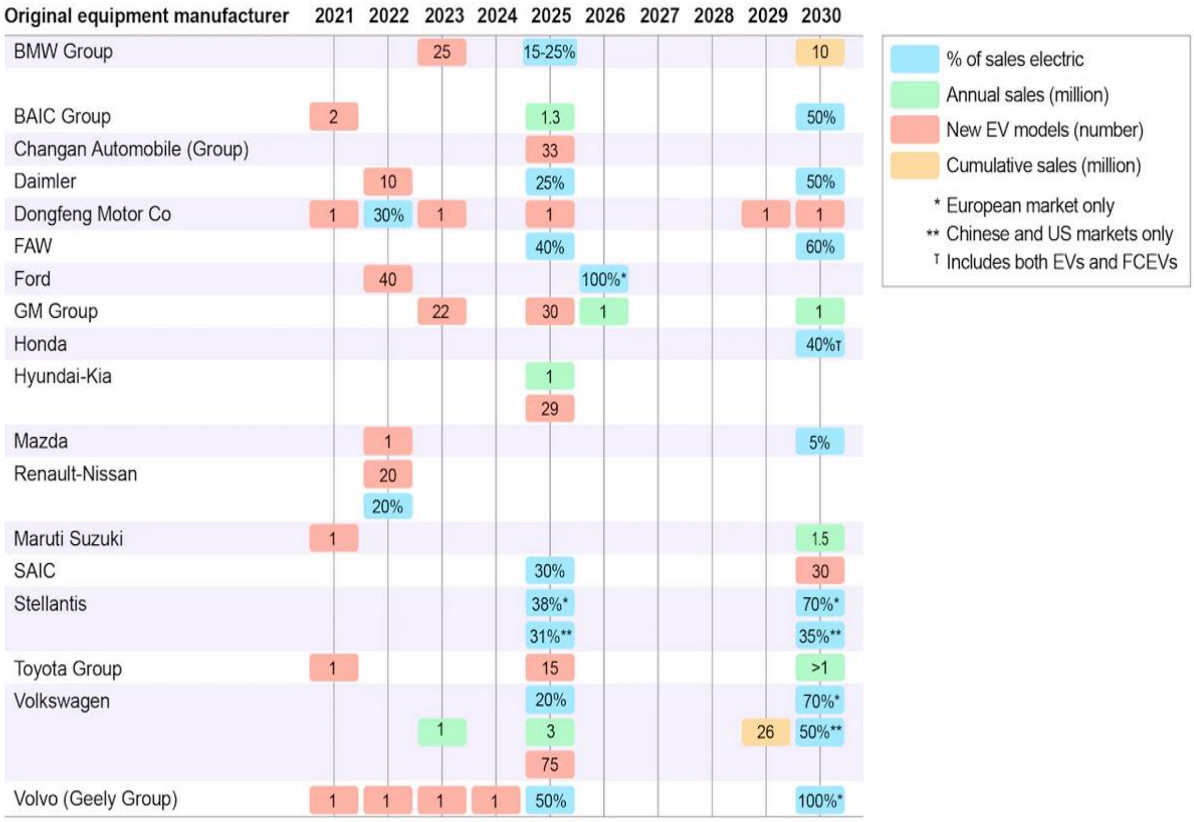
The explosion of home deliveries during the Covid-19 pandemic gave further impetus to the expansion of electric LCVs in some countries. The increase in deliveries has raised concerns about air pollution, particularly in urban areas. In response, some companies, such as Amazon, have announced plans to electrify delivery fleets.

Car manufacturers are expected to embrace electric mobility to a greater extent in the future. In particular, 18 of the 20 largest OEMs (in terms of vehicles sold in 2020), which together account for almost 90% of all global new car registrations in 2020, have announced their intention to increase the number of models available and to increase production of light electric vehicles (LDVs).

Some manufacturers have raised the bar to go beyond previous announcements regarding electric vehicles with a perspective beyond 2025. More than ten of the world's largest OEMs have declared electrification targets for 2030 and beyond.

It is also significant that some OEMs are planning to reconfigure their product lines to produce only electric vehicles. In the first quarter of 2021, these announcements included: Volvo will sell only electric cars starting in 2030; Ford will sell only electric cars in Europe starting in 2030; General Motors plans to offer only electric LDVs by 2035; Volkswagen aims to sell 70% electric cars in Europe and 50% in China and the US by 2030; and Stellantis aims to sell 70% electric cars in Europe and 35% in the US (Figure 15).

FIGURE 15 – OEM sales previsions, 2021-2030




Source: IEA analysis based on BMW (2021); BJEV-BAIC (2021); BYD (2021); Chery (2021); Changan Automobile (2021); Daimler (2021); Dongfeng (2021); FAW (2021); Ford (2021); GAC; General Motors; Honda (2021); Hyundai (2020); Mazda (2021); Renault-Nissan (2019); Maruti Suzuki (2019); SAIC (2021); Stellantis (2021); Toyota (2021); Volkswagen (2021)

Overall, OEM announcements result in estimated cumulative sales of electric light commercial vehicles of 55-72 million by 2025. In the short term (2021-2022), estimated cumulative sales are in line with the projections of electric light commercial vehicles in the IEA scenario. By 2025, estimated cumulative sales based on OEM announcements are in line with the IEA Sustainable Development Scenario trajectories.

Electric bus and electric truck (HDT) registrations increased in 2020 in China, Europe and North America. The global stock of electric buses was 600,000 units in 2020 and that of electric HDTs 31,000 units.

China continues to dominate the electric bus market, registering 78,000 new vehicles in 2020, an increase of 9% year-on-year, to reach a sales share of 27% (Figure 16). Local policies to reduce air pollution are the driving force.

In 2020, electric bus registrations in Europe amounted to 2,100, an increase of about 7%, well below the doubling of registrations in 2019 (Figure 16). Electric buses now account for 4% of all new bus registrations in Europe. It is too early to see the effect of the non-binding European initiative for clean bus deployment and demand may still be largely driven by policies at municipal level.

In North America, 580 new registrations of electric buses were registered in 2020, a decrease of almost 15 % compared to the previous year (Figure 16). In the United States, the spread of electric buses mainly reflects the policies of California, where most of the current e-bus fleet is located. In South America, Chile is leading the way, with 400 electric buses registered in 2020 for a total stock of over 800 units. India has increased electric bus registrations by 34% to 600 in 2020.

In 2020, global registrations of electric HDTs (Heavy-Duty Trucks) amounted to 7,400, an increase of 10% over the previous year. The global stock of electric HDTs is 31,000 units. China continues to dominate the category, with 6,700 new registrations in 2020, an increase of 10%, although much less than the fourfold increase in 2019. Electric HDT registrations in Europe increased by 23% to around 450 vehicles, while in the US they rose to 240 vehicles. In both cases, electric trucks are still below 1% of sales.

The availability of electric Heavy-Duty Vehicle (HDV) models is expanding in major global markets. Buses were the first and most successful case of electrification in the HDV market, but the growing demand for electric trucks is pushing manufacturers to expand product lines. However, model availability is not the only indicator of a healthy market: fewer total models may reflect the reliability and wide applicability of existing designs, while a greater variety of models may reflect the need to customise products for specific needs and operations.

The growth in the availability of electric models from 2020 to 2023 in all segments - buses, medium duty trucks (MFT), heavy duty trucks (HFT) and others - demonstrates manufacturers' commitment to electrification. Truck manufacturers such as Daimler, MAN, Renault, Scania and Volvo have stated that they see an all-electric future. The expansion of the range of available zero-emission HDVs, particularly in the HFT segment, demonstrates a commitment to providing fleets with the flexibility to meet operational needs.

FIGURE 16 – Electric bus (left) and truck (right) registrations by region, 2015-2020


Source: IEA analysis based on country submissions, complemented by ACEA (2021); EAFO (2021) and EV Volumes (2021)

The HDV segment includes a wide variety of vehicle types, e.g. from long-haul freight trucks to refuse collection trucks. China has the greatest variety of electric bus models available. The availability of MFT models is widest in the US. For HFTs - the segment where the largest growth in EV model offerings is expected - Europe offers the widest selection of models.

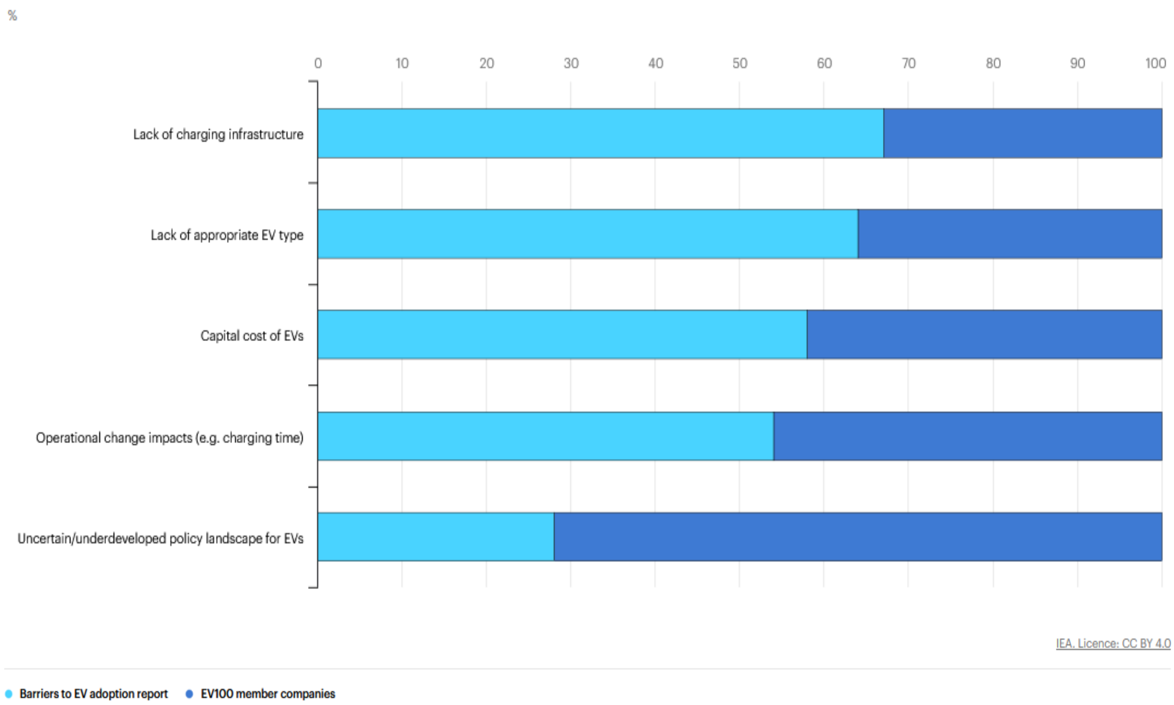
Despite a turbulent year, major companies around the world are accelerating the transition to electric mobility by shifting fleets to electric vehicles and installing charging stations.

The Climate Group's EV100 initiative brings together over 100 companies in 80 markets committed to making electric transport the new normal by 2030. This equates to 4.8 million vehicles switching to electric vehicles and 6,500 charging stations installed by 2030. Collectively, by 2020, EV100 members had already deployed 169,000 zero-emission vehicles, double the previous year's figure. Although companies identify commercial vans and heavy-duty vehicles as the hardest electric vehicles to find, the number of commercial electric vehicles increased by 23% in 2020, including a tripling of electric trucks. EV100 members are also expanding the availability of charging infrastructure for staff and customers, with 16,900 charging points installed in 2,100 locations worldwide. More than half of EV100 members use renewable sources to power all charging operations.

Significant barriers to EV adoption remain. EV100 members cited the lack of charging infrastructure as the main barrier (especially in the US and UK). Lack of availability of appropriate vehicle types was also highlighted by companies as a persistent barrier. Among the most important barriers to purchasing electric vehicles is still price, despite the fact that many companies recognise the significant savings that can be made over the lifetime of a vehicle due to lower fuel and maintenance costs (Figure 17).

To help overcome these barriers, 71% of EV100 members support more favourable tax breaks for the purchase of electric vehicles and 70% support more favourable policies at state, regional and municipal level. 60% of member companies support government targets to phase out petrol and diesel vehicles.

FIGURE 17 – Top 5 barriers to EV adoption reported by EV1000 member companies




Source: IEA analysis based on The Climate Group (2021)

The production of lithium-ion (Li-Ion) batteries for motor vehicles was 160 gigawatt hours (GWh) in 2020, an increase of 33% compared to 2019. The increase reflects a 41% increase in electric car registrations and a constant average battery capacity of 55 kilowatt hours (kWh) for BEVs and 14 kWh for PHEVs. The demand for batteries for other modes of transport increased by 10%. Battery production continues to be dominated by China, which accounts for more than 70% of global battery cell production capacity.

China accounted for the largest share of battery demand, with almost 80 GWh in 2020, while Europe recorded the largest percentage increase of 110% to 52 GWh. Demand in the US remained stable at 19 GWh (Figure 18).

Nickel-manganese-cobalt continues to be the dominant chemistry for lithium-ion batteries, with a sales share of about 71%, while nickel-cobalt-aluminium accounts for most of the rest.

The lithium-iron-phosphate battery chemistry has recovered sales share but is still below 4% for the electric car market.

According to BNEF's annual battery price survey, the weighted average cost of automotive batteries decreased by 13% in 2020 compared to 2019, reaching USD 137/kWh at the pack level. The lowest prices are offered for high-volume purchases, as confirmed by the teardown analysis of a VW ID3 showing an estimated cost of USD 100/kWh for its battery cells.

In Europe, the demand for batteries in 2020 exceeded national production capacity. Today, the main battery factories in Europe are located in Poland and Hungary. The production capacity is about 35 GWh per year, but the announced capacity could reach 400 GWh by 2025. The momentum was evident in 2020 in Europe, with many new battery plants announced or under construction with support from the European Investment Bank. In the US, both Korean and domestic battery manufacturers have reported large investments in a market currently dominated by a Tesla-Panasonic joint venture.

