The Impact of Electrification in Automotive Design for Light Vehicles

Versão Final Após Defesa

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O meu mais profundo obrigado.

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Abstract

This dissertation aims to explore the impact of electrification in automotive design. Pivotal historic events that helped shape the contemporary automobile are crucial, as they not only offer a view into varying trends across automotive history but also show how the electric vehicle was once the dominant choice through market share in the early 1900s.

This subject matter also elicits interest on the importance of manufacturers, brands and how they adapt to innovations, trends, legislation and consumer interest. The presentation of a case study comparison between electric and internal combustion powered vehicle granted a framework to observe the contrast between two means of propulsion, and what they entail. Subsequently, challenges and opportunities in regard to electric propulsion were researched and analysed.

The conclusion being that weight, price, energy density, inadequate infrastructure and lack of versatility as a result of time-consuming charging still plague the electric vehicle, however, home renewable energy, ease of use, solid state batteries, superior packaging, smaller drivetrain volume, absence of mechanical connections between components, lower maintenance needs and running costs, higher efficiency, lower center of gravity, and increased interior space all provide opportunities for electric vehicles to affirm themselves in the highly competitive automotive sector.

Keywords

Automotive Design, Electric vehicles, Mobility and Citizenship, Sustainability, Car Packaging Efficiency

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Resumo

Esta dissertação tem como objetivo explorar o impacto da eletrificação no design automóvel. Os marcos históricos relatados permitem adquirir uma compreensão das diversas tendências ao longo da história automóvel, nomeadamente, a predominância do veículo elétrico no início do séc. XX.

Este tema engloba ainda vertentes como a importância dos fabricantes e das marcas, bem como à forma como estes se adaptam às inovações, às tendências, às legislações e às preferências dos consumidores. A apresentação de um estudo de caso comparativo entre veículos elétricos e veículos com motor de combustão interna proporcionou um enquadramento que permitiu observar o contraste entre os dois modos de propulsão e as suas implicações. Subsequentemente, foram investigados e analisados os desafios e oportunidades associados à propulsão elétrica.

Conclui-se que fatores como o peso, o preço, a densidade energética, a infraestrutura inadequada e a falta de versatilidade decorrente do tempo de carregamento, continuam a representar desafios para o veículo elétrico. No entanto, a integração de energias renováveis no ambiente doméstico, a facilidade de utilização, o desenvolvimento de baterias de estado sólido, as superiores otimizações do espaço, entre outros, representam oportunidades para que os veículos elétricos se afirmem num setor automóvel altamente competitivo.

Palavras-chave

Design Automóvel, Veículos Elétricos, Mobilidade e Cidadania, Sustentabilidade, Eficiência das Embalagens Automóveis

Blanck page

Table of Contents

List of Figures

Blanck page

List of Tables

Blanck page

List of Acronyms

4WD	Four-Wheel Drive
ABS	Anti-lock Braking System
AC	Alternating Current
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Autonomous Vehicles
AWD	All-Wheel Drive
BEV	Battery Electric Vehicle
BMW	Bayerische Motoren Werke
CD	Drag Coefficient
CO	Carbon Monoxide
DC	Direct Current
DIN	Deutsches Institut für Normung
DOHC	Dual Overhead Cam
EC	European Commission
EPA	Environmental Protection Agency
ESC	Electronic Stability Control
EU	European Union
EV	Electric Vehicle
EVC	Electric Vehicle Company
FE	Faculdade de Engenharia
FWD	Front-Wheel Drive
GHG	Green House Gasses
GM	General Motors
GRP	Gabinete de Relações Publicas
HC	Hydrocarbons
HP	Horsepower
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IFS	Independent Front Suspension
IRS	Independent Rear Suspension
KG	Kilogram
KM	Kilometre
LCI	Life Cycle Impulse
MM	Millimetres
MPH	Miles Per Hour
NCAP	New Car Assessment Programme
NEDC	New European Driving Cycle
NiMH	Nickel-Metal Hydride
NM	Newton Meter
NOx	Nitrogen Oxide
PHEV	Plug-in Hybrid Electric Vehicle
RPM	Revolutions per Minute
RWD	Rear-Wheel Drive

SAE	Society of Automotive Engineers
SOHC	Single Overhead Cam
SUV	Sports Utility Vehicle
US	United States
USA	United Stated of America
UBI	Universidade da Beira Interior
V2H	Vehicle-to-House
VVT	Variable Valve Timing
VVT-I	Variable Valve Timing-Intelligent
VW	Volkswagen
WLTP	Worldwide Harmonised Light Vehicle Test Procedure

Introduction

This dissertation's main objective is to access the impacts of electrification in automotive design from an industrial design perspective. This means exploring how this change in the propulsion paradigm influences aesthetic, ergonomics, and design language as a whole; analysing the relation between sustainability, drivetrains and what the electric vehicle offers, examining how the electric powertrain interplays with new technologies and vehicle constraints.

Equally important is recognizing the challenges and opportunities raised by electric drivetrains across a variety of domains and, finally, examining not only how brands embrace these changes, but also how they reshape conceptual and functional aspects of automotive design and how consumer preference drives these design innovations.

To achieve these objectives, the fundamentals of the history of the automobile were explored through archival research and literature review to get a better understanding of how the automobile evolved over the years up to the modern era. Thus, a historical impact assessment was possible through thematic analysis, which offers a better understanding of the correlation between design shifts alongside trends, innovation, and legislation.

A case study comparison was executed across eight different models of a varying brands, on four different market segments, yielding a view on trends in car design, performance, and efficiency across both electric and internal combustion engine models. In this dissertation, the aforementioned points are structured by contextualization through both the history of the automobile and brand identity, followed by the case study comparison and culminating on the challenges and opportunities brought by this change in the propulsion paradigm.

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1 – Brief Technological History of the Automobile

1.1 – The First Self-Propelled Vehicles: 1769-1914

The history of the automobile begins with the steam engine, first used in road transportation in 1769. It was used to power an artillery tractor made by Nicholas Joseph Cugnot, a French army-officer. With three wheels and a top speed of 4km/h (2.5 miles per hour [mph]), the vehicle created by Monsieur Cugnot was designed for military purposes, built at the Paris arsenal (fig. 1). To function, it needed to stop in ten-to-fifteen-minute intervals to build up more steam pressure. After the partial success with the first built in 1769, a second was built in 1770. Its limited manoeuvrability resulted in an accident involving one of the vehicles. No further developments were made (Lovland, 2007; Norton, 2016; Thurston, 1886).

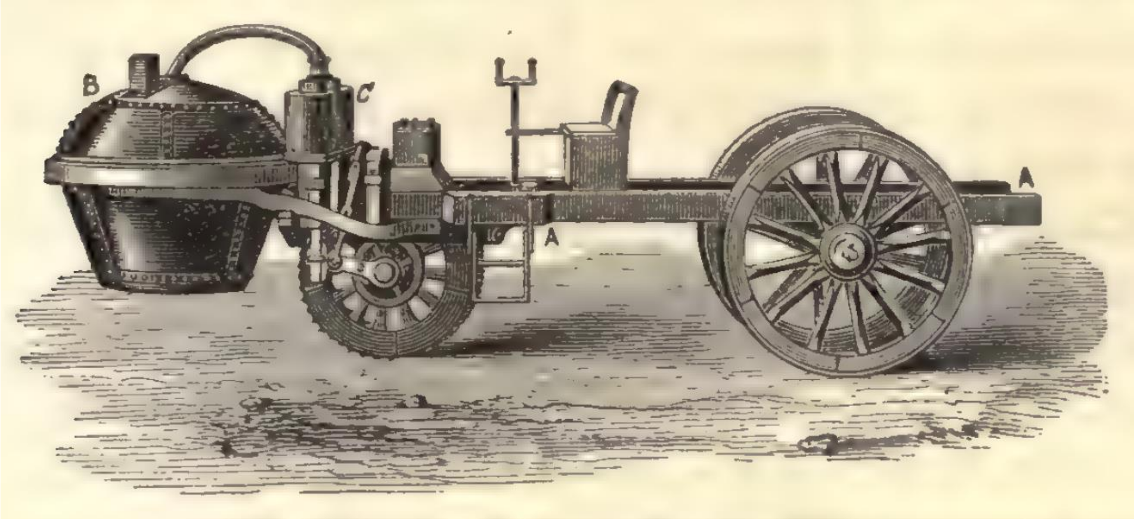


Figure 1: Cugnot's Steam-Carriage, 1770 (Thurston, 1886).

Richard Trevithick, the inventor of the steam locomotive, is recognised as the first to use a steam engine in a vehicle meant for passenger transportation. Trevithick built a "road locomotive" in 1800 and patented it in 1802, was also a first in Britain road use (Lovland, 2007; Norton, 2016).

Sir Goldsworthy Gurney built in 1825 a steam vehicle that pulled a carriage for passenger transportation and charged a lower fee than the horse-drawn carriages of the day. He later built a steam carriage in 1826, able to carry twenty-one passengers total, six in the interior and fifteen in the exterior. This carriage was equipped with two propellers with hopes of aiding the carriage in climbing hills, these were later removed when dimed unnecessary. Gurney's steam carriages began being used by Sir Charles Dance in 1831. During the four months they were in service, three thousand passengers were transported and covered a total distance close to 4000 miles (6437km). In a 14km trip, it took the steam carriage 55 minutes on average, sometimes making it in forty-five. Delays were common due to the unreliability of the technology, although no accidents occurred (Fletcher, 1891; Norton, 2016).

The first Stanley Steamer was produced by the Stanley brothers in 1897. Since the steam engine was able to quickly be stopped and restarted, assuming steam pressure was present, the vehicle didn't have a transmission, clutch or driveshaft, the engine powered the rear differential through a chain. Over two hundred cars were manufactured and sold between 1898 and 1899, more than any other car manufacturer in the US market that year. During the XIX century and the first decade of the XX century, steamers were much more powerful than their contemporary ICE counterparts. Producing a great amount of torque from a dead stop coupled with relatively low weight, Stanleys earned the reputation of being fast cars (Norton, 2016).

The Doble is regarded as the pinnacle of steam technology development in the automobile. It all began when Abner Doble built his first steam car alongside his brothers when he was still in high school. During the company's lifetime, merely thirty-six cars were built. With a development cost of around $55,000 and being sold for $20,000, they were sold at a loss. However, compared to the contemporary Ford Model T's $260 price tag, the Doble was still far from affordable. The company endured selling automobiles without generating a profit due to the brothers' considerable family wealth. By automating the valve manipulation and burner ignition, along with using a flash-tube steam generator capable of heating two quarts of water at a time, Doble solved the issue of slow starting that plagued Steamers. Starting in just 90 seconds at the turn of the key, and ready to move in 2 minutes, the doble steam car had a range of over 300 miles (482km). Even though it had its steam superheated to 800 ºF (426 ºC) at a pressure of 1200 psi (82 bar), no boiler ever exploded. The engine produced 2200 ft-lb (2982Nm) of torque (Norton, 2016). To put into perspective, the 8.0 litre, quad turbo, W16 internal combustion engine that powers the 2017 Bugatti Chiron achieves a torque figure of 1600 Nm (Gomes, 2017b). In similar fashion to other expensive brands, such as Rolls-Royce, Duesenberg, among others, the Doble was merely sold as a chassis. Costumers would then go to body makers for a custom body made to the costumer's specifications. Unlike any other internal combustion engine vehicle (ICEV) of the day, the Doble had great reliability, with some examples achieving several hundred thousand miles without requiring heavy mechanical intervention. In 1931 the company went out of business. The Great Depression resulted in multiple companies going under, steam car production disappeared with them (Norton, 2016).

The electric automobile has its origins in the inventions of Michael Faraday, mainly the Electric Motor in 1821, but also the Dynamo in 1831, allowing the conversion of mechanical energy into electricity. This led Robert Anderson to put that knowledge and technology into practice to develop the first electric horseless carriage between 1832 and 1839. However, this vehicle ran on non-rechargeable batteries due to the technological limitations of the time (Burton, 2013). Norton (2016) believes Anderson developed its electric carriage in 1837. Sibramdus Stratingh is also credited with creating some of the first electric horseless carriages before he passed away in 1841. These were at a smaller scale and with non-rechargeable batteries, making it no more than a novelty at the time (Burton, 2013).
To put into perspective, steam and electric were the dominating forces in self-propelled vehicles in the US market at the very beginning of the XX century.

The paradigm shift dawned with the first patent for a proper internal combustion engine (ICE) in 1877 by Nikolaus Otto in Germany (Norton, 2016). A breakthrough in battery technology was made by Gaston Plant in 1859, with the discovery of the lead-acid rechargeable battery, a functional electric vehicle (EV) became a possibility (Erakko, 2023). In 1881, Gustave Trouve unveiled a three wheeled EV with rechargeable batteries, making it the first true EV (fig. 2) (Burton, 2013; Erakko, 2023). In 1887 the breakthrough in pneumatic tire technology by John Boyd Dunlop meant the EV, in particular, could demonstrate its smoothness which would otherwise be lost (Burton, 2013). Anreas Flocken is believed to have designed the first electric car in 1888, the four wheeled German Flocken Elektrowagen (fig. 3) (Norton, 2016). In 1885, Carl Benz created the first gasoline powered vehicle (Burton, 2013). And in 1886, Benz patented the one cylinder, three wheeled automobile. This was followed by the first four-wheel ICE automobile in the world that very same year, made by Daimler, also a one-cylinder engine. The engine was placed ahead of the rear bench, making it the first mid-engine automobile (Norton, 2016). In late 1800s, the electric automobile outsold the ICE automobile 10 to 1 in the US (Erakko, 2023).

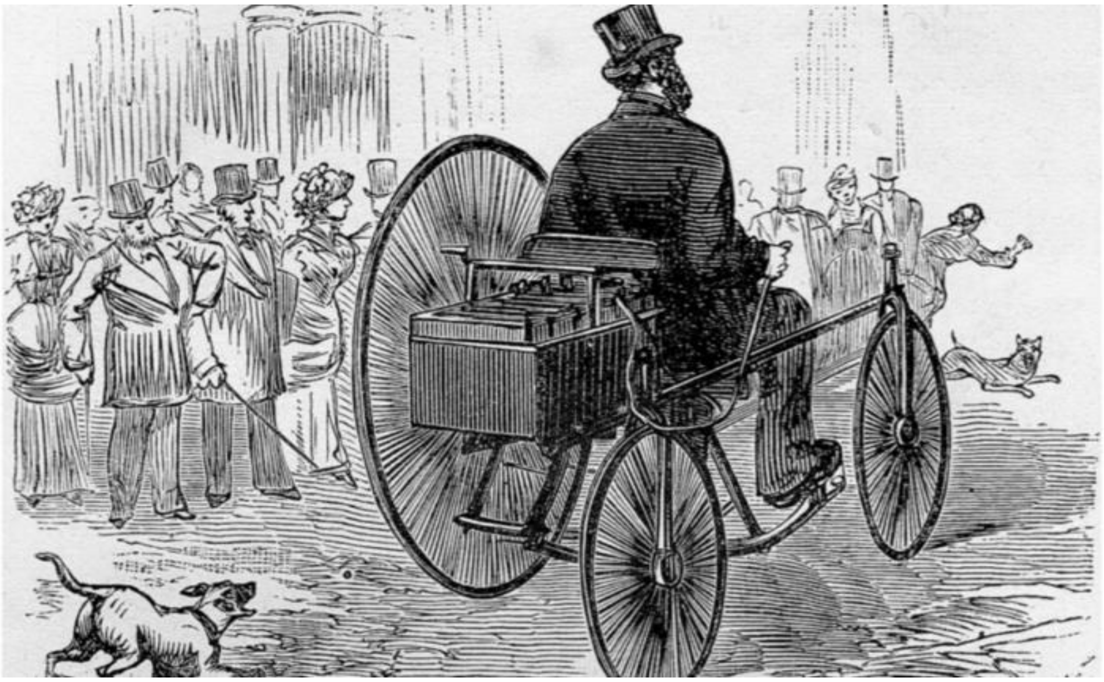


Figure 2: The Electric Tricycle Created by Gustave Trouve (Richard, 2018).

Figure 3: 1888 Flocken Elektrowagen (Franz Haag, 2011).

Thomas Edison joined the field by building his first EV in 1889, a three-wheeler with Nickel-Alkaline batteries (Erakko, 2023). By the 1890s, the EV was in the lead (Burton, 2013). In 1891, the first commercialized four wheeled EV went on sale, built by William Morrison. Electrics of the time had a key advantage over ICEVs, reliability due to less moving parts, this was aided by the fact the electric had, by default, the electric starter

20 years prior to the opposition (Erakko, 2023). These vehicles were no more than horseless carriages built out of wood, some being sold into the early 1900s with solid wood tires, such as the Spider electric horseless carriage, built by Woods Motor Company. In addition, they were not cheap, therefore the customer base was mostly the wealthy until sales began to shift to a new space, cabs. In the US, this movement began with Henry Morris and Pedro Salmo building their first electric in 1894, the Electrobat, and having it patented by the following year (Burton, 2013). By 1897 a fleet of these vehicles was already operating in New York, followed by other EVs such as fire trucks, ambulances, garbage trucks, delivery vehicles, among other (Burton, 2013; Erakko, 2023).

London Followed a similar trend, with dozens of electric cabs, built by Walter Bersey, designer of his own dry batteries, first seen in 1896 and on the road by 1897. Bersey's cabs were nicknamed "hummingbirds" due to their colour scheme (yellow and black) and the sound their motors produced (fig. 4). Tires were being destroyed as a result of the heavy weight of the batteries, which in fact were also suffering lack of reliability due to heavy usage. Bersey was forced to increase the cost of the leases to more than double. This coupled with a fatal accident involving a child, the first in Britain's history, spelled trouble for the electric car manufacturer. Bersey replaced the existing fleet with a new version with improved batteries, but after another accident involving one of his vehicles, Bersey was faced with hostile press. This coupled with rising costs made him give up, selling some of his cabs at a discount to independent drivers and scrapping the rest. The EVs that replaced them achieved success until the appearance of the gasoline powered cab, which offered longer range, replacing the electric fleet completely by the 1920s (Burton, 2013).

Figure 4: 1897 Bersey Electric Cab, nicknamed “hummingbird” (Hurley, 2012).

As this was happening, the ICE was also evolving. Bramah Diplock in England in 1893 patented a three differential all-wheel drive (AWD) system. Daimler created the inline engine in 1895 and Benz the boxer engine (horizontally opposed cylinders) in 1897, both were two cylinders. Finally, the Societe Parisienne in France patented first front-wheel drive (FWD) vehicle in 1898 (Norton, 2016). The Electric Cab proved its capabilities when a Snow blizzard hit New York a year earlier, 1897. Horse drawn Cabs were forced to stop operations, meanwhile the electric cabs kept going without a hitch, due to their 5-inch tires and heavy weight, they had no issue with traction under those conditions. To maintain these vehicles on the road, the charging method used was battery replacement at charging points, allowing the vehicles to be back on the road within a couple of minutes (Burton, 2013).

The EV was proving itself in other ways too, winning the first ever automobile race held in the US in 1895 (Erakko, 2023). Although in longer races the electric car could not complete the distance like an ICEV could. France saw the success of the EV with a purpose-built car breaking the land speed record, achieving a speed of 63.13km/h. This happened at the first ever, 1898 land-speed record attempt, where Chasseloup-Laubat overthrew a gasoline powered car who had just gone 9.6km/h slower right before (Burton, 2013). A year later, influenced by the rivalry between himself and Chasseloup-Laubat, Camille Jenatzy was the first man to break the 100km/h barrier, officially in 29 of April 1899, with a speed of more than 105km/h in his EV called La Jamais Contente (Never Satisfied) (fig. 5). By this point, the electric reigned supreme (Burton, 2013).

Figure 5: Camille Jenatzy after achieving 105km/h, the new land speed record, 1899 (Pelejão, 2018).

In the US this was visible as well, EVs were outselling Gasoline powered cars 10 to 1 in 1898. Data of the time showed five hundred Americans bought electrics while forty opted for gasoline (Erakko, 2023). Of the four options available (horse-drawn, steam, gasoline and electric), the electric was by far the best option. It was refined, smooth, easy to operate, noiseless, easy to start and more reliable, all things none of the three other options possessed all at once (Burton, 2013).

Electric Cabs came to solve a lot of problems the horse imposed, as in New York alone, an estimated amount of 2.5 million pounds (1.1 million kilograms) of excrement and 60,000 gallons (227 thousand litres) of urine, were a daily biohazard occurrence. On top of that, unlike horses EVs could not break a leg and become useless, broken parts could simply be replaced. And to top it all off, 15.000 dead horses impeding traffic had to be removed from the streets on a yearly basis. The self-propelled vehicle meant cleaner streets and a better quality of life in the cities (James Flink, 1974 as cited in Erakko, 2023). The EV was also the cheapest option of the two to run long term, this was due to lower costs and lack of unpredictability that a living animal possesses. It was also, at the time, still much more dependable than contemporary ICEVs, due to their simpler powertrain (Erakko, 2023).

In 1900, the rapidly expanding EVC (Electric Vehicle Company), who by 1899 had finished manufacturing a fleet of two hundred cabs with the latest technology, had been acquiring other EV manufacturers, such as Morris and Salom, and the Colombia and Electric Vehicle Company. The outcome was a total monopoly of manufacturing EVs, achieved with the purchase of Riker Electric Motor Vehicle Company. However, things were not as perfect as they seemed, the EVC showed financial concerns, requiring an injection of capital to stay afloat. The Company was experiencing difficulties as a result of battery failure in their cabs due to heavy usage, destruction of tires consequence of the electrics heavier weight, similarly to Bursey's cabs in London (this however was mitigated with the purchase of the Consolidated Rubber Tire Company), and the appearance of ICE competitors with much longer range figures. This was an early sigh that the EV was no more than a transition from the horse drawn carriage to the ICEV (Burton, 2013). Also in 1900, the first enclosed car body was created, the two passenger ICE Renault "Docter's Coupe", and Speedwell made the enclosed four passenger car in 1911, it was the first to be referenced as a "saloon" (Norton, 2016).

Both disk and drum brakes were invented around the same time, with Frederick Lanchester patenting the disk brake for automotive applications in 1902 and the expanding drum brake being invented by Louis Renault in France that same year. When compared, disk brakes have multiple advantages over drum brakes, the disk is exposed which means better colling and thus less inclined to fade during heavy usage. Additionally, disk brakes are quicker at returning their full capacity after being exposed to water and they offer stronger breaking power, reducing brake distance over drum brakes under the same conditions (Norton, 2016). However, drum brakes are cheaper to produce, require less maintenance through higher surface friction and high corrosion resistance materials (AUTODOC, 2023).

