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Patent Landscape Analysis of Batteries for Electric Cars

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Introduction

In recent years, we have witnessed a change in the paradigm of automotive transport: increased public awareness of environmental issues, combined with a series of international policies aimed at limiting harmful emissions into the atmosphere, have led to more and more investment in forms of propulsion with zero environmental impact, moving towards a reversal of the dominant paradigm of the last century: the internal combustion engine car. The system that currently seems to be the one that will become dominant in the near future is the electric drive, a technology that has been applied to the automobile since the first models in circulation but was later replaced by the endothermic engine for various reasons. Although the modern electric or hybrid drive has been on the market for more than a decade, there is still a lot of scepticism about it. One of the aspects slowing down the adoption of this system are the doubts related to batteries, their capacity, charging times and safety.

The aim of this thesis is to describe the state of the art of battery technology and to understand future development trends to see if these limitations can be overcome. To achieve this, a Patent Landscape Report will be developed, i.e. an analysis based on data from large patent databases. Patents are indeed an excellent source of information on the state of development of a technology, as the inventor is legally obliged to publish the description of his invention in exchange for legal protection. The first part of the paper is devoted to the description of the technology and a brief market analysis. The second part focuses on the description of the patent and its structure, before moving on to the third part, which describes the analysis process, which is in turn divided into two parts: the first part deals with the technology in general, while the second part focuses on specific technology sub-classes.

1. The Electric Car

1.1 History

An electric car is a vehicle that uses an electric motor for its propulsion. This may seem to be a recently developed technology, but the first rudimentary examples date back to the early nineteenth century: in 1827 Hungarian physicist Ányos Jedlik developed a prototype of an electric motor that he used to propel a small toy car, while what is considered the first real electric car was created in 1870 by Scottish inventor Robert Stevenson [1].

However, all the prototypes of the first half of the nineteenth century were not suitable for practical use: the motors were not powerful, let alone reliable, and the early batteries consisted of so-called primary cells, which are electrochemical cells that use a non-reversible chemical reaction to generate current, which is why they could not be recharged but had to be replaced when exhausted. This feature therefore made it not economically viable to use these early models.

In the late 1860s a series of technological developments led to the construction of the first dynamos. These machines connected to steam engines allowed potentially unlimited power generation at much lower cost than electrochemical cells. At the same time as the generators, the lead-acid battery, the first type of rechargeable battery, was developed. The combination of these two inventions gave a boost to the development of new models of electric cars: these began to appear in Europe and, slightly later, in the United States.

In the late nineteenth and early twentieth centuries, to publicize the electric car, manufacturers competed in races and competitions. The first cab services carried out by all-electric cars also emerged, and because of its ease of use and reliability, the electric car reached a peak of 38% market share in the United States, competing with the steam car (40%) and leaving the gasoline car at 22%. At the time, self-propelled cars were used for city travel, as they were not suitable for long distances because of unpaved roads. In the 1920s, the first highways began to emerge in the United States: the possibility of moving with cars over long distances made the technology that allowed the longest range, namely the ICE (Internal Combustion Engine) car, prevail. In addition to this, the discovery of new oil fields caused the price of gasoline to drop significantly, thus making gasoline cars competitive, which had at the same time also became easier to use thanks to the introduction of the electric starter motor.

After 1920, electric cars disappeared from the market, remaining popular for low-range services, such as golf carts and milk vans in the United Kingdom.

Interest in electric cars rose again in the 1970s, as the oil crisis sent gasoline prices soaring. In addition to this, during the 1990s there was also an increased focus on global warming issues: in 1992 the United Nations Framework Convention on Climate Change (UNFCC) was held, which laid the foundation for the subsequent Kyoto Protocol (1997). The latter is a treaty that legally obliged developed nations to reduce their greenhouse gas emissions by 2012. This commitment was then renewed in 2016 with the Paris Agreement. This series of agreements has obviously influenced the policies of signatory states, which have adopted instruments to promote zero-emission forms of mobility, such as electric cars. New prototypes began to be developed from the 1970s on, but mass arrival on the market did not occur until the 1990s thanks to the 1997 presentation of the first mass-market hybrid car (i.e., powered simultaneously by an electric motor and a heat engine): the Toyota Prius. A few years later, in 2003, Tesla was founded. The company's goal was to produce an all-electric sports car capable of traveling 200 miles on a single charge, the success of which prompted other carmakers to work on electric models. To date, several types of electric cars are available on the market [2] [3]:

- Battery Electric Vehicles (BEVs): they run exclusively on battery and electric drive train, without a conventional ICE. To recharge their batteries, they must be plugged into an external source of energy. They can recharge batteries also with regenerative braking (the electric motor works as a generator and helps slowing down the vehicle)
- Plug-in hybrid Electric Vehicles (PHEVs): most of the time they run on battery power, which can be recharged by connecting to the power grid. These vehicles are also equipped with an ICE which can both recharge the battery and move the car by replacing the electric motor when the battery level is low or more power is needed. Since they can be connected to the public grid to recharge, PHEVs are often more

economical than pure hybrid vehicles, but the real savings depend primarily on the distance travelled solely through electric propulsion.

- Hybrid Electric Vehicles (HEVs): move by harnessing a conventional ICE and an electric propulsion system, which can simultaneously help generate the power needed to be able to move the car. This type of vehicle cannot be recharged from the public grid; the electricity needed comes from the heat engine and regenerative braking.
- Fuel Cell Electric Vehicles (FCEVs): this type of car moves by generating electricity through the use of a fuel cell, which is a device that by chemically reacting hydrogen and oxygen is able to generate power, producing only water as an emission.

1.2 Main Components

Aesthetically, it is difficult to distinguish an electric car from one equipped with a traditional ICE; the major differences lie below the body and obviously concern the components related to the car's motion, namely the so-called *drivetrain* [2] [3].

In Figure 1 we can see the main components of an electric drivetrain:

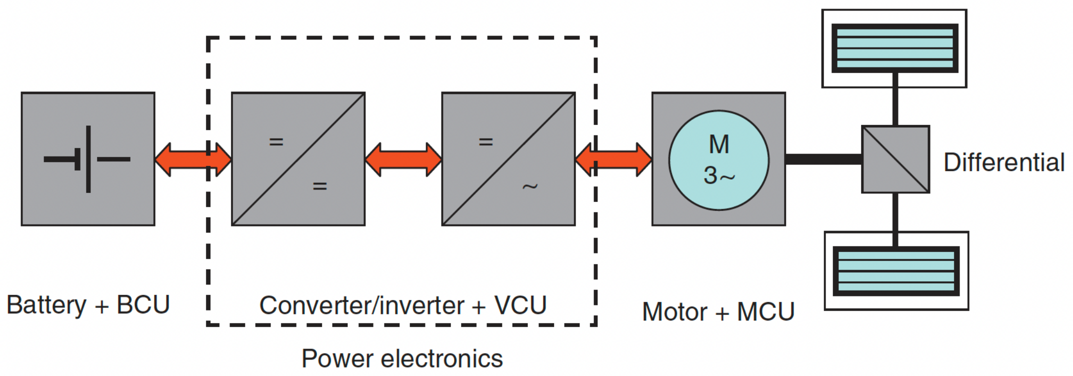


Figure 1: BEV drivetrain structure - adopted from [3]

The structure is very simple: we have a battery that powers an electric motor. The battery is managed thermally and electrically by a Battery Control Unit (BCU) and is connected to the motor via power electronics. The latter connection must be bidirectional:

- During traction it acts as an inverter by converting the DC current from the battery into the AC current needed to move the motor.
- During regenerative braking it acts as a rectifier, converting the AC current generated by the motor into the DC current needed to charge the battery.

We then have an AC electric motor (with its respective Motor Control Unit to manage motor operation) mechanically connected to the differential, which allows the drive wheels to be driven.

1.2.1 Electric Motor

An electric motor is a machine for transforming electrical energy into mechanical energy. These can essentially be classified into two types [3]:

- Direct current (DC)
- Alternating current (AC)

Compared to AC motors, DC motors are easier to control and less expensive, however, they turn out to be larger and heavier. With the development of power electronics, the control of AC motors has become easier, increasing their popularity in automotive applications. The most commonly used type is the three-phase asynchronous motor, which requires a 3-phase current supply. The structure of this motor consists of a fixed part called the stator and a rotating part called the rotor. The stator has electrical cable windings which, when current flows through them, generate an electromagnetic field, which in turn generates an electromotive force in the conductors of the rotor that allows it to rotate.

Compared to a combustion engine, the electric motor is more energy efficient – its efficiency is around 90 percent versus 20-30 percent of an ICE. From a management point of view, the electric motor is simpler and requires almost no maintenance, while in terms of performance, the electric drive allows for a large amount of torque almost instantaneously, which makes it possible to avoid the use of a gearbox as on cars with ICEs.

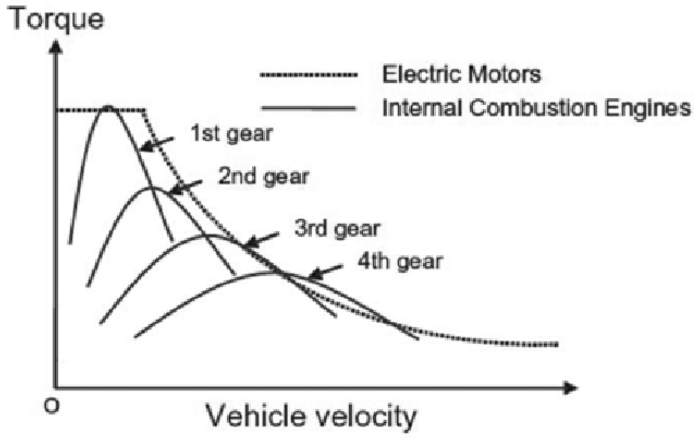


Figure 2: Torque-speed characteristics of electric motors and internal combustion engines - adopted from Novel electronic braking system design for EVS based on constrained nonlinear hierarchical control - Scientific Figure on ResearchGate

1.2.2 Energy Storage Device

Obviously, an electric motor needs an electric power supply to operate. There have been some highway infrastructure prototypes equipped with an overhead power system using technology similar to that in use on railways; however, it remained in the experimental stage and never caught on.

Figure 3: a truck runs with aerial electric feeding on Highway E16, Sweden – from https://shorturl.at/bowCX

The alternative to external power supply is to equip the vehicle with a system that can store energy and then convert it into electrical energy and transfer it to the engine. This is done by harnessing the chemical energy inherent in devices such as batteries or fuel cells.

1.3 Advantages and Disadvantages of Electric Cars

When talking about electric cars, but also more generally about electric mobility, the main advantage is the zero emission of pollutants into the atmosphere. It should be pointed out that the emissions that are reduced to zero are only the direct ones (i.e., those produced directly by the vehicle), and it must be considered that the electrical energy used to power this type of mobility, unless it comes from renewable sources, is produced by power plants that use fossil fuels and that in turn emit harmful gases into the atmosphere.

This reduction would not only bring environmental benefits, but also reduce the social costs of global warming. These costs are those society incurs to cope with the consequences of global warming in terms of "*impacts on agriculture and forestry, water resources, coastal zones, energy consumption, air quality, tropical and extratropical storms, and human health*" [4]. These appear to be the most important factors analysed in the literature, various models have been developed to try to assess this cost, however the list of factors is not exhaustive, and the phenomenon cannot be accurately quantified.

Another advantage of the electric drive over a conventional combustion engine is energy efficiency: an internal combustion engine can transfer approximately 20% of the chemical energy in the fuel to the wheels, whereas an electric motor can convert approximately 70 to 80%. This difference occurs due to both thermodynamic limits of the engine and mechanical friction, since the transfer of motion from the engine to the wheels in a car with ICE is carried out by passing through numerous mechanical parts (see paragraph 1.2.1) that reduce the efficiency of the system. Extending the analysis to primary energy sources as well, although not all the electrical energy produced is derived from renewable sources, the electric car is more efficient overall: according to Gelmanova et al. [5], whose results are shown in Table 1, the electric car is twice as efficient as a diesel engine.

Table 1: comparative table of energy efficeincy for different types of cars - adopted from [5]

Technology	Car	Original Source of Energy	Total efficiency of processing, delivery and refuelling	Distance travelled per unit of fuel	Energy efficiency of the vehicle	Full energy efficiency
CNG Engine	Honda CNG	Natural Gas	86,0%	17,5 km/kg	0,39 km/MJ	0,32 km/MJ
FCEV	Honda FCX	Natural Gas	61,0%	84 km/kg	0,7 km/MJ	0,43 km/MJ
Diesel engine	VW Jetta Diesel	Oil	90,1%	17,2 km/l	0,47 km/MJ	0,42 km/MJ
Petrol engine	Honda Civic VX	Oil	81,7%	14,2 km/l	0,46 km/MJ	0,38 km/MJ
Hybrid	Honda Civic Hybrid	Oil	81,7%	17,3 km/l	0,56 km/MJ	0,46 km/MJ
Electric	Tesla Roadster	Natural Gas	52,5%	151 Wh/km	1,84 km/MJ	0,97 km/MJ

The study considers consumption in the combined cycle, i.e., a mix of city, suburban and motorway driving. Obviously, the performance of the various technologies varies depending on the conditions: for example, heating the passenger compartment is not very costly for a car with a combustion engine as it uses the heat produced by the engine, whereas in an electric car this process is very costly for the batteries and the range. For city driving, the electric car is the best choice due to its fast acceleration, quietness and zero emissions.

Analysing the economic aspect, the purchase prices of electric cars are higher for the same type and class of vehicle. In many countries, however, there are subsidies and concessions that favour the purchase of this type of vehicle (cf. chapter 3). On the other hand, running costs are considerably lower: the cost of a "full tank" of energy is way lower than a full tank of petrol; maintenance costs are also reduced - frequent periodic maintenance such as oil changes and/or replacement of mechanical parts subject to wear and tear is not required. To compare the two technologies, it is useful to introduce the concept of Total Cost of Ownership. This is defined by Ellram [6] as "*a purchasing tool and philosophy which is aimed at understanding the true cost of buying a particular good or service from a particular supplier, thus being a useful measure for comparing the operating costs of two technologies*". According to Hagman et al. [7], it exists a discrepancy between purchasing price and TCO among the different vehicle drivetrains, where the BEV had significantly lower running cost compared to ICEVs and HEVs, leading to a competitive TCO. However, the authors also point out that the lack of consumer awareness of this tool could be one of the factors that are slowing down the spread of electric cars.

Among the disadvantages, it is worth mentioning the reduced range: on average, an electric vehicle has a range of around 380 km [8] on one charge, compared to the 500 to 700 km on average of a car with a combustion engine (obviously this depends on the tank capacity). However, one must consider the fact that the average distance of each daily trip varies between 25 and 50 km [9], so in terms of urban mobility, the reduced range should not be a disadvantage. Another element to consider is the charging infrastructure: although the number of charging points has been growing over the years, most of these are domestic or otherwise slow-charging charging points. Fast charging points are rarer and often operated by different companies, which forces the user to look for the nearest charging point of his provider or to subscribe to several charging plans, which increases costs.

2. Batteries

A battery is a device capable of converting the chemical energy contained in an electrochemically active material into electrical energy by means of an oxidation-reduction reaction. In the case of a rechargeable battery, the charging process occurs by reversing the process [2][3][10]. Since the conversion does not take place through combustion and/or heat exchange, the battery is not subject to the limitations of the Second Law of Thermodynamics; therefore, energy conversion takes place at much higher efficiencies than internal combustion engines.

A battery consists of several basic elements called cells, which are connected in series or parallel depending on the desired voltage or current. Each cell consists of three main components:

- **Anode** - negative electrode, gives up electrons to the circuit and is oxidized.
- **Cathode** - positive electrode, acquires electrons and is reduced.
- **Electrolyte** - an ionic conductor (typically liquid) that allows the transfer, via ions, of charge from the anode to the cathode.

Batteries can be classified into 2 main categories:

1) **Primary Cells**: batteries that cannot be easily or effectively recharged, therefore, to be disposed of once discharged.
2) **Secondary Cells**: batteries that, once discharged, can be easily restored to their original condition by simply reversing the direction of the current from the discharge phase. They are thus energy storage devices.