FIGURE 18 – Battery demand by mode (left) and by region (right), 2015-2020


Source: IEA analysis developed with EV Volumes (2021) data

Electric micro-mobility surged in the second half of the 2020s, one of the consumption trends that accelerated during the Covid-19 pandemic, further boosted by the construction of bike lanes and other measures to promote mobility. Sales of private electric bicycles in the US more than doubled in 2020, surpassing sales of all bicycles, which increased by 65%.

Many shared micro-mobility operators reduced or suspended services during the lock-in period due to Covid-19 in Q2 2020. However, with the easing of restrictions, services have rebounded strongly, with 270 cities worldwide relaunching operations. As of February 2021, about 650 cities have shared micro-mobility services. In Europe, e-scooter services have increased rapidly, with more than 100 cities adding operations since July 2020.

Preliminary data from operators indicate that average travel distances with e-scooters have increased by about 25% compared to before the pandemic. Operators are increasingly offering more powerful e-bikes and have plans to expand to electric mopeds, which could further shift longer trips currently made by car or public transport in this direction.

Many major operators are introducing interchangeable batteries to improve operational efficiency and reduce emissions. Although the use of interchangeable batteries increases the number of total batteries required to support a fleet, it can significantly reduce operational emissions and enable longer vehicle life.[18]

Privately owned two/three-wheel electric vehicles (which include motor vehicles such as motorbikes and mopeds but exclude micro-mobility solutions) are concentrated in Asia, with China accounting for 99% of registrations. The global stock of electric two/three-wheelers is currently around 290 million. Electric two/three-wheelers account for one third of all

[18] Bhuwalka, K., Field III, F. R., De Kleine, R. D., Kim, H. C., Wallington, T. J., & Kirchain, R. E. (2021). "Characterizing the changes in material use due to vehicle electrification". Environmental Science & Technology, 55(14), 10097-10107.

two/three-wheeler sales. While current sales are dominated by Asia, the market is growing rapidly in Europe, with a 30% increase by 2020, thanks to increased model availability and continued incentives.

Fuel cell electric vehicles (FCEVs) are zero-emission vehicles that convert hydrogen stored on board via a fuel cell to power an electric motor. FCEV cars became commercially available in 2014, although registrations remain three orders of magnitude lower than electric vehicles, as hydrogen refuelling stations (HRS) are not widely available and, unlike electric vehicles, cannot be recharged at home. Commercially available FCEV models are few and, due to high fuel costs and purchase prices, carry a higher total cost of ownership than electric vehicles.

To solve this problem for FCEVs, some governments have financed the construction of HRSs and employed public buses and trucks, such as rubbish trucks, to ensure a certain level of utilisation of the stations. Today there are about 540 HRS around the world supplying fuel to almost 35,000 FCEVs. About three quarters of the FCEVs are LDVs, 15% are buses and 10% are trucks.[19]

In 2020, Korea took the lead in FCEVs, surpassing the US and China and reaching more than 10,000 vehicles. To support these FCEVs, the number of HRS in Korea has increased by 50%, with 18 new stations in 2020. In China, FCEVs are almost exclusively buses and trucks, unlike most other countries where cars predominate. China accounts for 94% of global fuel cell buses and 99% of fuel cell trucks.

In 2020, the global stock of FCEVs increased by 40%, with Korea contributing half and doubling its total stock of FCEVs. Japan and China increased the number of HRS, each opening about 25 stations in 2020. Worldwide, the number of HRS increased by 15%.

[19] Sun X., Hao H., Liu Z., & Zhao F. (2020). "Insights into the global flow pattern of manganese". Resources Policy, 65, 101578.

Most European countries have not met the recommended targets for electric vehicle supply equipment (EVSE) for EVs in 2020 for publicly accessible chargers set by the Alternative Fuels Infrastructure Directive (AFID). However, there are wide disparities between countries.

AFID, the key policy regulating the distribution of public EVSE in the European Union, recommends that member states aim for 1 public charger per 10 EVs, a ratio of 0.1 in 2020. In the European Union, the average public EVSE per EV ratio was 0.09 at the end of 2020. But the situation is not uniform for every European country. The Netherlands and Italy, for example, are above the target with 0.22 and 0.13, respectively. Almost all, however, are slow chargers, although fast chargers account for 3% of installations in the Netherlands and 9% in Italy.

Countries with the highest EV penetration tend to have the lowest EVSE per EV ratios, such as Norway (0.03), Iceland (0.03) and Denmark (0.05). In these sparsely populated countries, with many single-family homes and private car parks, most EV owners can use private home charging. To a lesser extent, this also reflects the fact that the Nordic countries have a higher proportion of fast chargers, with shares of 40% in Iceland, 31% in Norway and 17% in Denmark.[20]

The introduction of public charging infrastructure has so far focused mainly on light electric vehicles. The electrification of heavy-duty trucks (HFT) is a long-term undertaking, with less than 40 electric HFTs in circulation in 2020.

HFTs need high-capacity batteries to meet the demands of heavy-duty cycles and long-range operations, and consequently require high-power charging. So far, charging options for HFTs have been limited to early stage demonstrations, proof-of-concept activities and efforts to facilitate standardization.

[20] Sun X., Hao H., Liu Z., Zhao F. (2020). “Insights into the global flow pattern of manganese”. Resources Policy, 65, 101578.

Mega-chargers of 1 megawatt (MW) or more would be able to recharge trucks operating over long distances in a reasonably short time. In order to avoid negative impacts on the electricity grid, long-term planning is required for the infrastructure of mega chargers. Some impact on the grids is unavoidable, given the high-power requirements of mega chargers. Significant investments may be required for grid reinforcement, modernisation, storage and integration with power systems. Planning and co-ordination between power producers, distribution system operators and mega-charger operations are necessary.

Efforts are underway to develop standards for mega-chargers. Working together, the CHAdeMO Association and the China Electricity Council have developed an ultra-high power (up to 900 kW) charging standard, called ChaoJi. A version up to 1.8 MW, called Ultra ChaoJi, is under development. In parallel, the CharIN initiative has set up a task force called the Megawatt Charging System Taskforce, which aims to develop a new high-power standard above 1 MW by 2023 for charging heavy trucks, based on the Combined Charging System (CCS) standard. Testing on prototypes started in September 2020. In late 2020, Tesla announced that it is working with third parties to develop a standard for mega-chargers that can be provided to owners of Semi trucks. Tesla is one of five to have submitted a project to CharIN.[21]

Industry experts involved in international standardisation are looking into the possibilities of harmonising mega-charger standards to ensure mutual compatibility in order to facilitate the introduction of electric HFTs.

There are also regional efforts to develop mega-charging infrastructure. Thanks to stimulus funding, Iberdrola, a Spanish electricity multinational, has expressed its interest in installing mega-charging infrastructure in HGV corridors in Spain by 2025. ElaadNL (Dutch grid operators' electric vehicle knowledge centre), together with local and national government

[21] Pellicelli G., "Le strategie competitive del settore auto". Wolters Kluwer, 06/2019.

bodies, launched a free-access test centre for companies and academia in September 2021, offering test facilities for mega-chargers. In the US, the West Coast Clean Transit Corridor Initiative aims to install charging sites capable of recharging HDTs at 2 MW along major transit corridors from Mexico to the Canadian border by 2030.

A further important step towards the electrification of the industry has recently been attempted. The European Parliament on 14 February 2023 approved the European Commission's proposal for a regulation wich provides for cutting carbon dioxide (CO2) emissions from cars and light commercial vehicles. Specifically, it defines CO2 emission performance standards for new cars and light commercial vehicles and envisages:

- by 2030, a 55% reduction in greenhouse gas emissions from cars and a 50% reduction in emissions from commercial vehicles compared to 1990 values.
- by 2035, a 100% cut in emissions, which equates to a halt in the production and sale of cars and commercial vehicles with petrol, diesel and hybrid engines.

But an abrupt halt to this measure occurred in March, when, against the backdrop of subsequent demands by Germany, a final vote has been postponed indefinitely. The adoption of the law requires the approval of 15 of the 27 member states, which together must represent at least 65% of the total EU population. Besides Germany, countries such as Poland and Bulgaria have recently refused to approve the plans, while Italy, previously in favour, has recently come out against the bill.

This kind of development, which could slow down the pace towards achieving complete electrification of the automotive sector, teaches us how more and more political and economic interests are at stake (with China on the one hand and the US/Germany on the other).

## 2.2 The impact of technology and crisis on the supply chain

The current supply chain for electric vehicles includes thousands of relevant components and raw materials (Bhuwalka et al., 2021)[22]. 17 most relevant commodities for the electric vehicle supply chain can be identified, from critical battery-related minerals to end products (Sun et al., 2020)[23]. The distribution of supplies of the different products and the extent to which different countries are affected by the pandemic determine the different probabilities of supply disruptions of the various products. Based on the infection rate and the growth rate of nationally confirmed COVID-19 cases (Sun et. al, 2022), a regional COVID-19 severity index has been developted (RCSI) to quantify the severity of the impact of the pandemic on each country.

First, they quantified the severity of the pandemic in 185 countries and regions to assess the likelihood of supply disruptions of 17 key EV-related commodities along their supply chain. Based on these findings, they developed a bottom-up projection model to estimate the available lithium-ion battery (LIB) production capacity under three pandemic development scenarios from 2020 to 2030. These production constraints were then incorporated as inputs into the Transport Impact Model (Hao et al., 2019)[24] to estimate future sales of electric vehicles.

In 2019, a total of 63 countries and regions were connected to the electric vehicle supply chain. Among these countries, Turkey, the United States, Brazil, Argentina and Spain were the top five countries with the highest RCSI (39, 36, 36, 34 and 32, respectively), while China (Mainland), Taiwan, Australia, Madagascar, Burma and Ghana were the five regions with the

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[22] Bhuwalka K., Field III F. R., De Kleine R. D., Kim H. C., Wallington T. J., & Kirchain R. E (2021). "Characterizing the changes in material use due to vehicle electrification". Environmental Science & Technology, 55(14), 10097-10107.
[23] Sun X., Hao H., Liu Z., Zhao F. (2020). "Insights into the global flow pattern of manganese". Resources Policy, 65, 101578.
[24] Hao H., Geng Y., Tate J. E., Liu F., Chen K., Sun X., ... & Zhao, F. (2019). "Impact of transport electrification on critical metal sustainability with a focus on the heavy-duty segment". Nature communications, 10(1), 1-7.

lowest RCSI (1, 10, 10, 13 and 14, respectively). These variations between countries mainly reflect differences in regional infection rates.

The supply of lithium ore, cobalt ore, nickel ore and lithium carbonate were the major sources of risk for the EV industry during the pandemic, with the highest CCI (Commodity Channel Index) of 1622, 1436, 1297, 1171 and 1159, respectively. The high CCI of lithium mineral was attributed to the large percentage of production in Chile and Argentina (with an RCSI of 28 and 33 respectively) and its irreplaceable role in the automotive battery industry. The US, France and Germany are the main sources for the high CCI of EVs, with an RCSI of 36, 29 and 27, respectively. The CCIs of LIB cathode materials were relatively low: 5 for lithium manganese oxide (LMO); 23 for lithium iron phosphate (LFP); 181 for lithium cobalt oxide (LCO); and 454 for lithium nickel manganese oxide and lithium nickel cobalt aluminium oxide (NCM and NCA). The low CCI of these raw materials benefited from the dominant supply positions of China, Japan and Korea (with an RCSI of 1, 17 and 19, respectively).[25]

The COVID-19 pandemic affects the supply-demand balance in multiple dimensions, including, for example, factory closures, logistics disruptions, company bankruptcies and decreasing purchasing power. In this study, the quantification of the impacts of the pandemic on the electric vehicle market starts on the supply side. As no information on long-term lithium ore supply planning is available and lithium is currently essential for all EV battery technology pathways, the authors mapped the probability of lithium ore supply disruption in LIB supply constraints and ignored the impacts of non-battery applications of lithium. A battery supply projection model was developed based on LIB suppliers' capacity planning and two key parameters: (1) the release efficiency of existing production capacity, which quantifies the influence of production interruption caused by lockout measures on the annual raw material production; (2) the construction efficiency of new production capacity, which quantifies the influence of the suspension of new plant construction on the annual capacity growth rate. In brief, the basic data for the calculation of these two parameters are the duration of each lockdown measure and the interval between the two pandemic waves. The average duration

[25] Zeng X., Li M., Abd El-Hady D., Alshitari W., Al-Bogami A. S., Lu J., Amine K. (2019). "Commercialization of lithium battery technologies for electric vehicles". Advanced Energy Materials, 9(27), 1900161.

of a single lockdown period is 64 days, according to a compilation of information on relevant measures taken by countries in the first half of 2020. Based on data from newly confirmed cases in typical countries (Dong et al., 2020),[26] the average interval between two COVID-19 pandemic waves is 79 days.

The future evolution of the COVID-19 pandemic is still very uncertain. Therefore, the authors developed three scenarios to explore the possible consequences of different pandemic development paths. The main difference between the scenarios lies in the assumptions about the duration of the pandemic. The business-as-usual (BAU) scenario is the reference scenario used to provide the future size of the EV market by 2030, based on the established climate targets and without the impact of the COVID-19 pandemic. The short-term recovery scenario (STR) is the conventional scenario in which the pandemic will be contained within a few years with the promotion of vaccines as predicted by the World Health Organisation (WHO) (World Health Organisation, 2020a). The long-term coexistence scenario (LTC) is the extreme scenario in which the pandemic will not be contained within a decade.

In the integrated model developed in this study, the model parameter with the greatest uncertainty is the duration of the strict lock-in measurements (hereafter referred to as the lock-in duration). This parameter directly affects the construction efficiency of new plants and the release efficiency of existing plants. Regarding the duration of the lockout, we assumed that this parameter is consistent with historical data during each wave of future outbreaks, while factors such as the severity of future outbreaks and the speed and willingness of governments to respond may be very different from the past. Even for the same country, the duration of isolation could change dramatically.