These developments were accompanied closely by not only the first Single Overhead Cam (SOHC) ICE engine, designed by Maudslay Motors in England, but also the introduction of interchangeable parts in production by Henry M. Leland in the US, all in 1902. The subsequent year, 1903, saw the first ICE four-wheel drive (4WD) automobile built by Spyker in the Netherlands trailed by two major breakthroughs just two years later: a patent for a mechanical automatic transmission for ICE applications by the Sturtevant brothers in the US which began manufacturing in 1905, running until 1908; the invention of the turbocharger by Alfred j. Buchi in Switzerland, also in 1905. The first automotive application of the turbocharger came much later however, with its invention being originally aimed at aircraft applications. That same year, the first cars with independent suspension were built by Sizaire Naudin in France and Christie in the US, also both in 1905. It is notable that many of the current ideas and technologies have their origins in the early years of the car industry (Norton, 2016).

The decade of 1900 to 1910 saw the apogee of the electric car with, for example in the US, 40% of all vehicles sold in the first year being electric, and just 22% being gasoline. The electric had ease of use on its side, and it did not burden the driver with the complicated contemporary manual transmission. Electric car companies of the day believed the EV was the future, and that a battery technology breakthrough was just around the corner. The short range became an issue when smooth roads were constructed connecting towns, making those journeys desirable (Burton, 2013).

In another hand, Erakko (2023) argues it was the lack of a proper road system that killed the electric. Roads were very primitive, even within cities, which affected the practicality of the electric automobile. Electrics were heavy, due to their batteries, and would get stuck in mud up to the axles. Meanwhile, the lightweight ICE Model T for example could be easily pushed out of a pothole by a single person (fig. 6).

Figure 6: 1909 Ford Model T, photo taken at Museu do Caramulo.

The year 1900 also saw the first four-wheel drive electric car, the Lohner-Porsche one-off special called Le Toujours-Contente (Forever Satisfied). It came equipped with a technology developed by Ferdinand Porsche, motors mounted directly in the wheel hubs, yielding an efficiency of 83% due to the lack of gears or driveshafts. Porsche won the 1901 Exelberg Rally driving the Lohner, with magazine reviewers complementing the cars composure through the corners. In total, three hundred all electric Lohner-Porsche cars were built, ranging from 10,000 to 35,000 Austrian Crowns depending on the options. To address the weight related issues (tires and range), Porsche set out to fix them by creating the first hybrid, a gasoline-electric vehicle called the Semper Vivus (Always Alive) (fig. 7). With two ICEs and two electric motors mounted at the front wheel-hubs, it was able to drive on electric power alone until the batteries were depleted, turning on the combustion engine to recharge them (Burton, 2013).

The production vehicle, ready in 1901, was named the Lohner-Porsche Mixte. To address the weight issues of the Semper Vivus it was equipped with a smaller battery, meaning range on electric power alone was reduced, and had the dual single cylinder combustion engines replaced by a single 5.5 litre 4-cylinder unit. It was also equipped with regenerative braking and a starter motor in the form of the generator, five Mixte were sold in 1901. Porsche Raced a Mixte with improvements in 1902 in a mountain race where he achieved first place. Unfortunately, due to the incredibly steep price of the Lohner-Porsche (double of a conventional car), even with all its technological advancements it translated into low sales, only managing to sell eleven examples. The full electric version however saw sixty-five vehicles sold until the end of 1905. That same year Porsche was awarded “as Austria’s most outstanding automotive engineer in recognition of his groundbreaking efforts”, leaving the company the following year for Daimler-Benz. Others quickly followed suit in developing hybrids, like the Paris Electric Car Company with the Krieger hybrid in 1903 being especially similar, and the Belgium Auto-Mixte in 1906. Ferdinand Porsche’s innovative design, the wheel hub electric motor, was later used on NASA’s moon rover (Burton, 2013).

Figure 7: Semper Vivus (Porsche, 2020).

The decline of the EV can be exemplified by what happened in the US: in 1915 the total amount of EVs on American roads hit 50,000, but the new vehicle registry was over 500,000 vehicles a year by then. Just 15 years later (1930), practically no electrics were being manufactured. Lack of infrastructure played a large part, not only were people with EVs in the cities struggling, but the American countryside was also almost completely deprived of electricity. Once outside the city, finding a charging station for an EV became extremely unpredictable. Consequently, charging at home became the preferred method due to its convenience (fig. 8). Potholes and lack of access to electricity were enough to kill the first electric automobile movement (Erakko, 2023).

Of the 38,842 electrics on the road in the USA in 1912, the best year for the electric in America, the majority were owned by big name companies (Erakko, 2023). None the less, the appearance of the electric starter motor that same year by Cadillac’s Charles F. Kettering sealed the fate of the EV (Burton, 2013; Norton, 2016).

The Milburn Charger

For those who wish to keep their car at home and do not have access to direct current, we recommend most highly the Milburn Charger, designed and manufactured especially for use in connection with the Milburn Light Electric.

This Charger is so designed that it is impossible to injure a battery while on charge. It automatically starts and tapers off at the proper rate. Any child can operate it—it being merely necessary to insert plug in charging receptacle and throw wall switch.

The use of this Charger will add to the life of the battery.

When wound for 110 or 220 Volt 60 Cycle Alternating Current the price of this Charger is $145.00 F. O. B. Toledo, Ohio.

For variations in voltage or cycle there will be a slight additional charge; prices quoted on application.

Milburn Dealers

Responsible dealers represent us in most large centers. They have our cars on hand to show and demonstrate.

If you do not know where to find the Milburn dealer in your locality, write to us and we will gladly supply his name and address.

With our increased production capacity we are prepared to extend our dealer organization. If we are not represented in your city we may find it advisable to establish a local dealer, and will be pleased to correspond with responsible parties to that end.

Figure 8: The Milburn home-charger (Burton, 2013).

Another issue was the short-range spelling the “Achilles heel” of the EV. The Woodrow Wilson presidency in the US used Milburns, which had a claimed range of 160 miles (257 km), but reports from the presidency claimed otherwise, stating a real range of 60 – 70 miles (97 – 113 km) (Norton, 2016). Ample availability of cheap gasoline on the other hand substantiated the ICEV argument. Even in the most rural of areas, there was always a convenience or merchant store where one could buy gasoline from. It had the added benefit of being easily storable, and able to be carried in the vehicle for an emergency, the same not being possible in an EV. Additionally, Gasoline powered cars took merely a few minutes to fill up, this was not the case for electric charging times, always taking a few hours. Where costs are concerned, in the US a kilowatt was worth 23 cents in 1903, while a gallon (3,79 liters) of gasoline was worth 10 cents, a decade later the opposite was true, a kilowatt was 7 cents while the gallon of gasoline was 23 cents. Costumers, however, were not looking for economy concerning money, but concerning time, and the gasoline car managed to do that efficiently. The issue in the US was simple, people did not want to own a car with a range of just 30 miles (48km) in a country with a length of 3000 miles (4.828km) (Erakko, 2023).

An important invention came along in 1905 by Henri Pieper, the Pieper’s patent, granted March 2nd 1909. It consisted of using both electric and combustion powers simultaneously to achieve better performance, akin to modern hybrid solutions. His work also included an engine mode selection through a hand-lever, making it the first engine management system. His innovation was ignored by car manufacturers of his day. By the time the patent was granted, the Model T was already on the road, the decisive moment that ended the first electric versus combustion market battle. While Pieper was developing his idea, Daimler-Benz was already at work on the Mercedes Mixte (Burton, 2013).

The hybrid vehicle saw developments outside of Europe as well, Galt motor company of Canada used a combustion engine to drive a generator, Chicago-based Woods had a combustion engine connected to an electric motor in 1916 and Owen Magnetics also had a hybrid by 1921, although without any direct connection between the combustion engine and the wheels (Burton, 2013). Other significant breakthroughs of the time were the first ever four-wheel mechanical brakes in a vehicle, by Isotta Fraschini in 1910, and the first Dual Overhead Cam (DOHC) engine, designed in 1912 by Peugeot in France (Norton, 2016).

Prior to the electric starter motor on ICEVs, there were two qualities separating the “men’s” car from the “women’s” car, those being the enclosed passenger compartment and the ease to start. A men’s car had an open cabin because they needed no such luxuries. It also had a hand crank to start the engine, something women preferred not to have to do, in large part due to how dirty the streets were on account of horse droppings. With the appearance of the enclosed cabin in ICEVs, men could finally enjoy comfort without being perceived as “less masculine,” leaving the manual starter as the last differentiator of “masculinity” surrounding the ICEV versus the Electric debate. As previously mentioned, the introduction of the electric starter, developed by Kettering and first introduced in a Cadillac in 1913, meant the final dividing piece was lost, men could enjoy comfort while women could finally enjoy ease of use in a gasoline powered vehicle (Erakko, 2023).

1.2 – The Assembly Line Revolution and the rise of Gasoline: 1914-1918

With the electric starter motor, women began to opt for gasoline powered cars in large quantities. By 1915, out of the 425 women who owned cars in Tucson, Arizona in the US, only thirty drove an electric. The monopolies of ease of starting and comfort were gone, the electric had lost its leverage (Erakko, 2023).

Manufacturing an automobile, using traditional methods, used to take 12,5 hours. The game changed when Walter Chrysler installed rails on the floor on his factory. The chassis of the vehicle being manufactured could be moved by the workers from station to station, resulting in four times the amount of production in the same timeframe (Erakko, 2023). Henry Ford Applied this approach to his factories in 1913 (Hennessy & Hester, 2011). Fords moving assembly line however had the chassis moving at a set speed at waist height, yielding a 93-minute car, a twelve-fold increase. Just a year later, in 1914, the Ford Motor Company hit a production of 1000 a day and to maximise productivity, only one colour was offered, black, because it was the quickest to dry (fig. 9). This lasted between the years 1914 and 1926 (Hennessy & Hester, 2011).

By WWI half the cars in the world were Ford Model Ts. The introduction of the assembly line cut production time, and consequently, production costs, leading to an almost 50% cost cut of a Ford Model T by 1915. The result was a sales success that barely kept up with demand (Erakko, 2023). The Model T came to market with a cost of $850 in 1908 while others sold their cars for around two to three thousand dollars, 19 years later the price had dropped to $260, giving every working person the opportunity to purchase one. High quality materials meant greater strength, and therefore, less need for materials used in parts, which reduced costs (Norton, 2016). Ford spearheaded the use of vanadium Steel to achieve this, light weight and robust (Hennessy & Hester, 2011). With fifteen million cars sold between 1907 and 1927, the Ford Model T became the best-selling automobile in the world, a record that stood for many years, only being broken by the Volkswagen (VW) Beetle (Norton, 2016).

Figure 9: Ford Model T assembly line (Panchal, 2017).

All major EVs manufacturers had given up on the EV by 1918. Between 1900 and 1920, the electric went from being deemed "unrivalled" to forgotten, with the gasoline powered car controlling the market by the mid-1920s. The electric was expensive, bought only by the wealthy, and with the introduction of the mass-produced Ford Model T with an unrivalled price point, the middle class could finally afford a motor vehicle. Since the majority did not have the financial capacity to purchase a second vehicle for just city driving, gasoline power was chosen, not only for being cheaper, but also as it offered the best overall performance. Advancements in electric technology were lacklustre as well, with the range of the first Electrobats of 1894 being similar to those of vehicles released more than a decade later, like the Milburn Light Electric. Hybrids also failed to give a solution to this by being too expensive and unreliable. Likewise, they disappeared by the 1920s due to high cost, battery unreliability, lack of a proper road infrastructure and reduced range. All these disadvantages by themselves would hurt any upcoming means of transportation, but combined meant the gasoline alternative simply made more sense. When compared with the present day, even though many of those drawbacks still constrain the electric, it now finally has rechargeable batteries with decent energy density, along with government support, with major manufacturers involved and the public knowledge that a cleaner option needs to exist (Burton, 2013).

1.3 – The Golden Age of Innovation: 1918-1939

The first electric age was over, by 1930 only one electric car manufacturer remained, and it built handmade costume cars to client's specs (Erakko, 2023). Therefore, in this section, almost all the developments described relate to ICE powered vehicles.

Renault, as previously stated, may have been the first to manufacture and sell a closed passenger car with its two-seater in 1900, however, it was not until Speedwell unveiled a closed sedan in 1919 that the industry quickly followed suite. This led some to manufacture vehicles with all steel and others steel over wood, with the second method enduring into the 1930s. Early cars had open tops due to lack of power, as engines of the day struggled with the extra weight of a closed car, but with the evolution of engine technology, the standards began to change. In 1920, the percentage of closed body cars was merely 17%, jumping to 55% by 1922 and again to 85% by 1927. Concerning the manufacture of all-steel bodies, Citroën was the first in Europe to do so by 1925, having paid royalties to the patent holder, the Budd Company (Norton, 2016).

In 1918, Lockheed invented hydraulic brakes with a focus on aircraft use. Duesenberg brought this technology to the automotive industry in 1921, with the first ever use of four-wheel hydraulic brakes in an automobile, as until then all brakes were manual (Norton, 2016).

Up to this point, all automobiles were built as body-on-frame, with the frame and body being either steel or wood (Norton, 2016). Body-on-frame construction increases strength for towing capacity at the cost of increased weight, poor torsion rigidity and a higher floor. Nowadays this method is mostly reserved for pickup trucks or Sport Utility Vehicles (SUV) with off-road use in mind (Macey & Geoff, 2014). Additionally, body-on-frame, or ladder frame (due to resembling a ladder with crossbars connecting two large side beams), facilitates the use of a single frame design for different vehicle bodies of the same brand, reducing cost (Furman, 2023). For this reason, a single frame can have a variety of different bodies placed on top, namely the previously mentioned example of brands such as Doble, Rolls-Royce, and Duesenberg, among other (fig. 11). This allowed consumers to send the chassis to a coach builder for a unique vehicle body (fig. 10) (Norton, 2016).

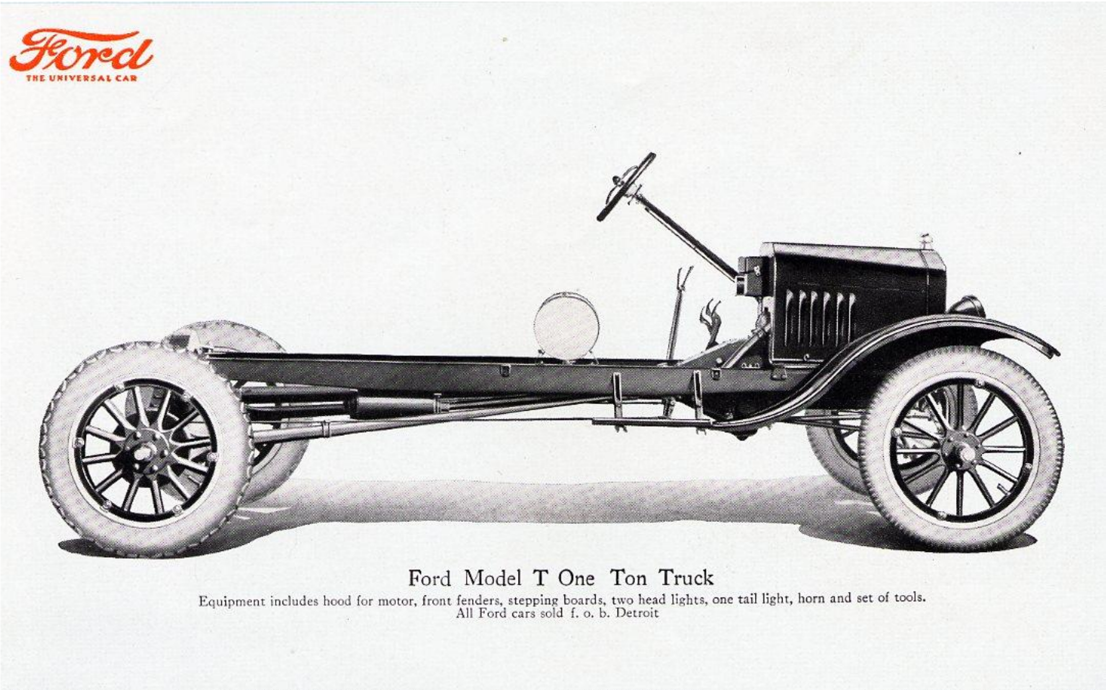


Figure 10: Ford Model T chassis displayed in a Ford brochure (1920 TT chassis, 2009).

Figure 11: 1930 Rolls-Royce Phantom II Sports Coupé, aluminium body by Weymann. Photo taken at Museu do Caramulo, Portugal.

In 1922 Lancia debuts the first partial monocoque in a production automobile with the 1922 Lambda, being sold until 1931 (fig. 12). Monocoque, (meaning single shell in French), or Unibody in English, denotes a sole structure where stress is distributed throughout the body of the vehicle, culminating in better rigidity and less weight. This improvement meant ten times more body the rigidity over a body on frame vehicle, hence why unit-body construction is the prevalent method today, although as previously mentions, some continue to build body on frame for specific vehicles, such as light trucks and SUVs sharing that same platform (Norton, 2016).

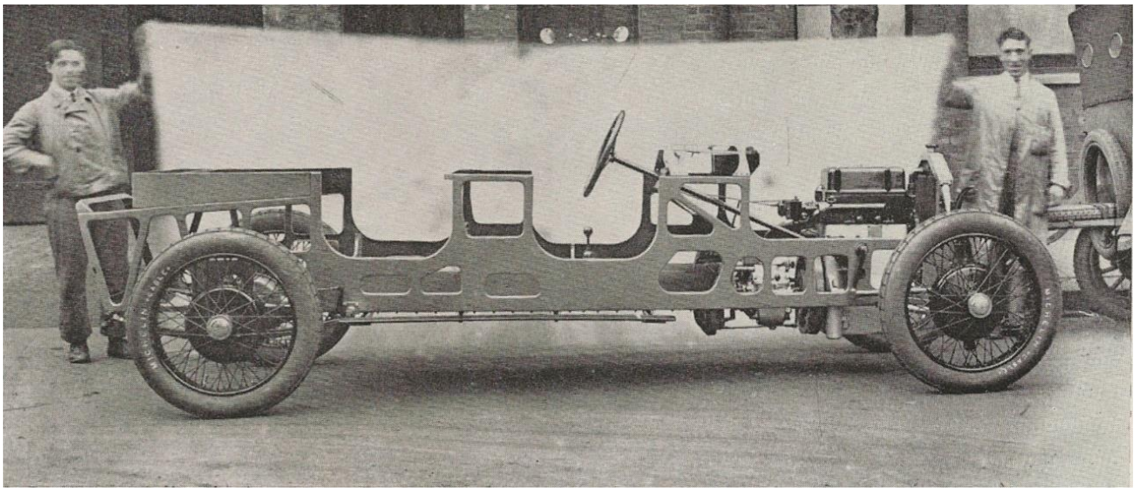


Figure 12: 1922 Lancia Lambda unibody (Branch, 2016).

In 1926 Francis W. Davis invented the hydraulic power steering, and had it patented by 1928, this was followed by Francis Wankel in 1929 with the Wankel engine, also known as the Rotary engine due to the rotary shaft in rotation at its center, therefore void of any cylinders. This engine design makes it extremely smooth when coupled with a second rotor placed 180° to the first. The Wankel engine, manages to produce similar power to a conventional piston engine using lower displacement, making also smaller and lighter, but has enormous disadvantages, such as a huge fuel consumption, oil consumption and a short life span, never becoming mainstream in the automotive industry. The Anti-lock braking system (ABS) was also invented that very same year by Gabriel Voisin for aircraft applications, only becoming a mainstream addition in automobiles in the 1970s (Norton, 2016).

Streamlining denotes aerodynamic efficiency in car design. It allows a vehicle to achieve a certain speed using less power than it would have otherwise. The lower the drag coefficient, the better. Cd or Drag coefficient is a quantitative figure used to quantify the resistance given by a body moving through air or a liquid. The smaller the Cd value, the greater the efficiency of the body in question (Norton, 2016).

The zeppelin, designed by aerodynamicist Paul Jaray, served as a proof of concept of the teardrop shape (still used in aircrafts today), with the broad segment at the front. Jaray helped Tatra with streamlined car body design, the first sample of this cooperation being the T77 (fig. 13). The 1934 Tatra T77 had a Cd of 0.24, which makes it an incredible achievement for the time. For context, cars from 1939 were near a Cd of 0.50 (fig. 14). The T77 achieved greater efficiency than the 0.29 Cd C6 Corvette, a sportscar from the XXI century, and matching the first Tesla Model S (Norton, 2016).

Figure 13: 1934 Tatra T77 (Ross, 2023).

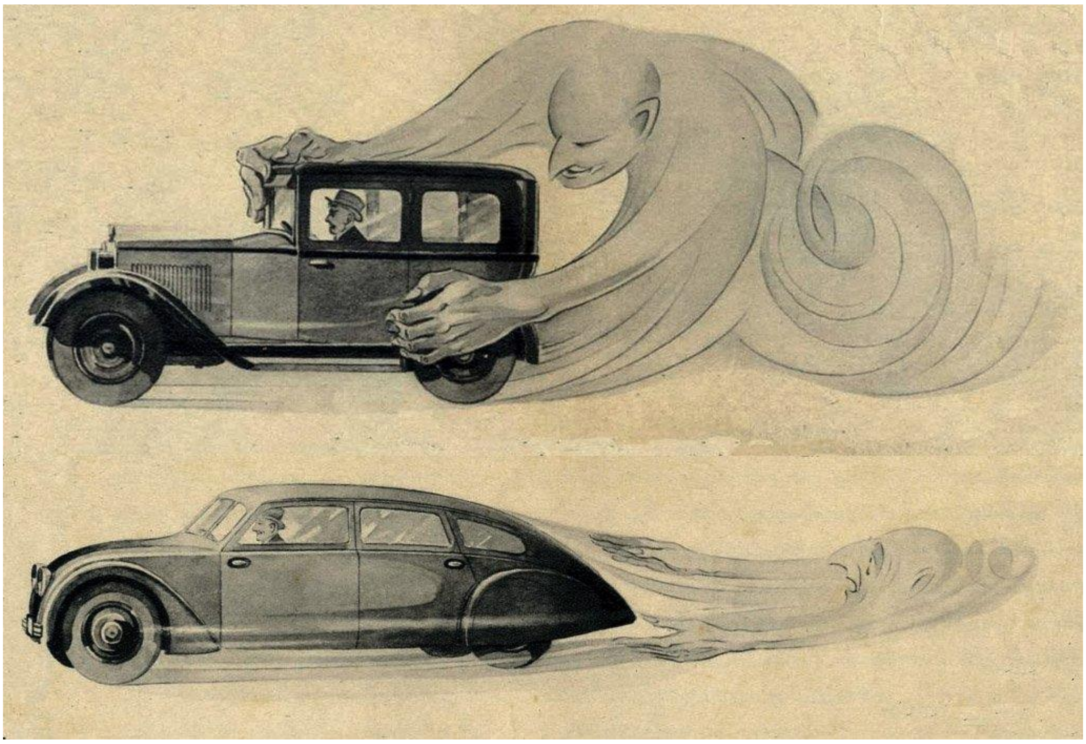


Figure 14: Tatra advertisement from the 1930s (Imgur, 2016).