The performance of different types of batteries can be evaluated and compared using two quantities, **power density** [W/kg] and **energy density** [Wh/kg]. It is interesting to note that these quantities depend on the mass of the battery: in addition to being an indicator of the electrochemical capacity of the battery elements, this turns out to be an important factor in the construction of an electric vehicle because keeping the energy conditions unchanged, reducing the mass increases both the acceleration and the range of the vehicle.

The two quantities can be related on a particular graph called the Ragone Plot: from this the performance of the various technologies can be evaluated.

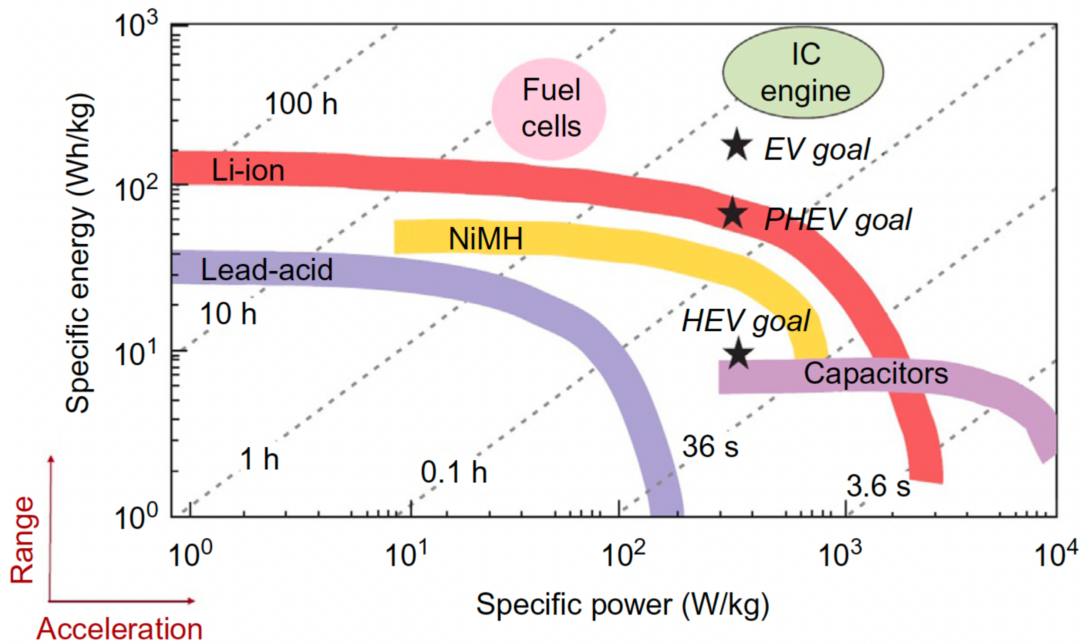


Figure 4: Ragone plot for energy storage devices - adopeted from [4]

In the Ragone plot in Figure 4 we have on the x-axis the specific power and on the y-axis the specific energy. Both axes are expressed in logarithmic form, the dashed lines represent the amount of time (in hours) during which a device can be operated at its rated power (given as the ratio between the specific energy and the specific power). The higher the curve for a specific technology, the better its overall performance.

Our analysis will focus on secondary-type cells. These, in addition to the possibility of being recharged, are also characterized by high power density, high discharge rate, flat discharge curves and good low-temperature performance, although their energy density and energy retention (i.e., the ability to retain charge over time) are lower than primary cells.

In the following paragraphs, the main battery types will be analysed.

2.1 Lead Acid Batteries

The lead acid battery was the first type of rechargeable battery to be developed: invented in 1860 by the French physicist Planté, it consists of a lead electrode, another lead oxide electrode and an electrolyte composed of sulfuric acid and water. Although its specific energy and energy density are low, it has an essentially reversible charge/discharge process and allows good performance at low cost and a long lifecycle. Thanks to these characteristics, it is still widely used today in applications such as emergency batteries, traction of industrial equipment (e.g., forklifts) and starter for internal combustion engines.

2.2 Nichel-Metal Hyride (Ni-Mh) Batteries

This type of battery is relatively recent (the first examples were marketed in Japan in the 1990s) and consists of a metal-hydride anode (usually the metal is a rare-earth intermetallic alloy), a nickel hydroxide cathode separated by porous nylon foil, with a KOH solution as the electrolyte. Since their introduction onto the market, Ni-Mh batteries have been widely used in various application areas, from electronic devices to HEVs - the first Toyota Prius was equipped with batteries of this type. The advantages of this technology lie in its low cost and ease of recycling once it reaches the end of its life. On the other hand, their main drawbacks include low specific energy, which limits their application in powertrain applications (lithium-ion batteries have twice as much), a high level of self-discharge (they lose around 20% of capacity in the first 24 hours after recharging and 10% per month) and a significant memory effect: this phenomenon consists in the loss of energy capacity if the battery is subjected to repeated recharging before the charge is fully depleted: a battery charged to 40%, if recharged several times from this charge percentage, will “fail to recognize” the 60% charge given, thus remaining at a maximum capacity of 40% due to the change in the structure of the nickel contained in the electrode. However, this alteration is not permanent and can be restored through complete charge and discharge cycles. An important disadvantage in terms of safety is the fact that these batteries generate a lot of heat during the fast charge and high-load discharge phases, which can make them dangerous, as well as diminishing their performance and longevity.

2.3 Li-ion Batteries

Lithium turns out to be the most suitable element for building a battery: it is the element with the highest electronegativity in the periodic table, so when coupled with any other element it is able to generate a high potential difference, which results in a higher energy density per unit weight. Early battery designs contained lithium in metallic form, however, this proved to be unsafe due to the high reactivity of the lithium itself. Subsequently, batteries were developed in a way which, through the use of lithium in ionic form, considerably improved the safety of the system, which nevertheless remains highly flammable. The battery consists of a carbon anode (usually graphite) and a cathode composed of lithium oxide, while the electrolyte consists of a lithium salt dissolved in an organic solvent. In addition to high energy and power densities (features that limit their size and weight), the advantages of a lithium-ion cell also include a limited memory effect - this allows them to be used with less than full charge and discharge cycles without compromising battery capacity. They are also batteries with a long service life, low self-discharge and can withstand high loads and fast charge cycles, yet they work efficiently in a limited temperature range of -10° to +30°, outside of which their degradation increases. Lithium-ion batteries are widely used in various types of devices such as smartphones, laptops, cameras, power tools and many more. Its characteristics make it the most suitable technology for electric mobility at the moment.

2.4 Solid state Batteries

All the technologies described above are characterised by the use of an electrolyte in liquid form, usually consisting of a salt dissolved in an organic solvent. However, this has certain characteristics that make it unsafe. Firstly, it can have harmful effects on the human body if the battery casing ruptures and the liquid escapes. In addition to this, the liquid possesses a low ignition point and low boiling point: these characteristics can cause dangerous phenomena such as thermal runaway, i.e., a highly exothermic process that is accelerated by the increase in temperature and, at the same time, releases energy that further increases the temperature. The narrow operating temperature range and decomposition at high voltages do not make the liquid electrolyte suitable for the high energy density batteries of the future [11]. The use of a solid electrolyte therefore allows for higher energy density, greater stability in charge and discharge cycles, and longer battery life [12]. These characteristics, applied to electric mobility, translate into a greater range, shorter charging times, batteries that weigh less and take up less space, and greater safety for occupants. At the moment, it is not economically viable to produce this type of battery because assembly must be carried out quickly and accurately due to the high sensitivity of the components to oxygen and moisture, and also because the anode, cathode and electrolyte must be mechanically joined using high forces to avoid the formation of dendrites, i.e., metal filaments that could create short circuits. Recently, Toyota claimed to be close to developing a system that allows solid-state batteries to be produced at the same rate as conventional batteries. This would allow a big step forward in electric mobility. [13]

2.5 Fuel Cells

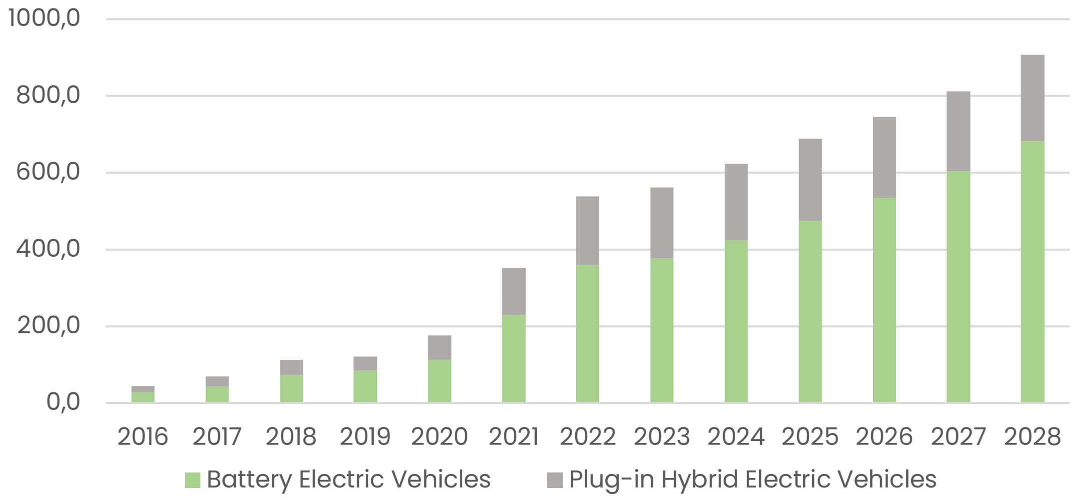
A fuel cell is a device capable of converting the chemical energy of a fuel and an oxidant into electrical energy. Unlike a battery where the anode and cathode are an integral part of the device and are consumed during discharge, the fuel cell requires a continuous supply from an external source of both fuel and oxidant for its operation. Therefore, it is only able to produce energy as long as active materials are supplied to the cell [10]. The electrodes of a fuel cell are composed of inert materials, a gaseous material (usually hydrogen) is used at the anode, and oxygen or air is used at the cathode. Fuel cells can be divided into two categories:

1) Direct systems - the fuel reacts directly inside the cell.
2) Indirect systems - the fuel is converted into a mixture with a high hydrogen content and then sent inside the cell.

This technology has been used extensively in aerospace and has been used in the automotive industry since the 1990s. However, in recent years, mainly due to the falling prices of li-ion batteries, many carmakers have abandoned this technology. Lately, the development of fuel cells in the transport sector has been moving towards other vehicles such as trains (Alstom Coradia [14]) and prototypal aeroplanes.

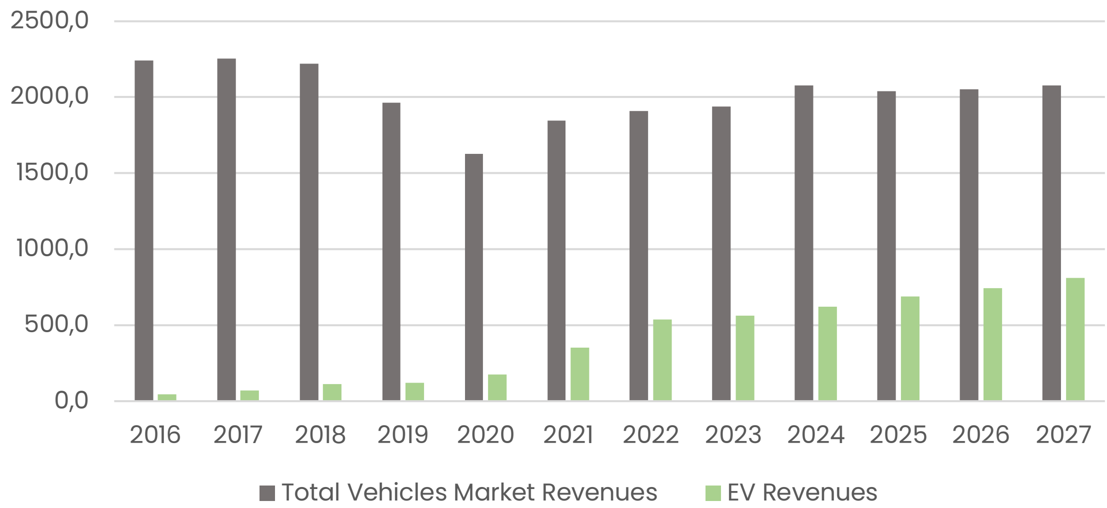
3. Market Analysis

The global electric car market is booming, albeit at different rates in different parts of the world. Analysing the data provided by Statista [15], we can see in Graph 1 the trend in revenues:



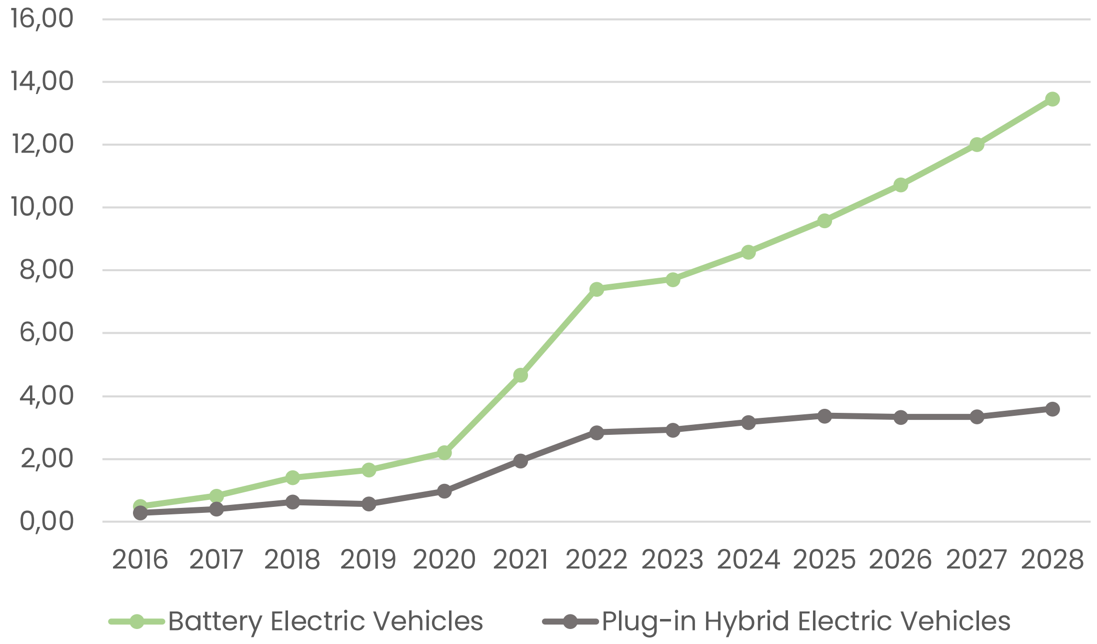
Graph 1: global EV revenues in billion USD

From the graph it can be seen that the market is booming, with the BEV paradigm strongly dominating PHEVs. Comparing EV revenues with total automotive market revenues, it can be seen that the EV market is profitable for carmakers and at the same time the percentage of revenues from EVs is increasing at the expense of the combustion engine market:



Graph 2: comparison between total car market revenues and EV revenues, billion USD

From this graph one can begin to see an interesting phenomenon: the COVID-19 pandemic has caused the automotive market to shrink, but the EV segment has not been affected, instead increasing its growth rate. This is also reflected in the sales figures:

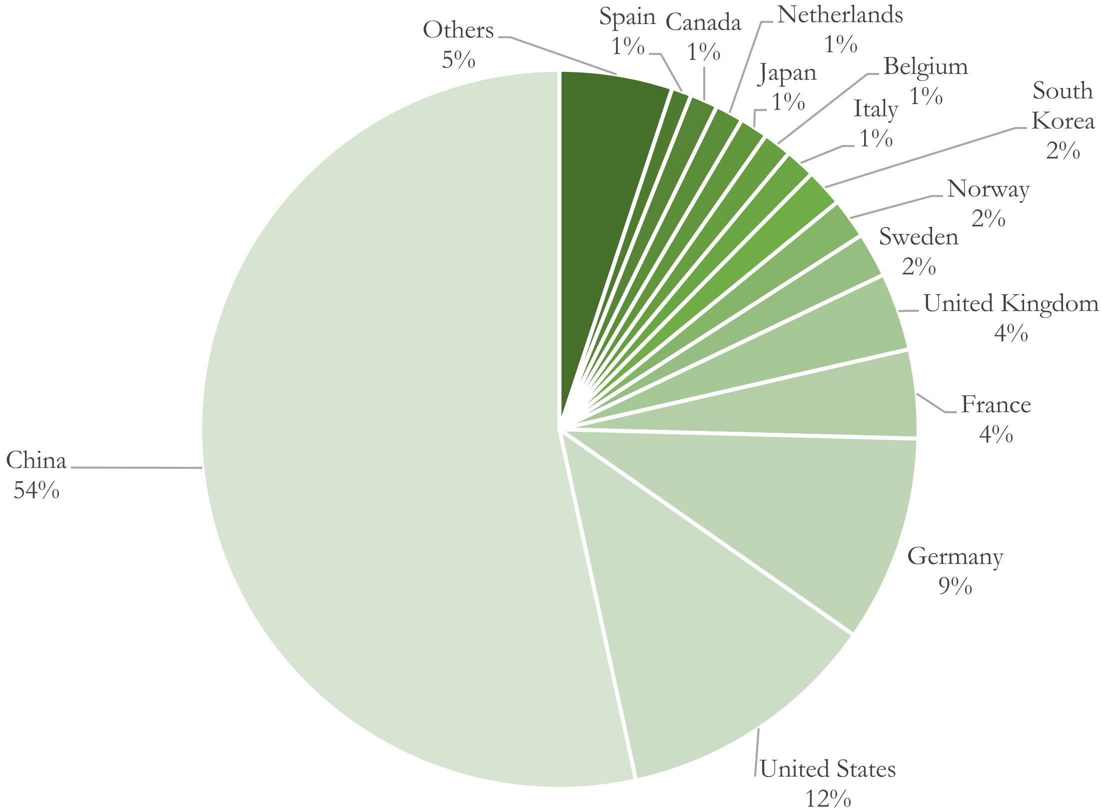


Graph 3: global EV sales [million vehicles]

It is evident from the graph that there is a significant increase between 2020 and 2021, where sales roughly double from around one million vehicles to two. A study conducted by Lieven and Hügler [16] revealed that the reasons for this incongruent market behaviour lie in the fact that the pandemic appears to have heightened environmental awareness among the population. This phenomenon appears to be due to the origins of the virus, in particular its zoonosis, i.e., the transmission of pathogens from animals to humans, which occurs in highly degraded environments.

The graph also shows future sales forecasts: from this data, too, it is clear that BEVs are the technology that will assert themselves in the near future over PHEVs.

In the next graph, we look at the geographical distribution of revenues:



Graph 4: geographical distribution of EV revenues

China appears to be the largest and most developed market, accounting for 53% of global revenues. This is followed by the United States and then a number of European nations, including Germany, France and the United States. We will see in the following section what are the determinants in the diffusion of EVs and why the political framework is important.

3.1 Determinants of EV diffusion

As we have already seen from market data, electric cars are becoming increasingly popular globally. We will now analyse the factors driving the adoption of this new mobility paradigm. These factors can be divided between supply and demand (Figure 5), with three main players influencing the market:

1) Governments
2) OEMs
3) Consumers

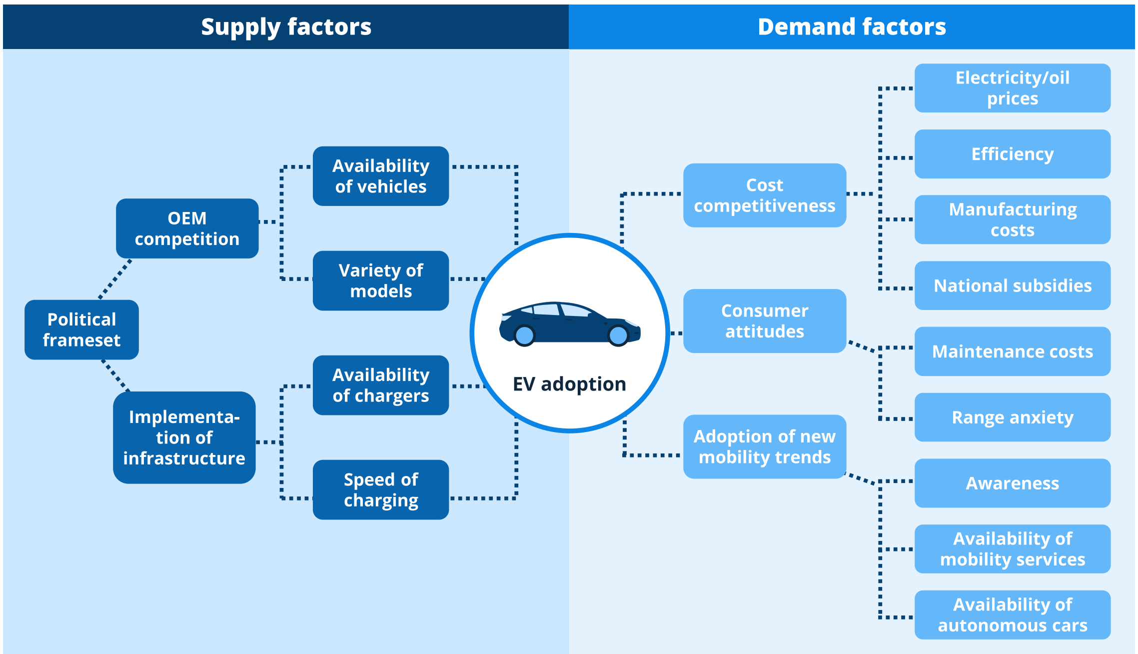
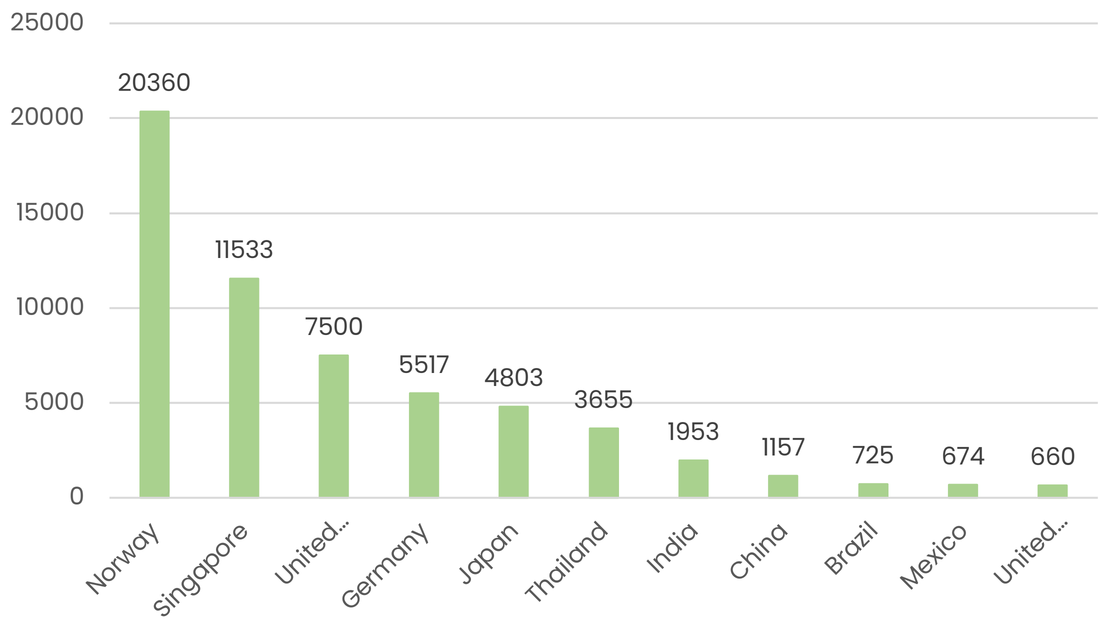


Figure 5: supply and demand factors in adoption of EV - adopted from [15]

Governments play a very important role, the political frameset has a strong influence on the market, both on the demand and the supply side. Firstly, through universities, governments finance and support basic research, providing market competitors with the technological foundations on which their innovations will then be developed. Secondly, the political approach of a government (or a supranational body such as the European Union) can push towards the adoption of electric cars. In this respect, governments can act on incentive mechanisms that reduce the purchase price of new cars. In Graph 5 we can see the average amount per country of purchase incentives:

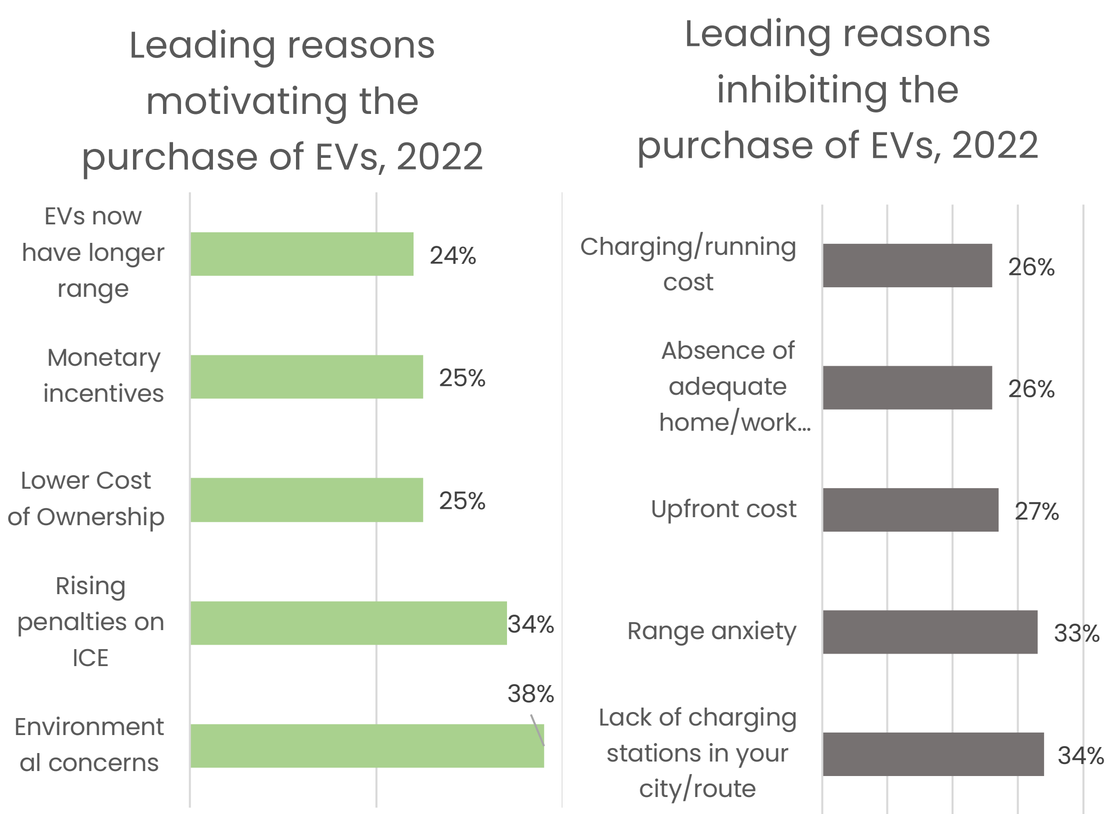


Graph 5: average subsidies at purchase [USD]

Of note is the case of Norway, where the high amount of incentives (in this case expressed as VAT tax deductions) has made the purchase price of an electric car lower than that of a car with a combustion engine. The presence of incentives therefore increases demand, also prompting OEMs to increase volumes and availability of vehicles, with the desirable result of achieving economies of scale to lower purchase prices. In addition to incentives, to increase the uptake of electric cars, governments can also adopt policies that limit the spread and circulation of conventional cars. For example, there are already some cities that have blocked the circulation of non-electric cars in central areas and others that plan to do so. Furthermore, also at the European level, the Union has mandated that from 2035 no more cars with combustion engines can be purchased, with the goal of achieving carbon neutrality in 2050. Finally, governments also play an important role with regard to the recharging infrastructure: by intervening in what is a market closely linked to that of cars, they can adopt policies that favour its expansion, increasing the availability of recharging points and fostering the proliferation of a high-speed recharging network, thus making recharging an increasingly simple and fast process.

Looking instead at OEMs, it can be said that carmakers can help increase the adoption rate by working to increase both the availability of vehicles and their variety, covering more and more market segments. In addition, an expanding market fosters competition: as this is a relatively new and developing technology, a more competitive environment stimulates OEMs to invest in R&D to outperform rivals and gain market share.

On the demand side, the actors are obviously the consumers. There are a number of factors that fuel people's scepticism towards electric cars and thus hold back their expansion. Firstly, one can speak of a limited knowledge of the technology and its advantages. In addition, many people show scepticism especially with regard to the question of autonomy, so-called range anxiety: there is the fear of being left with a flat battery and without the possibility of recharging as easily as refuelling with petrol, both because of the time required and the limited spread of fast charging points. Among the factors that can instead increase diffusion we have, firstly, a greater and growing awareness of environmental issues and the impact of CO_2 emissions on our planet. In addition to this, there are also economic factors including the ever-increasing price of oil, reduced maintenance costs compared to a conventional car, and finally the government subsidy system. We can see in Graph 6 a summary of the factors motivating or inhibiting demand, based on an EY survey reported by Statista:



Graph 6: results of EY Survey, adopted from [15]

4. Intellectual Property and Patents

4.1 General Overview of Intellectual Property

The products we use and the services we enjoy in our daily lives are all the result of a process of innovation that has brought them, gradually improving them, to the level of functionality we can appreciate today. Innovation can be defined as the economic exploitation of an invention [17][18]: an invention becomes an innovation when it is put on the market and consumers recognise its value. But how can an invention be protected from a competitor who wants to exploit its economic value? The processes and creations of the mind that lead to an invention are not physical assets protected by property laws. Intellectual Property Rights come into play for their protection: these take the form of property rights and allow the creator (or owner of the right) to enjoy the benefits of his work or investment, preventing - for a period of time that can be limited or unlimited - the exploitation of his work by others [19]. The 1967 Stockholm Convention [20] that established the World Intellectual Property Organisation (WIPO) defines IP as "*the rights relating to*:

- *literary, artistic and scientific works,*
- *performances of performing artists, phonograms, and broadcasts,*
- *inventions in all fields of human endeavor,*
- *scientific discoveries,*
- *industrial designs,*
- *trademarks, service marks, and commercial names and designations,*
- *protection against unfair competition,*

and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields" [3].

In today's society where access to information and knowledge is quick and easy, intellectual property plays a crucial role in the protection of knowledge. This importance is based, according to the European Patent Office (EPO) [21], on five points:

- Most technical innovations require a large investment in R&D. If a market offers IP protection, the prospect of a higher economic return is more attractive to companies' funds. If not, competing companies that have not invested in research may be able to offer the same product or service at lower prices.
- Intellectual property is an asset that can generate profits for companies. Indeed, an intellectual property right can be sold or licensed to other companies.
- IP is a tool that can protect the products or services of small innovative start-ups from large companies that can copy them.
- IP can also be used to protect public ownership of intellectual property. An example is the Creative Commons licence or open-source software.
- IP protection prevents the unlicensed use of trademarks, assuring consumers that products displaying such a mark meet the promised standards.

The various types of intellectual property can be classified into two macro-categories [5]. The first is **copyright**, which consists of copyright protection on literary works (novels, poems and plays), films, music, artistic works (drawings, paintings, photographs and sculptures) and architectural design. Live performances by artists and TV or radio programmes are also protected by copyright. Unlike other types of intellectual property, this right is granted automatically (without the need for registration) when the work is created and generally lasts up to 70 years after the author's death.