Moreover, there are great differences in the implementation of pandemic prevention policies by national governments. We distinguish the impact of the duration of the lockdown on the

[26] Dong E., Du H., & Gardner L. (2020). "An interactive web-based dashboard to track COVID-19 in real time". The Lancet infectious diseases, 20(5), 533-534.

open rate at the country level according to the RCSI. However, for countries with similar indices, the application and orientation of blocking measures can vary considerably. In some countries, blocking measures are limited to controlling social distance to keep the economy functioning. Other countries may suspend all economic activities in an attempt to quickly contain the pandemic.

Another important source of uncertainty is the weight coefficient of the two parameters, the infection rate and the growth rate of confirmed COVID-19 cases, used to calculate the RCSI. Due to insufficient information to support the set of weights, the authors assumed that the two parameters contribute equally to the regional supply risk. Variations in the weight coefficient may lead to a different relative size of the RCSI value of the country.

The study concludes that although the COVID-19 pandemic has caused a huge shock to the global economy, the pace of the energy transition has not been hindered, with countries tightening emissions reduction regulations and adopting corresponding fiscal stimulus policies. Global vehicle sales in 2020 reached 78.03 million units, down 13% from 2019. Global sales of electric vehicles, however, increased by 43% to 3.2 million units. The model results suggest that this development trajectory is promising if the pandemic can be effectively controlled in the short term, as the amount of production capacity is more likely not to be a constraint. However, this does not mean that the current overcapacity of LIB production is worth sustaining; this is particularly true if one considers that the automotive battery market is oversupplied with low-quality batteries and undersupplied with high-quality batteries (Chen, 2018).

The market performance of leading companies and small companies shows a polarisation. The global capacity utilisation rate of automotive batteries in 2019 was only 38% (comparison with public company information). CATL and LG Chem, the two largest LIB suppliers, had a capacity utilisation rate of 51%. The next eight companies had an average capacity utilisation rate of 33%. The remaining LIB companies had a capacity utilisation rate of 22%. According to our estimates, the current planned expansion of LIB suppliers' production is sufficient to meet future LIB demand by 2030. Capacity utilisation will remain above 90% by 2030. Therefore, future stimulus and investment should be directed more towards improving production levels and product performance, rather than capacity expansion.

The future looks good for electric cars, but there are warning signs coming from their supply chain, with the price of bulk materials rising for the entire automotive industry. By 2021, the price of steel has risen by up to 100%, aluminium by around 70% and copper by more than 33%, affecting both conventional and electric cars. For electric cars, further challenges have been posed by the rising prices of the materials needed for battery production: the price of lithium carbonate has risen by 150% year-on-year, graphite by 15% and nickel by 25%, to name but a few.[27]

For the time being, and perhaps surprisingly, volume-weighted average battery prices have not increased since 2020. Three factors explain the price stability. Firstly, battery prices are on a long-term declining trajectory and continued technological advances have helped to offset rising raw material costs. Second, there is a time lag between material price spikes and battery price increases, as costs take time to work their way up the value chain. Third, the increased use of lithium ferrophosphate (LFP) chemicals in batteries has reduced the impact of some price increases. However, if the prices of the metal used for batteries continue to rise, the final prices of batteries will be affected.

Several car manufacturers have been faced with microchip shortages that have held back production. The context of the microchip shortage is complex, but in general the faster than expected recovery in sales of cars and other microchip-based products has come up against a limited supply of microchips. The shortage is problematic for electric vehicles, which require about twice as many chips as equivalent conventional vehicles, mainly due to the additional power electronics. It is possible that, without these disruptions, sales of electric cars could

[27] Pellicelli G., "Le strategie competitive del settore auto". Wolters Kluwer 06/2019.

have been even higher in 2021. Several electric vehicle production lines have been blocked for weeks, causing delays in the delivery of electric vehicles.

While some of the 2021 supply constraints will ease as the market rebalances, others may persist. The electric vehicle value chain proved to be robust in 2021, managing to meet demand beyond expectations. However, for EVs to continue their current growth trajectory, battery supply chains and EV production capacity will need to expand at a rapid pace. Over the past two years, both short-term demand and long-term ambitions have skyrocketed, but supply chains have struggled to keep pace.

As highlighted in last year's IEA special report on the role of critical minerals in the clean energy transition, the world faces a potential shortage of lithium and cobalt as early as 2025 unless sufficient investment is made to expand production. The further growth of electric vehicles requires not only an expansion of the extraction of key minerals, but also of the entire electric vehicle value chain. This includes the processing and refining of battery metals, the production of cathodes and anodes, the production of separators, the production of cells, the assembly of batteries and, finally, the assembly of electric vehicles. Each of these industries, some of which are in a nascent stage, must expand rapidly to avoid bottlenecks that would slow down the transition to all-electric mobility.[28]

Electric vehicles are set to enter a new phase in which the supply of raw materials and components is the focus of political attention as a critical element of the clean energy transition. For the first time, supply-side bottlenecks are becoming a real challenge for the electrification of road transport and are added to the traditional demand-side challenges. Political action must adapt and provide the market with clear long-term signals to facilitate investment in further supply-side expansions.

[28] ZVEI. Entwicklung der Halbleiterindustrie 2020

The latest US infrastructure bill, aimed at stimulating investment in battery raw materials, or the emphasis on batteries by the EU's major projects of common European interest, are examples of this new focus.

Current problems have been caused in part by COVID-19 affecting global supply chains and the shortage of semiconductors, a vital component of modern vehicles. In spring 2022, Tesla had to close its Shanghai plant for three weeks due to plant closures in China. Before then, Tesla produced about 2,000 cars per day for the Asian and European markets, so it may have lost production of about 42,000 vehicles.[29]

This is due to the fact that Tesla, like many other manufacturers, does not produce all the components to build the cars in one plant (although it does produce more than the industry average), so as the factories that supply Tesla also close due to lockouts, the necessary components do not arrive. CEO Elon Musk has now suggested that his company may stop accepting orders, telling the Financial Times: “The frustration we're seeing from customers is the inability to supply them with a car”. He added: “We will probably stop taking orders beyond a certain period of time, because some times are a year away”.

Again, the problem is not just Tesla. Semiconductor problems are continuous and it is not uncommon for many vehicles to be shipped without functions or parked in fields waiting for spare parts. These backlogs take a long time to clear and are a big problem for all concerned. While manufacturers and customers have to deal with frustration, politicians who rely on electric vehicles for the future of transport policy may have to adjust their expectations and demands.

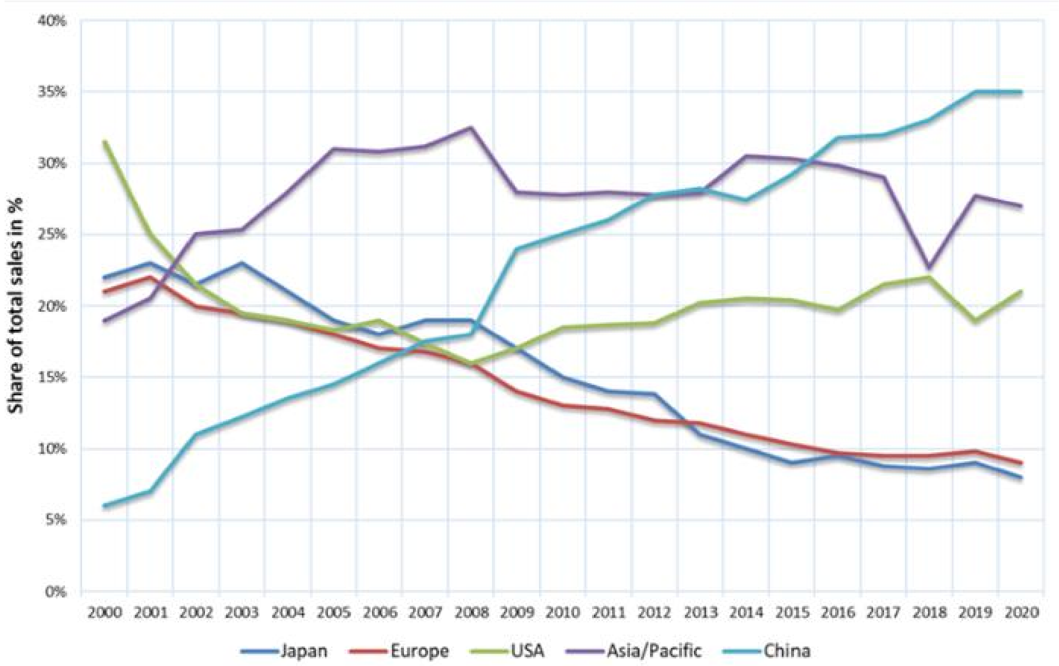
The current structure of the semiconductor market does not point to any short-term capacity increase for automotive customers, as it only accounts for a small share of sales compared to other segments (such as communications). In 2020, for example, they accounted for only about

[29] Fitzgerald A. E., Kinsley C. Jr., KuskoA., “Macchine elettriche” (FrancoAngeli, 1991).

11% of global sales, while the communications and data technology segments accounted for almost 65% of total sales, or EUR 352 billion.

China is now the world's largest sales market for semiconductor applications, with a market share of 35% in 2020. The market share trends for the world regions of China, the USA, Europe and Asia/Pacific since the year 2000 are shown in Figure 19: Europe and Japan have a combined market share for semiconductors of less than 10% worldwide, and demand is mainly driven by the automotive sector: the automotive industry accounted for 37% of semiconductor sales in Europe and 28% in Japan in 2019. In comparison, other segments dominate demand in the US (with a 10% automotive share) and China (7%). In the US, for example, the 'Computer' segment leads with a 38% share.[30]

FIGURE 19 – Market share of semiconductors, 2000-2020




Source: ZVEI. Entwicklung der Halbleiterindustrie (2020)

[30] Pellicelli G., "Le strategie competitive del settore auto". Wolters Kluwer, 06/2019.

In conclusion, many issues related to the supply chain remain open. The evolution of the electric car and how this is affecting the supply chain will still be a debated topic, as will the impact of technology and the crisis on the supply chain, both of which have a strong effect on its structure and functioning in the global market. These open issues suggest the need for further research and analysis to understand how the supply chain will evolve in the future.

# CHAPTER III: THE SHORTAGE OF KEY COMPONENTS

## 3.1 The semiconductors shortage

A microchip, also known as an integrated circuit (IC), is a small semiconductor device containing computer circuits used primarily for logic or memory functions in an electronic device. Chips are widely used in electronic objects such as smartphones, computers and other medical devices, as they perform the main functions of these devices. These chips consist of millions of transistors packed into a small piece of silicon and help devices transform into a smaller unit by removing or incorporating several components into the integrated circuit.

Microchips serve as key units for logical program functions and computer memory, such as random-access memory (RAM), and are also used for special purposes such as gateways, bit slicing and analogue-to-digital conversion. The increase in the huge potential of the microchip market can be attributed to the availability of cheap raw materials and huge production facilities in many developing countries in the Asian region, including China and India.

Depending on product types, the global microchip market is divided into embedded, fabless and foundry devices. The embedded devices segment is expected to witness strong growth in the future due to the growing demand for embodied and implanted microchips for various applications, including consumer electronics, medical and automotive industries. The fabless segment holds a substantial market share due to wide adoption in various electronic devices such as computers.

Based on end users, the market is divided into consumer electronics, automotive, healthcare, military and civil aerospace, and others. The consumer electronics segment contributes to the major share of the market and is expected to grow substantially in the coming years due to the increasing usage of mobile phones, laptops and other electronic items across the globe and the growing demand for new telecommunication services such as 5G networks. In particular, the healthcare segment is growing strongly due to the increasing adoption of chips in medical devices, including surgical and therapeutic devices.

Worldwide the market is broadly classified into Asia-Pacific, North America, Latin America, Europe-Middle East and Africa. Among the regions, Asia-Pacific currently holds the largest market share and is expected to witness strong expansion in the future due to the presence of major global players and the establishment of huge production facilities in the region. The growing government initiatives of emerging economies, including China, India, South Korea and Australia, are the key drivers of the immense development of microchip manufacturing in the region. Meanwhile, North America is expected to experience significant growth in the coming years, driven by early technological advances and high capital expenditure.

Major players competing in the global microchip market include Samsung Electronics, Intel Corporation, Texas Instruments, Cypress Semiconductor, Analog Devices, IBM, Qualcomm, Broadcom Ltd., Advanced Micro Devices (AMD), MediaTek, NVIDIA, TSMC, United Microelectronics, STMicroelectronics, Semiconductor Manufacturing International Corporation and Taiwan Semiconductor Manufacturing Company. Some of these companies have engaged in adopting various market strategies such as mergers and acquisitions, collaborations or partnerships, new product launches, R&D development and expansion of their units to enhance their business portfolio and market expertise.

In 2022, semiconductor sales reached $580.13 billion worldwide. Semiconductors are key components of electronic devices and the industry is highly competitive. The annual growth rate in 2022 reached 4.4%. The global semiconductor industry is ready for a period of growth and is expected to become a trillion-dollar industry by 2030.

The industry has been in the news for the past year. Supply shortages led to production bottlenecks in many sectors, from cars to computers, and highlighted how small chips are vital to the smooth functioning of the global economy. In many ways, our world is "built" on semiconductors. With demand for chips set to increase over the next decade, semiconductor manufacturing and design companies would benefit from an in-depth analysis of where the market is headed and what will drive demand in the long run.