The 1934 Chrysler Airflow was not only a milestone in aerodynamics for the automobile in the US but also the first American car to move towards unit-body construction (fig. 15). Its chassis was modified from the norm, usually, car manufacturers of the day placed the rear bench seats above the rear wheels, shifting the weight distribution towards the rear and increasing polar moment of inertia. On the airflow however, the rear bench seats were pushed forward, forcing everything in front to move as well, resulting in the engine being moved from behind the front axle to above it, improving weight distribution to a near 50/50 split and decreasing the polar moment of inertia. Less weight at the back also meant the ability to run softer springs on the rear axle, which led to a better ride (Norton, 2016).

Polar Moment of Inertia denotes that a vehicle with its weight distribution closer to the center of gravity will have superior handling, such is the example of front engine rear-wheel drive (RWD) or the mid-engine layout. A front-engine FWD vehicle however, with weight biased towards the front, will naturally have a worse weight distribution across the chassis, seeing as both the engine and driven wheels sit on the same axle and the same is true for rear-engine rear-wheel drive cars. This creates a pendulum in rotation not seen in the other mentioned layouts, because they tend to have a lower polar moment of inertia (Norton, 2016).

Figure 15: 1934 Chrysler Airflow Coupe (Paddock, 2022).

The Airflow with its revolutionary aerodynamic design proved too much of a leap for the public. Among the changes, including the fender integrated headlights as opposed to the traditional position on top of them, the slanted V shaped windshield replacing the common flat glass position of the time and the previously mentioned change in rear passenger bench placement which allowed the body to be sloped and thus achieving a smooth angle towards the rear bumper. However, the change that gathered the strongest negative reaction proved to be the front grill, no longer a vertical radiator but a sloping “waterfall” grill. As such, Chrysler reverted to the traditional, less aerodynamic, vertical grill after 1935 (fig. 16) (Norton, 2016).

Figure 16: 1937 Chrysler Airflow with the updated vertical radiator grill (1937 Chrysler Airflow Series C-17 Eight Coupe, 2023).

Citroën launched in 1934 the first mass produced FWD vehicle in the world, the Traction Avant (fig. 17) (Norton, 2016). This drive train layout would grow to revolutionise the automotive industry, becoming the most common in market share with over 48% of vehicles worldwide being FWD in 2023 (Fortune Business Insight, 2024).

Figure 17: 1951 Citroën 15-Six D "Traction Avant", this particular vehicle is a replica of the car raced by João Lacerda at Rally Monte Carlo. Photo taken at Museu do Caramulo, Portugal.

1.4 – Conflict, Innovation, and the Car for the Masses: 1939-1945

In Germany, Hitler wanted a car for the people, and Ferdinand Porsche rose to the occasion with what became the Volkswagen Beetle in 1937 (Erakko, 2023). Hitler's request was essentially a car following Tatras essence, more precisely the 1933 Tatra V570. Notable similarities were the air-cooled engine, the rear engine placement, and the fact it was a flat boxer unit. Other hints were seen in its shape, also taking a page from Tatras book on its streamlined design. Consequently, Tatra filled a lawsuit on grounds of patent infringement although at first nothing came of it, Hitler's invasion of Tatras home country Czechoslovakia in 1938 led to it being forcefully dismissed at that time, but was later settled after the war ended, with Volkswagen paying a determined amount in compensation for patent infringement. Produced at first merely for military use, civil use did not take place until after the war, when the factory was ordered to resume production under British occupation (fig. 18). It was later returned to the Germans in the 1950s (Norton, 2016). Production of the standard variant took place in Germany until 1978, with the cabriolet being made until 1980. That, however, was not the end of the Beetle, seeing as its production continued in other parts of the world, with the last one built coming out of a factory in Mexico in 2003 (Hennessy & Hester, 2011). It surpassed the Model T in sales with the record number of twenty-one million vehicles produced

(Hennessy & Hester, 2011; Norton, 2016). The Beetles success boils down to a couple aspects: price; Reliability and its ability to be cheaply produced; Relatively high efficiency due to its low weight and streamlined design, resulting in reasonable performance for the power output; Usability subsequent of the large wheels and torsion-bar suspension that made it ideal to tackle worse roads; And dependability, resultant of mechanically simplicity and a very low stressed engine, with a low power output, which assured reliability (Hennessy & Hester, 2011). Additionally, the rear engine position allowed the car to suffer front end collisions and survive, eventually gaining the reputation of being nearly indestructible (fig. 19) (Erakko, 2023).

Figure 18: Part of the first batch of cars built under British occupation (Volkswagen, 2019a).

Figure 19: 1952 Volkswagen Beetle Typ 11 Export. Photo taken at Museu do Caramulo, Portugal.

During the Second World War, some manufacturers were forced to build electric cars due to restrictions imposed to preserve gasoline. Peugeot unveiled a micro electric car in 1942 called Voiture Legere de Ville, three hundred and thirty-seven were built before an electric car ban was imposed by Germany. Post WW2 Japan also encountered major difficulties and, as such, a small two door EV was made as an answer to the country's needs. It went on sale in 1947 and was called the Tama E4S-47-1 (Burton, 2013).

1.5 – The Automotive Boom: 1945-1973

In Europe, the Citroën 2CV appeared in 1948, it was to France what the Model T was to America, an inexpensive way to get the average working person on wheels capable of using degraded roads. Introduced after the war, it gave people in the countryside an alternative to the horse, with four million being sold until 1990 (Norton, 2016).

In 1958 the first automotive application of ABS was made by Jensen on its FF model, although mainstream adoption began later. The following years, the revolutionary 1959 Austin/Morris Mini-minor was released. It may not have been the first transverse engine FWD car, but it quickly became a staple of the FWD hatchback world. Earlier examples of this layout are the briefly produced English Lloyd of 1946 and the Japanese Suzuki Suzulight of 1955. Sir Akec Issigonis, designer of the Mini-Minor, took advantage of this layout to increase interior space. With the wheels placed closed to the corners, the result was a great handling, small, light, and economical car that could carry four people. Most of the FWD cars nowadays follow this blueprint (fig. 20) (Norton, 2016).

Figure 20: The first mini, 1959 (Mini, 2023).

By the 1960s people began to realize the ICE was not perfect, and cracks in the narrative were beginning to show. The US National Conference on Air Pollution Control concluded in 1962, through acquired evidence, that air pollution contributes to respiratory chronic disease. The ICE produced, in the 1960s, more than 150 identifiable chemicals (Erakko, 2023).

Car safety was also beginning to gain traction, with the pioneering use of purposeful crash deformation in Mercedes Benz cars. Béla Barényi is responsible for the invention of the crumple zone. The Daimler-Benz engineer has his name on over 2500 patents, but the one issued in 1952 outlines how an automobile with areas built for deformation can absorb kinetic energy from an impact, taking that energy away from the driver and passengers which sit inside a rigid section. This development was put into practice in the 1959 Mercedes-Benz W111 Fintail, making it the first ever car with crumple zones (Barényi, 2010; Grabianowski, 2009).

The impact through deformation became the example of what should be done with the automobile, having the vehicle absorb the energy of the impact as opposed to the passengers. Additionally, a study conducted in 1960 by the Cornell Aeronautical Laboratory concluded that seatbelts resulted a near one third reduction in injuries (Erakko, 2023).

General Motors (GM) attempt at their first electric car during this time was the “Electrovair,” a concept based on a 1964 Corvair, with a second-generation concept unveiled in 1966 (fig. 21) (Burton, 2013). The Electrovair II used silver-zinc batteries which, according to GM, cost $10,000 (Erakko, 2023).

Figure 21: The Electrovair (Burton, 2013).

GM also developed the first hydrogen fuel-cell vehicle, but due to safety concerns it never became anything more than a concept (Burton, 2013). The vehicle was called Electrovan, and it was the first attempt of the automotive industry at capturing the large energy source available in account of the combination of hydrogen with oxygen to form water (Erakko, 2023).

Other North American brands began developing concepts as well, Ford developed the Comuta, a small 200cm in length electric car prototype that was unveiled in 1967 (Burton, 2013). The prototype was built in England with its focus on the city environment. Small, electric, affordable and it followed corporate criteria. It was never put into production and, as soon as media attention faded, production plans vanished (fig. 22) (Erakko, 2023).

Figure 22: The Comuta prototype, Ford's attempt at an electric city car in the 1960s (Burton, 2013).

As previously stated, ABS was invented in 1929. However, it wasn't until 1971 that the first use of ABS for automotive applications in all four wheels was made by Chrysler on the Imperial, with an ABS system by Bendix. Other manufacturers such as Ford and Gm also offered this technology around this time but on the rear wheels only. Nowadays it comes as standard in all modern cars and even motorcycles, where it managed to have a 37% reduction in fatalities when introduced. ABS was a noteworthy breakthrough in safety, reducing accidents by being a major tool in safely stopping a vehicle, particularly on slippery conditions (Norton, 2016).

In 1959, Volvo engineer Nils Bohlin introduced the three-point seat belt in the Pv544. Volvo then waved the patent rights, making it available to every manufacturer and saving millions of lives in the process (Volvo, 2020a). In 1968, lap belts or lap and shoulder belts were made obligatory in the US for all vehicles, including front and rear seats (U.S. Department of Transportation, 1972). In 1991 the European Union (EU) introduced a legal requirement for the obligatory use of seatbelts in all seats that have them equipped, taking effect in 1993 (EU, 2017).

The idea for Electronic Stability Control (ESC) came to Mercedes-Benz engineer Frank-Werner Mohn in 1989, after skidding into a ditch during testing in the snow. Two years later the technology received approval to go into production, making its debut in the 1995 Mercedes S-Class (Autocar, 2017). A gyroscopic sensor and steering angle sensor allow the system to detect the cars direction and steering angle. When these become unaligned, the system applies the brakes to each individual wheel, correcting the cars trajectory (Autocar, 2017; Norton, 2016).

Other safety breakthroughs include the use of independent suspension, which began gaining traction in Europe in the 1920s, and in the United States of America (USA) in late 1930s. By 1929 several manufacturers had either independent front suspension (IFS) or independent rear suspension (IRS), but nine manufacturers had both (Norton, 2016).

The first Air pollution legislation was passed in 1955 in the USA, with the administration being part of the newly formed Environmental Protection Agency (EPA) in 1970 (Fenger, 2009). The Clean Air Act passed that same year set limits for hydrocarbons (HC), nitrogen oxide (NOx) and carbon monoxide (CO), forcing new cars to meet EPA emission standards (EPA, 2023).

With the 1973 Oil Crisis the west realised it was economically at the mercy of the of the Middle East, public interest for large gas guzzlers went down and interest for small economical cars was at an all-time high in the USA. All post war United States (US) cars were RWD except for two models, but the sudden interest for European and Japanese small FWD economy cars forced Detroit to adapt. By the mid-1990s the majority of cars sold by US manufacturers were FWD (Norton, 2016).

The first form of variable valve timing (VVT) engine patents were bestowed in the 1920s in the US. However, the Italian manufacturer Alfa Romeo was the first to produce an engine with VVT in 1972. To achieve better performance, one would need to run a more aggressive camshaft, increasing engine efficiency at higher revolutions per minute (RPM) at the expense of performance at lower RPM. Variable valve timing allows an engine to run the appropriate valve profile across the rev range, resulting in not only better performance, but also better efficiency and fuel economy, that’s one of the reasons mainstream interest for this technology resurfaced in 1973 (Norton, 2016).

1.6 – The Efficiency and Globalization Era: 1973-2009

The 1973 oil crisis forced governments to rethink fuel consumption, more so the USA than any other due to the country’s reliance on large displacement, inefficient engines, unlike the European and Japanese markets which already had small more efficient units (Burton, 2013).

During this time, a couple manufacturers began developing concepts and low volume EVs. In 1984, Peugeot launched an electric variant of their 205 model, it lasted only that model year. During this time, Volkswagen also developed and sold EVs, these were based on the Golf and Jetta platforms and had the name citySTROMer. Audi, in 1990, unveiled an EV called the Audi Duo, which ran for three generations, with the third being sold to the public, but not too much success. In 1992 Renault showed the Zoom concept to the world, a small EV with the ability to reduce its length tilting the rear upwards, making it easier to park in small spaces. In 1992 Citroën also unveiled an electric concept, equipped with a modular system which allowed it to transform to a pick-up or estate, according to the needs of the user. In 1995 Peugeot began selling the 106 Electric, with 2,000 being sold in its home market alone (Burton, 2013).

In 1986, the Mercedes VaMoRos van equipped with Saccadic Vision, Parallel computers and Kalman filters, was developed by Ernst Dickmann Bundeswehr in Germany at the university of Munich. It achieved a speed of 96km/h on a 20km stretch of street without traffic in a completely autonomous fashion, a considerable step for Autonomous vehicles (Avs) (Research Car Design, 2016).

AV development can be traced back to the first radio-controlled car in the world, the “Linriccan Wonder” of 1926. Presented in New York by Houdina Radio Controller, it was controlled by a second vehicle close by which sent signals, then received by the antennae of the driverless car (Bimbraw, 2015).

The Stanford Cart, developed in the 1960s, later further developed by Hans Moravec in 1979, traversed a room full of chairs without external intervention (fig. 23 and fig. 24). Up to this point, attempts at Avs relied on preexisting systems imbedded in the road to function, such is the example of RCA Labs and GMs prototype first in 1953 and later in 1958 at a greater scale. It involved the use of detector circuits embedded in the road that then communicated direction and speed to the vehicle. The Transport and Road Research laboratory in the UK attempted a similar feat during the 1960s, using a Citroën DS, and two cabled under the road, one controlling speed and the other steering, among others attempts (Research Car Design, 2016).

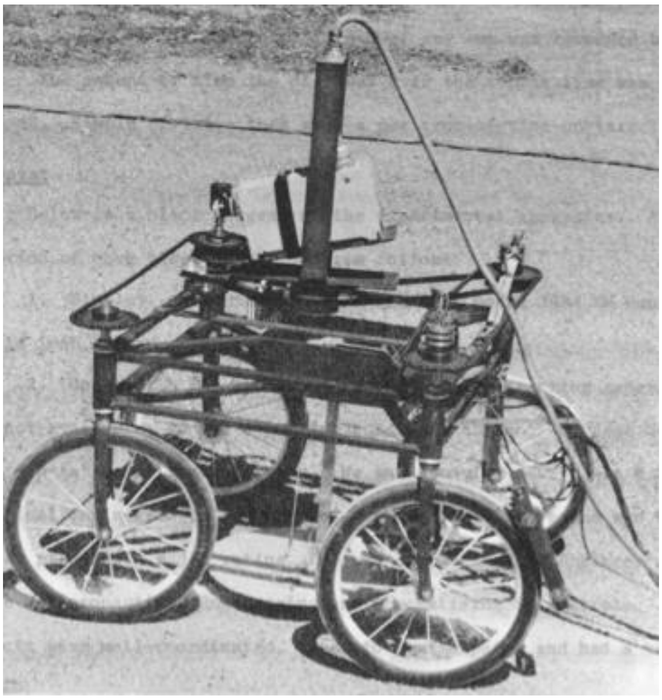


Figure 23: The Stanford Cart in 1961, with cable (Earnest, 2012).

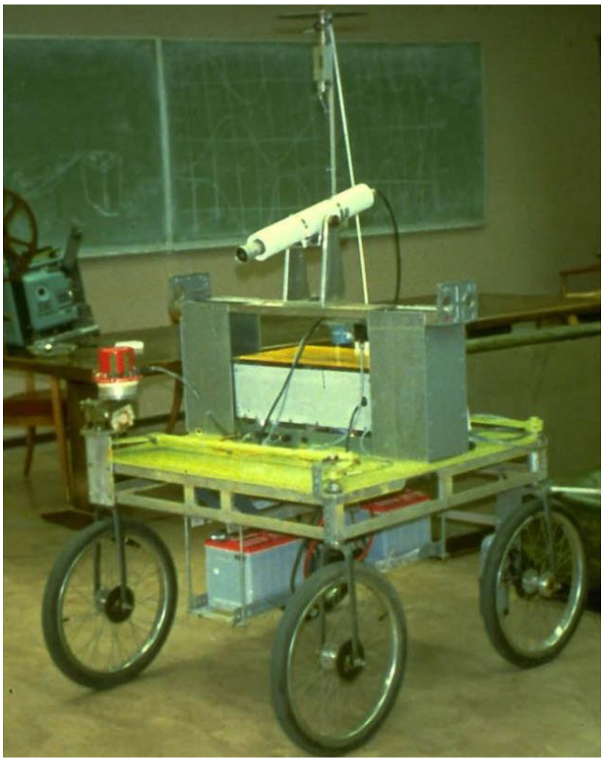


Figure 24: Stanford Cart with slider, 1979 (Cyberne1, 2009).

An S class, based on the technology developed in the Mercedes VaMoRos van was later developed in 1995. Able to identify road markings and possessing positional awareness of itself and other vehicles, it performed a 1600km trip with merely 5% human intervention and achieving speeds up to 177km/h (Research Car Design, 2016).

The 1987 to 1995 Prometheus programme saw an unprecedented amount of funding be put into the development of AV technology in Europe where multiple projects, including the Mercedes VaMoRos van and S-Class, were developed to further this technology. The DARPA challenge, created in 2004, served a similar purpose in the US, to further technological advancements in the AV field. A monetary prize was given to the project able to complete a closed course in the shortest amount of time (Research Car Design, 2016).

During the early 90's, GM was developing the first mass produced purpose built electric of the modern age with the EV1, beginning deliveries in 1996. The car was not sold to the public, being exclusively available through a lease contract, so the consumers never legally possessed true ownership of the vehicles. With a drag coefficient of 0.19, it was the best of any production vehicle. However, due to a lack of interest, the programme was cancelled, and the cars were taken back to GM at the end of the lease contracts. Only a few remain in museums without the power train, all others were destroyed (fig. 25) (Burton, 2013). It must be stressed that the first generation EV1 still used conventional Lead-Acid batteries, basically the same technology invented in 1859. The second-generation model however used Nickel-Metal Hydride (NiMH) batteries (Burton, 2013; Scott, 2023). Developed by Stanford Ovshinsky, the NiMH battery uses potassium hydroxide as an electrolyte, which is safer when compared to the sulphuric acid mixture found in lead-acid batteries. NiMH batteries also have higher energy density and power, a much longer life cycle and a stable power output, regardless of state of charge (German, 2004; Scott, 2023).

Figure 25: General Motors EV1 (Winfield, 1997).

In 1996, Toyota began selling the RAV4 EV, an electric variant of the traditional RAV4, with the only difference in the exterior being the lack of an exhaust pipe. The second-generation Toyota RAV4 EV, unveiled in 2010, was developed with the cooperation of Tesla (Burton, 2013). Like the second-generation EV1, the RAV4 EV was also equipped with a Nickel-Metal Hydride battery (Scott, 2023).

The year 1997 was marked by the launch of the Toyota Prius, the first mass-produced hybrid and winner of many awards, including the Japanese Car of the year award and New Car of the year award simultaneously, a first in the industry. With the Prius, Toyota aimed to be the leader in this new era of the automobile, they saw the American clean-car initiative, and they wanted to achieve it first. The clean-car initiative aimed to push American manufacturers to build accessible and appealing cars with fuel economy up to three times more efficient, all in a ten-year window. Toyota was also aware of rising demand in large markets such as India and China, which would drive fuel prices upwards, making an extremely fuel-efficient vehicle even more desirable. The project, completely made in-house, became the company's top priority. During production, it was concluded that improving ICE technology would not be enough, and that hybridisation would be required. The Prius would use a parallel design, using the ICE and an electric motor (Burton, 2013). A parallel system consists of having both means of propulsion connected to the wheels, meaning both can be used to propel the vehicle. This system is the most used currently (Denton, 2020).

The result was a highly efficient Atkinson Cycle principled 1.5 litre engine, an electric motor, and a generator. The Atkinson cycle, invented in 1882, consists of having the valve for the air intake stay open until the halfway point of the compression stroke, achieving greater efficiency in exchange of a lower torque figure. In this case however, the electric motor fills that gap. The result was an efficient ICE, equipped with Toyotas state of the art Variable Valve Timing-Intelligent (VVT-I), that assumed the greater part of the load, it was then aided by the electric motor, filling the gaps, and providing support under power intensive situations. Typically starting in EV mode, the Prius could run in full electric mode, later transitioning to the ICE as speed increased. Insights gained with the RAV4 EV were also valuable towards the Prius NiMH batteries that were placed behind the rear seats. On December 10th, 1997, the Prius went on sale in Japan. Outstanding sales proved doubling production prior to release was not enough. This achievement changed Toyota's overall public perception, going from being seen as a follower to a leading brand in state-of-the-art technology (fig. 26) (Burton, 2013).

Figure 26: 1997 Toyota Prius (Clifford, 2015).

Ford introduced the Ranger EV in 1998, in similar fashion to the EV1, through a lease, but unlike GM however, Ford allowed costumers to keep their cars. It was equipped with a lead-acid battery pack. The Honda Insight was released in 1999, a hybrid in similar fashion to the Prius, although compromised due to the limited 2-seater arrangement (Burton, 2013).

The Honda FCX Clarity was the first fuel-cell hydrogen vehicle to be sold to the public, it went on sale in 2007 (Burton, 2013). Like the Ranger EV and EV1, it was available through a three-year lease program and achieved a range of 435km (Honda, 2007).