The second category is Industrial Property rights. This includes various types of IP:

- **Patents**: legal instruments to protect technical inventions. Patents have a limited duration (maximum 20 years from application) and are granted following an evaluation process of the application made by the applicant to a patent office (local or national).
- **Utility Models**: offer weaker protection than a patent and for a shorter period of time, with less stringent requirements than a patent that make the approval process easier.
- **Trademarks**: consist of the protection of distinctive marks capable of discriminating the commercial origin of a good or service. They may

consist of words, names and logos, but also any other feature that can identify the commercial origin (e.g., packaging). They last ten years and can be renewed for an unlimited number of times.

- **Registered Designs**: protect the aesthetics, shape and style of objects, but not their functional aspect. The requirements for granting are absolute novelty and individual character.
- **Plant Varieties**: new plant varieties can be protected for twenty years, subject to novelty and breed stability constraints.
- **Databases**: Databases, being organized collections of data, can be protected by copyright if their content is original or by other IP protection if the creator demonstrates substantial investment in organizing the content.
- **Geographical indications and Appellation of Origin**: guarantee the quality and characteristics of a given product when these are closely linked to its geographical origin.
- **Semiconductor topography design**: in the case of semiconductors, it is possible to apply for protection of the topography, i.e. the design of the various layers of material that make up the semiconductor. The protection prevents commercial use, but reproduction for non-commercial or educational purposes is permitted. [22]
- **Trade secret**: this consists simply of keeping the characteristics of the object or service you wish to protect hidden from the public.

4.2 Patents

As we have already seen in 4.1 General Overview of Intellectual Property, a patent is a legal instrument that grants the applicant the exclusive right to prevent others from making, using, offering for sale, selling or importing products that infringe their patents, for a limited amount of time in the country in which the patent was granted [21]. The purpose of patents is to foster innovation and progress, by placing on the one hand the economic benefits from the competitive advantage gained through the monopoly granted by the patent, while on the other hand there is the obligation to make public the technical description of the invention.

Patents can also be seen as a contract between the applicant and society, with benefits for both parties. Indeed, on the one hand, the applicant can fully exploit the economic benefits of his invention, excluding others from the commercial exploitation of his invention. Moreover, the rights derived from patents can be sold or transferred to others. On the other hand, the social benefits are:

- Encourage innovation: the prospect of having exclusive profits encourages inventors to develop new technologies.
- Protection of small innovative companies by making them competitive even against large established firms.
- Full disclosure of the innovation giving other inventors the basis on which to improve the product.
- Promotion of technology transfer: the exclusive rights guaranteed by a patent are an incentive for companies to invest the necessary resources to finalise the development of technologies born from basic research carried out in universities, thus enhancing the investments made by the State.

4.2.1 Requirements for patentability

In general, to be patented, an invention must be new, involve an inventive step and be susceptible of industrial application [21]. However, not all inventions can be patented. For example, Article 52 of the European Patent Convention [23] includes a list of everything that cannot be considered an invention, while Article 53 lists what is excluded from patentability despite being an invention, namely:

- Inventions whose commercial exploitation may be contrary to public policy or morality.
- Biological processes for the production of plants and animals.
- Methods for the treatment of the human or animal body and therapies or diagnostic methods practicable on humans or animals.

The requirements to be met to obtain a patent may vary from country to country, however there are three basic conditions common to all jurisdictions:

1) **Novelty**: an invention is considered new if it is not anticipated by prior art, i.e. by anything that has been made available to the public by any means (verbal or written) prior to the date of the application, including by the inventor himself.

2) **Inventive step (or originality)**: an invention implies inventive step if, to an expert in the field, it is not obvious on the basis of a combination of prior art (prior art) - this requirement, unlike the novelty requirement, can be highly subjective.
3) **Industrial applicability**: to have industrial applicability, an invention must be able to be manufactured or used in any industrial field, i.e. it must be able to solve a technical problem at industrial level.

The three requirements discussed are the most important, other characteristics that the invention must have to obtain a patent are:

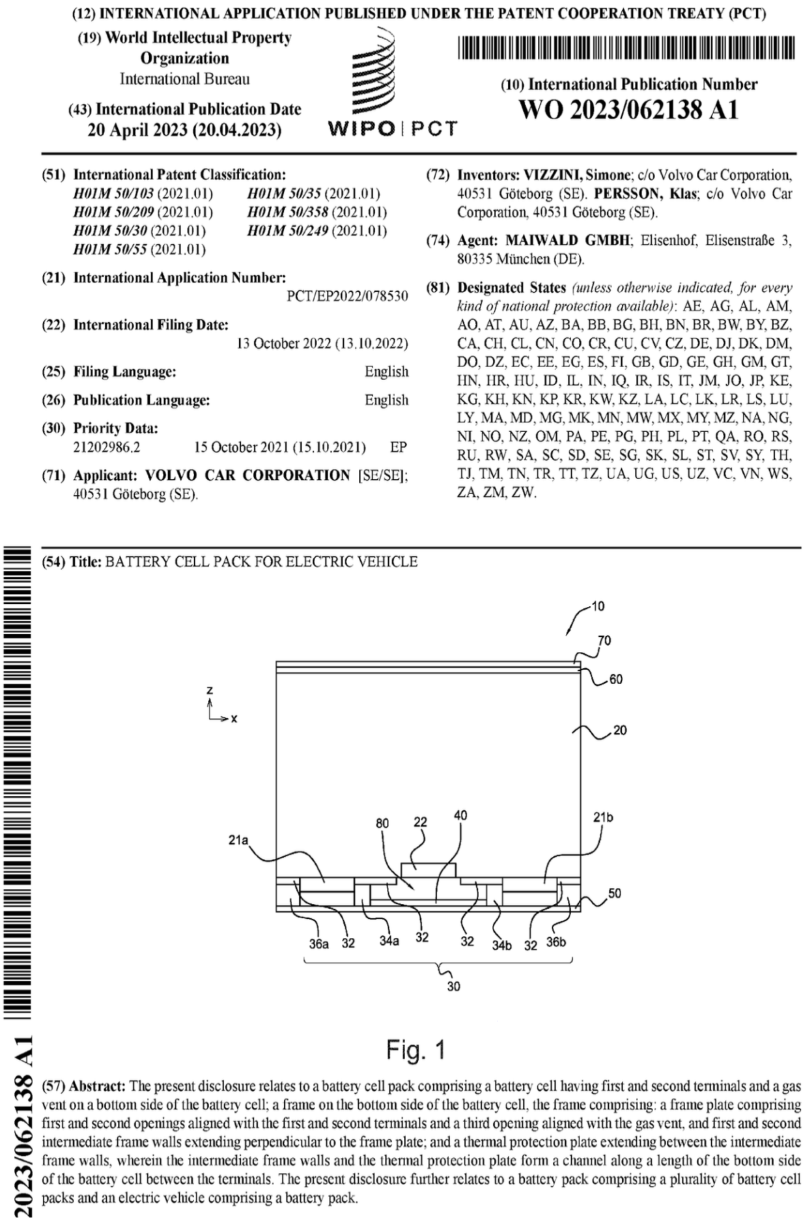
- **Lawfulness**: to obtain a patent, the invention or its application must comply with the principles of public policy or those of accepted morality.
- **Sufficient Description**: the application for a patent must be accompanied by a clear title and a description that is sufficiently clear and complete so that a person skilled in the art can implement the invention.

4.2.2 Structure of a Patent Document

Patent documents have a well-defined structure [21] that helps to easily distinguish and analyse both the technical characteristics of the invention and the quantitative data relating to the patent. The first section is the bibliographic information of the patent, i.e. general information about the patent and the technology. The data in this section is crucial for patent classification and for searching for patents on similar or related technologies. The information in this section are:

- **Title of the invention**. This should give the reader a clear, concise but as detailed as possible first impression of the content of the patent [24].
- **Name of the inventor and applicant**, i.e. the person who files the patent application and who will benefit from the effects of the patent. If the patent application is accepted, the applicant will become assignee of the patent.
- **Date of filing**, the date on which the patent application is filed. This date is of fundamental importance: in the application evaluation process, it determines the date from which prior art is sought, while in the event of a patent grant, it will determine the patent's expiry date.

- **Date of Patent Grant**, i.e. the date on which the patent was granted.
- **Summary of the invention (abstract)**: this section defines the technical problem from which the need for the invention arises and a description of the technical solution.



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(54) Title: BATTERY CELL PACK FOR ELECTRIC VEHICLE

Fig. 1

(57) Abstract: The present disclosure relates to a battery cell pack comprising a battery cell having first and second terminals and a gas vent on a bottom side of the battery cell; a frame on the bottom side of the battery cell, the frame comprising: a frame plate comprising first and second openings aligned with the first and second terminals and a third opening aligned with the gas vent, and first and second intermediate frame walls extending perpendicular to the frame plate; and a thermal protection plate extending between the intermediate frame walls, wherein the intermediate frame walls and the thermal protection plate form a channel along a length of the bottom side of the battery cell between the terminals. The present disclosure further relates to a battery pack comprising a plurality of battery cell packs and an electric vehicle comprising a battery pack.

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Figure 6: first page of a patent - from [25]

In the second part of a patent document, the invention is described in detail, also with the help of drawings or diagrams. The main points of the **description** are [26]:

- **Technical Field of the invention**: This section indicates the broad area of technology under which the patent falls.

- **Background Art**: a brief description of the prior art relating to the technology to which the patent relates, which may be useful for understanding the invention. This analysis should possibly be correlated with appropriate references, both to patent and non-patent literature.
- **Description and disclosure of the invention**: the invention must be described in such a way that the problem and its solution can be understood, also describing the improvements made with respect to the prior art.
- **Description** of figures and diagrams, if any.
- If not obvious from the nature or description of the invention, state how the invention is industrially applicable.

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BATTERY CELL PACK FOR ELECTRIC VEHICLE

TECHNICAL FIELD

[001] The present disclosure relates to a battery cell pack for an electric vehicle, a battery pack comprising a plurality of battery cell packs, and an electric vehicle comprising a battery pack.

BACKGROUND

[002] Electrical vehicles (EV) such as battery electric vehicles (BEV) use a high voltage battery to act as an energy source for the vehicle. To provide enough range with current cell technology, a battery is located underneath the cabin. The battery typically includes a plurality of cells connected in serial or in parallel. Each cell has two terminals and a cell vent on a top side of the cell facing the cabin of the electric vehicle. The cell venting allows flammable gas, produced by an electrolyte in the cell, to be released during battery life.

[003] In order to handle a safety thermal event, like thermal runaway, a thermal protection material plate is typically placed between a top cover and the top side of the battery comprising the terminals and the cell vent, protecting the passenger cabin of the vehicle from high temperatures.

[004] Moreover, in order to reduce the temperature of the cells, a cooling plate is typically placed below a bottom side of the cells, opposite to the top side. Moreover, in order to reduce thermal losses from the cell and cooling system to the ambient, a thermal insulation material is placed below the cooling system.

SUMMARY

[005] According to an aspect of the present disclosure, the present application provides a battery cell pack comprising a battery cell having first and second terminals and a gas vent on a bottom side of the battery cell; a frame on the bottom side of the battery cell, the frame comprising: a frame plate comprising first and second openings aligned with the first and second terminals and a third opening aligned with the gas vent, and first and second intermediate frame walls extending perpendicular to the frame plate; and a thermal protection plate extending between the intermediate frame walls, wherein the intermediate frame walls and the thermal protection plate form a channel along a length of the bottom side of the battery cell between the terminals. The intermediate frame walls may extend along a thickness direction of the battery cell. Consequently, also the channel may extend along a thickness direction of the battery cell. As mentioned in the background, typical configurations require a thermal protection plate between the battery cell and the vehicle's cabin floor in order to protect passengers when thermal runaway occurs. The present configuration provides a protection barrier for the vehicle cabin due to the placement of the cooling plate on the top side of the cell. The specific configuration and placement provide this

Figure 7: description section of a patent - from [25]

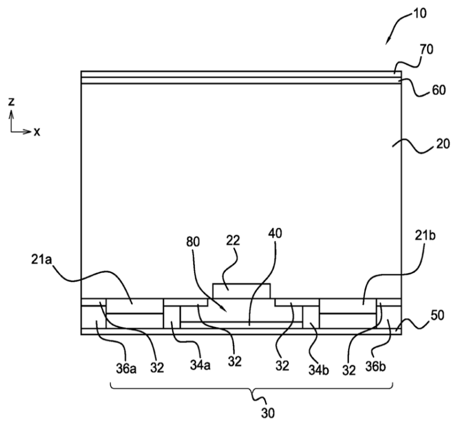

Fig. 1

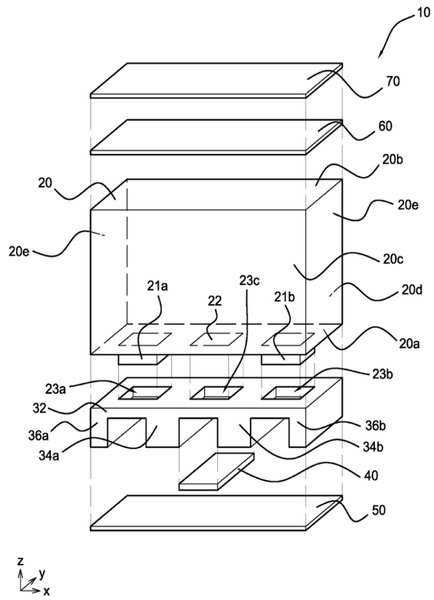

Fig. 2

Figure 8: diagrams of the invention - from [25]

The third section concerns the patent **claims**. This is a very important part as the content of these determines the technical aspects for which patent protection is valid. The claims are divided into two types:

1) **Independent claims**, which refer to the essential features of the invention.
2) **Dependent claims**, which refer to details related to the features expressed in the independent claims.

According to the European Patent Convention [7], claims shall contain *"a statement indicating the designation of the subject-matter of the invention and those technical features which are necessary for the definition of the claimed subject-matter but which, in combination, form part of the prior art"* and a *"characterising portion [...] specifying the technical features for which [...] protection is sought"*. It is also specified that more than one independent claim is allowed only if the subject matter of the application includes a plurality of interrelated products, different uses of the product or alternative solutions to the problem.

There are specific rules to be followed in the writing of claims, which are often drafted by lawyers specialised in the subject matter, so they may be unclear to those unfamiliar with their interpretation.

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CLAIMS

1. A battery cell pack (10) comprising:
   - a battery cell (20) comprising first and second terminals (21a, 21b) and a gas vent (22) on a bottom side (20a) of the battery cell (20);
   - a frame (30) on the bottom side of the battery cell, the frame (30) comprising:
     - a frame plate (32) comprising first and second openings (23a, 23b) aligned with the first and second terminals (21a, 21b) and a third opening (23c) aligned with the gas vent (22); and
     - first and second intermediate frame walls (34a, 34b) extending perpendicular to the frame plate (32);
   - a thermal protection plate (40) placed between the intermediate frame walls (34a, 34b),
   - wherein the intermediate frame walls (34a, 34b) and the thermal protection plate (40) form a channel (80) along a length of the bottom side (20a) of the battery cell (20) between the terminals (21a, 21b).