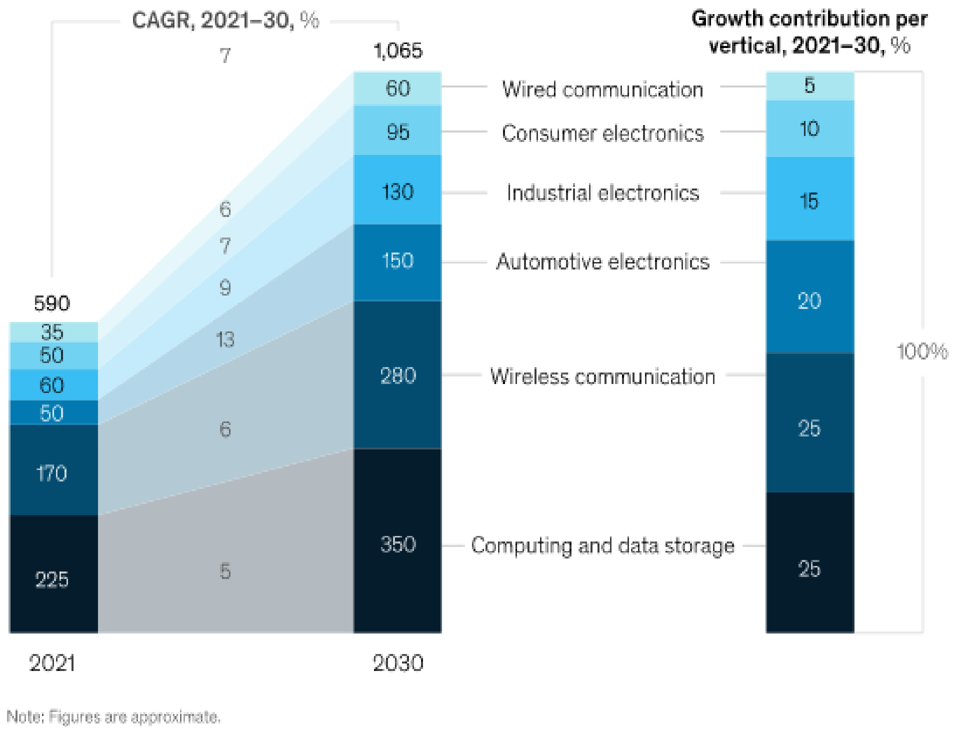
With the accelerating impact of digital on life and business, semiconductor markets are booming, with sales growth of more than 20% to nearly USD 600 billion in 2021. A McKinsey analysis, based on a number of macroeconomic assumptions, suggests that aggregate annual growth in the industry could average 6-8% per year until 2030 (Figure 20).[31]

The result would be a USD 1 trillion industry by the end of the decade, assuming an average price increase of around 2% per year and a return to a balance between supply and demand after the current volatility. With trends such as remote working, artificial intelligence growth and soaring demand for electric vehicles, manufacturers and designers should now take stock and make sure they are in the best position to collect the fruits.

Assuming EBITA margins of 25-30%, current stock valuations support an average revenue growth of 6-10% until 2030 across the industry, as shown by the analysis of 48 listed companies. However, some companies are better positioned than others, and growth in individual subsegments could range from a low of 5% to a high of 15%.

[31] cfr. https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductor-shortage-how-the-automotive-industry-can-succeed

FIGURE 20 – Global semiconductor market value ($ billion), 2021-2030

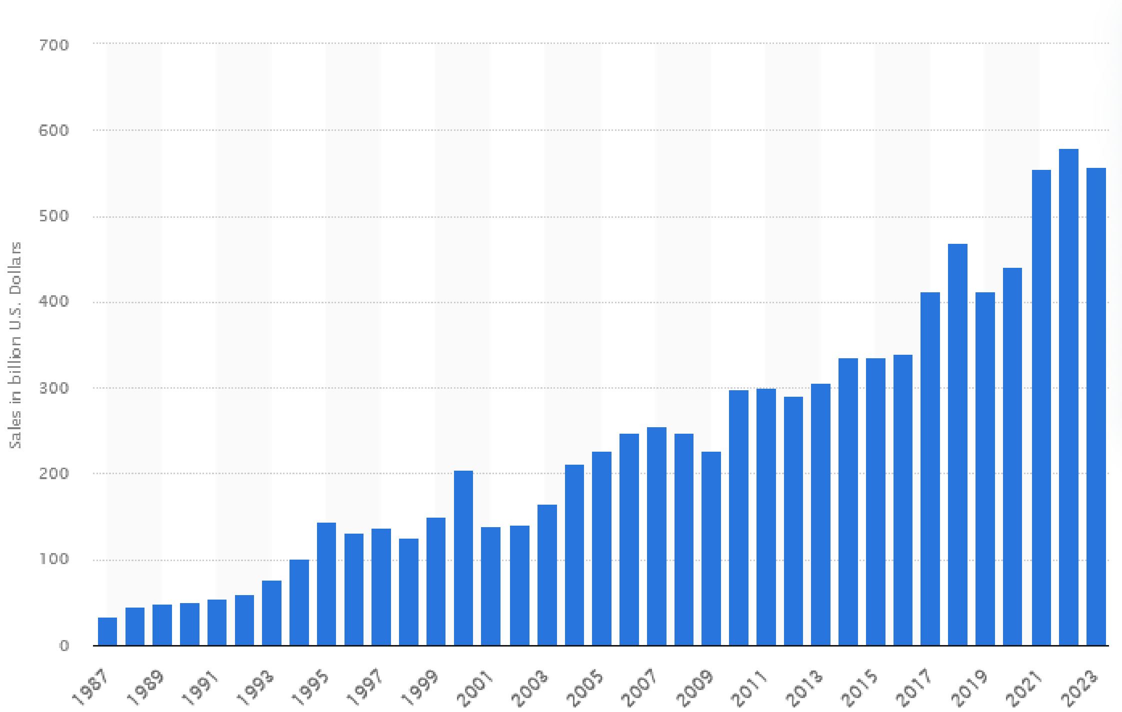



Source: McKinsey & Company

The fastest growing segment is likely to be the automotive sector, where we could see a sharp increase in demand, fuelled by applications such as autonomous driving and electric mobility. In 2030, the cost of semiconductors in a Society of Automotive Engineers (SAE) Level 4 car with electric drive could be around $4,000, compared to $500 for a SAE Level 1 car with an internal combustion engine. The automotive industry, which accounts for only 8% of semiconductor demand in 2021, could account for 13 to 15% of demand by the end of the decade. On this basis, the segment would be responsible for as much as 20% of the industry's expansion in the coming years. Modern cars have over 100 sensor modules, each of which contains multiple microchips bringing the roughly estimated number anywhere between 1,400 to 3,000 chips per vehicle. Working together with the ECU (electronic control unit), chips are responsible for controlling every system on the car including the electrical system, the powertrain, safety and comfort systems, and the infotainment and connectivity systems.

The computing and data storage market growth, equal to 4-6%, could be fuelled by demand for servers to support applications such as artificial intelligence and cloud computing. In the wireless segment, on the other hand, smartphones could account for most of the expansion, thanks to the shift from low-end to mid-range segments in emerging markets and the growth of 5G and the support of new technologies as such as augmented reality (AR), virtual reality (VR) and artificial intelligence (AI). Semiconductors for use in servers and data centers are set to become an even more important opportunity, with semiconductor innovation required to support cloud data centers and the rise in edge computing. [32]

FIGURE 21 – Semiconductor market size worldwide (in billion U.S Dollars), 1987-2023




Source: Statista (2023)

Also known as foundries, these semiconductor companies are specialised in the manufacture or production of chips. “Factory-less” chip manufacturers - companies that design their own chips and supply hardware but have no production facilities - outsource their chip production

[32] Alsop T., “Semiconductor industry sales worldwide 1987-2023”. Statista (Jan. 30, 2023).

to foundries, mainly in Asia. Taiwan, China and South Korea account for about 87% of the global foundry market (Figure 22).[33]

FIGURE 22 – Largest companies in semiconductor sector

| Company | Market share | Country |
|---|---|---|
| TSMC | 54% | Taiwan |
| Samsung | 17% | South Korea |
| UMC | 7% | Taiwan |
| GlobalFoundries | 7% | U.S. |
| SMIC | 5% | China |
| HH Grace | 1% | China |
| PSMC | 1% | Taiwan |
| VIS | 1% | Taiwan |
| DB HiTek | 1% | China |
| Tower Semiconductor | 1% | Israel |
| Other firms | 5% | N/A |

Source: Visual Capitalist

TSMC, which stands for Taiwan Semiconductor Manufacturing Company, is by far the world's largest chip manufacturer. It is also the sixth most valuable company in the world, with a market capitalisation of over USD 600 billion, and supplies chips to the likes of Apple, Intel and Nvidia. TSMC and Samsung are the only companies capable of producing the most advanced 5-nanometre chips that are built into iPhones. However, the Taiwanese company is one step ahead and is ready to produce its 3 nanometre chips in 2022, offering the most advanced foundry technology.

Other companies on the list (Figure 22) include China's largest chipmaker SMIC, one of 60 Chinese companies blacklisted by the US in 2020. Domestically, Taiwan accounts for 63% of

[33] cfr. https://www.visualcapitalist.com/top-10-semiconductor-companies-by-market-share/

the foundry market, followed by South Korea with 18%. In both countries, most of the market share belongs to one company.

When chip shortages first brought automotive production lines to a halt in 2021, the semiconductor industry found itself in an unaccustomed spotlight. Suddenly everyone was talking about the tiny chips that enable various functions in cars, from interior lighting to seat control to blind spot detection. Attention intensified even further later, when some high-tech and consumer electronics companies started reporting chip shortages or expressing concerns about supply chains.

In simpler terms, the current chip shortage is due to high demand and a lack of supply. This is due to the COVID-19 blocks in Q2 2020, when demand for work-from-home technology increased exponentially and carmakers found themselves competing for semiconductor capacity located in Asian foundries. To compound the problem, downstream operations in South Asia were negatively impacted by the COVID-19 Delta variant, creating additional bottlenecks in the supply chain. Malaysia, in particular, has many "back-end" operations, such as chip packaging and testing, which are more labour-intensive than wafer fabrication processes, so the business is more likely to be affected by public health measures.

The COVID-19 pandemic started the chip shortage and its long-term effects, labour challenges and geopolitical uncertainties fuelled it. Every link in the global supply chain continues to be disrupted. Unfortunately, there are no signs of recovery in the short term. This is because the pandemic has also stimulated such a large and unpredictable upswing in demand growth that supply chains will struggle to keep up until demand falls to a more manageable level or until capacity and component supply chain issues are resolved. Initially, all raw materials saw demand drop precipitously with the onset of COVID-19 and the closure of factories. Then, the massive consumer spending we witnessed after the initial pandemic shocks settled created a V-shaped recovery in the global economy, stimulating an extraordinary need for semiconductors.

The impact of this sustained demand is especially felt on wafer foundries. Wafer start-up is the main constraint in the chip supply chain. Even the world's largest chip producer, TSMC, which controls 28% of global semiconductor production capacity, is experiencing continuous shortages. To increase chip production, manufacturers such as Texas Instruments, Intel and TSMC are investing billions of dollars in building new factories. However, this is not a complete solution: these new plants have started to be operational and openings will increase in 2023 and beyond. But these factories were designed when demand was high in all sectors. Semiconductor manufacturers must now watch out for the risk of overcapacity if demand continues to weaken and balance supply accordingly.

In addition to wafer foundries, wire bonding, substrates, materials and testing are experiencing shortages or delays. In China, continuous outbreaks of COVID-19 have impacted the supply of raw materials, assembly and testing. In addition, the invasion of Ukraine has increased prices and restricted the supply of raw materials used in semiconductor manufacturing, causing turbulence in all key markets in the industry.

Despite these challenges, delivery times are starting to stabilize and, in some cases, decrease. In early 2023, delivery times for most standard semiconductors will last an average of 26-52 weeks, with a steady improvement in the second half of 2022. Later this year, average delivery times for most non-automotive chips could fall below 35 weeks, still much longer than the average delivery times before the pandemic.

Automotive and high-end semiconductors, such as microcontrollers (MCUs) and chipsets, remained severely limited. Most of these high-end components are in the allocation phase, with average lead times ranging from 52 to 78 weeks.

The automotive industry has probably been the hardest hit by the chip shortage. Depending on the level of connectivity, an average car can have thousands of chips on board, and many vehicles require a large amount of semiconductors to control safety functions, electrical and propulsion systems, infotainment, connectivity and more.

As a TSMC spokesperson told Time, the roots of the chip industry's current challenges go back to 2018. Everything was becoming connected, from packaging to refrigerators, and demand for smartphones was skyrocketing, but demand for cars was weak. To cope with the need, semiconductor manufacturers started to allocate more of their now critical automotive components, such as MCUs, to other sectors. This turned into a big problem when demand for cars unexpectedly surged in the last quarter of 2020 and continued throughout the first half of 2021 thanks to low interest rates and the fact that consumers had more spendable income than expected.

In spring 2021, the ramifications of the chip shortage became evident for the automotive industry. Factories have been forced to reduce production or even to close down temporarily due to component shortages. Adding to the pressure on this limited chip supply is the increasing number of mandates for electric vehicles issued by governments around the world.

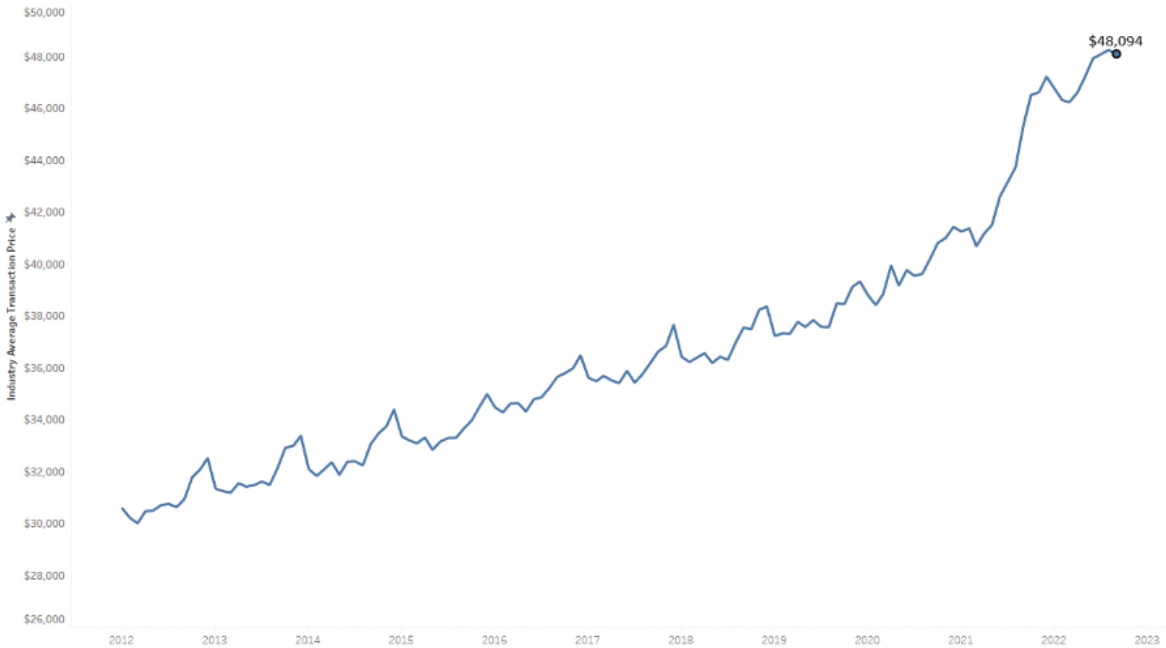
Industry experts and car manufacturers have expressed fears that a prolonged chip shortage could delay the launch of these new vehicles, especially in the US. Analyst firm AutoForecast Solutions predicts that carmakers will face a production shortfall of three million vehicles in 2023 due to the chip shortage: a setback, no doubt, but an improvement over the 4.5 million in 2022 and the 10.5 million vehicles lost in 2021.[34]

The shortage of car chips is also driving up the price of new cars. The average transaction price (ATP) of a new car reached record levels throughout 2021 and 2022, standing at USD 48,094 at the end of 2022 according to Kelly Blue Book[35]; over the last 10 years, the ATP has

[34] cfr. https://www.autonews.com/manufacturing/latest-numbers-automotive-microchip-shortage-78
[35] cfr. https://www.coxautoinc.com/market-insights/kbb-atp-september-2022/

grown steadily, with an increase of 30% from 2012 (around $30,000) to 2020 (around $39,000) and a further 30% in the last two years alone (Figure 23).