In 2009 the Nissan Leaf marked a new era with its unveiling, it was a mass produced, built from the ground up, electric car sold to the public. In the first year alone, it became the bestselling EV in history (Burton, 2013). Nissan was the first to use Lithium-ion for automotive applications with the 1998 Nissan Altra EV, Tesla later released the first production car with Lithium-ion battery technology in the Tesla Roadster and Nissan in 2009, with the launch of the Nissan Leaf, became the first manufacturer to sell over 300.000 vehicles with this technology (fig.27) (Scott, 2023). The Leaf had a range figure of more than 160km with a single charge, could seat five adults, was made available at an affordable price and could charge up to 80% in 30 minutes (Nissan, 2009).

Figure 27: 2009 Nissan Leaf (Cunningham, 2009).

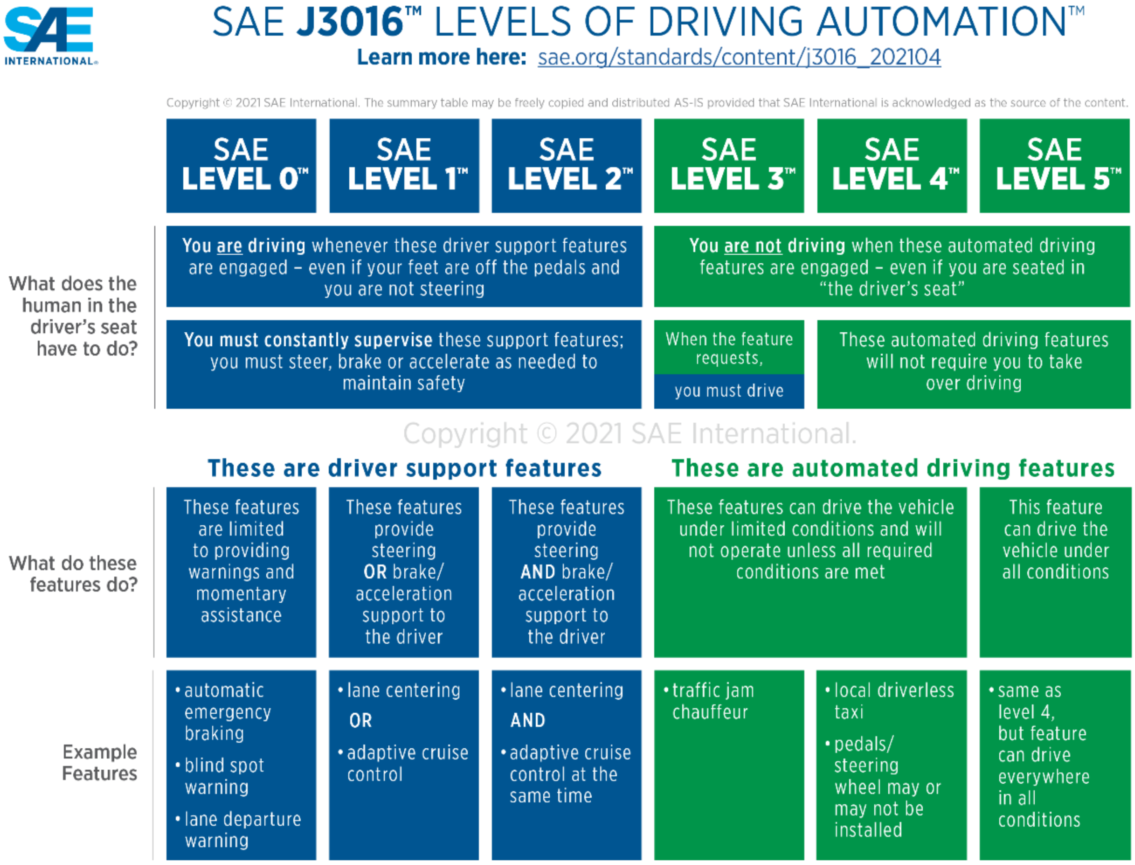
In 2009 Google joined the world of AV and began experimenting with a second-generation Toyota Prius, where it reached 300.000 miles (482.803km) in testing. Google later moved to a fleet of Lexus RX450h in 2012, where it eventually began testing in cities. In 2014 Google unveiled its very own in house designed AV prototype, the same year Tesla began equipping the Model S with the necessary hardware to drive autonomously (Research Car Design, 2016).

1.7 – The Electrification and Automation Age: 2009-2024

In 2012, Tesla presented the Model S, a luxury vehicle with great performance, a desirable recipe (Wilson, 2023). Depending on the battery option specified, the four door EV achieved between 225km up to 426km of range. Efficiency was key, so the Model S achieved a 0.24 drag coefficient as previously mentioned (Sherman, 2014). However, the most recent iteration of the Model S reduces this figure to a 0.208 Cd, the lowest in a production car (Tesla, 2024d).

A 2013 Mercedes Benz S Class, using the standard setup of sensors, aided by added vision and radar sensors, performed, completely autonomously, a route of 103 km through small villages, narrow streets, a large plethora of different traffic scenarios and real traffic. The route in question was the Bertha Benz Memorial Route, first performed Bertha Benz in 1888, the world's first cross-country automobile journey (Julius Ziegler, 2014).

In 2015, the Volkswagen group was caught cheating emissions in the US on their diesel models, leading to Dieselgate (Bovens, 2016). This steered consumers to look to EVs as possibly the most efficient way to tackle consumption and emissions (Denton, 2020).
First implemented in 2014 and developed by the Society of Automotive Engineers (SAE), the SAE J3016, also referred to as SAE Levels of Driving Automation™, specifies six tiers of autonomous driving, providing a tool to define the autonomous capabilities of a vehicle (fig. 28) (SAE, 2021).



SAE J3016™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 28: SAE Levels of Driving Automation™ (SAE, 2021).

In recent years, EV sales have been gradually increasing in the global market with the evolution of the technology, seeing a steady increase through the 2010s until 2020, where it began increasing rapidly. Where in 2017, 2018 and 2019 EV sales had a market share of 1.4%, 2.3% and 2.6% respectively, 2020, 2021 and 2022 saw an increase to 4.2%, 8.7% and 14%, respectively. This equates to ten times increase in 2022 over the global sales seen just five years prior in 2017 (Carlier, 2024).

In 2023, EV sales increased 35% globally, making up 18% of the market, up from the 14% the previous year. Of all EVs, Battery electric cars made up 70% of the EV stock in 2023. China made up 60% of all EV sales, followed by Europe with 25% and the US with 10%. These three markets make up 95% of the global EV market, with sales being sparce in other markets. Nonetheless, the impact of these three markets on global trends is major, seeing as they make up around two-thirds of total sales. The largest auto exporter of the three is China with over four million cars in 2023, 1.2 million of which were EVs. This makes China the worlds lager auto exporter (IEA, 2024). Furthermore, China has surpassed Japan as the leading EV manufacturer in 2023 (Moss, 2024). In the US, EV registrations increased by 40% when compared to the previous year, albeit with a slower growth than previous years. In Europe EV registrations increased by 20% relative to 2022 (IEA, 2024).

In the Chinese car market, the sales market share for EVs, Plug-in Hybrid Electric Vehicles (PHEV) and Fuel Cell vehicles has surpassed that of ICEVs for the first time in June 2024. This increases the share of registered EVs, PHEVs and Fuel Cell vehicles to 43,1% of its market (Teles, 2024b). Norway is at the forefront of the move to EVs in Europe. As of 16 of September 2024, the number of registered EVs (754,303) has Surpassed that of Gasoline cars (753,905). This is possible due to EVs making 94,3% of all new cars registered in Norway. Diesels however still have the largest share of Norway's market with just shy of one million registered vehicles (Agence France-Presse, 2024).

BYD, a Chinese manufacturer, has surpassed Tesla as the world's leading EV manufacturer. New Chinese EVs are built to a higher standard than before, winning over those who test them. The higher build quality coupled with the lower price point and the smaller and attractive designs result in a winning formula in the European market (French, 2024). These new Chinese EVs are now a threat to European manufacturers (French, 2024; Jolly, 2024). The sales of western manufacturers have decreased in the Chinese market, with European manufacturers such as Volkswagen, BMW and Mercedes reporting a decreased interest in their vehicles for that market. Volkswagen in particular has reported a 60% drop in profits in the first nine months of 2024 due to sales being down 12% in China and 1% in Europe. As a result, Volkswagen is considering shutting down three plants in Germany, cutting down staff and reducing wages (Jolly, 2024).

The Extremely low prices of Chinese EVs are proving too cheap for western manufacturers to be able to match. These unnatural prices can be explained by an investigation published by the European Commission (EC). This investigation concluded that Chinese EVs were benefiting from great amounts of subsidization to a level deemed "unfair" by the EC, which puts in jeopardy Battery Electric Vehicle (BEV) European Manufacturers. Both the US and the EU have put in place extensive tariffs to Chinese EV imports. The escalation of this trade war could lead to tariffs being imposed by China as a response, putting even greater pressure on western manufacturers (Moss, 2024). Tariffs for Chinese EVs in Europe reach 45,3% while in the US the figure is 100% (Deutsche Welle, 2024). To avoid these tariffs, Chinese manufacturers such as BYD have announced plans to open plants in Europe. This led the Stellantis group to report, in similar fashion to Volkswagen, its plans to close plants in Europe. This comes as a response to this move by Chinese manufacturers, which the group sees as a threat to itself (Lusa, 2024).

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2 – Identity in the Automotive Design of Passenger cars

2.1 - The role of Design Studios in shaping Brand Identity

General Motors is recognized as having the first formal design department in the automotive industry. Established in 1928, the department was born as the "Art and Colour" section with Harley Earl at the helm. Earl is credited with multiple innovations that make the industry what it is today. Some of his ideas, like the concept car which Earl pioneered with the Y-Job, modelling clay, and face-lifts through "Dynamic Obsolescence," are now the industry standard. Others, such as the iconic fins of the 1950s, and the Chevrolet Corvette have become icons. His influence is evident not only through the reach of his concepts, but also for the establishment and recognition of design, and the designer, as legitimate and crucial components of the automotive industry (Automotive Hall of Fame, 2020; Knoedelseder, 2018).

For brands, brand identity has as its primary function the task of giving a product individual character, unique to that brand, making it stand out from the crowd. For this reason, a brand should have a cohesive and decisive essence. A strong brand will create this essence through its identity, to excel and be one-of-a-kind. Furthermore, brand identity is shaped by the brands' values (Bluntzer, Ostrosi, & Sagot, 2015).

Branding has its core in brand identity, a vision of what is expected of the brand, what it aims to be. Identity is then a tailormade image of the brand whose drive is to channel the aim of marketing to a certain goal or standard. The creation of brand identity has two steps. The first is to stand out from the crowd so consumers can differentiate it, the second is the development of the vision of the brand, to be perceived by the costumer in accordance with the plan established by the brand developer. A brand therefore establishes unique characteristics which motivate the consumer, serves as a tool for brand recognition and stands out by being unique, forming the image and model of the brand (Ianenko, Stepanov, & Mironova, 2020).

Dialogue between the design and marketing departments regularly centres on identifying emotion. These general objectives are the characteristics that will be seen on the final product. Subjectivity, fashion and culture predicate the style of the product overall, being not merely the combination of these single expressions but a combination of considerably greater complexion (Catalano, Giannini, Monti, & Ucelli, 2007).

When faced with the development a new car, a briefing is sent to the designers containing all the general requirements and targets for the vehicle, usually benchmarked. The resulting product should comply with brand convictions, like brand books, the brands heritage, but also trends (Catalano, Giannini, Monti, & Ucelli, 2007). When such convictions are applied, brands are known to maintain certain shape characteristics, developing, and maintaining a cohesive family of products and thus building brand identity. These characteristics can range from the proportions of the vehicle to specific elements such as the glass line, the roof line, or the grill, such is the example of Alfa Romeo where the lines in the hood lead to the front grill, converging on the logo (fig. 29 and fig. 30) (Catalano, Giannini, Monti, & Ucelli, 2007).

Figure 29: The lines on the hood of the 2024 Alfa Romeo Giulia converging on the front grill (Alfa Romeo, 2024).

Figure 30: The lines on the hood of the 1990 Alfa Romeo 33 converging on the front grill (Alfa Romeo, 2019).

Engineers work to perfect the technical traits of a product, while designers aim to improve its aesthetic qualities and simultaneously safeguarding brand identity (Sareh & Rowson, 2009).

Brand identity can be displayed in two forms. One, the decomposition approach, uses recurring elements that the costumer recognises from the preceding product. The other establishes a visual brand identity through the prospect of the shape of the product to evoke an idea, a feeling or another emotion within the user (Bluntzer, Ostrosi, & Sagot, 2015).

References can be used to create associations. Usually context dependent and culturally formed, these references can be used through coupling (groups of associations, frequently two, which regularly go together) to communicate brand values through design in more indirect pathways (fig. 31 and fig. 32) (Karjalainen & Snelders, 2010).

Figure 31: The interior of the Bentley Continental GT evokes luxury through a combination of materials, such as leather and wood, coupled with a high level of craftsmanship (Bovingdon, 2019).

Figure 32: The interior of the Tesla Model 3 evokes future and technology through a combination of its simplicity with the large screen as the focal point of the dashboard (Tesla, 2020).

The successful development of visual brand recognition considers the usually evident use of explicit design cues, but also, and often more significant, the manifestations of implicit references into product design (Karjalainen, 2007).

The shape of a vehicle, in some situations, creates feelings of familiarity through unique brand lines, thus making recognisable the philosophy of a certain car manufacturer merely though the vehicles shape (Catalano, Giannini, Monti, & Ucelli, 2007).

Design features implemented with the objective of being instantly identifiable are categorized as explicit references. Often, these are characteristics in the design with relative defined boundaries (for example the BMW quad headlights and kidney grille) or that appear multiple times throughout the design (for example the complex body shapes in BMW models of the latter half of the first decade of the 2000s) (fig. 33 and fig. 34) (Karjalainen & Snelders, 2010).

Figure 33: Quad headlights and kidney grill present in the BMW E85 Z4, press photo, 2002 (BMW, 2002).

Figure 34: Quad headlights and kidney grill present in the 2007 BMW 5 series, press photo (BMW, 2007).

On the other side there are implicit references, which have their basis on characteristics less easily discernible, but implemented with the intent of being inherently recognized and perceived without the consumer having conscious awareness of them. To uninformed consumers, these design feature-based references will not be easily identified. When applied to a design however, implicit references can still exist on a more intuitive level, as they just "make sense." An example of this is the BMW Hofmeister kink, which to most consumers is an implicit reference. At the C-pillar, this small corner, present in nearly all BMW saloons since the 60s, gives the impression of the rear of the vehicle being positioned perfectly on the rear axle, which forms the perception of a powerful RWD car. Its importance, even after its existence is acknowledged, may remain elusive to most people (fig. 35 and fig. 36) (Karjalainen & Snelders, 2010).

Figure 35: Hofmeister kink present in the 2022 BMW M5 CS (Kennedy, 2022).

Figure 36: Hofmeister kink present in the 1984 BMW M5 (Fordham, 2021).

As a car matures with new model years released, a conservative evolutionary approach linked to the history of the model in question should be followed to diminish the impact on the customer. Every brand should be on par with the elements of its core (Bluntzer, Ostrosi, & Sagot, 2015). There needs to be a consistency between the interior and the exterior of the vehicle in a coherent and harmonious fashion. What is perceived from the interior must confirm the user's judgment of the exterior (Asensio & Bouchenoire, 2003).

2.2 – Approaches for Consumer Attraction and distinct Brand Identity Elements

Brands don't merely stir the rational side of an individual, they also engage the emotional and the physical. The needs of consumers are constantly evolving, so questioning them directly is not the way, one must stay ahead and seek how those needs will evolve. Design, when used for progress and growth, generates emotion and seduction, capitalizing on perceived quality to strengthen brand identity. Also, brand character is who the brand is, and how it interacts with people, it is not merely PR used for communication (Asensio & Bouchenoire, 2003).

The first interaction between a costumer and the product is visual. As a result, the appearance must be attractive. The Audi brand is quoted in Kreuzbauer and Malter (2005) as cited in Bluntzer et al. (2015) with the statement that 60% of car buying decisions come down to the style of the product.

An increasing trend in car purchases sees consumers paying closer attention to styling, more than they would with other products. The evolution of consumer behaviour has brought with it an increase in the attention and aesthetic perception of consumers regarding automotive styling. This means the consumer places more attention on craftsmanship, luxury, symbolism and the contemporaneity conveyed by automotive design (Liu, et al., 2024).

The seduction of the costumer is the strength of design. It draws on all levels of the consumer’s emotions, seducing and creating pleasure and desire. Brands aid in acknowledging and defining who the people who use them are. Brand loyalty used to exist because it was a promise of consistency in quality and reassurance that the right decision was being made. Nowadays brands go beyond this and are more elaborate on their meaning, having their own character (Asensio & Bouchenoire, 2003).

Value-based design characteristics can be replicated throughout the portfolio of a brand, (with specific changes) and not just on a single product. Depending on the type of industry and even geographical location, the level of consistency that is desired can differ. Some may opt for recognizable design characteristics that are repeated throughout the portfolio and product lines, such is the example of Jaguar, BMW and Citroën, others may opt for a more flexible approach that emphasises on the design of individual products, such is the example of Ford, Toyota, and Nissan (Karjalainen & Snelders, 2010).

Design elements reflective of a brand’s characteristics are the primary emphasis of shape grammar-based morphological extraction, and as such, front-end styling is the most representative element of car design, with the others being rear-end styling, body waistline and CMF (colour, material, finish) (Liu, et al., 2024). Design cues may be seen as artificial if the correlation with the core brand values is missing. The BMW grille is an artificial design cue, it is also an example of artificial design cues, when consistently used, becoming a clear sign of recognition (Karjalainen, 2007).

As previously stated, the decomposition approach uses recurring elements that the costumer recognises from the preceding product (Catalano, Giannini, Monti, & Ucelli, 2007). The front grille is what makes a BMW, a Mercedes, or a Rolls Royce unmistakable and easily identifiable apart from the badge and stature (fig. 37 and fig. 38). The grille has evolved alongside the car in areas such as aerodynamics, pedestrian safety, and its adaptability to new trends in car design. Audi’s grille, unveiled in 2003, gave the brand a clear element at the front of their vehicles that was then emulated by other brands, such as Lexus. Mercedes is a great example of a skilful brand in this context, moving form a vertical grill in the 60s to the horizontal grill of today, which has three main variants as well (Lewin, 2017).

Figure 37: 2024 Rolls Royce Phantom (Rolls Royce, 2024).

Figure 38: 2024 Mercedes Benz S Class (Mercedes-Benz, 2024).

Chris Bagle (2002) as cited in Karjalainen (2007), establishes that two different design strategies exist regarding automobile manufacturers. The single driven strategy has the manufacturer following a single value system where products are recognizable and similarly designed, therefore creating a single vision that occupies a certain market segment, and costumers with that design preference will consistently gravitate towards that segment of the market. Brands such as Mercedes, Audi and BMW adhere to the single driven strategy. Market driven strategy however focuses on establishing different value systems. The needs of the costumer are met by creating a variety of products that fulfil those costumer market needs. Toyota, Hyundai, and Honda are examples of brands that adhere to market driven strategy (Karjalainen, 2007).

The importance of grille design can be seen in younger brands and their struggle to find their footing beside the long-established premium brands. Lexus have developed the large “spindle” grille (fig. 39), and Infinity choose a more discreet route with a distinguishing C-pillar design, in similar fashion to BMW’s “Hofmeister” kink. Different brand signifiers will be used by other brands, according to their heritage such as Land Rover with the Clamshell hood, Porsche with its rounded and smooth body design or the browed windscreen distinct of Saab. Similarly, a Buick used to be distinguishable just by the round exits on the hood or fenders (fig. 40) and the illuminated badge used to distinguish a Wolseley from the rest, unfortunately that is no longer the case (Lewin, 2017).

Figure 39: The large grille of the 2024 Lexus LC500 (Lexus, 2024).

Figure 40: The four fender portholes of the 1952 Buick Roadmaster (Gray, 2018).

In the 1950s, the most striking feature of Cadillacs were the famous tailfins first seen in 1948. These elements extended at the top of the rear fenders on each side, a defining feature that sparked a trend and came to define an entire era. Its origin and inspiration come from before World War 2, when a couple of designers were taken by Harley Earl to the Selfridge Field near Detroit to observe military aircraft. The two tail stabilizers on the P-38, new at the time, are said to be the source of the Cadillac tail fins. The fins were introduced in sketches and models made during and after the War which eventually saw production. The fins design increased in size, becoming more elaborate over time (Pittenger, 2013). This trend spread through Detroit and eventually became a rivalry between Harley Earl at GM and Mr. Virgil Exner to see who achieved the greater fin size and complexity, reaching its peak with the now iconic Cadillacs models of 1959 (fig. 41) (Parker, 2014). The fins became more unsafety for pedestrians as they grew in size, with cases of kids riding bicycles fast down the streets and being impaled by the fins of parked Cadillacs. These were later abandoned (Erakko, 2023).

Figure 41: 1959 Cadillac Eldorado (MCG, 2020).

One must question when these aspects stop being just quirky tricks and become legitimate brand identifiers or even innovations that enhance brand loyalty. Such cases are the once blue instruments backlight used by Volkswagen which has been dropped, or the triple rectangle taillights that became a core characteristic of the Ford Mustang (fig. 42) (Lewin, 2017).

Figure 42: The iconic triple rectangle taillights present in the 2025 Ford Mustang (Ford, 2024).

The "Spirit of Ecstasy" became a mascot of Rolls Royce in 1911, being featured in its cars thereafter and the BMW 303 of 1934 was the first to adorn the twin "Kidney grille" which is still present in BMWs to this day (fig. 43) (Hennessy & Hester, 2011). BMWs newly explored midsized car came to its own in 1962 with the Neue klasse 1500 series, with its geometric architecture and adorning the “Kidney Grille” at the front, both aspects have been integral to the brand since then (fig. 44). Each iteration of the 3 and 5 series cars have been a gradual evolution of this form (Design Museum, 2009).

Figure 43: BMW 303 (BMW, 2021a).

Figure 44: BMW 1500 (ACP, 2022).

2.3 – Lead Products, Legacy, and Design Philosophies: Techniques of Automotive Styling

A brand may have one product as the central piece, one that is closest to its identity. According to Ealey and Troyano (1997) as cited in Karjalainen & Snelders (2010), these are called “lead products” or “flagship products”. One example of a lead product is the Volkswagen Golf. The Golf was the first of its kind on the market and one of the first hatchbacks, it instantly became the success it is today. Through the models’ generations, its design has remained faithful to the previous generations through evolutionary changes, always including design traits that relate to its good value for the cost, quality German engineering and functional design (fig. 45). A lead product can be born through the special experience it offers to costumers or, such as the example of the Golf, high sales, which in turn create a strong brand presence in the market. Forming an authentic heritage for the brand is the historical function of lead products. According to Kapferer (1992), as cited in Karjalainen & Snelders (2010), the large majority of brands have key products in their portfolio that most faithfully transmit the essence of the brand.