Figure 9: claims of a patent - from [25]

4.2.3 IPC Classification of Patents

In order to carry out statistical analyses of patents, they should be classified and organised into categories. The classification scheme used by all patent offices worldwide is International Patent Classification. This classification was introduced by WIPO in 1968 and has been recognised as a common classification for patents since 1975 with the signing of the Treaty of Strasbourg. It is a hierarchical classification, at the highest level of which we find the sections [27]: these are indicated by capital letters to which a title is associated and indicate the field of technology to which the invention belongs. The sections are:

- A - HUMAN NECESSITIES
- B - PERFORMING OPERATIONS; TRANSPORTING
- C - CHEMISTRY; METALLURGY
- D - TEXTILES; PAPER
- E - FIXED CONSTRUCTIONS
- F - MECHANICAL ENGINEERING; LIGHTING; HEATING; WEAPONS; BLASTING
- G - PHYSICS

- H – ELECTRICITY

Each section is divided into several classes, which thus represent the second hierarchical level of classification and enable the type of patented technology to be distinguished in even greater detail. The classes are indicated by the section letter followed by two numbers (e.g. H01 ELECTRIC ELEMENTS). In turn, classes are subdivided into subclasses, which are indicated by a capital letter following the class code and thus represent the third hierarchical level. Finally, subclasses may be divided into one or more groups, which may be either main groups (i.e. fourth hierarchical level) or subgroups (with hierarchical level five and above). Each main group symbol consists of the subclass symbol followed by a one- to three-digit number, the oblique stroke and the number 00, while for subgroups the number is two digits but different from 00. Figure 10 summarises the hierarchical division and structure of IPC codes:

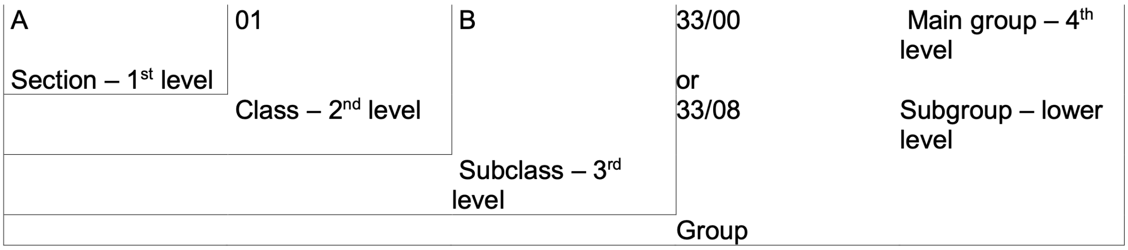


Figure 10: structure of IPC codes - from [27]

4.2.4 Forward Citations of a Patent

In addition to classifying patents into categories, a statistical study of patents must somehow take into account the different value assumed by one patent compared to another. One of the most widely used methods is the analysis of the number of Forward Citations [28], i.e. the citations of the patent in question in subsequently filed patents. According to Hall et al. [29], the number of citations provides information on:

- Linkages between inventions, inventors and assignees in time and space, thus allowing an assessment of both the temporal and geographical dimension of the innovation process.
- Importance of the individual patent: citations are a measure that can make one patent stand out from the others, allowing its real value to be measured. Indeed, if a patent is cited numerous times, it means that the

technological solution introduced laid the foundations for subsequent research in that field.

- Looking at the economic side, the number of citations is an indicator of how active research is in each field, thus also giving an indication of the existence of a possible market.

4.3 Patent Landscape

Patents contain a lot of information regarding the state of the art of a technology or innovative trends in a particular sector. In the past, many technology decisions were made solely on the basis of qualitative factors such as intuition or personal knowledge of the decision maker, but with the advent of patent data analysis, it has become possible to develop tools that can exploit this data to obtain quantitative information. One of the main tools is the Patent Landscape Report. This is the output of a process of analysing large patent databases that can provide insights into the state of the art of a technology and trends in a given technology sector. The main objectives of a PLR are:

- In the public sector, to support policy makers' decisions on innovation, research and development and technology transfer
- Understand, in general, innovation trends in a given sector
- Identify the main innovators in the field
- Understand competitor strategies
- Evaluate research and development projects
- Identify potential partners

Obviously, depending on the objectives, a PLR may contain more or less detailed analyses in order to present the results in the most appropriate form.

5. Results

This section will describe the tools, method and results of the Patent Landscape Report, the objective of this work. The first part will summarise the high-level results, followed by an analysis of the results for the individual technology classes.

5.1 Database

The basis for building a PLR is access to patent data. There are various databases accessible online, developed by both public organisations and private companies. One of the best known is PATENTSCOPE, provided by WIPO, which contains patent documents from all national treaty offices as well as non-patent literature. The database is updated daily and makes it possible to view the full text of an application the same day it is published. The European Patent Office also has its own database, called Espacenet, which also allows access to the data of the national offices of the European Union member states. Private companies, on the other hand, rather than an actual database, provide search and indexing services for patent data from multiple databases belonging to various international organisations or national patent offices. Among these, the best known is certainly Google Patents but there are many others such as, for example, The Lens and Derwent. The common denominator between all these services is the possibility of extracting large amounts of information without the constraint of reading individual documents in full.

For this work was chosen The Lens. This is a service developed by an Australian non-profit company, with the aim of linking and making usable from a single portal, lens.org, different sources of open-knowledge related to patents and academic publications. It is a very powerful tool, able to handle complex queries even in text form but at the same time easy to use.

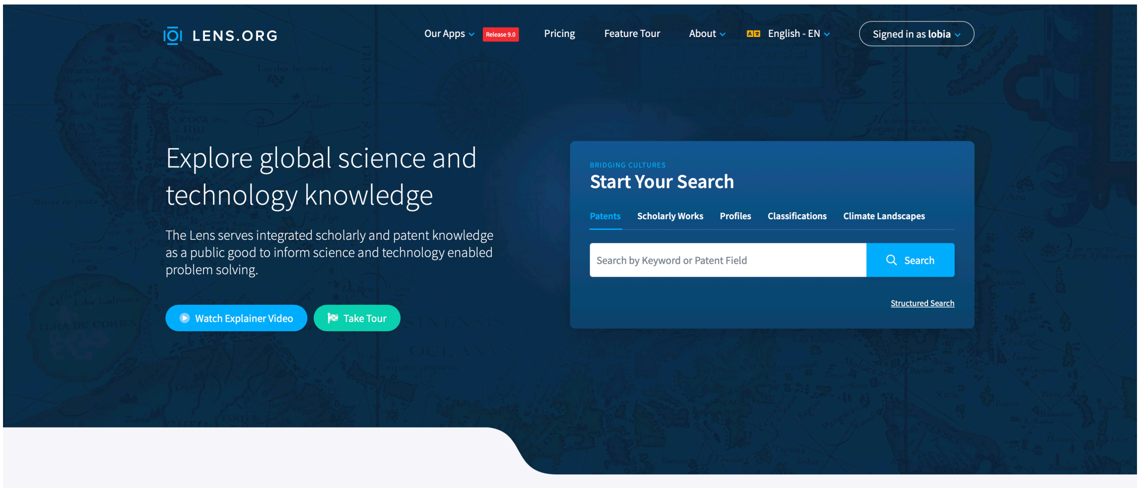


Figure 11: The Lens homepage

5.2 Query

All patent databases can be queried through more or less complex queries - some allow filtering through menus, while others allow the use of textual queries. The languages for creating such queries may vary from database to database, but basically all of them are based on the basic logical operators.

For the purpose of this work, it has been chosen use a query based on both IPC codes, dates and textual elements of the document abstract. The process of creating the query began by identifying the IPC codes corresponding to the technology of interest. The aim of the work is to analyse patents on electric car batteries; therefore, the search for the most suitable IPC codes began through keyword searches for the two fundamental concepts, “battery” and “electric vehicle” on WIPO's IPC portal. The two results were then compared in order to highlight the codes present in both of them, which were then evaluated as to their actual relevance to the research objective. The output of this process is summarised in Table 2, which shows the codes used in the construction of the query:

Table 2: description of IPC codes chosen for the query

IPC		DESCRIPTION
B60L50/00		Electric propulsion with power supplied within the vehicle
	B60L50/50	using propulsion power supplied by batteries or fuel cells
	B60L50/60	using power supplied by batteries
	B60L50/61	by batteries charged by engine-driven generators, e.g. series hybrid electric vehicles
	B60L50/62	charged by low-power generators primarily intended to support the batteries, e.g. range extenders
	B60L50/64	Constructional details of batteries specially adapted for electric vehicles
	B60L50/70	using power supplied by fuel cells
	B60L50/71	Arrangement of fuel cells within vehicles specially adapted for electric vehicles
	B60L50/72	Constructional details of fuel cells specially adapted for electric vehicles
	B60L50/75	Using propulsion power supplied by both fuel cells and batteries
B60L53/00		Methods of charging batteries, specially adapted for electric vehicles; Charging stations or on-board charging equipment therefor; Exchange of energy storage elements in electric vehicles
	B60L53/80	Exchanging energy storage elements, e.g. removable batteries
B60L58/00		Methods or circuit arrangements for monitoring or controlling batteries or fuel cells, specially adapted for electric vehicles
	B60L58/10	for monitoring or controlling batteries
	B60L58/30	monitoring or controlling fuel cells
	B60L58/40	for controlling a combination of batteries and fuel cells
H01M10/00		Secondary cells; Manufacture thereof
H01M8/00		Fuel cells; Manufacture thereof
H02J7/14		[Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries] for charging batteries from dynamo-electric generators driven at varying speed, e.g. on vehicle

The next step was to determine the conditions binding the codes to each other in the query: since these represent different properties and characteristics of the electric propulsion, it was decided that the codes should all be part of the filter and be bound to each other by an OR condition. In addition to the IPC codes, it was decided to apply further filters:

- the first one concerning the time horizon: applications submitted in the last 20 years, from 01/01/2004 to 01/01/2024, were considered.
- the second on the abstract of the document: the term 'vehicle' in the IPC classification appears to have a generic meaning and can refer to any vehicle, from bicycles to aircraft. Therefore, it was necessary to make it a condition that the abstract contained the words "battery", "car", "vehicle" but not terms such as "aerial", "rail", "bike", "scooter", "airplane", so as to exclude irrelevant results.

The query is therefore:

```
(class_ipcr.symbol:B60L50/00 OR class_ipcr.symbol:B60L50/50
OR class_ipcr.symbol:B60L50/60 OR
class_ipcr.symbol:B60L50/61 OR class_ipcr.symbol:B60L50/62
OR class_ipcr.symbol:B60L50/64 OR
class_ipcr.symbol:B60L50/70 OR class_ipcr.symbol:B60L50/71
OR class_ipcr.symbol:B60L50/72 OR
class_ipcr.symbol:B60L50/75 OR class_ipcr.symbol:B60L53/00
OR class_ipcr.symbol:B60L53/80 OR
class_ipcr.symbol:B60L58/00 OR class_ipcr.symbol:H02J7/14
OR class_ipcr.symbol:B60L58/10 OR
class_ipcr.symbol:B60L58/30 OR class_ipcr.symbol:B60L58/40
OR class_ipcr.symbol:H01M10/00 OR
class_ipcr.symbol:H01M8/00) AND application_reference.date:
[2004-01-01 TO 2024-01-01] AND abstract:"battery" AND
(abstract:"car" OR abstract:"vehicle") AND NOT
abstract:"aerial"AND NOT abstract:"rail" AND NOT
abstract:"bike" AND NOT abstract:"scooter" AND NOT
abstract:"aeroplane"
```

5.3 High Level Results

In this first part, the results for the sample extracted in its entirety will be analysed, without distinguishing between the various types of technology. This analysis may be useful to get a general idea of the innovation trend in the battery macro-area.

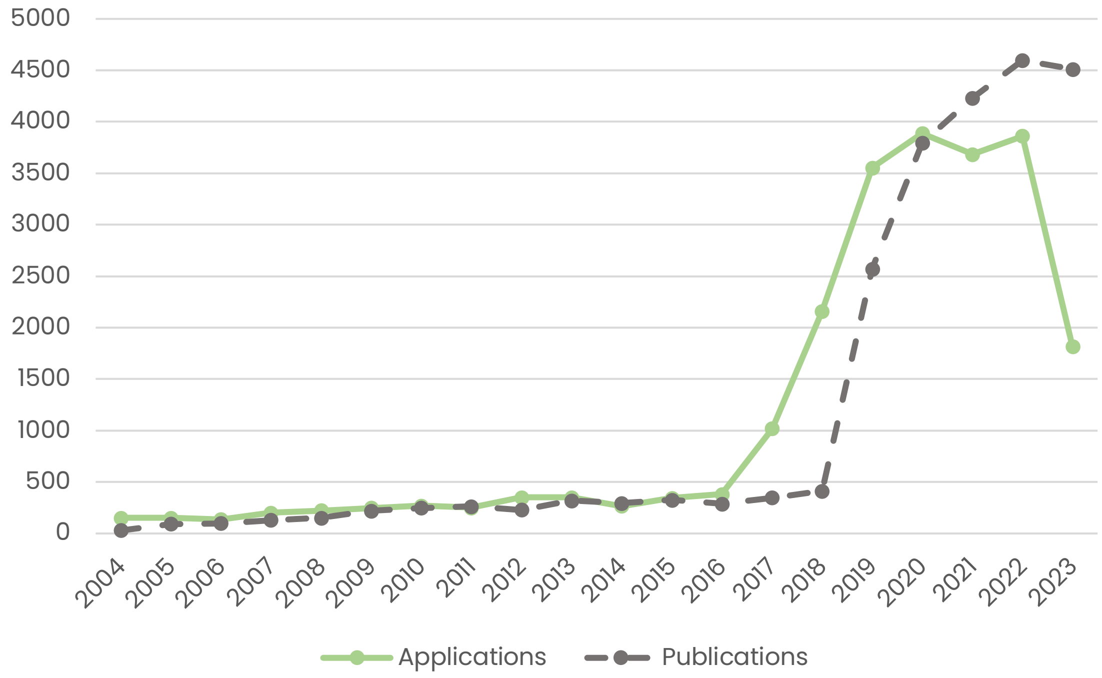
The query execution returned 23,299 results. The database was subsequently analysed and cleared of outliers or entries with missing fields. Subsequent analyses were carried out partly by using the tools available on The Lens website, and partly by downloading the data from the portal and processing them in Excel.

5.3.1 Temporal Trend

The first analysis consists of assessing the time trend of patent applications over the last twenty years. As can be seen from the graph, the trend has been upward since 2004, averaging around 200 applications/year until 2017, the year in which a vertiginous growth started, leading to a peak of almost 4000 applications in 2020. The number remained - albeit with some minor fluctuations probably due to the Covid19 pandemic - constant between 2019 and 2023, only to plummet in 2023.

The latter phenomenon can be explained by the choice of using the application year field as the starting data. This choice may lead to misleading results as a patent application can be secreted up to a maximum of 18 months before being made public; moreover, processing the data at the beginning of 2024 may also lead to delays in the electronic transmission of patent applications. In fact, comparing the two trends on the graph, the dashed line on publications, although showing a slight decrease, does not show the slump present on applications.

The high number of patents and the trend shown in the graph both indicate a booming market and great interest in electric mobility. Furthermore, the great growth present since 2017 can be explained by the growing market interest in electric vehicles, stimulated by the ratification of the Paris Treaty in 2016.



Graph 7: Applications and Publications per year

5.3.2 Geographical Trend

The second analysis aims to understand which countries are most active and involved in battery technology development in order to identify any trends related to geographical factors.

For this purpose, data on the countries of application of individual patents were considered. Table 3 summarises the results: China stands out, with just over 13,000 applications, or 57% of the total. This is followed by the United States of America with about 4,000 patents (17%) and Japan with just over 2,000 applications. Table 3 shows the top 15 Patent Offices, the remainder have been merged under 'Rest of the World' as they had insignificant numbers.

Table 3: Applications per Patent Office

Application Office	Patents	Percentage
China	13290	57,84%
United States of America	3981	17,33%
Japan	2087	9,08%
World Intellectual Property Organisation (WIPO)	1510	6,57%
Republic of Korea	1035	4,50%
European Patent Office (EPO)	229	1,00%
Canada	165	0,72%
Australia	112	0,49%
Chinese Taipei	111	0,48%
United Kingdom	107	0,47%
Russian Federation	68	0,30%
Germany	66	0,29%
Mexico	38	0,17%
Sweden	38	0,17%
France	28	0,12%
Rest of the World	112	0,49%
Total	**22977**	**100%**

Figure 12, on the other hand, is a visual representation of the results obtained: a higher colour intensity corresponds to a higher number of applications and vice versa. In the top two positions are the world's two largest economies, the USA and China. The latter can also count on the presence of numerous natural resource deposits that are important for the development of the electronics industry, making them available at low cost and thus attracting some of the largest global players in the sector to the area. In general, Asia is the most active continent in this respect, with around 70% of patents coming from this area.