FIGURE 23 – New-vehicle average transaction price (ATP), 2012-2022



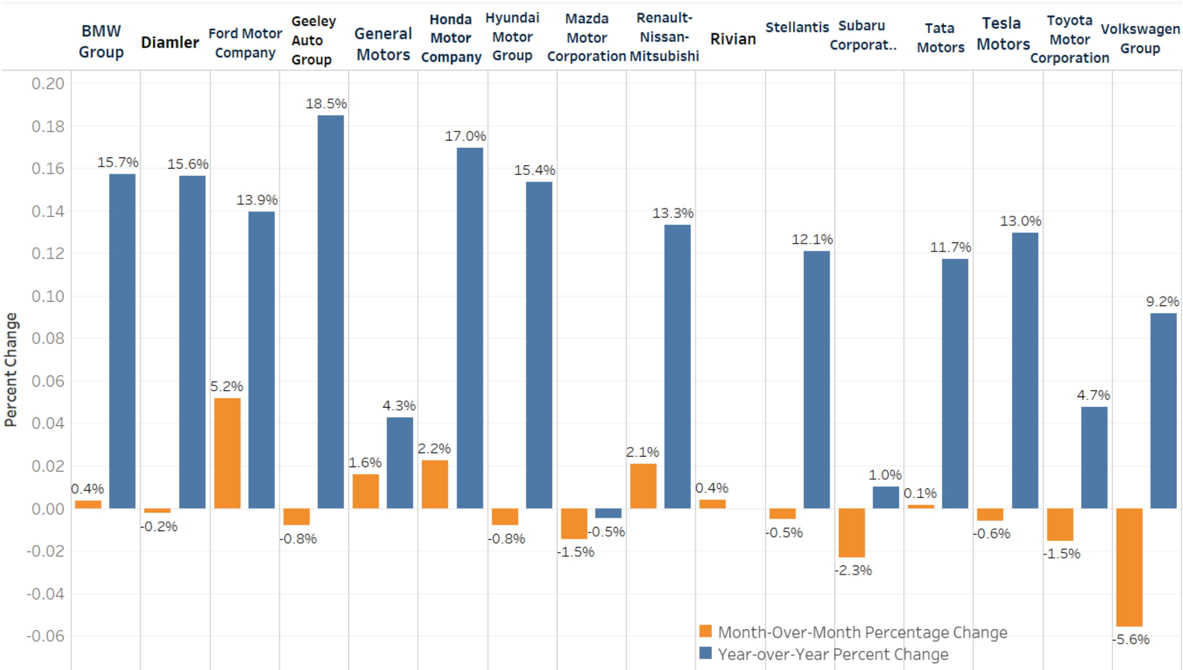

Source: Cox Autmotive Inc.

The average price paid for a new non-luxury vehicle in September 2022 was around $44,000, down $256 month over month. On average, car shoppers in the non-luxury segment paid $829 above sticker price, a slight decrease from August.[36]

As we can see in the figure below (Figure 24), most automakers had a strong price increase during the past year, with China's Geeley Auto Group having the highest percentage increase (18.5%), followed by Honda, BMW and Daimler. In September alone, some automakers had strong percentage increases (Ford +5.2%, Honda +2.2%, Renault-Nissan-Mitsubishi +2.1%) while Volkswagen bucked the trend with a 5.6% decrease.

[36] cfr. https://www.coxautoinc.com/market-insights/kbb-atp-september-2022/

FIGURE 24 – Price change percentage by automaker, September 2022



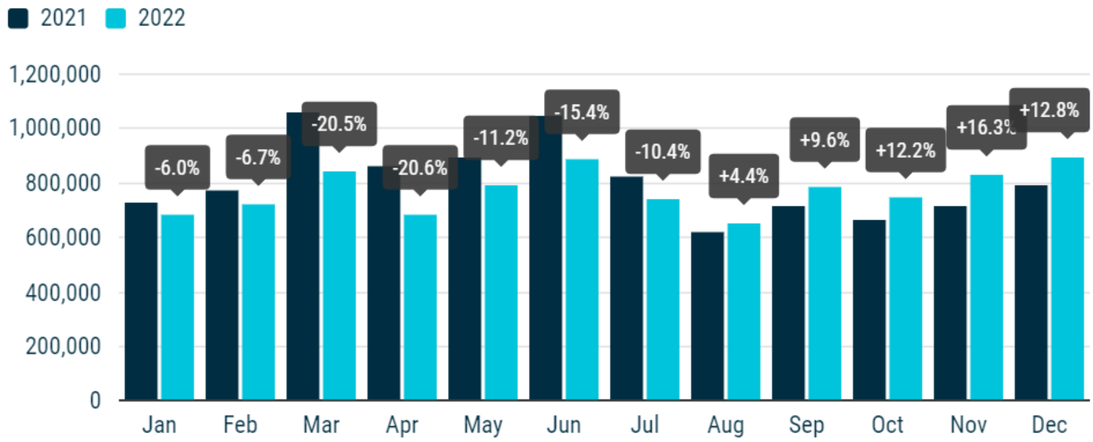

Source: Cox Autmotive Inc.

According to the European Automobile Manufacturers's Association (ACEA), in 2022 the European Union passenger car market contracted by 4.6%, mainly due to the impact of the component shortage in the first half of the year. Although the market improved from August to December 2022, cumulative volumes stand at 9.3 million units, the region's lowest level since 1993, when 9.2 million units were registered (Figure 25). From August to December, as we can see below, there was a marked improvement, with the German and Italian car markets having a particularly strong end. [37]

At the same time, the US car market in 2022 saw a slight but steady improvement over the previous year, at the end of which it took a sharp drop. The trend, as we can see in the figure below is strongly negative since 2019 (Figure 26).[38]

[37] cfr. https://www.acea.auto/pc-registrations/passenger-car-registrations-4-6-in-2022-12-8-in-december/
[38] cfr. https://tradingeconomics.com/united-states/car-registrations

FIGURE 25 – New passenger cars registrations in the EU, 2021-2022




Source: European Automobile Manufacturers's Association

FIGURE 26 – New passenger cars registrations in the U.S. (thousands of units), 2019-2022


Source: TradingEconomics.com, U.S. bureau of economic analysis

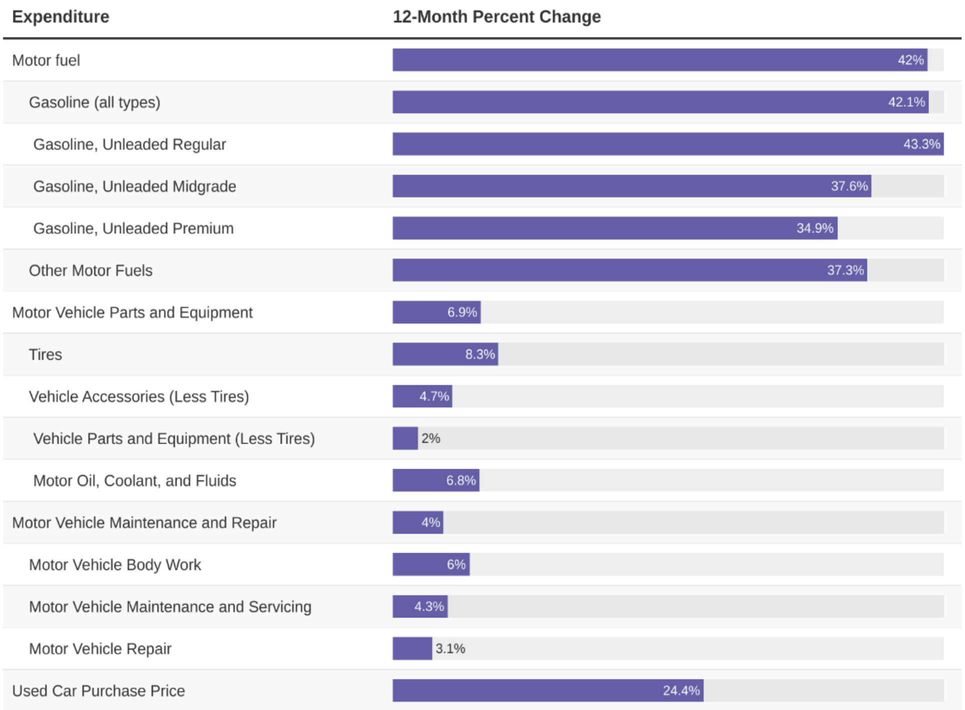
Overall, despite high prices, chip shortages and economic pressures, such as rising interest rates, are believed to have led to the lowest sales totals for carmakers since 2011, with many individual brands continuing to record lower than expected quarterly results and adjusting their financial targets for 2023 accordingly.

Inflation is having a major impact on the car market, being one of the main drivers of price increases, with a level of 7% in the US and 9% in the EU by 2022. Key changes that have led to this situation include supply chain slowdowns (both for new vehicles and spare parts), the war in Ukraine, which has led to increases in transport costs, ports closures and increases in fuel costs, and trucker strikes in North Korea, which has reduced ports trade volumes.

A study conducted in the US by CarInsuranceComparison.com estimated the impact of inflation in the following industry items: [39]

- *Fuel*. Gasoline experienced high levels of inflation during 2022, with regular, mid-grade, and premium gas averaging a 42% increase in price (Figure 27).
- *Used cars*. Prices in the used car market have soared since the beginning of the pandemic, due to the production stoppage of many companies. The price of used cars and trucks has risen 24% in 2022.
- *Car repair and parts*. The average inflation for car repair and parts was 5.1%.

FIGURE 27 – Auto industry inflation in the US, 2021-2022




Source: BLS.gov

[39] cfr. https://www.carinsurancecomparison.com/car-inflation/

Until now, industries have dealt with the chip shortage in mostly short-term ways. The automotive industry has relied on immediate decisions, such as cutting high-tech functions from new car models. Meanwhile, the smartphone industry managed to get through the early stages of the shortage by using the semiconductors it had stockpiled at the beginning of the pandemic. This industry has had supply problems, but now faces the complete opposite problem: there are too many memory chips available and too little demand for the new smartphones that require these components. According to a recent survey by Nikkei analysts, the oversupply of semiconductors for phones, PCs and other consumer electronics devices will probably last until the autumn of 2023. [40]

These circumstances, with shortages of critical chips in one area and unforeseen component oversupply in others, spread throughout the global supply chain, make it difficult to elaborate a recover strategy.

The year 2022 has so far been characterised by production disruptions on many fronts. In addition to the current semiconductor shortages, the conflict between Russia and Ukraine and the COVID-19 outbreak in China have again affected global supply chains and automotive production.

“The US market, like the market in other regions, has been characterised by strong pricing power from original equipment manufacturers (OEMs)”, said Jose Asumendi, head of European automotive research at J.P. Morgan. “This has been supported by low inventory levels, strong underlying demand and tight semiconductor supply due to tight supply chains”.

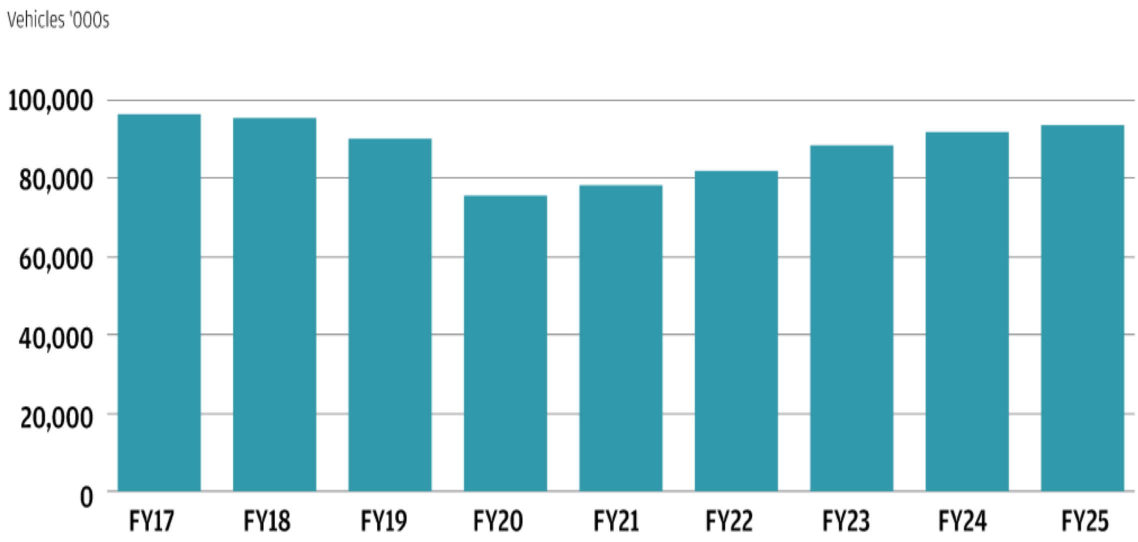
According to a new forecast by S&P Global Mobility, a world leader in information, global new light vehicle sales will reach nearly 83.6 million units in 2023 with a 5.6% increase year-

[40] cfr. https://asia.nikkei.com/Business/Tech/Semiconductors/Chip-glut-to-last-most-of-2023-while-automotive-crunch-persists

over-year (Figure 28). S&P Global Mobility remains wary on recovery prospects. Destroyed demand is a key feature of the tepid forecast outlook – impacted by a blend of general economic impacts, higher interest rates, tight supply chains, an intensifying affordability squeeze, higher new-car prices, weakening consumer confidence, and heightened energy price/supply concerns.