Figure 45: VW Golf generations 1-8 (Miles, 2019).

Brands which have been long established not only evince their former selves but also yesteryears. A brand that incites in a consumer the feeling of nostalgia connects them to their positive perception of the past and the brand, strengthening that connection. One of the reasons consumers get steered towards established brands is due to their history (Leigh, Peters, & Shelton, 2006). The formation of recognition is affected by the reputation and established image of a brand in the market. An early-established identity and a robust heritage shape a solid foundation for brand recognition (Karjalainen & Snelders, 2010).

Volvo’s new design philosophy introduced in 1998 established several explicit design characteristics: The shoulder line, V-shaped hood, the grille and soft nose, the taillights, the flowing roof line and the third side window. The execution of these characteristic varied from model to model, but between 1998 and 2004, they were present in Volvos entire lineup (Karjalainen & Snelders, 2010).

Volvos new design characteristics are a shift from the previous 20 years of models. The previous generation were known to be robust and functional with a static “box” like design. The new design characteristics, apart from the headlights and grille, were not present in the box era. Many of these design characteristics however were present on prior historic Volvo models, such as the PV 444/544 and P120 “Amazon” of the 40s and 50s with the V-shaped hood and strong shoulder lined visible (fig. 46). The brands promotion linked to its heritage was crucial in giving the consumer a view of these new design characteristics and being a part of Volvo (Karjalainen & Snelders, 2010).

Figure 46: The shoulder line, V-shaped hood, the grille, and soft nose present in the Volvo PV 444 1946-1958 (Volvo, 2002a).

Figure 47: The shoulder line, V-shaped hood, the grille, and soft nose present in the 1998 Volvo S80 (Volvo, 2004).

Figure 48: The shoulder line, V-shaped hood, the grille, and soft nose present in the 2002 Volvo XC90 (Volvo, 2002b).

Although the XC90 and the S80 belong to two distinct market segments, it is possible to observe the design elements that bring them together into a cohesive brand design language. Both have the previously mentioned V-shaped hood that culminates in a soft nose and hallmark front grill, along with the strong shoulder lines that run across both models ending at the taillights (fig. 47 and fig. 48).

Across the automotive industry, light and shadow are used to bring three-dimensionality to a solid object, making it feel livelier. The upper panels of a vehicle reflect the light coming from above, while the bodysides tend to reflect the ground, bringing dynamic contrast. "Light catchers" is the term used to describe the interplay applied to the sides of mostly larger vehicles. The aim is to achieve the visual perception of decreased visual density through shaping the lower section of the door panel, made to reflect the sky as opposed to the ground. Another way of altering perception is through the appearance of a longer glass house which is achieved through the use of dark glass in the pillars (Lewin, 2017).

The EX30 is an example of these tricks in use (fig. 49). The top of the door panel, where it meets the glass house, reflects the sky, this is apparent by the lighter tone present, while the middle begins to reflect the horizon and then the ground, visible though a darker second shade followed by an even darker third shade. From the middle to lower part of the door panel the pattern repeats itself, albeit in shorter form. The darkest shade in middle of the door panel suddenly becomes a light first shade again, the way the panel is shaped goes from reflecting the ground to reflecting the sky. This is followed once more by a short reflection of the horizon through the Intermediate shade ending with a reflection of the ground once more. While most of these lines remain parallel, the top line extrudes to the wheelarch, giving a further degree of tree-dimensionality. It is also possible to observe the previously mentioned dark glass in the pillars, which come into play with the dark roof and dark side skirts to further reduce the visual mass of the vehicle.

Figure 49: 2024 Volvo EX30 (Volvo, 2024).

The previously mentioned design change Volvo went through beginning with the S80 in 1998 was not named.

But beginning with Cadillac just two years later this trend took form. Manufacturer began naming their own design philosophies, such as Arts and Sciences, Athletic Elegance, Sensual purity, and so on. Naming them served not only as a call to action to the designers but also to show consumers how much the brand values design. This trend of naming innovative design languages began to gain traction at the turn of the XXI century with Cadillac's new "Arts and Sciences" design philosophy, being sharp, square, and bold (Lewin, 2017).

"Arts and Sciences" was the brand managers' way of shifting Cadillacs image form the soft boat like cars purchased by elderly consumers to performance cars akin to BMWs, and other manufacturers dominating the luxury market in the US. The result was flat surfaces with crisp folds inspired by stealth bomber designs, such as the F-117 with its faceted surfaces to evade radar detection (fig. 50) (Pittenger, 2013).
Ford unveiled its "New Edge" style with both the Ka and the first generation Focus in 1998, comprised of wide curves contrasted by sharp points, being replaced by the more ambiguously defined "Kinetic Design", seen in 2010 with the third iteration Ford Focus (Lewin, 2017).

Japanese and European manufacturers also took to naming their design philosophies. Lexus and Toyota aimed to bring a livelier language to its bland public image with "L-Finesse" and "Vibrant Clarity" respectively. This resulted in a sharper and more complex design for Lexus and shock value for some Toyotas. As a profuse promoter of its design motifs, Mazda has been at the forefront with more notably "Nagare" in mid-2000s and "Kodo", soul of motion in the present. BMW created "Flame Surfacing," the addition of creases and curves to otherwise bland panels, in other to create reflections and highlights to captivate attention (fig. 51). Mercedes followed a similar path but has since withdrawn from complexity towards a vision of form rather than line with its "Sensual Purity" motif. Companies who do the least to communicate their design language are usually the ones with the greatest accomplishments in either strengthening an already robust brand image or a deep change in design motif (Lewin, 2017).

Figure 50: 2004 Cadillac CTS-V “Arts and Sciences” (Cadillac, 2007).

Figure 51: BMW Z4 “Flame Surfacing” (Sey, 2015).

2.4 – Rebranding and Revival of Icons, Platform Sharing and resulting Implications

Some brands are redesigning themselves to reflect their past such as Fiat, for example, which has its redesigned emblem as a call back to its own emblem from 1959. This redesign aligns seamlessly not only with its pioneering role in the retro trend of the early XXI century but also its flagship model, the 500. 2021 also saw the updates of both Renault and Peugeot with new interpretations of symbols that hark back to the 60s and 70s, recovering historic elements of both brands (fig. 52) (Carcavilla Puey, 2021). Renault recently made pre-orders available for the 2025 Renault 5 E-Tech, a retro design EV with similar shape and design cues to the Renault 5 and Renault 5 Turbo from the seventies (fig. 53) (Renault, 2024).

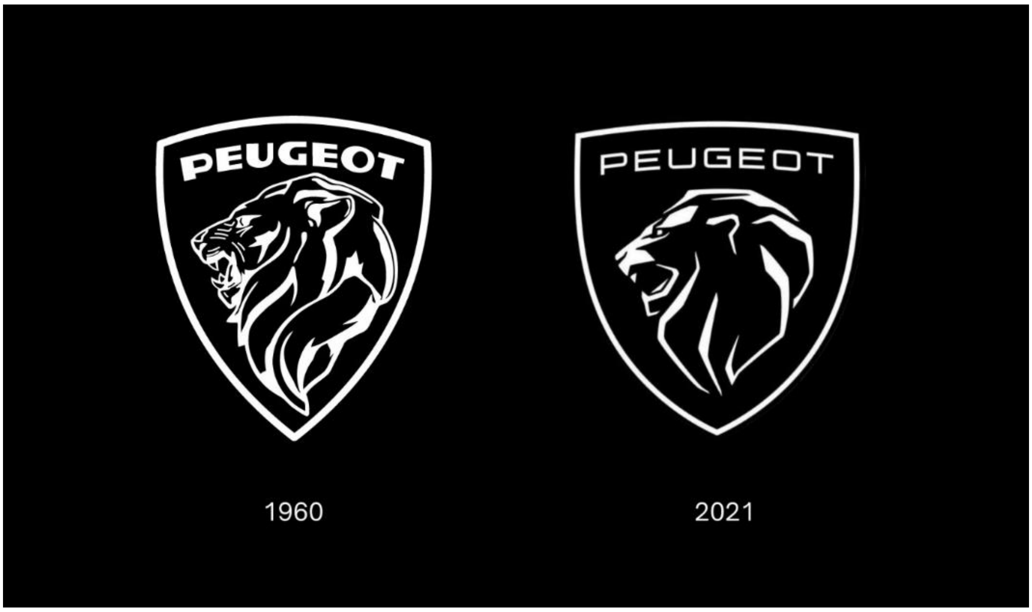

Figure 52: 1960 Peugeot logo and 2021 updated logo (Grapheine, 2021).

Figure 53: The Renault 5 launched in 1972 and the 2025 Renault 5 E-Tech (Sena, 2024).

Other brands take a different rout. Such as the DS brand which was reactivated in 2010 by the PSA group (shareholder of Peugeot, DS, Citroën, Vauxhall, and Opel). DS, synonymous with French luxury cars, was originally launched in 1955, building upon a remarkable heritage of DS automobiles. And Volkswagen which revived the Beetle with the New Beetle (fig. 54).

Figure 54: The original model in the form of a 1949 Beetle (left), the 1998 New Beetle (right) and the latest iteration, a 2019 Beetle (center) (Volkswagen, 2019b).

In the early 1990s, Volkswagen sales in the US were seeing fewer and fewer numbers, with just 40,000 cars sold compared to all time high of over half a million units sold in 1970. The US population did not associate Volkswagen with the Golf, as market research showed, but instead with the original Beetle. Designed in California and lead by designers Freeman Thomas and J. Mays, the original prototype of the New Beetle named Type 1 was based on the Polo platform as opposed to the Golf platform later used for the production version. The nostalgia evoking retro design had worked, the Type 1 proved to be a great success with audiences, prompting Volkswagen to put it into production. In its first year, 84,434 New Beetles were sold in the US alone. The New Beetle became not only a sales success, but also a successful Halo model, attracting consumers to Volkswagen dealerships. In 2012 Volkswagen launched a third generation called Beetle (McAleer, 2018).

DS on the other hand has not attempted to reinterpret the cars unique aesthetics, valuing excellence and innovation and the pioneering spirit carried by the original car. The brand presents connections to its past through symbolic, technical, and aesthetic links between its previous cars and new ones, guiding the consumer on how its heritage has been reinterpreted in its new product line. DS therefore used the strong basis present due to its strong heritage not to draw on nostalgia, but to highlight the pioneer spirit (Dion, 2022).

In the case of the New Beetle, this new interpretation of the original Beetle was possible due to platform sharing, and as such was not able to follow its original formula. The New Beetle was based on the Golf platform, meaning the engine was up front along with the driven wheels, a contrast to the original's rear engine RWD layout. This allowed VW to cut costs and make the vehicle more affordable. Platform sharing was also apparent in the interior, with the dashboard being incredibly deep, proving to be a result of the New Beetles curved exterior design placed over the Golfs established platform (McAleer, 2018).

Platform sharing is a method of product development that has been gaining traction. It consists of the sharing of architecture, technology, components and service strategies between products and brands. This method offers advantages and cost savings in the development of new products, manufacturing, and service costs. In the automotive industry, a great example of this is the Volkswagen Golf and the Audi A3 (fig. 55). This however imposes restrictions, more prevalently in higher-class brands sourcing from lower class-brands, which may find their way to be perceived by the consumer, such as the loss of the brands unique style, technical characteristics, or uniqueness. Sharing platforms restricts designers in such a way that the platform can lose its uniqueness (Olson, 2008).

As such, similar exterior car shapes can be found in not only the same manufacturer but also in different manufacturers, it is the small variations of these structures that form different characteristics for brand identity. Manufacturers establish unique styles in their tendencies regarding variations of these structural parts (Hyun, Lee, Kim, & Cho, 2014).

Shared platforms, when compared to a unique platform, have the tendency of having inferior quality, value, or performance due to the increased number of compromises required and being forced to cover a wider range of price and quality settings. Studies indicate that higher-class brands benefit by having distinct features regarding style and technical aspects, as distinctions from lower-class brands which in turn establishes and preserves strong, unique, and positive attitudes and associations towards the brand. These unique brand associations should be maintained and enhanced by means of benefits and unique features by the brand portfolio manager. These will also require constant improvements and innovations to preserve the uniqueness of the brand, seeing as competitors typically copy popular features and benefits (Olson, 2008).

Brand values can be embodied by a design, which can be strategically structured around lead products. These lead products became a physical representation of what the brand stands for while paving the way for subsequent new products within the brand. The brand message within product design is the sum of the design features, which embody the brands core values. Alongside the other communication mediums, the brands' identity is represented by the design features (Karjalainen & Snelders, 2010).

Figure 55: Audi A3 8Y and VW Golf 8 (Bergander, 2020).

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3 – Impact of Electric Propulsion on Automotive Design

3.1 – Comparison of Combustion, Electric and Hybrid propulsion Systems

3.1.1 – Range

The ICE still reigns supreme in the range department, but EV technology has been steadily evolving with ranges of new EVs increasing year after year, and it is expected that ongoing advancements will close the gap in the coming years, with new EVs consistently achieving longer ranges with each iteration. The main problem EVs have is the smaller energy density of batteries compared to Gasoline or Diesel fuels.

While a lithium-ion battery has a gravimetric energy density (the stored energy divided by the mass of the fuel/battery) of 3,6 MJ/kg, fuels like gasoline and diesel have more than ten times that value (Table 1.) (Fischer, Werber, & Schwartz, 2009).

Table 1.

Gravimetric energy density of different fuels

Fuels	MJ/kg
Hydrogen	142,00
Natural gas	55,00
Gasoline	46,50
Diesel	45,80
Biodiesel	34,00
Charcoal	30,00
Ethanol	29,80
Wood log	14,76

Note. Data from "Fuel energy density: What is it and why is it important?" by Cutler Cleveland, 2024, Institute for Global Sustainability, retrieved from: https://visualizingenergy.org/fuel-energy-density-what-is-it-and-why-is-it-important/

To turn the energy present in either source into mechanical energy, an energy conversion system is required. For an EV that system is the electric motor and its electronic controller, while gasoline and diesel have the ICE. As an electric motor and controller is much more efficient than an ICE, it maximises the energy present in the battery while the ICE wastes the majority in the form of heat and this strongly attenuates the energy density gap (Calhamar, Monteiro, & Londrim, 2024).

A gasoline ICEV has a global efficiency between 12% and 30%. This means that between 88% and 70% of the energy present in the fuel tank is wasted through heat, friction and the engine peripherals such as the fuel pump. The inverse is true for an EV, which has a global efficiency between 80% and 85%, this meaning that only between 20% and 15% of the energy available in the battery is lost (fig. 56) (U.S. Department of Energy, s.d.a; U.S. Department of Energy, s.d.b).

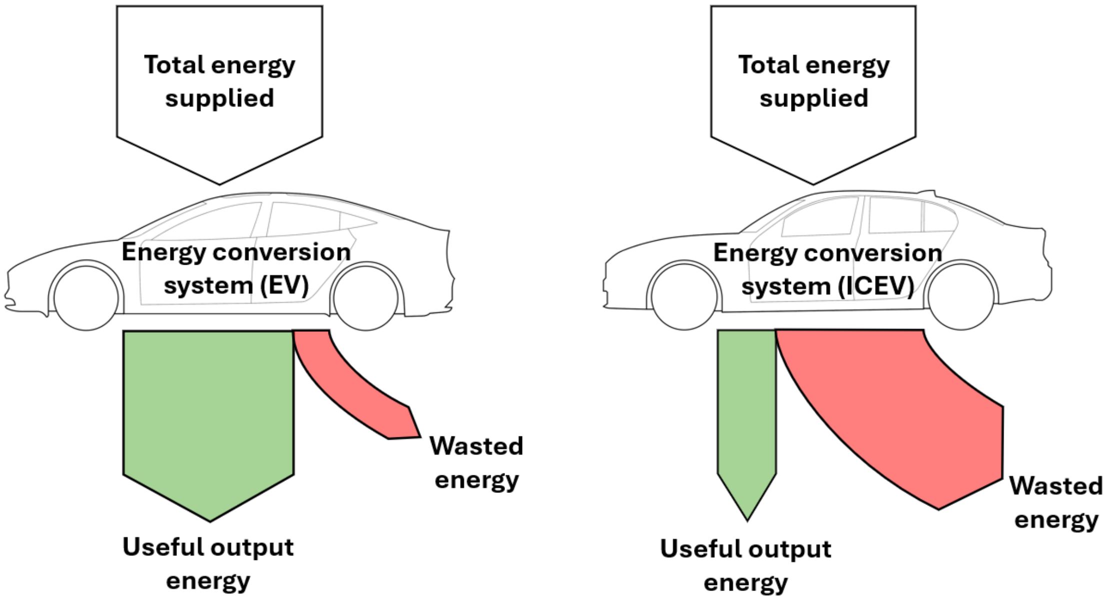

Figure 56: Process of turning energy into motion in EVs and ICEVs. Efficiency is the ratio of useful energy/total energy available *(Calhamar, Monteiro, & Londrim, 2024)*.

The efficiency of the global drivetrains of EVs and ICEVs already offer a contrasting reality to what one could perceive from the energy density alone of batteries and fossil fuels. However, the energy storage disadvantage of EVs is further reduced if a third critical variable is considered, that being the mass of the drivetrain itself. That allows us to calculate the effective energy density of a vehicle, as the electric global drivetrain is not only much simpler, but also much lighter that its ICE counterpart (Fischer, Werber, & Schwartz, 2009).

In fact, the global effective energy density of a vehicle is the “stored energy transformed into mechanical work” divided by the “mass of the fuel/battery” plus “drive train mass.” Considering this ratio, it is possible to conclude that the EV has a higher effective energy density than a hybrid or economy ICEV up to 130km and of 180km over an ICE sports car (Fischer, Werber, & Schwartz, 2009).

Beyond these distances the additional batteries required to extend the range of an EV would reduce its effective energy density below that existing ICEVs. Additionally, a comparable ICEV could just require a couple more litres of fuel, marginally influencing its weight and thus its effective energy density (Calhamar, Monteiro, & Londrim, 2024). Due to this, ICEVs with range figures into the 1000km exist, while comparable EVs do not.

3.1.2 – Volume of Components

When comparing the drive train of an ICEV to an EV, it is interesting to compare the volume of the components take in each vehicle type. The electric motor in an EV is extremely compact and simple, able to be placed low within the vehicle, aiding in lowering the center of gravity. The ICE on the other hand, takes a lot more space and has a lot more complexity.

The performance of an ICEV is often directly connected to the displacement of its engine. Larger displacements usually come with a larger fuel tank as well, another component that takes a large amount of space requires thoughtful placement to ensure the safety of the occupants and a low center of gravity. The EVs equivalent to the fuel tank is the battery, which is the largest and heaviest component in an EV, much more so than its ICE counterpart.

The battery is usually placed flat on the floor of the vehicle, under the occupants, aiding significantly in lowering the center of gravity. Like the fuel tank, it is also a safety hazard, and as such requires a strong casing, capable of enduring large impacts without becoming compromised, this in turn further increasing its already large weight. Unlike the EV however, the ICE requires a complex mechanical transmission, including a gearbox, to put its power to the ground. The volume occupied by the transmission varies depending on the power and position of the ICE engine. A transversely front mounted engine, usually seen in FWD vehicles, commonly has a compact design, meanwhile a longitudinally front mounted engine, usually seen in RWD vehicles, commonly takes up more volume and, in an AWD vehicle, requires a transmission tunnel and a driveshaft to connect the transmission to the rear wheels.

All ICEVs must have some sort of clutch, as the engine must be able to spin while the vehicle is stopped, as for example when powering the car the first time. Clutches are heavy and complex devices, with a limited life span and requiring maintenance. EVs do not have a clutch as an electric motor has its maximum pulling power at zero rotations.

All ICEVs also need a gearbox as a combustion engine must operate within a rigid range of RPMs to produce useful pulling power. EV's do not have a gearbox as it is not needed, because an electric motor has useful pulling power from zero rotations onwards. What electric motors need is just a simple reduction gear, allowing the electric motor to spin about ten times faster than the wheels. The absence of clutches and gearboxes in EVs are enormous advantages that must not be underestimated.

The cooling system is an integral part of both types of drivetrains. However, it has a much more prevalent role in an ICE. A combustion engine requires large amounts of cooling to remain at the optimal running temperature, much more so when it is under load. It may also require a separate cooling system for the transmission, and yet another if it has a turbocharger and/or supercharger, as these devices heat the admission air when compressing and lowering its density, which could have a very detrimental influence on its performance if not cooled. Meanwhile EVs, even though they still have cooling systems, have much less cooling needs which translates in much smaller and lighter cooling systems such as radiators.

An ICE requires air to operate, so both an intake and exhaust system are needed to get the air into it, as well as the combustion gases safely out of the engine. Intake size and length vary depending on engine orientation, displacement and/or performance. The exhaust system begins in the ICE and ends usually at the back or side of the vehicle, its size and volume also dictated by the displacement of the engine. As a result of the combustion process, the engine itself and exhaust system reach very high temperatures and require thermal insulation, therefore consuming extra space.

The modern automobile requires a variety of peripheral systems to stay relevant and competitive depending on the price range and environment. Some of these systems may be as common nowadays as a radio or electric windows and others less so, such as soft closing doors or the latest level of Advanced Driver Assistance Systems (ADAS). All these systems add weight and complexity to a vehicle, and as such they take space. Unlike EVs, non-Plug-In Hybrid ICEVs don’t receive electrical energy from outside sources, and as such they rely on the alternator using the engines movement, generally through a belt to produce electricity, therefore diverting useful energy to it. Additionally, most EVs also have the advantage of not requiring oil circulation to run, aiding in its simplicity and dispensing an oil pump.

As a final note, some telling numbers: the drive train of an ICEV has around 2000 parts, while the one of an EV has around 20, that is 100 times fewer parts (Raftery, 2018).

3.1.3 – Package Design

The main advantage of EVs in package design is the freedom they give designers when compared to ICEV. The ICE requires mechanical links between components, the engine must be coupled to the clutch, the gearbox and several drive shafts.