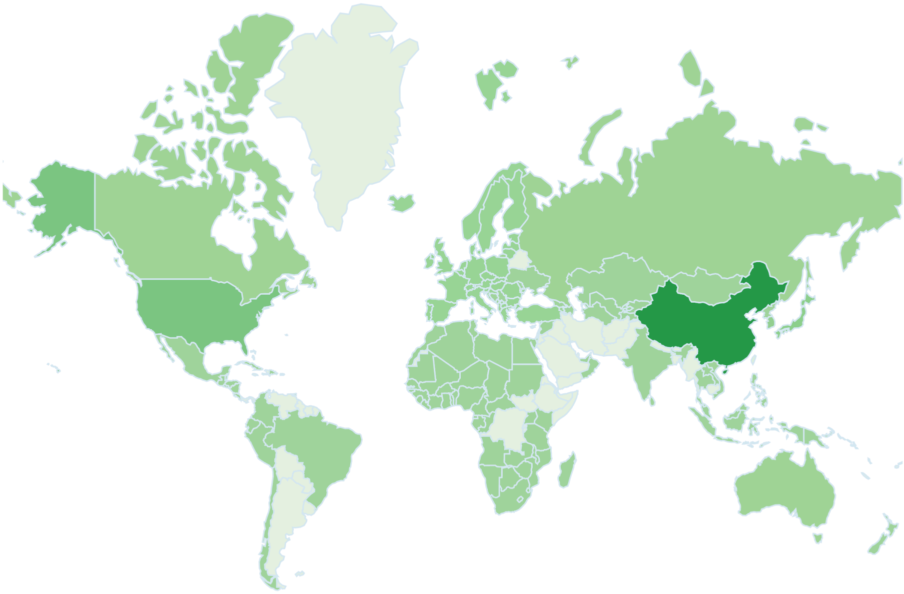


Figure 12: Choroplet map of patent applications

5.3.3 Top Assignees

In this section, the sample was analysed in order to understand which companies are most involved in battery-related patenting activity. In order to obtain this data, the "applicant" field of the database was used, i.e. considering the companies that filed the patent application. In addition, the following reprocessing of the data was necessary for this analysis:

- Patents filed by subsidiary companies were combined under the parent company.
- Patents with more than one applicant were counted once for each applicant.

The results obtained are summarised in Table 4

Table 4: top 10 assignees

Assignee	Country	Patents
Toyota Motor	JP	2051
Aulton New Energy Automobile Tech Co Ltd	CN	1106
Hyundai Motor	KR	1032
Honda Motor	JP	972
Kia Motors	KR	865
Ford Motor	US	628
Mitsubishi Motors	JP	530
Byd	CN	462
Denso	JP	390
Subaru	JP	382

The company with the greater number of patents is Toyota with 2051 patents, a company that was among the first to invest in electrics and is a leader in innovation in the field. In second place is a less popular company than the others, Aulton, with 1106 patents. This Chinese company is a leader in the development of battery swap solutions, i.e. a system for replacing the discharged battery of one's own vehicle with a charged battery. Such a system allows you to significantly reduce vehicle downtime, as the swapping operation is faster than the recharging operation. Returning to the ranking, the next positions are all occupied by major carmakers who are already leaders in the ICE car sector. The presence of BYD and Denso is worth mentioning: the former is a leading Chinese company in battery production but also present on the car market with its own models; while the latter deals with the production of car components and systems.

It can be seen that, as can easily be imagined, the companies shown in the table all operate in the automotive industry.

Geographically, consistent with the previous section, Asia is the most represented continent. However, contrary to the geographical analysis, there are only two Chinese companies in this ranking, which is dominated by Japan. This indicates that research and patenting activity in China is in the hands of many more companies, with only a few giants emerging on a global level.

The set of companies identified in this section will be taken as a reference for further analysis in the individual technology classes.

5.3.4 Top IPC Codes

In this section, we will analyse the distribution of the most recurrent CPI codes in the sample in order to get a rough idea of the composition of the sample in terms of technological areas. The results are summarised in Figure 13:

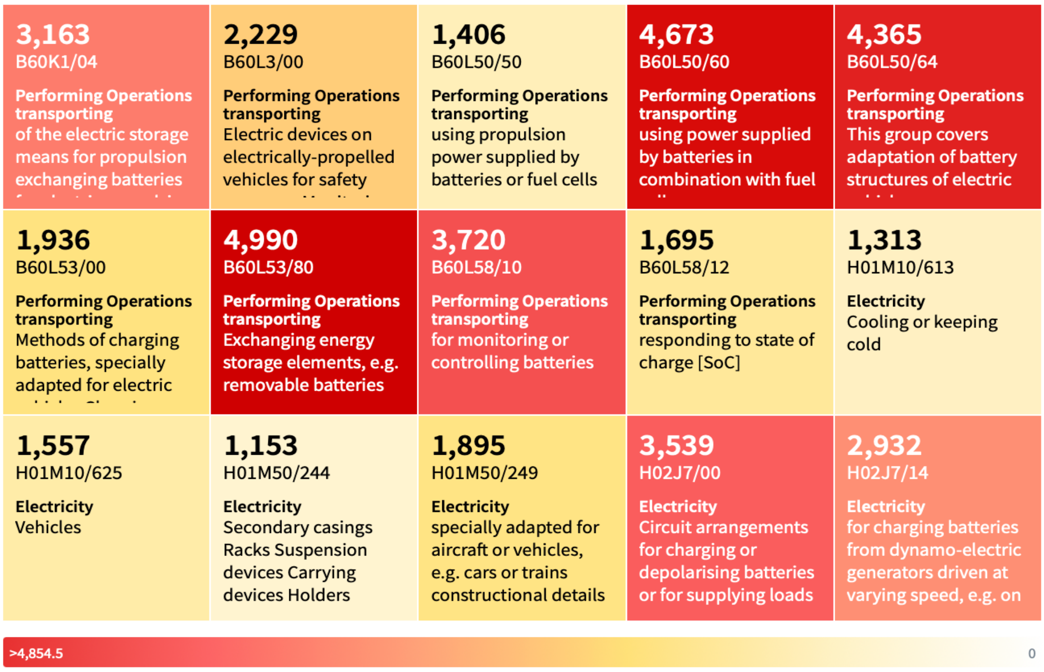


Figure 13: top IPC codes in the sample

The figure shows that the most represented section is B - PERFORMING OPERATIONS; TRANSPORTING, followed by H - ELECTRICITY. Going down to class level, the most frequently found is B60 - VEHICLES IN GENERAL, while for section H we have H02 - GENERATION, CONVERSION, OR DISTRIBUTION OF ELECTRIC POWER. The most frequent subclass, on the other hand, is B60L - PROPULSION OF ELECTRICALLY-PROPELLED VEHICLES, with its subgroup B60L50/00 - ELECTRIC PROPULSION WITH POWER SUPPLIED WITHIN THE VEHICLE and lower-level subgroups.

Consistent with the query, two macro-areas emerge: electric vehicles and batteries. An analysis of the most frequent complete codes, on the other hand, reveals a great deal of attention concerning battery removal and exchange systems with code B60L53/80 - [METHODS OF CHARGING BATTERIES, SPECIALLY ADAPTED FOR ELECTRIC VEHICLES] EXCHANGING ENERGY STORAGE ELEMENTS, E.G. REMOVABLE BATTERIES, as well as towards battery adaptation systems (B60L50/64), battery integration and control (B60L58/10).

5.4 Results by technological area

After analysing the sample in its entirety, a more specific analysis was carried out, relating to certain technology subclasses, with the aim of identifying technology trends within the sample. For this purpose, it was decided to start from the IPC codes used in the query and assign them to one or more technology classes, each relating to a different aspect of the technology under examination. The identified classes are:

1. Storage systems: batteries
2. Storage systems: fuel cells
3. Charging systems
4. Battery control systems and integration with the vehicle

The codes were classified as follows:

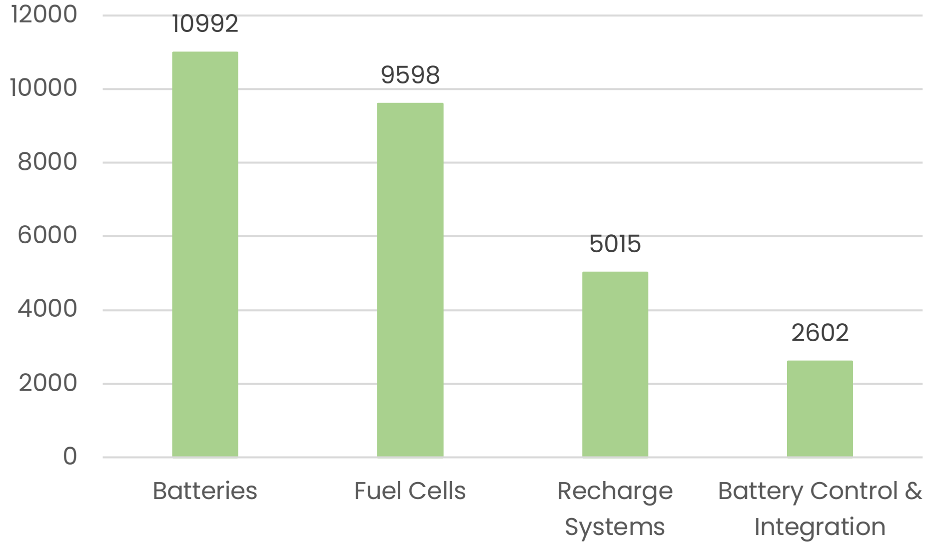
Table 5: classification of IPC codes

IPC		DESCRIPTION	CLASS
B60L50/00		Electric propulsion with power supplied within the vehicle	1,2
	B60L50/50	using propulsion power supplied by batteries or fuel cells	1,2
	B60L50/60	using power supplied by batteries	1
	B60L50/61	by batteries charged by engine-driven generators, e.g. series hybrid electric vehicles	1
	B60L50/62	charged by low-power generators primarily intended to support the batteries, e.g. range extenders	1
	B60L50/64	Constructional details of batteries specially adapted for electric vehicles	1
	B60L50/70	using power supplied by fuel cells	2
	B60L50/71	Arrangement of fuel cells within vehicles specially adapted for electric vehicles	2
	B60L50/72	Constructional details of fuel cells specially adapted for electric vehicles	2
	B60L50/75	Using propulsion power supplied by both fuel cells and batteries	1,2

B60L53/00		Methods of charging batteries, specially adapted for electric vehicles; Charging stations or on-board charging equipment therefore; Exchange of energy storage elements in electric vehicles	3
	B60L53/80	Exchanging energy storage elements, e.g. removable batteries	3
B60L58/00		Methods or circuit arrangements for monitoring or controlling batteries or fuel cells, specially adapted for electric vehicles	4
	B60L58/10	for monitoring or controlling batteries	4
	B60L58/30	monitoring or controlling fuel cells [2019.01]	4
	B60L58/40	for controlling a combination of batteries and fuel cells	4
H01M10/00		Secondary cells; Manufacture thereof	1
H01M8/00		Fuel cells; Manufacture thereof	2
H02J7/14		[Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries] for charging batteries from dynamo-electric generators driven at varying speed, e.g. on vehicle	3

The database was processed in Excel in order to assign each individual patent one or more classes (depending on complexity and scope, some patents may cover several aspects) based on the presence of one or more codes of each class in the patent. It turned out that 83% of the patents belong to one class, 12% to 2 classes, 3% to 3 classes and a final 2% to 4 classes.

Graph 8 represents the number of patents belonging to each class:

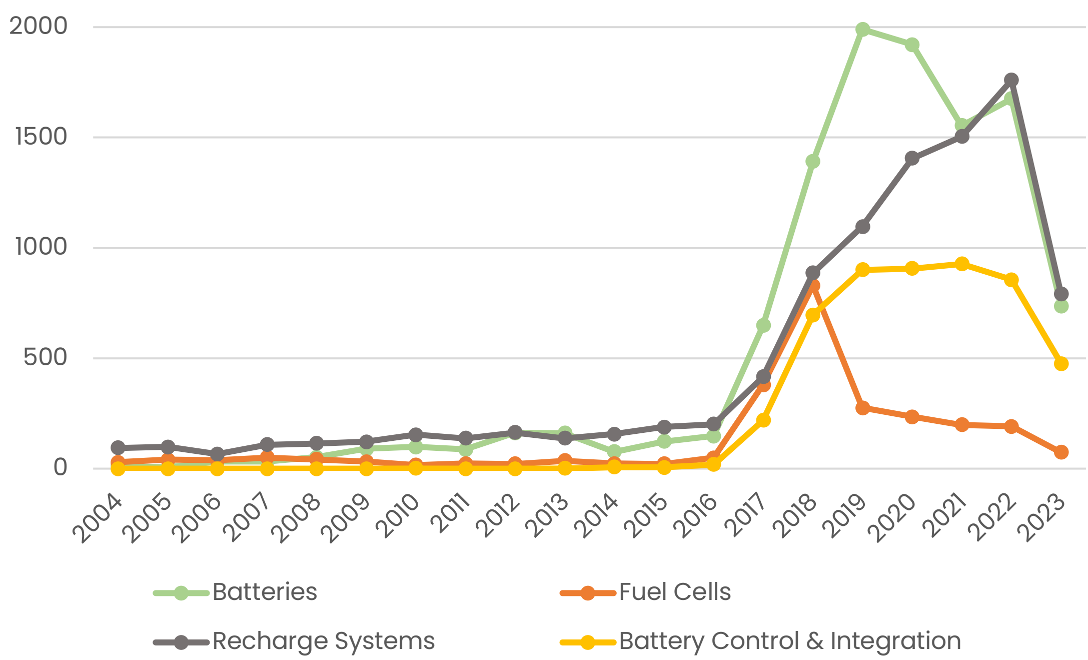


Graph 8: patents per technology class

The most populated class is batteries (39% of patents), followed by charging systems (34%), control systems (18%) and finally fuel cells (9%).