"2023 is expected to be a year of recovery, but likely a cautious one as the world approaches a gloomy trio of anniversaries – three years of COVID, two years of semiconductor disruption, and one year of Russia-Ukraine war impacts", said Colin Couchman, executive director, global light vehicle forecasting, S&P Global Mobility. "The rapid zero-COVID policy exit in mainland China provides further food for thought as we approach the New Year". [41]

FIGURE 28 – Global light vehicle production (thousands of units), 2017-2025




Source: S&P Global Mobility

[41] cfr. https://press.spglobal.com/2022-12-20-S-P-Global-Mobility-forecasts-83-6M-units-in-2023-as-light-vehicle-market-cautiously-recovers

Worldwide, each continent is facing different conditions and challenges:

- "Western/Central European 2022 vehicle sales should post 12.9 million units (-6.7% y/y). Order fulfilment remains a struggle, with long waiting lists, stretched lead times and challenging logistics. For 2023, the narrative shifts from supply constraints to demand destruction. With a mild recession looming for Western Europe, 2023 demand is forecasted at 13.9 million units (+7.4% y/y)", according to S&P Global Mobility;

- "US sales volumes are expected to reach 14.8 million units in 2023, an estimated increase of 7.0% from the projected 2022 level of 13.8 million units. The US auto market is struggling, impacted by supply chain, labor, logistics, inflation, and wider economic concerns," said Chris Hopson, manager, North American light vehicle sales forecast, S&P Global Mobility;

- "In China, with 2022 set at 24.8 million units (+3.6% y/y), some demand fulfilment has been effectively delayed into 2023-24. For 2023, the CNY100 billion extension of NEV incentives and recovering local vehicle production should support domestic sales. 2023 should see a recovery to 25.9 million units (+4.5% y/y)", according to S&P Global Mobility. The market still faces significant uncertainty due to the potential surging of COVID infection levels. [42]

On the demand side, incentives fell to their lowest level since January 2013. This is indicative of high consumer demand in the car end market, as dealers do not need to offer cash incentives to attract consumers.

Another major problem is the availability of batteries, a factor that is inextricably linked to the electric car sector. "The automotive industry faces a shortage of batteries and raw materials in the coming years as part of its transition towards electric mobility", the head of Stellantis Carlos Tavares said at the FT Future of the Car 2022 conference. In his speech, the

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[42] cfr. https://press.spglobal.com/2022-12-20-S-P-Global-Mobility-forecasts-83-6M-units-in-2023-as-light-vehicle-market-cautiously-recovers

CEO of the world's fourth largest carmaker predicts a significant dependence of the Western world on Asia due to the batteries short supply. Tavares said raw material supply could also pose structural challenges in the coming years as electric vehicles were on average 500 kilos heavier than traditional combustion engine ones.

The European Union is heavily dependent on the production of electric batteries, a sector in which China has a growing dominance. Six of the world's top 10 manufacturers are Chinese, with a market share of 56%, which is growing steadily. CATL, an industry leader and supplier to car manufacturers such as Tesla and Volkswagen (with a market share among the world's top 10 manufacturers of 34%), has doubled its sales by 2022. By 2031, China will have more electric battery production capacity in the EU than any other country, thanks to the ongoing expansion program on the European continent. EU, in response to this trend, has set a target for 2025 to achieve a production capacity of around 70 per cent of European demand for electric vehicle batteries. [43]

European dependence on the production of complex products such as batteries is due to a deeper dependence on the extraction and processing capacity of raw materials.

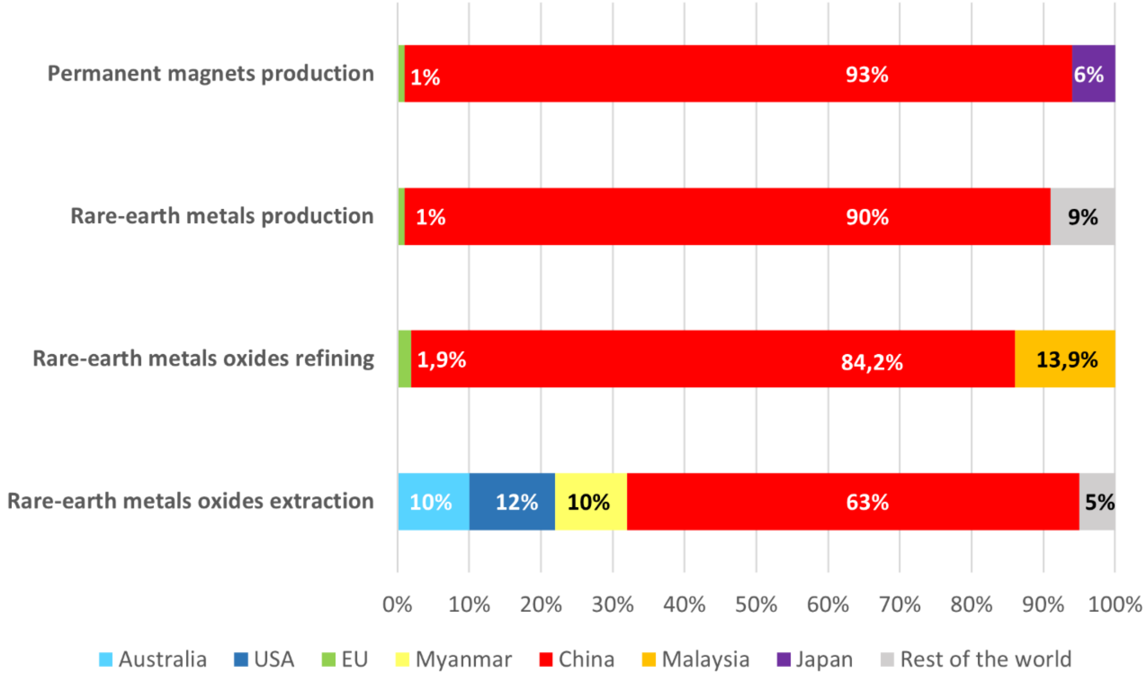
Rare earths are metals with chemical-physical properties that make them key materials for the manufacture of certain technologies. Due to the difficulty in extracting them with environmentally sustainable processes, activities related to these materials have become concentrated in countries with low environmental standards. China today holds world leadership in the entire rare earth value chain. It extracts 63% of the world total with a market share of 85% at the refining stage (Figure 29).

In addition, China produces as much as 90% of rare-earth based magnets: a prime material with a very high global demand, being a central component for electric vehicles. Currently,

[43] cfr. https://lab24.ilsole24ore.com/terre-rare-europa/

the EU does not mine rare earths and accounts for 1% of the global production share of permanent magnets.[44]

FIGURE 29 - Share in rare-earth metals value chain processes per country, 2023




Source: European Commission

Europe is also dependent for other critical materials, in particular those required for the production of so-called clean technologies. "On the way to climate neutrality in 2050, Belgium's Katholieke Universiteit (KU Leuven) estimates an increase in European demand for lithium of 3535%, cobalt of 330% and nickel of 100%".[45]

Today, for all these minerals, the EU is again dependent on China, which processes 35% of all nickel in the world, 58% of lithium and 65% of cobalt (70% is mined in the Democratic

[44] cfr. https://lab24.ilsole24ore.com/terre-rare-europa/
[45] cfr. https://lab24.ilsole24ore.com/terre-rare-europa/

Republic of Congo, but of the 19 industries in the country, 15 are wholly or partly owned by Chinese companies).

In summary, the worldwide chip shortage was caused by the Covid-19 pandemic and the increased demand for electronics. Consumers and companies started buying new laptops and servers to cater for staff working remotely and children studying at home. Thus, while global semiconductor sales declined between 2018 and 2019, they increased by 6.5% in 2020. This rapid growth continued in 2021, and by February 2022, total worldwide chip sales amounted to $52.5 billion, up 32% year-on-year. It is therefore not surprising that manufacturers are struggling to keep up, but the pandemic has also exposed the pressure points in the global chip supply chain, with the vast majority of production carried out by two companies: TSMC of Taiwan and Samsung of South Korea. These foundries are particularly dominant when it comes to cutting-edge chips used in mobile devices or for military applications.

In addition to the pandemic, other factors that have contributed to the shortage include a drought in Taiwan, the worst in 50 years, which has left TSMC and other manufacturers struggling to find sufficient quantities of water, critical for chip production. “Other events have held back supply, such as factory fires, power outages and the Suez Canal transport blockade” said Shane Rau, semiconductor analyst at IDC.

The war in Ukraine has also caused problems for the chip industry, particularly with regard to the supply of neon gas, used in the lithographic printing process that chip manufacturers rely on. Ukraine produces between 40-50% of the global neon supply and the two largest companies selling the gas, Ingas and Croyin, closed their doors when the war broke out. Although many in the industry claim that supplies are still at a decent level, if the conflict continues for a long period, major problems could arise.

Although in the past chip company executives have been optimistic about the prospects of an early end to the shortage, in recent statements many have expressed more caution. Jensen

Huang, CEO of Nvidia, recently stated that he expects “at least another year” in which demand will far outstrip supply. Intel's Pat Gelsinger, on the other hand, declared to analysts during the April 2022 earnings press conference: “We expect the industry to continue to experience difficulties until at least 2024 in areas such as foundry capacity and tool availability”.

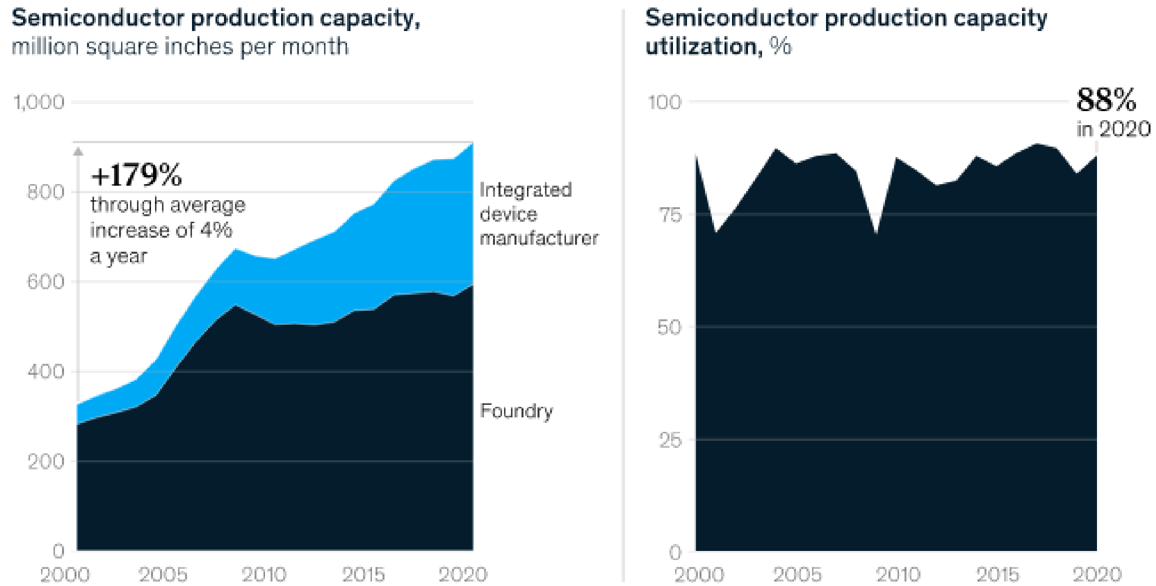
Even when the current global chip shortage ends, more supply problems are likely to be around the corner as demand for electronics grows further. “The capacity that [chipmakers] are putting in now will be sufficient for the next few years, and as these things come on stream there will be too much capacity”, said Alan Priestley, an analyst at Gartner. “But then, in another five years, capacity will be at capacity again, because everyone wants the latest smartphones and we expect to see increased demand for things like smart homes and electric vehicles”.