The EV on the other hand can have the battery in one place and the electric motor near the wheels, as they are connected by electric wires. No need for a gearbox, a clutch, and fewer drive shafts. This simplicity coupled with the much smaller footprint of the components gives ample space to place the components in whichever way is more appropriate for the purpose of the vehicle.

An electric sportscar may have the battery placed behind the driver to offer a similar weight distribution to a traditional mid-engine sportscar, and a small city car may have the battery under the passenger compartment to lower the center of gravity and give the driver a better view of the road (fig. 57). Furthermore, placing the electric motor near the front or rear wheels would free up the opposite side of the vehicle for storage while still being able to offer some space for extra storage above the motor. This design freedom also means the exterior of the vehicle does not need to be so heavily determined by its components as in an ICEV, which allows for more freedom in exterior design and more efficient aerodynamics. Interior space can also be increased greatly in an EV when compared to an ICEV, as the lack of a bulky engine, clutch, gearbox, complicated transmission shafts, and transmission tunnel in RWD automobiles, result in more passenger space in the cabin, which is further increased by the ability to extend the wheelbase, all while maintaining the vehicles' length, merely placing the wheels closer to the corners which in turn also aids stability.

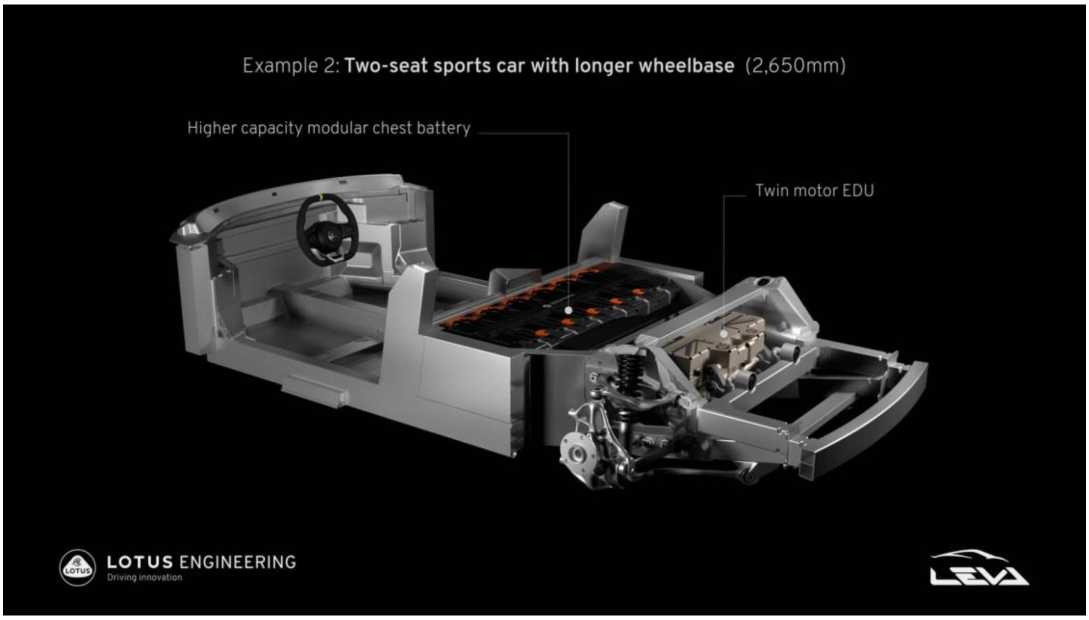

Figure 57: Lotus sports car battery placement (Lotus, 2021).

3.1.4 – Safety

The mechanical simplicity of the EV results in a safer vehicle overall. Seeing as there isn't usually a bulky engine to absorb the impact at the front of the vehicle, crumple zones must be added at a structural level. The positioning of the battery under the occupants helps lower the center of gravity, reducing drastically the risk of rollovers. Using the battery as a structural element, and not merely as a large component placed on the chassis aids in increasing rigidity and reducing weight as there is less structural material needed in the vehicle's chassis structure, the battery now takes an active role in this task. The risk of fires in EVs is also reduced when compared to ICEVs, once again because of its simplicity and lack of flammable liquids. EV fires however are substantially more difficult to put out, while an ICEV fire can usually be put out in a couple of minutes. EV fires can take up to multiple hours or days to extinguish, being known to burn even under water.

The battery casing is meant to protect the battery in case of a collision, but as a result of its strength it also protects the occupants by minimising chassis deformation during side collisions. The materials used in the battery result in the need of a strong casing which in turn plays a vital role in reducing the risk of the occupant compartment becoming compromised in an accident, while also increasing torsional rigidity. A comparable ICEV suffers further deformation in the same crash scenario, putting the lives of the occupants at risk (Muhammed Cimendag, 2023).

3.1.5 – Emissions

Unlike ICEVs, EVs have zero tailpipe emissions, and as such they seem like the logical choice on paper to fight climate change and offer a great alternative in areas affected by air pollution. However, the emissions produced during manufacture should also be taken into consideration. In this regard the ICEV is superior, in the sense that, at the present time, emissions produced by manufacturers during the production of EVs, more precisely the batteries, offset the ecological advantages under some scenarios. One example would be a consumer that replaces their vehicle every couple of years and uses it very little. Assuming the consumer in question does not drive the vehicle enough to offset productions emissions before selling it, that EV would now have a negative personal environmental footprint compared to an ICEV driven the same distance. That vehicle would eventually be driven the necessary distance with its second or third owner, achieving a greener footprint, but the first consumer would not. Another example would be in the case of an accident where the vehicle is written off. If the vehicle is taken off the road before achieving the necessary milage, the environmental footprint of that particular EV would be higher than the equivalent ICEV.

ICEV emissions are predictable, falling within the manufacturer's specifications, while EVs emissions are dependent on the way electric energy is produced. In the best-case scenario, the EV will be charged with electricity derived from 100% renewable sources and as such, depending on the capacity of the battery, it may take merely a couple years of driving to offset the impact of emissions produced during manufacturing when compared to a similar ICEV. In the worst-case scenario, the opposite is true, the electricity used to charge the EV originates 100% from fossil fuels. At the end of the day, both vehicles run on fossil fuels in this scenario, even though zero emissions come out of the EV. Furthermore, a larger number of emissions were produced as a result of manufacturing the EV than the ICEV, and as such the EV is the more polluting option of the two. In the real world neither scenario is likely to be true, as such it is important to take into consideration: 1) the emissions produced during manufacturing of the EV of choice (usually, the larger the battery and more potent the vehicle, the longer it will take to offset emissions); 2) the percentage of clean energy in each charge, and finally 3) the distance likely to be driven before replacing vehicle.

According to Volvo, the XC40 Recharge takes 47,000km of being charged with wind electricity to break even when compared to the ICE XC40, 84,000km using EU28 electricity mix and 146,000km using the global electricity mixture. This is due to the emissions from materials, production and refining being around 40% more in the EV than in the ICE model (Volvo, 2020b). Both ICEVs and EVs pollute through other means, such as brake pad dust and rubber particles from the tires. EVs with their heavier weight wear tires more easily and as such pollute more in that regard, but due to regenerative breaking they use the breaks seldom and, as such, produce much less brake pad dust than ICEVs.

EVs tyres on average last less 26,1% than ICEV tyres, with the first tyre change taking place at 28,944km versus 39,163km in ICEV and 39,655 in hybrids (Roberts, 2023). Additionally, EVs should be equipped with tires created specifically for them, which have been designed to address their specific stress requirements such as heavier weigh and higher power and torque figures, along with lower noise levels, all without affecting efficiency (Automóvel Clube de Portugal, 2023).

3.1.6 – Costs

At the present time, the average entry cost of an EV is higher than that of an ICE. However, EV prices have been coming down, with more affordable options becoming available each year. General maintenance is extremely reduced in an EVs due to their simplicity, as they do not require oil changes, changing engine belts or chains, replacing clutches and so on. One possible downside however is the limited life expectancy of the batteries, considered to be around 10 to 20 years, with most manufacturers offering 5 to 8 years warranty on their batteries (MG, 2024).

An EV has the possibility to be charged at home at an exceptionally low cost, unlike an ICEV that must be refuelled at a fuel station. Uncertainty regarding fossil fuels and global conflicts may drive the price of fuels upwards, but as governments begin to remove the advantages and benefits given to EVs and increase the costs to publicly charge them, the lines become blurred. Depending on the region, either an EVs or an ICEV may be the more cost-effective choice.

Depreciation is also important to factor in, with differing brands, models, and segments each having their own depreciation curve, or even appreciation in some rare cases. This greatly affects the EV market, as the perceived cost of replacing batteries may scare some buyers, and as such it is possible to see a quicker decline in resale value.
In Europe for example, the operating cost per 100 Km of an EV charged at home is around €2,62 compared to around €9,84 in an ICEV.

The average price per litre of gasoline across 41 different countries in Europe was €1,64 as of May 6th 2024, while the average cost of the kWh of electricity across 39 different countries in Europe was €0,17 in the first half of 2024. The average fuel consumption of gasoline powered new cars in 2019 was 6.0 litres per 100km while the average energy consumption of typical midsize EV (ID3) is of 15,4 kWh per 100km (Cargopedia, 2024; Eurostat, 2024; IEA, 2021; Volkswagen, 2023).

3.1.7 – Usability

Drivers who experience EVs may find the driving experience enjoyable due to its smooth power delivery and immediate throttle response, while offering a comfortable ride and improved usability in city environments. The lack of engine sound, vibration and gear changes also aid in its smoothness and comfort. ICEV on the other hand require more of the driver, for example: the driver must master the clutch point when operating a manual transmission to operate it in all conditions, or a driver may need momentarily quick acceleration only to find themselves in a high gear and having to wait for the automatic transmission to shift down. The EV simply erases these impracticalities.

An EV, in some models, even offers one pedal driving, where the driver operates the vehicle using merely the steering wheel and the accelerator pedal, lifting the accelerator pedal to engage regenerative breaking, reducing the need for the driver to use the brake pedal, making use of it merely in emergency situations. If the owner of the vehicle has the ability to charge the vehicle at home, they may find themselves saving money when compared to an ICEV (depending on the region) and no longer requiring visiting fuel stations.

On the other hand, longer journeys may become a challenge in an EV due to the need to stop to charge the vehicle, while an ICEV would likely have a longer range and would just take a couple minutes filling up.
In extreme temperature scenarios, both too hot and too cold, the battery of an EV can also become depleted quicker or even too hot or too cold to operate, while an ICEV suffer minor to no impacts due to these environments.
In the Winter, the heating system in an EV needs energy from the propulsion battery therefore reducing its range, while the wasted heat from the ICE is used to warm the interior of the vehicle having no impact on its range.

3.2 - Analysis of Case Studies on similar Vehicles with Different Propulsion Systems

The present case studies are comprised of eight automobiles, four being pure ICEV and four being BEVs. The benchmarked ICEVs are the VW Golf, the BMW 3 series, the Audi Q3 Sportback and the Kia Picanto, while the benchmarked EVs are the VW ID.3, the Tesla Model 3, the VW ID.5 and the Fiat 500e.

The aforementioned vehicles were chosen by a variety of factors, first and foremost by being comprised of the same market segment and considering its relevant 2022 worldwide sales (Car Industry Analysis, n.d.). Additionally, the information collected comprises the most recent manufacture data of all previously mentioned models as of 1/12/2023. The VW Golf and VW ID.3 engage the same share of the market and belong to the same brand. The BMW 3 Series and Tesla Model 3 address the same market segment and belong to two distinct premium brands, one being a legacy brand while the other is relatively recent. The Audi Q3 Sportback and VW ID.5 belong to two distinct brands both owned by the same holding company, the Volkswagen Group. Additionally, as the Q4 Sportback is strictly electric, the Q3 Sportback was elected as the neighbouring contender to the ID.5. Finally, the Kia Picanto and Fiat 500 are both models with historic sales success in the city car market segment.

3.2.1 – Volkswagen Golf vs. Volkswagen ID.3

Volume of Components

The 2023 Volkswagen Golf (mk8) and the 2023 Volkswagen ID.3 are two models of the same brand with differing means of propulsion that tackle the same share of the market, the five-door hatchback. The Golf mk8 can be had with a multitude of engine options, such as Diesel and Gasoline and Mild or Plugin Gasoline Hybrid. The ID.3 on the other hand is purely an EV. As a result, their architectures present multiple distinct differences regarding the volume of components and package design (fig. 58).

The Golf, being an ICEV, has a large part of its volume designed around the drive train, with the engine and transmission occupying most of the front end of the vehicle. The radiator, air intake system and the 12-volt battery all sit at the front as well. This shifts a large percentage of its overall weight to the front end, reducing the possibility of a 50/50 split weight distribution, therefore negatively impacting the driving dynamics.

The ID.3 has its motor close to the rear axle, low down in the vehicle. This position coupled with its small size and lower weight compared to its ICE equivalent means it impacts the driving dynamics positively. The radiator and the 12-volt battery are placed at the front, resulting in greater weight distribution.

The Golf's fuel tank sits bellow the rear seats. It comes as a 45-litre unit in both ICE and mild hybrid variants, a 50-litre unit in the sport variants and a 40-litre unit in the plugin hybrids. The ID.3 has two battery options, a 62.0 kWh and an 82.0 kWh variant. Using the fuel tank as the battery's equivalent, the Golf fuel reservoir is much more compact, having the footprint of half of the back seats. The battery of the ID.3 on the other hand, occupies a large portion of the vehicle beneath the passenger compartment, mostly under the front seating area. As the footprint of the battery extends beyond the space available under the rear seats, the floor must be raised to accommodate it, increasing the height of the passenger compartment. To maintain a similar interior height, the height is increasing by 112mm relative to the Golf.

Volkswagen offers the Golf with 4Motion AWD alongside the default FWD. As such, the Golf's platform requires a transmission tunnel to establish a mechanical connection between the engine and the rear wheels. This affects all Golf variants, even those that do not come equipped with AWD. The result is less space in the passenger compartment, more predominantly in the form of diminished leg space for the rear passengers. The ID.3, with its rear axle mounted electric motor and lack of mechanical links between components is not affected by this limiting factor.

Lastly, the Golf's exhaust system covers the length of the vehicle, producing large amounts of heat and requiring shielding from the cabin. This along with other mechanical components lead to in a rough underside. The ID.3 on the other hand has a flat underside, improving aerodynamics.

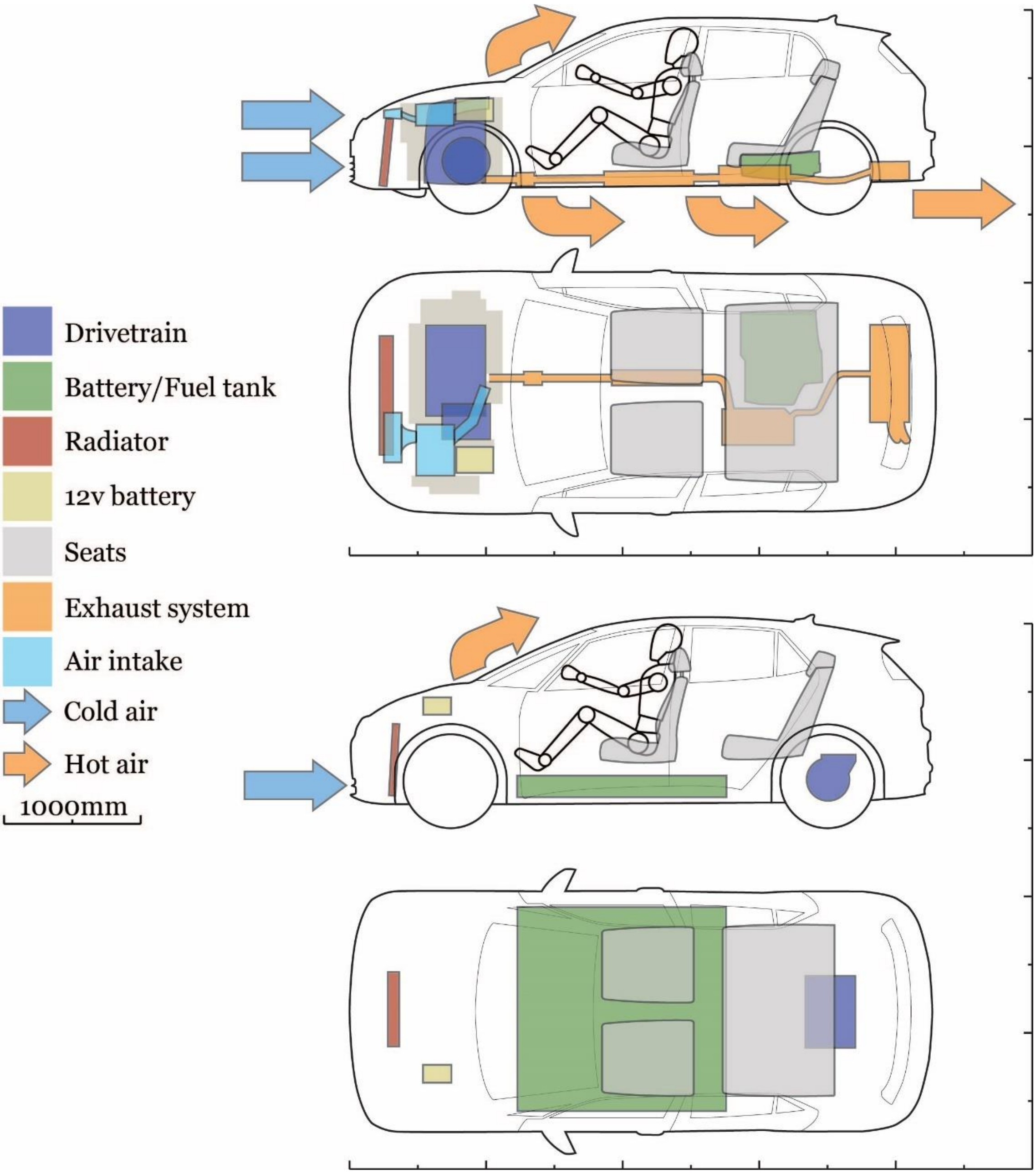

Figure 58: Package Layout of components in the 2023 Volkswagen Golf 8 and Volkswagen ID.3 of 2023.

Range

The standardised test used to determine the range of a modern vehicle is the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). The WLTP, which replaced the New European Driving Cycle (NEDC), was introduced with the purpose of obtaining real world results for vehicles on a global scale. This procedure accurately portrays real day to day driving using a more dynamic driving profile which is reviewed from a standardized perspective as opposed to the previous NEDC tests, which resulted in figure which differed from the real vehicle consumption figures. As opposed to previous metrics, the WLTP is based on data obtained from analysis of the most common driving profiles, including higher acceleration, greater average speeds and also higher top speeds, with these tests now being conducted across 4 different speeds (Volkswagen, 2024e).

As previously mentioned, EVs take much longer to recharge than ICEV take to refuel, and this fact affects the public perception of EVs. The Golf has multiple range figures depending on engine and power choices. Its most fuel-efficient pure ICE variant is the 115hp 2.0 TDI diesel variant with the 6-speed manual transmission, this version achieving a combined WLTP of 4.2-4.6L/100km (Volkswagen, 2023b). This variant of the Golf coupled to its 45-litre fuel tank means it can cover between 1071km and 978km with a full tank.

The R version of the Golf however is the most powerful and least fuel-efficient version. Equipped with a 2.0 TSI 320hp gasoline ICE, “4Motion” AWD and 7-speed DSG automatic transmission results in a combined WLTP figure of 7.7-8.1L/100km (Volkswagen, 2023a). This version is equipped with a 50-litre fuel tank and can cover between 649km and 617km, a drastic reduction when compared to the 115hp 2.0 TDI variant.

The ID.3 has two different variants with differing WLTP range figures. The version with the largest battery and thus the longest range is the 77kWh 204hp Pro S with a combined WLTP range of 545-557km, while the variant with the least range is the 58kWh 204hp Pro variant, which has a WLTP combined range of 418-428km. The Pro S averages a WLTP of 15.4-15.7kWh/100km and the Pro a WLTP of 15.2-15.6kWh/100km (Volkswagen, 2023c).

The differences between the range figures in the ID.3 models is drastically lower than in the Golf, but so are all the other figures besides battery size. Power (202hp), torque (310Nm) and top speed (160km/h) are identical in the two ID.3 variants, with a difference in 0-100kmh time of 0.4s between the two, 7.4s in the “Pro” and 7.9s in the “Pro S”.

On the other hand, the gap in figures in the two Golf variants could not be wider. The 2.0 TDI has 115hp, 202km/h top speed and a 0-100km/h time of 10.2s, while the R has 320hp, 270km/h top speed and 0-100km/time of 4.7s. The closest figures being the torque, even though the TDI has almost one third of the power compared to the R, the difference in torque is much lower since diesel ICEs have naturally more torque than equivalent gasoline ICEs. As such, the diesel variant achieved a torque figure of 300Nm and the gasoline powered R 420Nm, just 120Nm difference.

Charging times vary in the ID.3. The 58 kWh Lithium-Ion battery of the Pro takes 31h to charge from 0% to 100% in 2.3Kw AC current, 6h15min in a 11kW AC current and in DC current it takes 35 minutes to go from 5% to 80% battery charge. The 77 kWh “Pro S” takes 39h, 7h30min and 30 minutes, respectively.
In the case of these two models, due to the size of the gas tank coupled with lower weight, the least efficient pure ICE variant of the Golf manages to achieve a longer range, and superior performance than the most efficient ID.3.

The Battery alone weighs 374kg in the 58kWh “Pro” and 489kg in the 77kWh “Pro S”, resulting in final weights oft 2,270kg and 2,280 respectively (Volkswagen, 2023c).
The curb weight of the Golf 2.0 TDI is much lower, with a figure of 1384kg (UltimateSPECS, 2020). Meanwhile the heaviest variant of the golf, the automatic AWD R, has a curb weight of 1579kg (Volkswagen, 2022).

Package Design

Concerning dimensions, the Golf is the longest of the two, being 4284mm in length versus the 4264mm of the ID.3. However, the ID.3 has a longer wheelbase, 2770mm contrasting with the 2619 mm of the Golf. The Golf's longer overhangs are a result of its propulsion system, while the electric drivetrain better utilises its volume, gaining interior space relatively to the longer Golf. Comparing the width of both vehicles, excluding the side mirrors, the ID.3 is wider, with a width of 1809mm comparatively to the Golfs 1789mm. The ID.3 is also taller, with a height of 1564mm in contrast with the Golfs 1491mm. This is a result of the batteries that sit in the floor of the vehicle, with the higher floor meaning the vehicle needs to be taller to maintain a similar interior space to its ICE counterpart. Boot space is slightly larger in the ID.3 with 385 litres of available space while the Golf has 381 litres (Volkswagen, 2024a; Volkswagen, 2024c). In summary, the Golf has greater length, and the ID.3 is larger in every other metric.