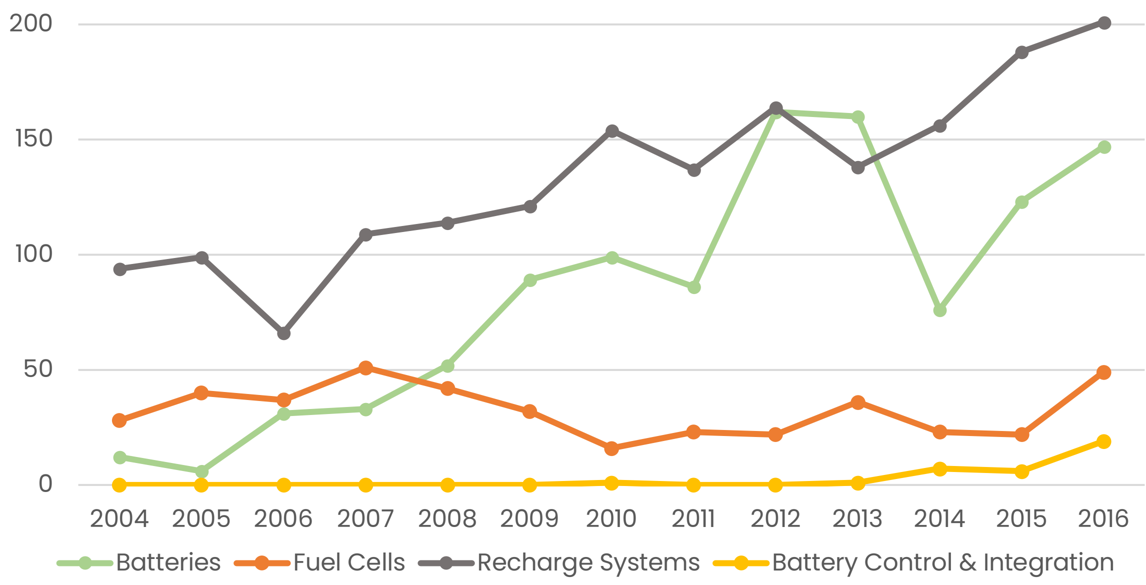
5.4.1 Temporal Trend

The purpose of this section is to analyse the time trends of the applications of the various subclasses and to compare them with each other, in order to understand their behaviour and the presence of trends. As with the analysis carried out on the entire database, the starting point here was the application year, considering the last 20 years. Graph 9 shows the trends for all subclasses:



Graph 9: applications per technology class

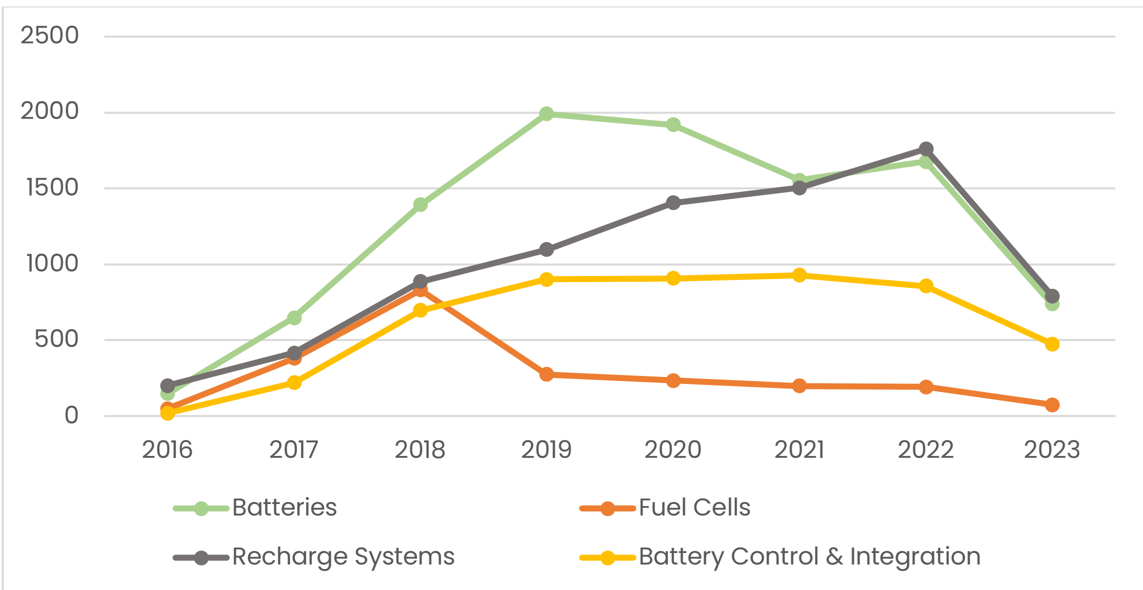
From the graph, it can be seen that all technologies maintained a relatively low and constant level of patenting from 2004 to 2016, a year in which, as with the time trend for the entire database, there was a significant increase in patent activity. To better analyse this first period, Graph 10 represents the curves for applications between 2004 and 2016.



Graph 10: Applications per technology class - 2004 to 2016

From this second graph, it can be seen that patents relating to vehicle control and integration systems are almost zero in these first 11 years, indicating that technology in general relating to electric cars was still at a little more than basic level. Fuel cell activity remained more or less constant, always below 50 patents/year. Instead, an increasing trend can be seen for both batteries and charging systems, with the latter having higher numbers.

Graph 11 shows a detail of the second part of the time horizon under analysis, from 2016 to 2023:

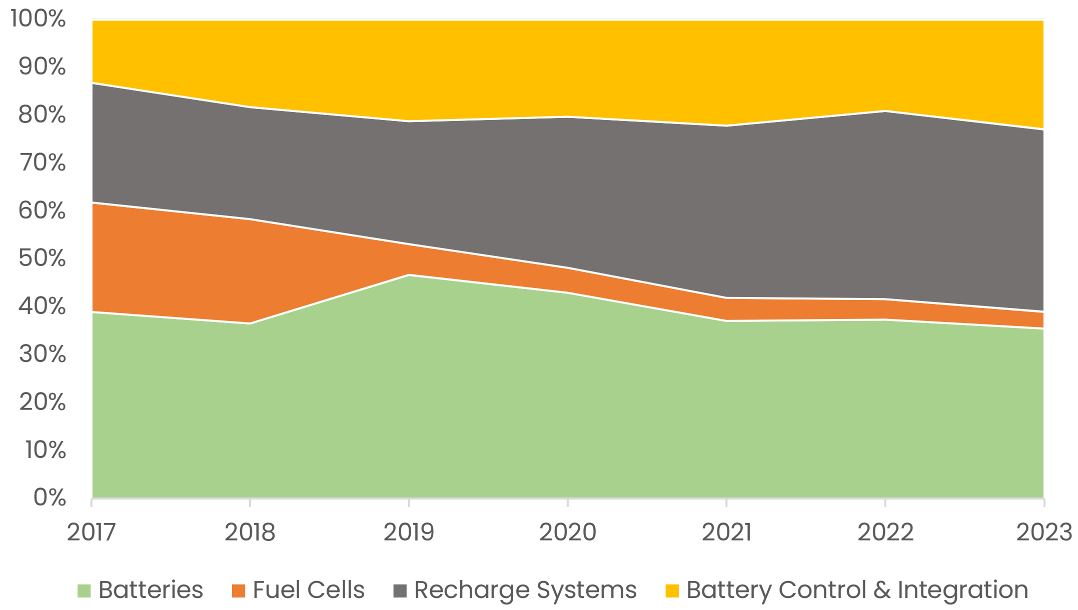


Graph 11: Application per technology class - 2016 to 2023

From this graph, the increase in patenting activity between 2016 and 2017 is even more evident, with increases ranging from 6 to 10 times those of the previous year: for example, for batteries, from 147 to 648 patents/year; for fuel cells, from 380 to 830 patents/year. As already mentioned in the analysis of high-level time trends, this innovative drive could be explained by certain political actions - the Treaty of Paris and its ratifications - which have placed time limits on the circulation of ICE-equipped cars, thus stimulating research into alternative propulsion methods. Some particular trends can also be noted:

- Research on fuel cells, after an initial stimulus, has collapsed to almost pre-2017 levels. As already seen in 2.5 Fuel Cells, a fuel cell can be seen as a battery with inert electrodes which, in order to function, must be continuously supplied with fuel and oxidising agent. The most common fuel is hydrogen, but apart from safety issues, this element only occurs in nature bound to other molecules, which makes its synthesis an energy inefficient process. A future development of a more efficient method could make this technology popular again.
- The shape of the two curves shows us that the focus of research is shifting from batteries to charging systems. This trend is an indication that the technological advancement of the latter is lower than that of batteries: to make the electric car a more mature and market-attractive product overall, this gap must be closed as soon as possible.

Another interesting analysis is summarised in Graph 12, which represents, in the form of an area, the percentage of patents related to individual technology classes out of the total number in each year. The graph has been drawn up for the years 2017 to 2023 in order to identify the most recent trends:



Graph 12: percentage of patent applications per class over total

The graph shows that batteries account for about 40% of patent activity for each year under review, a percentage that remains roughly constant over time. On the other hand, patents for battery control & integration systems show a slight increase, rising from just over 10% to almost double this past year. In contrast, the collapse in fuel cell activity and the steady increase in patents on charging systems are evident.

Table 6 summarises the patent data for the technology classes under consideration, grouped by year.

Table 6: patent applications per technology class

Year	Batteries	Fuel Cells	Recharge Systems	Battery Control & Integration	Total
2004	12	28	94	0	134
2005	6	40	99	0	145
2006	31	37	66	0	134
2007	33	51	109	0	193
2008	52	42	114	0	208
2009	89	32	121	0	242
2010	99	16	154	1	270
2011	86	23	137	0	246
2012	162	22	164	0	348
2013	160	36	138	1	335
2014	76	23	156	7	262
2015	123	22	188	6	339
2016	147	49	201	19	416
2017	648	380	416	219	1663
2018	1391	830	886	696	3803
2019	1990	275	1096	901	4262
2020	1920	234	1405	907	4466
2021	1554	198	1504	927	4183
2022	1676	191	1759	856	4482
2023	737	73	791	475	2076

5.4.2 Geographical Trend

For the analysis of the geographical distribution of patents, we proceeded in the same way as for the high-level analysis, i.e. by grouping patents according to the country of application and dividing them by the respective technology classes. Table 7 summarises the data obtained: data for the 15 countries with the highest number of patents are shown, the others are grouped under "other".

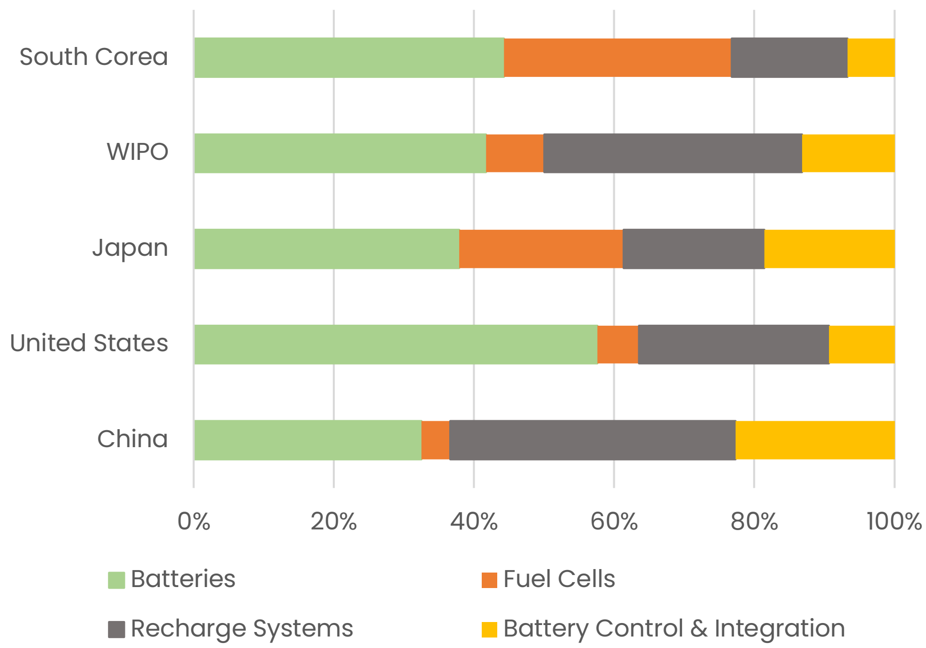
Table 7: patent applications per class and country

Patent Application Office	Batteries		Fuel Cells		Recharge Systems		Battery Control & Integration	
	Patents	%	Patents	%	Patents	%	Patents	%
CN	4886	44,5%	628	5,7%	6130	55,8%	3413	31,0%
US	2676	24,3%	276	2,5%	1261	11,5%	436	4,0%
JP	1467	13,3%	910	8,3%	780	7,1%	719	6,5%
WO	741	6,7%	148	1,3%	653	5,9%	235	2,1%
KR	702	6,4%	515	4,7%	262	2,4%	106	1,0%
EP	112	1,0%	26	0,2%	98	0,9%	29	0,3%
CA	92	0,8%	18	0,2%	67	0,6%	23	0,2%
AU	47	0,4%	15	0,1%	64	0,6%	10	0,1%
GB	57	0,5%	19	0,2%	45	0,4%	15	0,1%
TW	52	0,5%	12	0,1%	53	0,5%	10	0,1%
RU	36	0,3%	6	0,1%	32	0,3%	3	0,0%
DE	23	0,2%	4	0,0%	39	0,4%	0	0,0%
MX	21	0,2%	5	0,0%	17	0,2%	2	0,0%
SE	14	0,1%	2	0,0%	19	0,2%	6	0,1%
ES	11	0,1%	8	0,1%	16	0,1%	4	0,0%
Other	55	0,5%	10	0,1%	62	0,6%	4	0,0%

China proves to be the most prolific country in three out of four categories, namely Batteries, Recharge Systems and Battery Control & Integration. For the first two categories, it achieves very high percentages, 44.5% for Batteries and over 55% for Recharge Systems, and 31% for Integration Systems. On the other hand, the situation is very different with regard to Fuel Cells, a category in which there is a greater geographical dispersion of patent activity. In this case, the most active country is Japan, with 8.3% of patents, followed by China with 5.7% and South Korea with 4.7%. The United States, on the other hand, has good patent activity on batteries, with 24.3%, and charging systems, where they reach 11%; while they are less prolific on Fuel Cells and Battery Control, where they do not exceed 5%.

It can be seen that, even at the level of technology class, most battery research is done in Asian countries such as China, Japan and Korea, followed by the United States.

Graph 13 represents the composition of the patent portfolio of the top five countries considered in the analysis:



Graph 13: patent portfolio of top 5 countries

The graph was constructed considering the percentage of patents in each category compared to the total number of patents filed, in order to identify any trends towards one or more classes. Interestingly, except for Japan, the portfolios of the various countries are not balanced and each shows a trend towards one or two technology classes, thus denoting a higher level of specialisation for each country in some areas than others.

5.4.3 Patent Portfolio

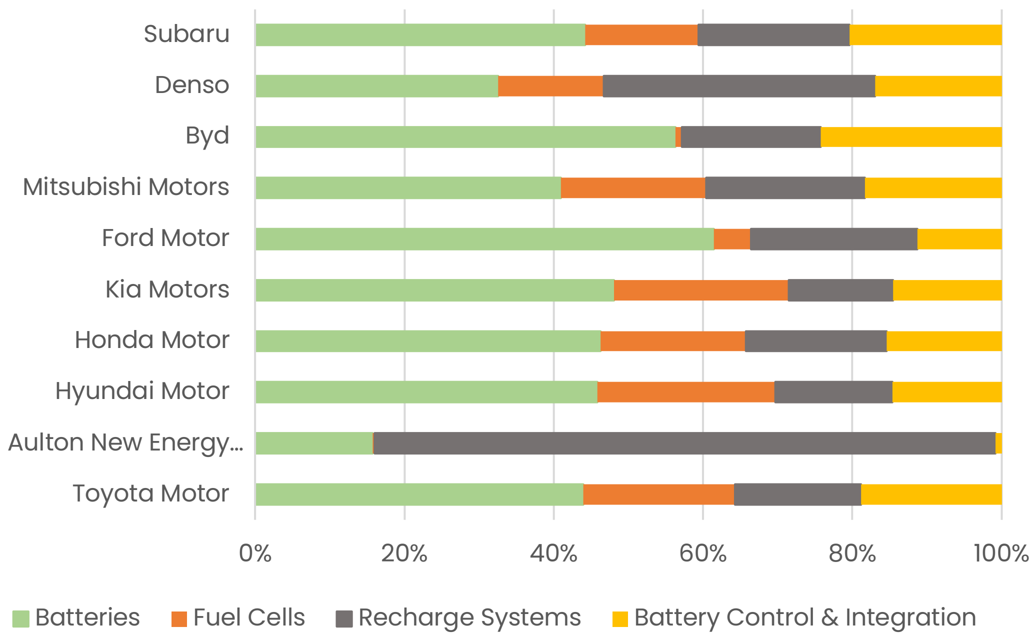
In this section, the composition of the patent portfolio of the top 5 innovative companies will be analysed, distinguishing their patents according to their classification in the 4 main technology sub-categories. The purpose of the analysis is to assess possible specialisations and highlight the most innovative companies in each class. The principles used are the same as in the assignee analysis performed in 5.3.3 Top Assignees. The resulting data are summarised in Table 8:

Table 8: portfolio composition

Assignee	Batteries	Fuel Cells	Recharge Systems	Battery Control & Integration
Toyota Motor	901	417	347	386
Ford Motor	386	31	140	71
Byd	260	4	86	112
Aulton New Energy Automobile Tech Co Ltd	174	3	920	9
Denso	127	55	142	66
Honda Motor	450	189	183	150
Hyundai Motor	473	246	162	151
Kia Motors	416	202	121	126
Mitsubishi Motors	217	103	113	97
Subaru	169	58	77	78

The data show that for the Batteries, Fuel Cells and Battery Control & Integration categories, the company with the most patents is Toyota. In contrast, for the Recharge Systems category the largest patent activity is Aulton.

The next step in the analysis is to assess the patent portfolio of each of the companies under review, the results of which are summarised in Graph 14:



Graph 14: patent portfolio composition

The graph shows that, albeit in different percentages, each of the companies under review registered patents for all technology categories. The composition of the various portfolios indicates that:

- Aulton New Energy Automobile Tech Co Ltd proves to be a strongly specialised company in Recharge Systems.
- The portfolios of the other companies are not perfectly balanced and show a general preference of patenting activity towards batteries, however no technology category is totally excluded from development.