## 3.2 Possible strategies and the role of politics

There are no short-term solutions for the automotive semiconductor crisis. Chip production times are on average at least four months if capacity is available and no expansion is needed (Figure 30); otherwise, it will probably take at least 18 months. Increasing production might seem the most obvious answer, but it takes more than three years to build a new factory and start wafer production. Delivery times for production equipment have also increased in the last two years due to the supply chains complicated by COVID-19, making expansion even more difficult. [46]

[46] cfr. https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductor-shortage-how-the-automotive-industry-can-succeed

FIGURE 30 – Lead times for semiconductor production, 2000-2020

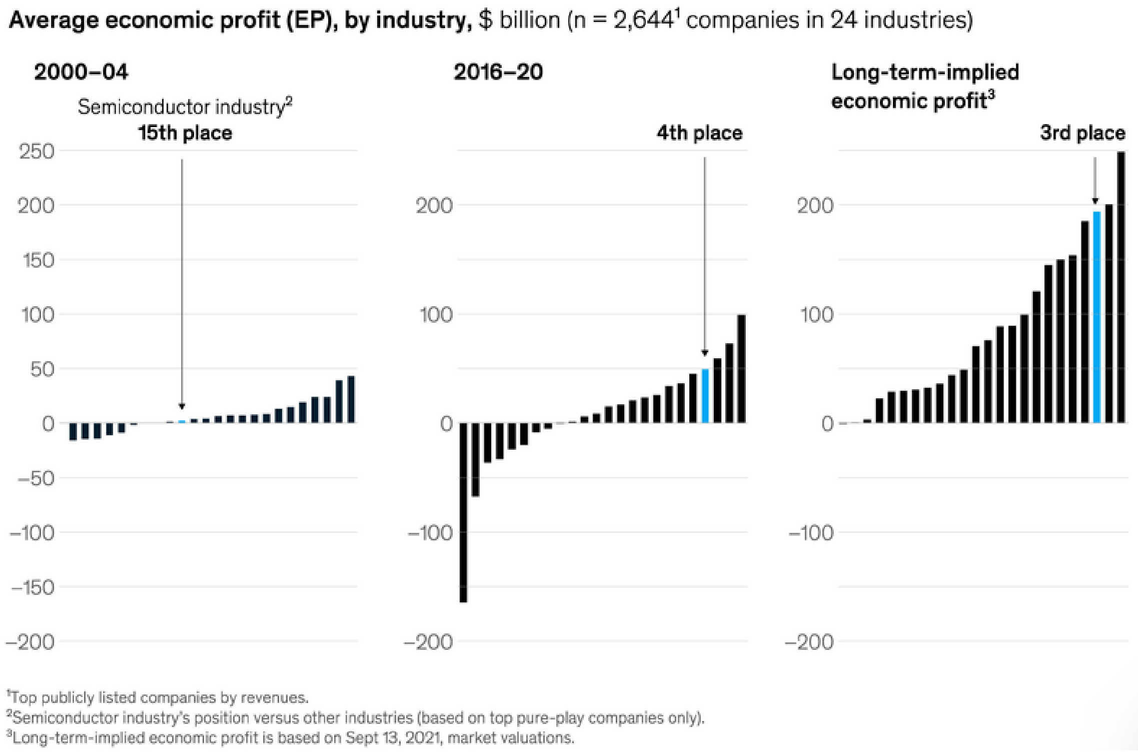



Source: IHS-Omdia; McKinsey analysis

The semiconductor supply chain was already under stress before the pandemic. COVID-19, combined with the recent challenges of power outages, natural disasters and geopolitical uncertainties, has only intensified the problem. Many companies in need of semiconductors are already reconsidering their long-term procurement strategies. Some, for example, may be switching from a just-in-time ordering model, which helps minimise inventory costs, to one in which they order semiconductors well in advance. For their part, many semiconductor companies are changing their long-standing strategies to remain strong. The decisions semiconductor companies make could have enormous economic significance, both for their industry and for the economy as a whole. In the early 2000s, the profit margins of semiconductor companies were low and most of them generated returns below their cost of capital.

Over the past decade, however, profitability has improved due to the surge in demand for microchips in most industries, the rapid growth of the technology sector and increased use of the cloud, as well as ongoing consolidation in many subsegments. One consequence is that the profitability of the semiconductor industry has improved significantly compared to other industries and this trend is expected to continue (Figure 31).

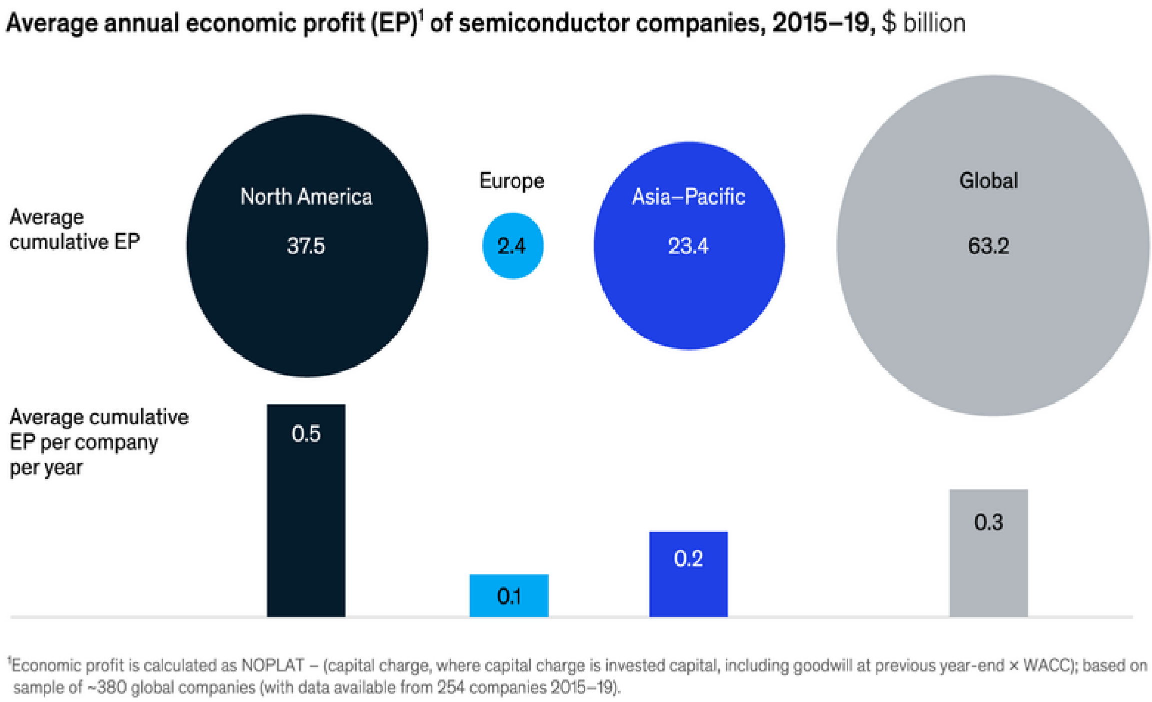
FIGURE 31 – Semiconductor industry's economic profitability trend




Source: McKinsey Strategy Practice and Corporate Performance Analytics

As in any industry, value creation varies by product category, so changes in some segments may have a greater impact than others. For example, the most profitable segment was memory, followed by fabless companies that design their own chips but outsource their production. Below are some differences by region (Figure 32). North America, home to some of the largest fabless players, accounted for about 60% of the global semiconductor value pool in 2015-19. Europe accounted for almost 4% of the industry's total economic profit, which went mainly to capital goods companies. Asia, still the centre of contract chip production, accounted for the remaining 36%. With this geographical distribution, value creation within the semiconductor industry can influence economies around the world (see below).

FIGURE 32 – Semiconductor industry's global value pool, by region, 2015-2019




Source: Company reports; S&P Capital IQ; Corporate Performance Analytics by McKinsey

Capital markets have rewarded the increased profitability of the semiconductor industry, with companies in the sector delivering an average of 25% annual total returns to shareholders from the end of 2015 to the end of 2019. Last year, shareholders saw even higher returns, averaging 50% per annum, thanks to increased purchases of digital equipment of all types by consumers and businesses, partly in response to the COVID-19 pandemic. The question is whether the semiconductor industry can continue to deliver such high returns, especially as the pandemic continues to create uncertainties about demand patterns, supply chains and other aspects.

In addition to increasing production capacity, semiconductor companies could consider several measures to continue their growth and meet customer demand. A first might be to engage in more M&A and/or partnerships to gain an advantage in profitable segments and expand their customer base. Semiconductor companies could also increase investment in innovative technologies that will help them develop cutting-edge chips for autonomous cars, such as the Internet of Things, artificial intelligence and other high-growth areas. Lastly, more agile working methodologies could be important in these uncertain times.

The US government is doing all it can to revive domestic semiconductor production, injecting billions of dollars into the beleaguered industry and deploying all available policies to give it a leg up on Asian competitors.

When the pandemic hit in 2020, companies initially reduced orders for these micro-components needed for smartphones, computers, cars and many other products. Then, when people started working from home, demand for information and communication technologies - and the chips that power them - soared. The shortage of chips took place and car plants had to stop production because they could not get the chips. This contributed to the soaring prices of new and used vehicles, a major factor in the inflation that Americans currently are experiencing. In a statement released in early 2022, Commerce Secretary Gina Raimondo called the semiconductor shortage a "national security" problem because it highlighted the US manufacturing industry's dependence on semiconductor imports from abroad. It is necessary to remark in this context how chips are also needed for critical military applications and are required for cybersecurity tools.

The Biden administration and lawmakers mobilised in response, passing the CHIPS and Science Act in August 2022. The Act aims to catalyze investments in domestic semiconductor manufacturing capacity, providing $50 billion in investments over five years to expand semiconductor manufacturing in the US. Of this, $39 billion is earmarked for manufacturing incentives to accelerate domestic chip production, $11 billion for advanced research and development and workforce training. Another $24 billion worth of tax credits for chip production and $3 billion slated for programs aimed at leading-edge technology and wireless supply chains. [47]

In this context, several major companies have announced significant investments in US manufacturing. Taiwan Semiconductor Manufacturing Company (TSMC), an industry

[47] cfr. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-chips-and-science-act-heres-whats-in-it

powerhouse, has committed at least $12 billion to build a semiconductor manufacturing plant in Arizona, with start of production scheduled for 2024. Also Intel said it planned to build a $20 billion semiconductor manufacturing plant in Ohio.

The US still has a lot of catching up to do, however. US-based factories, or chip production facilities, currently account for only 12% of the world's modern semiconductor manufacturing capacity, according to data from the trade group Semiconductor Industry Association. About 75% of the world's modern chip production is now concentrated in East Asia, mostly in geopolitically vulnerable Taiwan. And even with these renewed efforts, the US does not currently have the same talent pipeline and supply chain that some Asian markets have to support a robust domestic industry.

As far as the EU strategy is concerned, mention must be made of the European Chips Act. The European Chips Act (ECA), also known as simply the Chips Act, is a large-scale investment plan for its microchips sector and presented new powers to secure chips in times of crisis, in an effort to "make Europe a leader in this market", its President Ursula von der Leyen said. [48]

As part of the strategy, which includes a regulatory European Chips Act proposal, the Commission wants to launch a large-scale "Chips for Europe" investment plan, combining almost €5 billion in EU investment with private investments and member countries' contributions for the purposes of research and innovation funding.[49] The Chips Act tries to strengthen the EU foothold in high-tech industries with a program divided in three "pillars":

1) research, development and innovation (R&D&I) policies
2) a new state aid exemption for cutting edge foundries (semiconductor manufacturing plants)
3) measures to monitor the supply chain and intervene in crises

[48] cfr. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-chips-and-science-act-heres-whats-in-it
[49] Poitiers N., Well P., "Is the EU Chips Act the right approach?". Bruegel (June 02, 2022).

The disruption that the production of several products essential to the continent's economy has suffered in recent years prompted the European Commission to submit this proposal. The text adopted by the EU Council, mediated by the Czech Presidency, introduced some significant changes. "The EU needs to reduce its over-dependence on the world semiconductor leaders in Asia and the US and, with the Chips Act, is taking matters into its own hands", said Jozef Síkela, Czech Minister of Industry and Trade.

Semiconductors are highly sophisticated technologies, whose development is extremely long and capital-intensive. Therefore, this complex supply chain is characterised by a solid concentration of manufacturing capacity in Far-East Asia and design expertise in the US.

To address these strategic dependencies, the Chips Act establishes a legal framework that defines the conditions under which public funds can be provided to finance new plants in Europe, the so-called *mega fabs*, introducing the concept of "first-of-a-kind". In other words, these mega fabs will have to significantly advance Europe's technological capacity. The definition of first-of-a-kind facilities was at the heart of the Council negotiations, as the innovation requirement was extended to include elements such as computing power and energy efficiency.

The requirements that these mega-factories will have to fulfil have also been changed, in particular because they will have to produce positive "spill-over effects" on the entire EU semiconductor value chain. This requirement is a symptom of the widespread concern among member states that these mega-factories only benefit those with the deepest pockets, who are able to subsidise these expensive plants. Indeed, the spill-over effect could take different forms, e.g. as a research centre or training programme.

When the Commission assesses the mega-factory project, it will have to consider aspects such as the financial sustainability of the business plan and the willingness of the host country to build the facility.

The EU executive can revoke the first-of-a-kind whenever the mega fab no longer meets the requirements, but only after consulting the European Semiconductor Board, a body that will bring together representatives of national governments. In addition, in cases of emergency of overriding public interest, mega-factories may be built in derogation of EU environmental procedures.

The *Chips for Europe Initiative* will fund the building of advanced design capabilities, new pilot lines for cutting-edge chips, building engineering and technology capabilities, creating a network of competence centers (at least one per Member State) and facilitating access to finance for semiconductor SMEs.

The Initiative itself would have an €11 billion budget, but only €3.3 billion of this would come from the EU itself, by redirecting funds already committed through *Horizon Europe* and the *Digital Europe Programme*, some of which were earmarked for chips anyway. A 'Chips Fund' will leverage EU and European Investment Ban funding to raise €2 billion in equity financing for start-ups in the sector. [50]

The Commission and EU countries will establish an early-warning mechanism and map potential bottlenecks during a crisis. In the event of a crisis, the Commission could place priority orders to mega-factories for critical sectors such as defence and health, or joint purchase orders, along the lines of COVID-19 vaccines. There was a long discussion in the Council as to whether the automotive sector should be considered critical, but in the end the idea was abandoned because it would have broadened the scope too much.

During crises, the EU Executive could also impose mandatory information requests, which Member States have developed to include safeguards in terms of proportionality and security

[50] Poitiers N., Well P., "Is the EU Chips Act the right approach?". Bruegel (June 02, 2022).

interests. Failure to comply with information obligations and priority orders could lead to significant financial penalties, in the most serious cases up to daily fines of 1.5% of the daily global turnover.

To receive public funding, the Chips Act introduced the legal entity of the European Chips Infrastructure Consortia (ECIC). However, this model caused controversy, as smaller Member States felt that these approaches usually favoured larger Member States to take the lead in projects and questioned the usefulness of a new instrument in addition to traditional research consortia. In the end, ECIC was retained in the text, but became optional.