Both models belong to the same brand, as such, similarities in design language and brand philosophy are bound to be found. The overall shape is visibly different, with the ID.3 presenting a more streamlined, egg like, oval shaped profile, while the Golf maintains a more traditional silhouette, with the bonnet size and angle to the windshield being the first takeaway. The ID.3 has a shorter overhang at the front and this, coupled with its windshield connecting to the bonnet at around one quarter way into the front wheel and at a higher angle, substantially reducing bonnet area when compared to the more traditional Golf, which results in a more oval shape than the Golf. As previously stated, the ID.3 is taller than the Golf, the highest point of the roof line being where the front and rear doors meet and sloping down towards the rear. This is likely to reduce the perceived size and hight of the vehicle, resulting on a more egglike shape. The Golf contrasts by also having a roof line that slopes towards the rear, but at a smaller angle.

In the ID.3, regarding the side windows, the glass line begins where the windshield meets the bonnet, proceeds downwards at an angle towards the side mirror, and maintains a flat line until the rear quarter window, where it raises again which may be an attempt to reduce its perceived size. The Golf's glass line begins the same way at the meeting point of the windshield with the bonnet, but in maintains a straight line throughout. The black roof, thin metallic A pillar and black piece under the doors all play together to reduce the perceived size of the ID.3 (fig. 59). However, the ID.3 has a Cd of 0,267 while the Golf has a Cd of 0.33, a clear demonstration of the greater potential efficiency of an EV (EVSpecifications, 2019; Volkswagen, 2022).

Figure 59: 2020 Volkswagen Golf profile (left) (Volkswagen, 2019c). 2020 Volkswagen ID.3 profile (right) (Volkswagen, 2020).

At the front of the vehicles the same can be observed. The Golf has one upper and another lower front grille, while the ID.3 only has one lower grill. Running between the headlights to the VW logo, the Golfs slim grill is used for the engine's air intake, while the lower grill is used for the cooling system. The ID.3 has a light strip in the place of a top grill, and the lower grill is also used by the cooling system. Both models have "aggressive" front facias with sharp headlights, the Golf being “sharper” while the ID.3 is “smoother”. Additionally, both have a large lower grill that increases in size in the corners, although merely for aesthetic reasons as only the space between the headlights has an actual opening (fig. 60).

Figure 60: 2020 Volkswagen Golf front end (left) (Volkswagen, 2019c). 2020 Volkswagen ID.3 front end (right) (Volkswagen, 2020).

At the rear, both vehicles once more present similar designs clues. Both taillights follow a similar overall shape, with the Golf's being more angular and the ID.3's sharper. The ID.3 also plays with a two-tone colour scheme while the golf maintains a single colour. The Golf offers two chrome exhaust like shapes in the lower rear bumper even though the real exhaust pipe is hidden, while the ID.3 has a simple panel (fig. 61).

Figure 61: 2020 Volkswagen Golf rear end (left) (Volkswagen, 2019c). 2020 Volkswagen ID.3 rear end (right) (Volkswagen, 2020).

Safety

For an analysis on the safety of these vehicles, the most recent data from EURO NCAP, with both vehicles receiving a five-star rating. The Golf achieves a safety rating for "Adult

Occupant” of 88%, closely matched by the ID.3s 87%. The results for “Child Occupants” remain similar, with the Golf achieving 87%, close to the 89% of the ID.3. “Vulnerable Road Users” results in 74% for the Golf and 71% to the ID.3, this due to the inferior footprint of the hood that results in a harder surface for head collisions, and thus a “Head Impact” score of 14,3 for the ID.3 versus the Golfs 17,0. Finally, for “Safety Assist” the Golf achieves 82% versus the 88% of the ID.3, this due to the superior amount of safety and assistance systems in the ID.3 that aid in accident prevention (European New Car Assessment Programme, 2020; European New Car Assessment Programme, 2022).
Overall, both vehicles offer a similarly safe experience without any real winner.

Sustainability

Both models are made by Volkswagen, and as such both are built under an equal philosophy and following EU end of life regulations, these including improving circular design for material reuse and recycling (European-Commission, 2023). On its path to follow EU regulations and achieve net zero carbon neutrality, Volkswagen used recycled materials and non-animal leather. The first model in the ID. lineup to receive this new sustainable treatment was the ID. Buzz, incorporating recycled materials across the interior reducing its manufacturing environmental footprint (Volkswagen, 2023d).

Following this, the ID.3 was also equipped with sustainable materials and is animal-free. Artvelours Eco, a microfiber material that is composed of 71% recycled material, is used in the interior of the vehicle (Volkswagen, 2023c).
The Golf follows a similar path, with 28% of its textiles and 6% of its thermoplastics originating from recycled materials (Volkswagen Group, 2023).

Emissions wise it is important to take a couple aspects into account. The Golf has an ICE, and as such it has tailpipe emission while the electric ID.3 does not. Consequently, the WLTP emissions data provided for the Golf is 110-117 g/km of CO2 for the least polluting 115hp 6 speed manual 2.0 TDI, and 178-182 g/km of CO2 for the most polluting version, the 320hp 2.0 TSI 4Motion 7 speed DSG R, while both versions of the ID.3 have “0” emissions (Volkswagen, 2023a; Volkswagen, 2023b; Volkswagen, 2023c).

The reduction of Green House Gasses (GHG) in EVs versus ICEVs can be as low as 30% or as high as 80%. This discrepancy has to do with the mix of energy sources in electricity production. Furthermore, GHG emissions produced during manufacturing of EVs is more than double those emitted during ICEV production (Tang, Tukker, Sprecher, &

Mogollón, 2023). As such, before these vehicles are even sold, both already bring emissions footprints with them.

Costs

Where costs are concerned, assuming the previously stated European cost average of €1,64/L for gasoline, €1,56/L for diesel as of May 6th 2024, and 0,17/kWh for electricity through the first half of 2024, it is possible to fairly compare the two platforms using the WLTP consumption for each variant. Of the analysed variants, the Golf 2.0 TDI and the ID.3 Pro are the least expensive to run. Assuming the average combined WLTP consumption, the Golf 2.0 TDI costs between €6,55 and €7,18 every 100km while the ID.3 Pro costs between €2,58 and €2,65 every 100km. Conversely, the Golf R costs between €12,63 and €13,28 every 100km while the ID.3 Pro S costs between €2,62 and €2,70 every 100km. This data reveals a minor change for the EV, and a considerable contrast of close to double for the ICE. The Golf is available starting from €24,457, while the ID.3 begins at €42,460 (Costa, 2023; Mendes, 2023). This results in a difference of €18,003 which must be taken into consideration along with the fuel/energy costs, maintenance costs and vehicle depreciation.

3.2.2 – BMW 3 Series vs. Tesla Model 3

Volume of Components

The 2023 BMW 318i (G20) and the 2023 Tesla Model 3 Base model (60kWh) are two vehicles of two distinct brands with differing means of propulsion that tackle the same share of the market, the four-door sedan (fig. 62). The BMW G20 3 Series Life Cycle Impulse (LCI), a term used by BMW to refer to facelifts, is offered in a multitude of engine options, including gasoline, diesel, and plugin Hybrid variants. Tesla offers the 2023 Model 3 as EV only.

The Tesla Model 3 Rear-Wheel Drive is a rear engine RWD EV as its name suggests, while the BMW 318i is a front engine RWD ICEV. Both vehicles offer a near 50/50 weight distribution, which contribute to their excellent road behaviour. Space at the front of the BMW is limited due to the ICE engine and transmission, and its mechanical peripherals such as the intercooler, the 12-volt battery and the air intake and the large radiator. The Tesla on the other hand only has a small radiator for the cooling system, the battery, the 12v battery and a front trunk for extra storage. The electric motor is placed in the rear, and sits low down in the chassis, contributing to a low center of gravity and still allowing for usable rear trunk space, which results in a much more effective use of space when compared to the BMW.

The Tesla Model 3 has its 60-kWh battery under the whole length of the passenger compartment, slightly raising the floor. The 3 series on the other hand has a 59-litre fuel tank under the back seats, which allows the floor to be closer to the ground. The transmission and drive shaft of the BMW require a transmission tunnel to connect the ICE to the rear wheels, reducing overall interior space and foot space for the rear passengers. Additionally, the exhaust system connects the engine to the back of the vehicle, adding a large component that emits large amounts of heat, requiring thermal shielding. The Tesla has a flat bottom to improve aerodynamics while the ICEV does not.

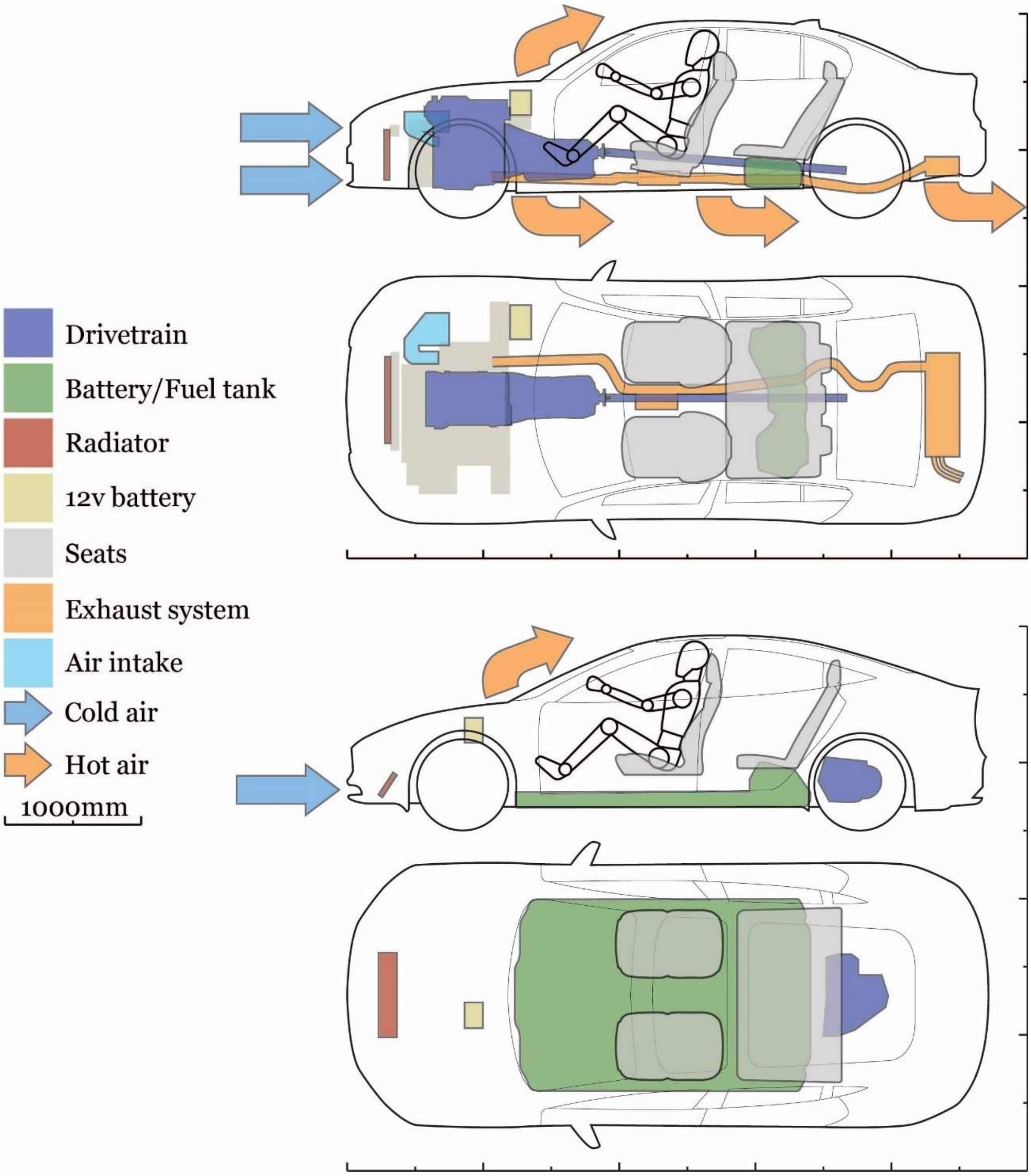

Figure 62: Package Layout of components in the BMW 3 Series G20 and Tesla Model 3 of 2024. Adapted from Calhamar, A., Monteiro, J., & Londrim, J. (2024). Mobility, Citizenship and Energy Transition - Challenges and Opportunities in the Electric Automotive Design Process. Manuscript submitted for publication.

Range

The BMW 3 series offers a wide range of variants to choose from, as such there is a plethora of range figures for this model.

The most fuel-efficient pure ICE models are the “318i” (156hp and 250Nm of torque) and “320i” (184hp and 300Nm of torque), both with the same power plant but distinct power and torque figures. Equipped with an 8-speed automatic transmission, both variants achieve a combined WLTP of 6,4-7,2 L/100km (BMW, 2022b). Like the previously analysed Volkswagen Golf, the low power diesel variants of the BMW 3 series achieve higher fuel efficiency but has a mild hybrid system, meaning that even though their day-to-day use remains the same of a pure ICE model, they can no longer be considered pure ICEVs. The most fuel-efficient ICE variants of the BMW 3 series coupled to a 59-litre fuel tank results in a range figure of 922km-819km, while its less fuel-efficient version is the high performance M3 variant, which achieves a combined WLTP of 10.3-10.6 L/100km. Coupled to the same capacity 59-litre fuel tank, that means that the M3 can cover 573km-557km on one tank of fuel, a drastic reduction by comparison.

The Tesla Model 3 is available in three variants of which the most efficient is the AWD 491hp Long Range variant with a combined WLTP of 629km, while the least efficient is the 279hp Rear-Wheel Drive variant with a combined WLTP of 513km. It is also significant to mention that even though these are the advertised ranges for the two variants of the Model 3, both see a range increase when coupled with the 18” wheel option, increasing it to 678km and 554km respectively. The Long Range averages a combined WLTP of 14,0 kWh/100km while the Rear-Wheel Drive averages a combined WLTP energy consumption of 13,2 kWh/100km (Tesla, 2024a; Tesla, 2024b). The Long Range is equipped with a 75-kWh battery and has 493Nm of torque and the Rear-Wheel Drive comes with a 57,5-kWh unit (Electric Vehicle Database, 2024a; Electric Vehicle Database, 2024b).

The discrepancy between capabilities is larger in the BMW 3 series than in the Tesla Model 3. The large variety of drivetrains in the BMW means a wider range of choice and ability for each variant, while the available variety in the Tesla is smaller.

Comparing the most efficient variant both models offer, the Model 3 Long Range achieves an impressive range for an EV, it however lacks behind the most fuel-efficient ICE 3 Series, mostly due to the BMW’s large 59-litre fuel tank. On the other hand, acceleration is superior in the Tesla "Long Range", achieving a 0-100km/h time of just 4,4s, substantially faster than the 7.4s of the 320i and almost half of the 8.6s of the 318i. For top speed however the roles reverse, the “Long Range” is artificially restricted by software to 201km/h, while the 3 series is not, therefore able to do 223km/h in the form of the 318i, and 235km/h in the 320i. These are illegal speeds in most situations, or countries for that matter, so the Tesla benefits by having the most usable performance of the two.

On the least efficient side however the results are distinct. The Model 3 Rear-Wheel Drive is the least powerful Model 3 variant offered, while the base M3 is one of the most powerful BMW 3 series variants available. The Tesla Rear-Wheel Drive is capable of a 201km/h top speed due to the artificially imposed software restrictions and reaches 100km/h from a standstill in 6,1s. Meanwhile the M3 can achieve a top speed of 250km/h (290km/h with a factory removed limiter) and a 0-100km/h time of 3,9s. These figures present a plain contrast between an entry model and an exclusive high-performance model, which is are also reflected in the purchase cost.

The Long Range charges in 38:30h with 2.3kW AC, 8:15h with 11kW AC and 27 minutes with 250 kW DC (Supercharger v3) (Electric Vehicle Database, 2024b). The Rear-Wheel Drive variant takes 29:30h, 6:15h and 25 minutes respectively (Electric Vehicle Database, 2024a).

As far as weight is concerned, the Model 3 is the heavier of the two vehicles, not only due to the weight of the batteries but also, in the case of the AWD model, the second electric motor. The Model 3 Rear-Wheel Drive weighs 1836kg, while the AWD Long Range weighs 1899kg (Tesla, 2024b). The 318i and 320i weight 1575kg and 1590kg respectively while the M3 tips the scale at 1780kg (BMW, 2021b; BMW, 2022b).

Package Design

The 3 series has a length of 4713mm, while the Model 3 has a figure of 4724mm, being therefore marginally longer. The Model 3 also has the longer wheelbase of the two, 2875mm comparatively to the 2851mm of the BMW 3 series. The Tesla is the wider by 23mm, 1850mm against the 1827mm of the BMW, both figures excluding mirrors. Concerning height, both models are matched with a figure of 1440mm. Luggage space is also superior in the Tesla Model 3, as not only is the trunk space larger at 594 litres in contrast with the 480 litres of the 3 series, but it also comes with additional storage space in the form of a front truck with an extra 88 litres of available space (BMW, 2024a; Tesla, 2024c). Overall, the Tesla Model 3 is the bigger vehicle in all regards with the exception of height, a great feat considering the placement of the large propulsion battery below the floor.

The overall shape of the Model 3 is that of a sharp hatchback with a sloped roof line. The front is low, and the lines of the rear culminate in a duck tail style trunk.

The BMW 3 series has a more traditional 3 box design, with a large front hood, more predominant than in the Model 3, and a duck tail style trunk. Additionally, it comes with the hallmark “Hofmeister kink” in the rear side windows, while the Tesla remains flat there. Overall, both have a similar shape, the BMW with the three-box shape more apparent, while the Tesla has smoother lines (fig. 63).

The result is a Cd figure of 0.27 for the BMW and a Cd figure of 0.219 for the Tesla, once more the EV having a clear advantage in aerodynamic efficiency over a similar ICEV (Csere, 2023; Lee, 2023).

Figure 63: 2023 BMW 3 series profile (left) (BMW, 2022a). 2024 Tesla Model 3 profile (right) (Tesla, 2023b).

At the front, the BMW has three major openings in the form two air intakes above the licence plate and one below it, while the Tesla only has one. The BMW 3 series has its hallmark "kidney" grill as its upper airway entrance and a larger lower grill, while the Tesla model 3 only has a slim airway lowdown in the bumper. Both have a sharp design language but while the BMW has a complex front facia full of shapes and details, the Tesla is simplistic and smooth. The light signature of the BMW also follows the traditional two light rings adapted to the new design language (fig. 64).

Figure 64: 2023 BMW 3 series front end (left) (BMW, 2022a). 2024 Tesla Model 3 front end (right) (Tesla, 2023b).

At the rear, the Tesla has a more pronounced rear wheel arch, with both vehicles having a pronounced duck tail style trunk, although in the Tesla it has a sharp edge. The lower rear bumpers follow closely the front, with the simplistic philosophy of the Tesla being ever present and the complex and sharp look of the BMW culminating in a small diffuser style lower bumper with two exhaust tips, one on each side (fig. 65).

Figure 65: Figure 60: 2023 BMW 3 series rear end (left) (BMW, 2022a). 2024 Tesla Model 3 rear end (right) (Tesla, 2023b).

Safety

The 2019 BMW 3 series obtained a EURO NCAP score of five-stars, being limited to that model year alone which is the most recent at the time of writing. The 2019 Tesla Model 3 also obtained a EURO NCAP score of five-stars, being reviewed and up to date from July 2019 until July 2023.

The BMW 3 series has a near perfect “Adult Occupant” safety score of 97%, while the Tesla Model 3 almost matches it with a score of 96%. The “Child Occupant” score is similar, although inferior in both, with the Tesla achieving 86% and the BMW once more almost matching it with 87%. Up to this point both models are perfectly matched but in the “Vulnerable Road Users” ratings is where things change. The BMW obtains a score of 87% while the Tesla falls behind with a score of 74%, 12% down compared to the BMW. The Tesla obtains 6.0 points for “Pelvis Impact,” while the BMW only gets 3.3 points. Where the BMW gains advantage is in “Head Impact” achieving 22.3 points versus the 12.1 of the Tesla. Along with an equal “Leg Impact” Score in both vehicles, this leaves the 3 series with 31.6 points out of 36 while the Model 3 only gets 24.1. Finally, for “Safety Assist” the roles reverse, the BMW obtains a score of 76%, and the Tesla 94%. The BMW has a worse performing Lane Support system of the two, additionally the Tesla gains by having slightly better performing systems for all other categories in this group (European New Car Assessment Programme, 2019a; European New Car Assessment Programme, 2019b). Overall, both vehicles offer a safe user experience, with the Tesla providing superior active safety means of crash protection in the form of safety systems and the BMW providing superior passive means in the form of better pedestrian safety in the eventuality of an accident.

Sustainability

The BMW 3 series uses cast aluminium parts made from around 50% recycled material, while the optional aluminium rims achieve a percentage of around 70% (BMW, 2024b). In 2023, BMW recycled or recovered 99,4% of waste generated by manufacturing, as of the 927,880 tons of waste produced, 91% was recycled and 8,1% used for thermal generation. For end-of-life vehicles, excluding motorcycles, BMW recycled 85% of materials and with a further 10% used for thermal use, achieved the 95% value stipulated by the European Union (BMW, 2023).

Tesla recycles around 90% of material from end-of-life products through their in-house recycling facilities, which then make their way into new batteries, reducing the requirements for primary mined materials. Tesla also uses recycled aluminium accompanied by primary material (Tesla, 2023a), but the amount of recycled material used in the Model 3 is not officially disclosed by Tesla.
Emissions wise, the Tesla produces zero, while the BMW 3 Series achieves in its most efficient pure ICE formats, the 318i and 320i, a combined WLTP CO2 of 145-162 g/km

and in its least efficient pure ICE format, the 480hp M3, a figure of 236-241 g/km (BMW, 2021; BMW, 2022b).