Table 9 summarises the percentage data of the composition of the portfolios:

Table 9: percentage composition of portfolios

Assignee	Batteries	Fuel Cells	Recharge Systems	Battery Control & Integration
Toyota Motor	44%	20%	17%	19%
Aulton New Energy Automobile Tech Co Ltd	16%	0%	83%	1%
Hyundai Motor	46%	24%	16%	15%
Honda Motor	46%	19%	19%	15%
Kia Motors	48%	23%	14%	15%
Ford Motor	61%	5%	22%	11%
Mitsubishi Motors	41%	19%	21%	18%
Byd	56%	1%	19%	24%
Denso	33%	14%	36%	17%
Subaru	44%	15%	20%	20%

5.4.4 Citations Analysis

It might be thought that obtaining a patent is the final step towards commercialisation and economic exploitation of the invention for which considerable research and development efforts have been made. However, as stated by Webster and Jensen [30], only about 40 percent of inventions are actually launched on the market and commercialised. For this reason, the measurement of the quality of research in a given technology sector cannot be based on a simple count of patents obtained in that sector. A suitable method to assess and measure the importance of a patent is based on citations.

As seen in 4.2.4 Forward Citations of a Patent, a patent can have two types of citations:

- Backward citations: the number of patents cited in the focal patent application to describe the prior art and on which the invention is based
- Forward citations: these are the citations of the focal patent made by later filed patents

In order to understand the value of a patent, only forward citations will be used, as they can give us an indication of the number of patents that mention the focal patent as a source of prior art. In this sense, the presence of forward citations indicates that subsequent investments were made in the development of the technology [31] and also that the focal patent was used by patent examiners to limit the scope of protection of a subsequent patent. Thus, forward citations are an index of "*both the private and the social value of inventions [...] and are commonly used to measure the technological impact of innovation*" [31].

A first method to compare the value of patents belonging to different classes is through the weighted average of citations per year. This is done by averaging the number of citations received by patents in a given class but taking into account the age of the patent. The latter factor must be considered for two main reasons:

- Older patents are more likely to be cited than newer patents.
- With the same number of citations, a more recent patent is more valuable than an earlier patent because they were obtained in a shorter

time, so the invention covered by the patent can be considered more technologically relevant.

For this analysis, the "Cited by Patent Count" field of the database and the application year of the patent were considered. Since the time period considered is 20 years, each year the weight is increased by 1/20, i.e. 0.05 so that more recent patents are given more weight. The citation data are summarised in Table 10:

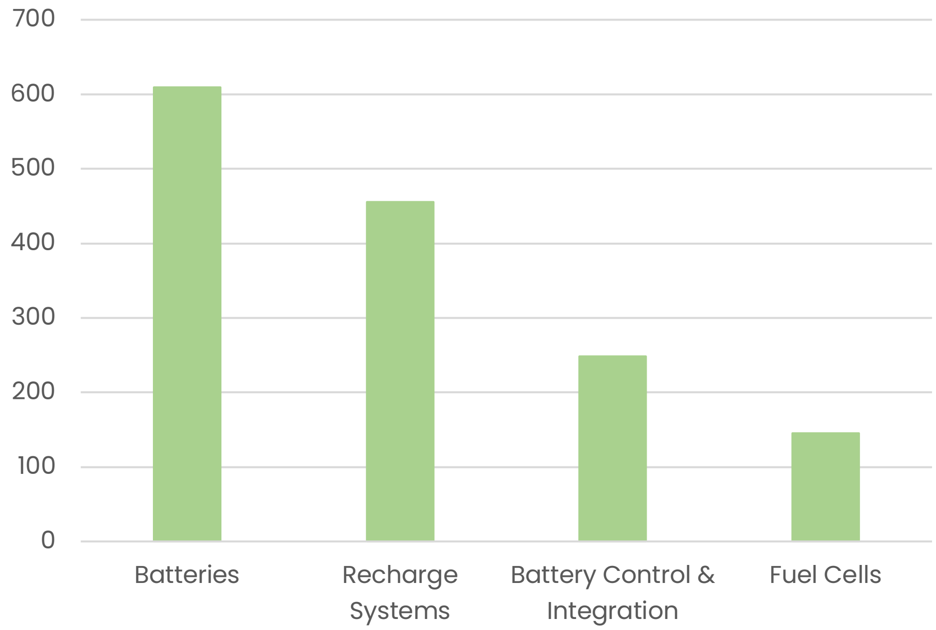
Table 10: weighted citations data

Year	Weight	Batteries	Fuel Cells	Recharge Systems	Battery Control & Integration
2004	0,05	104	292	1196	0
2005	0,1	129	543	952	0
2006	0,15	533	470	492	0
2007	0,2	1835	331	1273	0
2008	0,25	856	353	1252	0
2009	0,3	1453	237	752	0
2010	0,35	1048	93	674	5
2011	0,4	852	169	717	0
2012	0,45	1652	241	593	3
2013	0,5	1173	135	498	26
2014	0,55	448	64	578	38
2015	0,6	584	92	571	26
2016	0,65	635	105	456	38
2017	0,7	1597	705	799	407
2018	0,75	2419	1163	1462	1302
2019	0,8	3104	521	1880	2210
2020	0,85	1900	213	1945	1211
2021	0,9	803	119	985	637
2022	0,95	240	31	346	224
2023	1	36	2	66	43

The formula used to calculate the weighted average is:

$$\sum_{i=1}^{20} \frac{N_i \cdot w_i}{20}$$

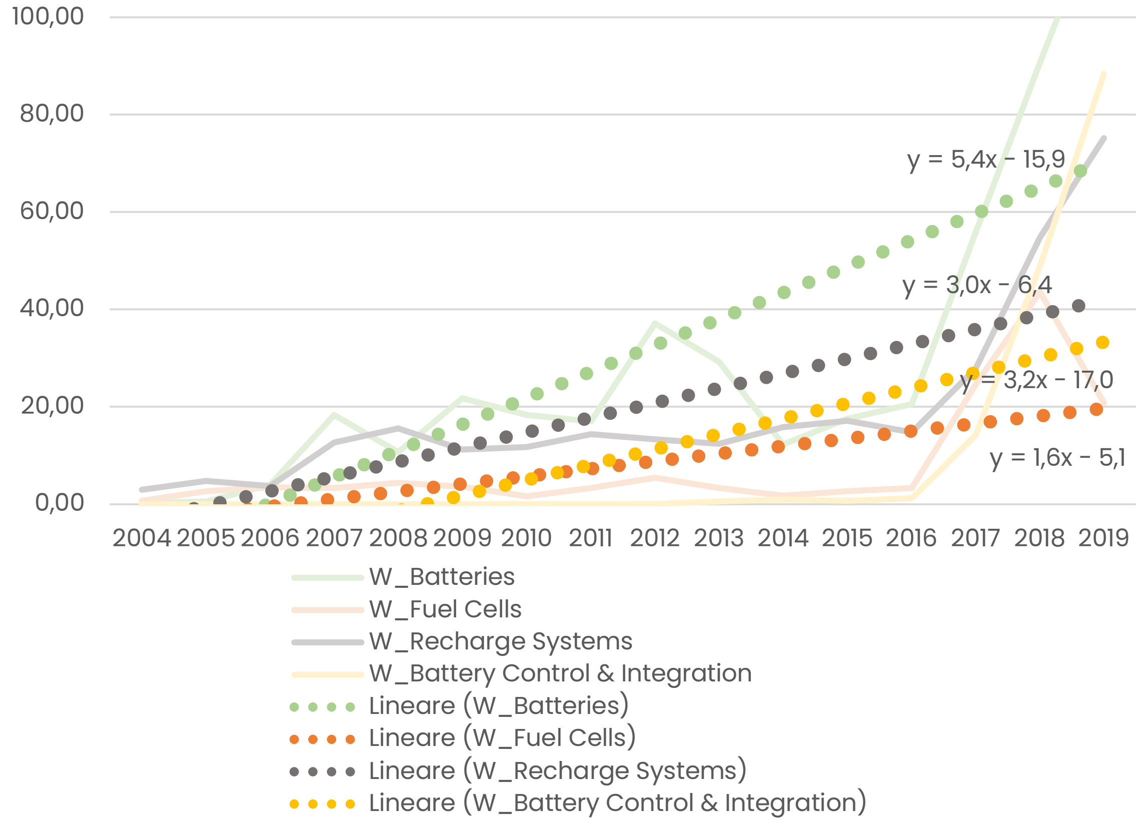
With N_i number of patents filed in year i and w_i weight of year i. The results obtained are summarised in Graph 15



Graph 15: weighted average citations per class

This analysis shows that the technology class with the highest number of mentions is batteries, followed by Recharge Systems and Battery Control & Integration, while Fuel Cells have the lowest average of the whole sample.

Another analysis is to predict the future trend of average citations, in order to highlight any trends other than the historical average. Given that the patent application year was used (which may lead to incomplete results - see 5.3.1 Temporal Trend), data from the last 4 years were excluded to predict the time average. The trend of the previously calculated weighted average was represented on a graph, with the application year as abscissa. The prediction was made by interpolating the data obtained for each class with a straight line, which, although an approximation with a high degree of error, can nevertheless give us an idea of the future trend of the average citations. The results are summarised in Graph 16:



Graph 16: future citations trend

Observing the trend of the straight lines, one can deduce that all technologies show an increasing trend, but at different speeds: the technology class with the highest growth is Batteries, followed by Battery Control & Integration, Recharge Systems and finally Fuel Cells.

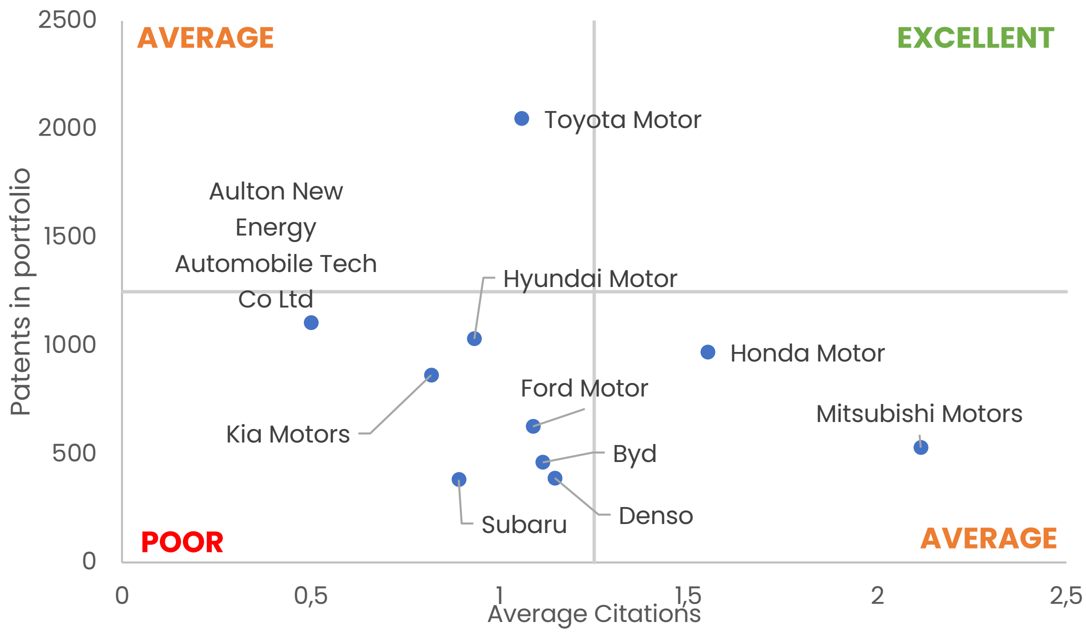
5.4.5 Portfolio Analysis

This section will compare the portfolios of the 10 largest innovative companies identified above, both in terms of quantity of patents and their quality.

For this analysis, all technology classes have been aggregated, thus considering the totality of patents filed by each applicant within the battery. Again, the calculation of patent quality is based on the weighted average of forward citations, considering a factor of 1/20 for each year after 2004, using the same formula as shown in the previous section. The results obtained were then represented on a quadrant chart: this type of chart consists of a scatterplot with, in this case, on the x-axis the values corresponding to the average number of forward citations received in the portfolio and on the y-axis the number of patents in the portfolio. The graph area is then divided into four quadrants, which allow the points in the scatterplot to be categorised:

- Points falling in the top right quadrant have high values of the features under scrutiny and, therefore, above average.
- Points falling in the top left and bottom right quadrants have average values.
- Points falling in the bottom left quadrant have values below the average.

Graph 17 represents the quadrant chart of the portfolios of the top 10 innovative companies:



Graph 17: portfolio quadrant chart

The graph shows that the portfolios of most companies fall in the bottom left quadrant, thus presenting below average values in number of patents in the portfolio and citations. No portfolio is in the excellent quadrant, while the three best companies fall in the average quadrants: Toyota confirms its leadership in the sector with the best portfolio, the below-average number of citations being balanced by the high number of patents in the portfolio. The opposite case is that of Mitsubishi, whose portfolio is composed of relatively few but highly cited patents. The third best portfolio, on the other hand, belongs to Honda, which falls almost in the middle of the graph: it has a slightly below-average number of patents but above-average citations.

6. Conclusions

The analyses carried out in the paper describe the battery industry as a very active research and development sector, with the number of patent applications growing year by year and future forecasts confirming this trend. The main players in this research are, for the most part, carmakers who have already gained a well-defined market share in the internal combustion car sector, using the revenues obtained to finance research into technologies related to electric mobility. However, the group of the leading innovators does not coincide with the leading carmakers active in the ICE car market, indicating that not all of them have decided to invest or, at least, not at the same time. Furthermore, research activity is quite fragmented, with the top 10 companies holding 36% of the total patents: this phenomenon is an indicator that the sector is attracting new companies, most of which were not previously active in the car market.

Geographically, patent activity is most concentrated in Asia, the continent from which around 70% of patent applications originate (50% of the total coming from China alone). This geographical concentration is a confirmation of the specialisation developed over the years in this part of the world, which offers both natural resources and cheaper labour, thus attracting the biggest players in the sector.

The subsequent analysis at the level of technology class revealed that there is a certain disparity in the research carried out on the various aspects of a battery, a disparity that also emerges in the unbalanced composition of the portfolios of the main innovating companies. The battery class (understood as research on storage systems) appears to be the one with the greatest patent activity, followed by battery charging and changing systems and systems for integration with the vehicle, while little activity is recorded for fuel cells. The results of the analysis lead us to state that:

- companies believe that battery propulsion is the paradigm that will become established in the near future.
- investment in research is high, and there is a desire to overcome the structural limitations of batteries that are slowing down the spread of the electric car.

- the time trend in technology class applications indicates that research is shifting from battery technology to charging systems. This phenomenon could be an indicator that battery research is reaching a technological limit that is slowing down its growth, and companies are shifting their focus to charging systems, so that they can work on speeding up charging to balance the structural limit of battery capacity.
- the fuel cell technology that in the early 2000s seemed to be the future of electric mobility is instead losing interest, probably due to unresolved economic and safety issues.

The analysis of forward citations made it possible to assess, on average, the influence that patents belonging to individual classes had on patents following them. The number of citations of the patent in future papers can be used as an estimate of the measure of the patent's value, as citations indicate that research was continued and expanded. The results of this analysis showed that the battery technology class had a higher average number of citations per year than the others. Subsequently, the portfolios of the leading innovative companies were also evaluated using this methodology and, through the use of a quadrant chart relating value and portfolio size, it emerged that most of the companies have portfolios of medium to low quality compared to the total sample. This is an indication that quantity and quality of patents do not go hand in hand and it is possible to have disparities in this respect, e.g. small companies with few patents under their belt may produce patents that are of higher quality than those of a multinational company.

The result of this Patent Landscape Report is therefore a description of a highly innovative sector, driven by large investments and favoured by international policies, which aims to improve a product - the battery - with the ultimate goal of improving and making more attractive the final product that is the electric car.

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