Looking ahead to 2023, global macroeconomic and geopolitical factors are emerging as the dominant forces affecting the semiconductor industry. Rising interest rates, high inflation, declining consumer confidence and stock market declines led by the technology sector have been leading to a dramatic loss in market capitalization.

Another blow for the industry came in October 2022 after the US Department of Commerce announced severe restrictions on the sale of semiconductors and equipment to China. The damage to industry stocks was significant: as of October, the SPDR S&P Semiconductor ETF (XSD) was down 38.97% since the start of the year.[51] All major companies in the sector reported serious consequences within a few days of the announcement of the restrictions:

- Market leader Nvidia (NVDA) fell 7.13% (down 58.5% for the year)
- Advanced Micro Devices (AMD) was hit even harder, falling 14.86%
- Taiwan Semiconductor Manufacturing (TSM), the world's largest semiconductor foundry, fell 14.49%

In response to rising capital costs, customer and supply chain inventory depletion and falling profits, many chip companies are cutting costs, reducing headcount and foregoing (but not

[51] cfr. https://www.morningstar.ca/ca/news/227742/why-are-semiconductor-shares-being-crushed.aspx

cancelling) capital expenditure (capex) to increase production capacity. Capital expenditure for 2023 is still likely to be higher than in 2020, but lower than previous expectations for the year.

There may be a silver lining: a downturn may offer the industry an opportunity to focus on things other than trying to catch up during a shortage. As the following sections show, Deloitte, for example, predicts that 2023 could be the pause that refreshes and allows the industry to reconsider five big aspects: [52]

1. Industry and governments recognise that no country or region can be truly self-sufficient but must rely on trusted friends and allies for parts of their supply chain.
2. Managing the risks and challenges of diversification arising from localisation and friendshoring.
3. Transforming and digitising many parts of the process: financial planning and operations, order management and supply chain.
4. Addressing and balancing the talent equation in semiconductors: shortages in some roles, but dismissals in others.
5. Establish and accelerate the path towards the achievement of environmental, social and governance (ESG) objectives, in particular with regard to sustainability.

In the US and Europe, the goal for both chipmakers and politicians is to make national industrial capacity adequate and, in general, more self-sufficient, while recognising that perfect independence is unattainable. As Ursula von der Leyen, President of the European Commission, said in her speech presenting the EU chip law: “It should be clear that no country, or even no continent, can be completely self-sufficient”.

After all, chips are not a monolithic category: many types (memory, logic, mixed signals, power semiconductors, etc.) are produced for many different markets (chips for smartphones and PCs are different from chips for cars). Each type of chip may require different wafer sizes

[52] cfr. https://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/articles/semiconductor-industry-outlook.html

and process technologies, and requires different materials, structures, equipment and design tools, radiation tolerance, etc.

Manufacturing processes are also different, as they use different semiconductor materials and rely on numerous other inputs (such as specialised epoxy resins) and a wide range of equipment for fabrication, testing and assembly. Sometimes there is only one manufacturer or source for a critical part. Furthermore, the concentration of plants can increase risks: any plant or cluster may be shut down due to drought, earthquake, fire, flood, military conflict, pandemic, power failure or typhoon, among other causes.

Finally, given the realignment of the cutting-edge manufacturing in North America and Europe, US and European semiconductor manufacturers may be forced to locate more back-end assembly and test (AT) activities nearby, as essential parts of the process on a par with large factories. This is because leaving almost all of the AT in Asia will do nothing to mitigate supply chain risk.

At a high level, policy-makers in almost all countries and regions are aware that the new supply chain is likely to be characterised by a mix of solutions and that countries should consider rethinking their footprint according to the ongoing developments with trade restrictions. Some production plants may be in our country or region (onshoring); others may be in geographic areas very close to our country or region (nearshoring); and some may be in countries we consider friends and allies (friendshoring). These countries may be relatively close, they may be on the other side of the world. Moreover, any strategy will have to be accompanied by a comprehensive fiscal policy.

Recently, we have seen a flurry of news about semiconductor shortages leading to production disruptions and supply shortages in many product categories. Since semiconductors play a role in almost every sector of the modern economy, the shortage has created a bipartisan consensus that something must be done. However, to understand the actual scope and strategy of ‘doing something', we must first understand what the current shortage, and the resulting market dynamics, reveal about the economy.

The current semiconductor shortage is best understood as an acute and long-lasting crisis. Given current capacity constraints in shipping and widespread economic disruptions due to the pandemic, the current shortage is not surprising. At the same time, semiconductor production has experienced a general decline in capital expenditure over the past two decades. It would be easy to assume that the shortage is due to a supply shock from the disruption of global value chains in the face of steady demand. In reality, the situation is exactly the opposite: the semiconductor shortage is the product of a demand explosion in the face of constant supply. Despite the pandemic, demand for semiconductor-based capital goods has emerged from an almost 20-year slumber. In short, the increase in demand has led to an increase in production capacity.

Supply conditions - labour supply, capital expenditure and capacity utilisation rates - are closely linked to current and expected demand conditions. At the same time, production bottlenecks can result from poor investment planning. To prevent future bottlenecks it will be necessary for fiscal policy to use conventional demand-side instruments together with coordinated investments in strong supply chains.[53]

Spending on capital goods has come out of its ten-year slump very quickly. Of course, part of this surge can be attributed to the one-off need for technology equipment to support a home-based lifestyle. Demand from home is certainly playing a role, but total spending on computers and peripherals has continued to increase quarter after quarter, more persistently than a pure "one-off dynamic".

[53] Dunn J., & Leibovici F. (2021). "Supply chain bottlenecks and inflation: the role of semiconductors". Available at SSRN 3988520.

The real motivation for this trend can be found in macroeconomic policy. Although the initial impetus of the pandemic caused an economic shock deeper than even the global financial crisis, the response of fiscal and monetary policy to the pandemic was much more incisive.

Large-scale, targeted fiscal transfers were much larger than in any previous economic downturn. At the same time, the Fed dramatically increased the speed and scope of its accommodation efforts. Thanks to unprecedented support for private sector balance sheets, typically cyclical sectors sensitive to interest rates, such as housing and autos, rebounded rapidly, even as the pandemic continued to depress demand for services.

The difficulties that car manufacturers face today in sourcing semiconductors, for example, are due more to a sudden surge in demand for cars than to a drop in semiconductor production capacity. To draw a useful lesson from this experience, we should recognise that supply and demand are not opposing forces. Changes in demand can lead to changes in supply, either by bringing new capacity on stream or by forcing companies to write off and dismantle existing capacity.

Although interest rates have fallen substantially over this period, in many cases it is not possible to lower interest rates sufficiently to stimulate investment in an environment of chronically low aggregate demand. However, the fiscal response to the pandemic has done what years of near-zero interest rates have failed to do: investment in capital goods that are so heavily dependent on semiconductors and other high-tech manufacturing is actually increasing.

The best lesson to be learned from these pandemic-driven policies is that seemingly intractable supply-side trends can, in fact, be resolved using demand-side macroeconomic policy. Policy cannot productively deal with supply-side shortages and problems without addressing the demand-side problems that produce and sustain them.

# Conclusions

The automotive industry landscape is changing rapidly, both in terms of evolving technologies and interests, thanks to the transformation of the global economy structure in favour of high-tech industries.

In the last 20 years market demand has changed a lot due to, firstly, the transition of the industry's life cycle in developed countries towards the saturation phase, when supply begins to exceed demand; secondly, the economic success of developing countries, where the huge unmet need for cars is transformed into actual demand as national economies grow and incomes rise.

This period has seen a steady growth in car production. However, this increase is very uneven: while more developed countries have experienced a slight to moderate decline, developing countries have experienced exponential growth. In particular, China has emerged as one of the most important growth markets for all players in the world automotive industry to establish itself in the recent years as the world leader in the production of cars.

The evolution of the electric car is a major factor to understand the industry's dynamics. Worldwide, sales of electric vehicles have increased by more than 40% per year since 2016. By 2035, the largest automotive markets will be fully electric. However, this impetuous march towards the electrification of mobility has recently been undermined by a series of exogenous shocks. The COVID-19 pandemic affected the supply-demand balance in multiple dimensions, including, for example, factory closures, logistics disruptions, company bankruptcies and decreasing purchasing power.

Starting in 2020, the global automotive industry faced a drop in demand and production disruptions due to the COVID-19 pandemic and a shortage of automotive semiconductors. Several car manufacturers have been faced with microchip shortages that have held back production. The context of the microchip shortage is complex, but in general the faster than expected recovery in sales of cars and other microchip-based products has come up against a limited supply of microchips. The shortage is even more problematic for electric vehicles, which require about twice as many chips as equivalent conventional vehicles, mainly due to the additional power electronics.

Everything started with the COVID-19 blocks in Q2 2020, when demand for work-from-home technology increased exponentially and carmakers found themselves competing for semiconductor capacity located in Asian foundries. To compound the problem, downstream operations in South Asia were negatively impacted by the COVID-19 Delta variant, creating additional bottlenecks in the supply chain.

The automotive industry has probably been the hardest hit by the chip shortage. Depending on the level of connectivity, an average car can have thousands of chips on board, and many vehicles require a large amount of semiconductors to control safety functions, electrical and propulsion systems, infotainment, connectivity and more. Factories have been forced to reduce production or even to close down temporarily due to component shortages.

Industry experts and car manufacturers have expressed fears that a prolonged chip shortage could delay the launch of these new vehicles, especially in the US. Analyst firm AutoForecast Solutions predicts that carmakers will face a production shortfall of three million vehicles in 2023 due to the chip shortage.

The crisis is afflicting the global car market in several ways: the average transaction price (ATP) of a new car reached record levels throughout 2021 and 2022, with most car manufacturers around the world have been forced to raise prices significantly; world passenger car market contracted during 2022 with record negative numbers for the European market in particular.

There are no short-term solutions for the automotive semiconductor crisis. US and European chip industries are trying to diversify not only the factories, but all parts of the supply chain of semi-finished products. The chip industry could move from its traditional strongholds in the Asia/Pacific region to North America (both the US and Canada) and Europe (e.g. EU countries, as well as non-EU states, notably the UK). The US and Europe have set ambitious targets for increasing domestic chip production capacity: the US intends to increase its share of domestic capacity from 11% in 2020 to 30% in 2030, while Europe aims to expand its share from 9% to 20% over the same period. In the same timeframe, the global chip industry is expected to roughly double. However, to realise these shifts, semiconductor companies need to consider certain nuances related to potential risks and challenges that need to be planned for.[54]

Through its policy measures, the European Union is trying to decrease its dependence on China. There are many possible future scenarios, depending on the economic choices and investments that Europe will make:

1. *Diversification of suppliers*
   Recently, European Commission has been trying to secure supply chains through means of trade with like-minded democracies like Chile, Mexico, New Zealand, Australia and India. India, in particular, is becoming increasingly important as a producer of automotive components, tranks to its skilled labour offer, a large component supplier base and a significant presence of global automotive manufacturers. Europe could also try to find alternative suppliers in ASEAN (Association of Southeast Asian Nations) countries: ASEAN countries such as Vietnam, Thailand, Malaysia and Indonesia are emerging as important automotive component manufacturers which offer cheap labour, access to raw materials and a

[54] Faulconbridge G., Kelly L., “Russian official warns of World War Three if Ukraine joins NATO”. Reuters, October 13, 2022.

strategic geographic location close to Europe. This attempt to diversify supply chains, instead of pushing for a more protectionist approach, is particularly appreciated by experts.

2. *Investments in research and development*

   This seems to be the strategy the European commission is currently implementing, as can be seen from recent legislative proposals such as the previously mentioned Chips Act and the European Critical Raw Materials Act, structured to tackle the growing dependence on China for refining raw materials lithium. Support for domestic companies, such as investments in R&A, subsidies, tax incentives and training programs are measures to strengthen its domestic production of materials and components for the industry, thus reducing the need to import from third countries. This could include investments in infrastructure and equipment for steel and aluminium production, as well as incentives for companies developing batteries for electric vehicles with innovative technologies that do not require the use of rare materials (like rare-earth metals widely extracted and refined by Chinese companies).

3. *International collaborations*

   Europe could collaborate with other countries or regions to develop an alternative supply chain. For example, it could collaborate with North and South America (in particular with US, which is having a similar approach and policies) to create an integrated supply chain for raw materials and automotive components, forming a united front in an attempt to counter the leadership of China. US, Japan and South Korea, which have advanced expertise in the production of electric batteries, are inclined to share knowledge, technology and investment. This could lead to the creation of a shared infrastructure for battery production.

Replicating the capacities of Asian production sites will not be easy. Until the supply chain, pandemic and trade issues emerged, Asia had secure supplies of raw and processed materials for the production of hundreds of components. The region still has state-of-the-art chip production facilities, has the most advanced AT services and can even ship final products to end customers, all in a highly efficient and reliable manner. Replicating and building this model in multiple geographically unconcentrated locations could take years or even decades. Nevertheless, starting in 2023, chip companies need to plan and prepare for the potential risks associated with diversification.

One of the key initial steps should be the identification of new supply and trade routes. The ongoing war in Ukraine and technology restrictions between the US and China introduce additional complications and risks and will likely require new air corridors, sea routes and compliance with export controls. These new routes are likely to increase transport and logistics costs and, consequently, the prices of final products, which are already high due to rising energy costs. In an extreme scenario, it is feared that the ongoing Ukrainian crisis will turn into a possible global war, with an even greater likelihood of affecting semiconductor production and supply chains.

Deciding which mix of onshoring, nearshoring and friendshoring (while almost certainly also relying on offshoring) will be best for each manufacturer or country/region will make 2023 an interesting year. Chip buyers, moreover, are starting to express preferences about where chips are made, not just what they make and how much they cost.

These critical decisions could have repercussions for years to come: new or expanded plants started in 2023 will probably still be in operation in 2030 and beyond, as well as their supply chain connections. The interests involved could go far beyond governments or chip manufacturers: the automotive industry relies on different chips than smartphone companies and usually employs many more workers; moreover, chip buyers are starting to express preferences on where chips are produced and not just on specifications/cost. In the years to come, these factors will bring greater societal implications and, as a result, the automotive sector will increasingly be at the centre of the national and global policy chessboard.

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