Costs

To compare de costs of both vehicles, the used metric, as in the previous comparison is the previously stated European cost average of €1,64/L for gasoline, €1,56/L for diesel as of May 6th 2024, and 0,17/kWh for electricity through the first half of 2024, which allows for a fair comparison the two platforms through the WLTP consumption for each variant. Of the benchmarked variations, the BMW 318i/320i and the Tesla Rear-Wheel Drive are the least expensive to run. Assuming the average combined WLTP consumption, the BMW 318i/320i costs between €10,50 and €11,81 every 100km, while the Tesla Rear-Wheel Drive costs around €2,24 every 100km. Conversely, the M3 costs between €16,89 and €17,38 every 100km while the Tesla Long Range costs around €2,38 every 100km. This data reveals once more a minor change for the EV range, and a considerable contrast for the ICEV. The BMW 3 series is available starting from €42,200, while the Tesla Model 3 begins at €39,990 (César, 2024; Gomes, 2019). This results in a difference of €2,210 which as always must be taken into consideration along with the fuel/energy costs, maintenance costs and vehicle depreciation.

3.2.3 – Audi Q3 Sportback compared to Volkswagen ID.5

Volume of Components

The 2023 Audi Q3 Sportback and the 2023 Volkswagen ID.5 are two models of distinct brands with differing means of propulsion that tackle the same share of the market, the five door SUV (fig. 66).
The Audi Q3 Sportback is available with a variety of engine options, with Diesel and Gasoline options and gasoline mild or Plugin Hybrids. The ID.5 on the other hand is solely EV.

The Q3 is a front engine FWD vehicle and has most of its components at the front. The intake, radiator, 12v battery, engine and transmission all share the same space under the bonnet. With most components sitting over the front wheels, the weight is biased towards the front, this often leads to compromised driving dynamics. The exhaust system runs under the whole vehicle, emitting large amounts of heat and taking up space.

Interior space is compromised due to the presence of a transmission tunnel, as the Q3 Sportback is also available with “Quattro” AWD. The ID.5 on the other hand is a rear engine RWD vehicle, with its motor very close to the rear axle while the radiator and 12v battery sit at the front. Additionally, it also has a flat bottom, a benefit for aerodynamic efficiency, unlike the Audi.

The fuel tank of the Q3 is a 58-litre unit that sits under the rear seats while the 77-kWh propulsion battery of the ID.5 sits under the passenger compartment, beginning in the front passenger foot well and extending all the way roughly until halfway under the rear seats. This battery placement means the floor is raised and seating position is higher, but the battery’s position coupled with the electric motor at the chassis level results in a lower center of gravity than in the Q3 Sportback, improving safety and lowering the possibility of a roll over which is typically more prevalent in this category of taller vehicles.

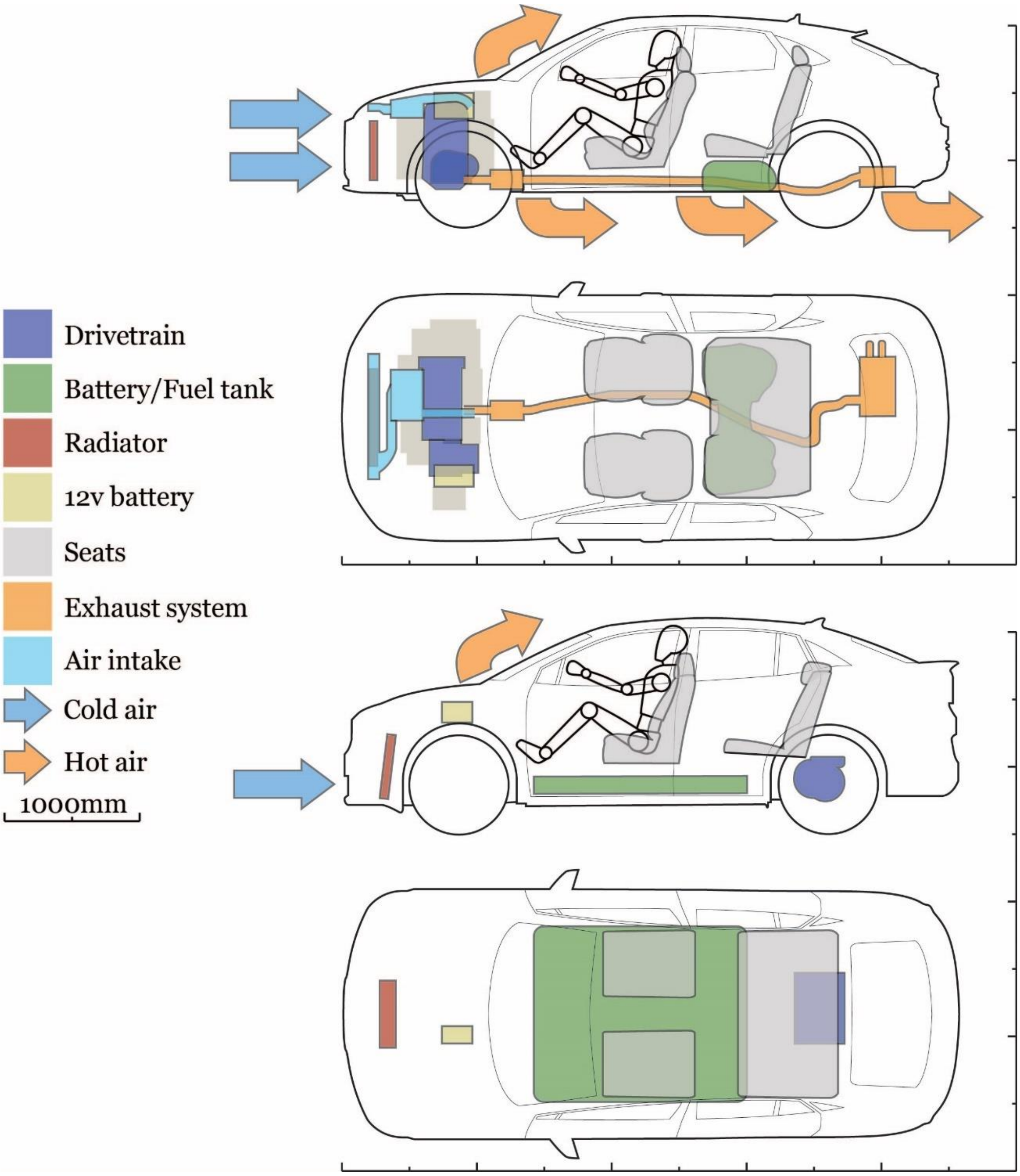

Figure 66: Package Layout of components in the 2023 Audi Q3 Sportback and 2023 Volkswagen ID.5. Adapted from Calhamar, A., Monteiro, J., & Londrim, J. (2024). Mobility, Citizenship and Energy Transition - Challenges and Opportunities in the Electric Automotive Design Process. Manuscript submitted for publication.

Range

The Q3 Sportback is available with a variety of engine options, of which the most efficient pure ICE variant is the 150hp 35 TDI with the 6-speed manual transmission. It achieves a combined WLTP of 5,1-5,5 L/100km (Audi, 2024). This version of the Audi Q3

Sportback, coupled with the 58-litre fuel tank results in a combined WLTP range of 1137km-1055km.

On the opposite side of the spectrum, Audi offers the 400hp RS Q3 Sportback, a high-performance version equipped with a dual clutch automatic transmission, permanent “Quattro” AWD, and a 63-litre fuel tank. It manages a combined WLTP of 9.6-10.1 L/100km (Audi, 2022). From full to empty, the RS Q3 Sportback has a range of 624km-656km, almost half of the 35 TDI.

The ID.5 has two variants available and the RWD 77 kWh 286hp PRO is the most efficient of the two, with a combined WLTP range of 554km, achieving it through an average energy consumption of 15.9 kWh/100km. The least efficient is the 77 kWh 340hp GTX, this variant of the ID.5 having a combined WLTP range of 537km via an average energy consumption of 16.3 kWh/100km (Volkswagen, 2024f). The contrast in range figures between the most efficient models of both brands shows that the ICE Q3 Sportback has double the range of the ID.5 Pro.

Performance wise a sharp contrast can be observed between the two platforms. The 35 TDI has a 0-100km/h time of 9,4s while the VW’s PRO achieves it in 6,4s. With a power output of 286hp and a torque figure of 560Nm, the ID.5 PRO totally outpaces the 150hp and 340Nm of torque of the 35 TDI from a performance point of view. The top speed figure is closely matched between the two models, with the Volkswagen achieving 180km/h and the Audi 200km/h. Once more, these are illegal speeds in most scenarios, and as such the GTX benefits by having the most usable performance of the two (Audi, 2024; Volkswagen, 2024f).

Comparing the high-performance versions of both vehicles the numbers are closer range wise and the RS Q3 Sportback has just 87km-119km more range than the ID5 GTX.

The ID.5 PRO has a WLTP of 15,9 kWh/100km and charges to 100% in 39h:30min with 2.3kW AC, 8h:15min on 11kW AC and 28 minutes on 150kW DC (Electric Vehicle Database, 2024b). The ID5 GTX has a WLTP kWh/100km of 16,3, takes 39h:30min and 8h:15min respectively, and 28 minutes on a 350kW DC charging point (Electric Vehicle Database, 2024a).

Performance wise, both models deliver fast 0-100km/h times. The Audi RS achieves it in 4.5s and the ID5 GTX in 5.4s. The EV lacks behind in top speed, with a figure of 180km/h

due to software-imposed limitations, inferior to the Audis factory software limited figure of 250km/h (Audi, 2024; Audi, 2022; Volkswagen, 2024f).
The weight of the ID5 is 2680kg in the PRO and 2760kg in the GTX (Volkswagen, 2024f). In contrast, the weight of the 35 TDI is 1555kg while that of the RS model is 1700kg (Audi, 2024; Audi, 2022).

Package Design

The Q3 Sportback has a length of 4500mm with the ID.5 being nearly 100mm longer at 4599mm. This translates to a longer wheelbase on the ID.5, 2771mm versus the 2680mm on the Audi. This trend continues in the width dimensions, with the ID.5 being 1852mm wide and the Q3 Sportback slightly under with a figure of 1843, both excluding wing mirrors. The VW has a height of 1615mm, compared to the 1567mm of the AUDI. Lastly, storage wise, the ID.5 comes with 549 litres of available trunk space while the Q3 Sportback comes slightly reduced, at 530 litres (Audi, 2023b; Audi, 2024; Volkswagen, 2024d). In summary, the ID.5 is the larger vehicle in all metrics.

Both models present a similar silhouette. The ID.5 has a more rounded design language, while the Q3 Sportback is sharper. The Audi also has a more sloped look, with the highest point of the roof line being above the driver, while the more rounded ID.5 sees the highest point between the front and rear doors. The Q3 presents itself with bolder and sharper wheel arches than the ID5. Both have a small spoiler at the rear, the ID.5 below the real glass, leaving a clean and rounded roofline, while the Q3 has it above the rear glass, aiding to its sharper look (fig. 67).

The result is a Cd of 0,34 for the Audi, and of 0.26 for the ID.5, depicting a vast advantage in aerodynamic efficiency for the EV (Audi, 2024; VWPress, 2022).

Figure 67: 2022 Audi Q3 Sportback profile (left) (Audi, 2019). 2022 Volkswagen ID.5 profile (right) (Volkswagen, 2021).

At the front, the design philosophy of both brands is very present. Like the ID.3, the ID.5 has a single air entrance lower down in the bumper, with the upper grille between the headlights being replaced by a light stripe. The Q3 on the other hand follows the traditional grille layout, with an upper and lower air entrance. The Audi, with its large grille design gives the appearance of a greater air entrance, but the usable space only covers the upper half the grille, the remaining half being blocked to avoid overcooling the engine, followed by a second airway below the large hallmark grille, with a more discreet profile. The ID.5s grille follows a similar route, with a small percentage bellow the license plate area allocated to funnel air to its systems, while the remaining large area being blocked, existing simply for aesthetics. The ID.5 has a more rounded look due to its front features like the grille and headlights, while the Q3 Sportback continues the sharp motif with its front features like the grille, headlights and light signature (fig. 68).

Figure 68: 2022 Audi Q3 Sportback front end (left) (Audi, 2019). 2022 Volkswagen ID.5 front end (right) (Volkswagen, 2021).

At the rear both design languages remain consistent. The ID.5 mirrors its front light signature with a light stripe running from the taillights to the logo. The Audi has sharp taillights, with its rear light signature following suit. The lower bumper of the ID.5 has design features replicating the front, most prominently the fake outlets for brake cooling, while the Audi does have a small opening for air to get through. The lower bumper has a simple plastic piece in the VW and a small plastic diffuser in the Audi. The Q3 Sportback also has no visible exhaust pipes and no design features simulating them (fig. 69).

Figure 69: 2022 Audi Q3 Sportback rear end (left) (Audi, 2019). 2022 Volkswagen ID.5 rear end (right) (Volkswagen, 2021).

Safety

The Audi Q3 Sportback does not have EURO NCAP results available to its specific variant, and as such, the most recent results for the regular Q3, (which also includes all Sportback variants according to the test results provided by EURO NCAP), will be used for this comparison. The 2018 Audi Q3 attained a EURO NCAP five-star safety rating and was reviewed through December 2018 until December 2021, with the Volkswagen ID5 receiving a EURO NCAP five-star safety rating as well. The Audi received an "Adult Occupant" rating of 95%, while the VW is not far behind with a rating of 93%. In the "Child Occupant" rating the inverse is true, as the Q3 received a rating of 86% while the ID.5 89%. In "Vulnerable Road Users" both achieve a 76% and in "Safety Assist" both 85% (European New Car Assessment Programme, 2018; European New Car Assessment Programme, 2021b). Both vehicles offer an extremely similar experience regarding safety, achieving excellent results for their class without compromising either choice.

Sustainability

Audi revealed in its 2023 report that 140,352 tons of waste were recycled in 2023 as part of its efforts to achieve net carbon neutrality. The car manufacturer recycled 60% of aluminium and 85% of steel from end-of-life automobiles and used it to manufacture new vehicles. Models mentioned regarding recycled materials include the Q4 e-tron, which uses glass with a recycled content of 30%, derived from unrepairable windows from other vehicles (Audi, 2023a). In addition, Audi used material with 12% recycled content to build around 15,000 inner door panels for the A4 model (Audi, 2023c). The amount of recycled content used in the Q3 Sportback is not officially disclosed by Audi.

Regarding emissions, the Q3 Sportback in the form of the 150hp 35 TDI achieves a combined WLTP CO2 of 132-145g/km, while the 400hp RS model achieves a figure of 218-229g/km (Audi, 2022; Audi, 2024) with the ID5 emitting zero as it is an EV.

The ID.5, along with the whole ID family is set to receive a plethora of innovations related to sustainability pioneered by the ID.Buzz, as previously mentioned. These include SEAQUAL yarn for the seat covers, removal of chrome trim with its replacement being a bio-based binder equipped liquid paint and finally, the use of plastic collected from the ocean (Volkswagen, 2024b). The percentage of recycled content used in the ID.5 is not officially disclosed by Volkswagen.

Costs

To compare de operating costs of both models, the used metric, as in the two previous comparisons is the previously stated European cost average of €1,64/L for gasoline, €1,56/L for diesel as of May 6th 2024, and 0,17/kWh for electricity. Of the benchmarked configurations, the Audi Q3 Sportback 35 TDI and the VW ID.5 Pro are the more cost effective. Assuming the average combined WLTP consumption, the Audi 35 TDI costs between €7,96 and €8,58 every 100km, while the ID5 Pro costs around €2,70 every 100km. By contrast, the Audi RS costs between €15,74 and €16,56 every 100km while the ID5 GTX costs around €2,77 every 100km. These figures reveal once again a minor change in the EV variants, but a significant contrast for the ICEV versions. The Q3 Sportback is available starting from €54,150, while the ID.5 begins at €51,991 (Gomes & Costa, 2020; Teles, 2024d). This entry cost difference if of €2,159 which, as previously stated, must be taken into consideration along with the fuel/energy costs, maintenance costs and vehicle depreciation.

3.2.4 – Kia Picanto compared to Fiat 500e

Volume of Components

The 2023 Kia Picanto and the 2023 Fiat 500e are two vehicles of different brands with differing means of propulsion that tackle the same share of the market, the small city vehicle (fig. 70).

The Picanto is a front engine FWD compact hatchback available purely as an ICEV only with gasoline engines options. The Fiat 500e is a front motor FWD EV that also shares parts with a hybrid option in the form of the Fiat 500. These two vehicles however do not share architecture, with the Fiat 500e being a completely new platform built from the ground up to be an EV, and the Fiat hybrid 500 being built on the previous platform, therefore the 500e is considered a new model.

The Kia has the majority of drivetrain components at the front, with the radiator, intake, 12-volt battery, engine, and transmission under the bonnet. The Fiat 500e follows the same formula with the motor, 12-volt battery and radiator at the front of the vehicle, this meaning, overall, that both vehicles are front biased weight distribution wise.

The Kia has its 35-litre fuel tank under the rear seats, while the Fiat has its 42kWh battery under the passenger compartment, beginning in the back seats all the way to the foot space of the front seats. The size of the battery means the floor is raised in the Fiat 500e. Since the Picanto is exclusively FWD, there is no transmission tunnel robbing foot space from the back seats. As previously stated, both vehicles are biased towards the front regarding weight distribution, however, the Fiat 500e has a lower center of gravity due to its propulsion battery being placed under the passenger compartment, along with the electric motor placed low in the front axle. The Kia Picanto follows the traditional blueprint for component layout first seen in the original Mini of 1959. Additionally, the exhaust system beginning in the engine bay and ending at the back of the Kia, emits large amounts of heat, and creates a rough underside while the 500e has a partially flat bottom, optimizing its aerodynamics.

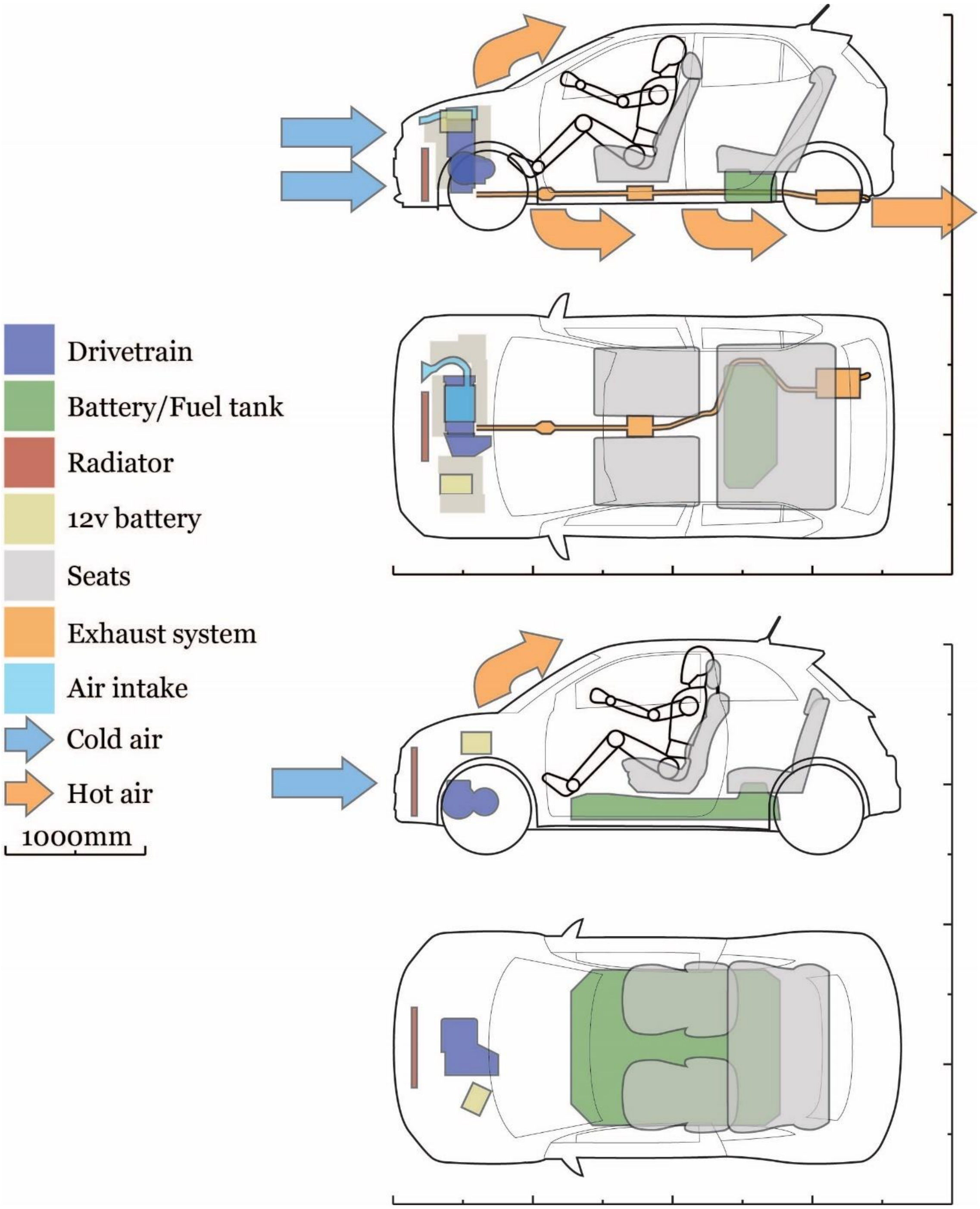

Figure 70: Package Layout of components in the 3rd generation Kia Picanto and Fiat 500 of 2023.

Range

The Kia Picanto is offered purely as an ICEV, with gasoline drivetrains as the only option and a 35-litre fuel tank. Its most fuel efficient, and coincidently least powerful version has a five-speed manual transmission and is named the 1.0 MPi, with 67hp and 96Nm of torque and a combined WLTP of 4,8-5,3L/100km. Its least efficient variant is the five-speed automatic transmission called 1.2 MPi with 84hp and 118Nm of torque with a combined WLTP of 5,6L/100km. This means the 1.0 MPi can cover 729km-660km from a full to an empty fuel tank, while the 1.2 MPi manages 625km of range (Kia, 2022a; Kia, 2022b).

The Fiat 500e is offered with two battery options, 24kWh and 42kWh. The 24kWh variant with 95hp and 220Nm of torque has the smaller range of the two, with a combined WLTP of 190km, while the longer-range model with the 42kWh battery has 118hp and also 220Nm of torque with a combined WLTP of 320km (Fiat, 2021; Fiat, 2023a). The 24kWh variant, which really has a 23,7kWh unit, has a usable capacity of 21,3kWh, and a combined WLTP kWh/100km of 13. The 42kWh variant has a usable capacity of 37,3kWh and a combined WLTP kWh/100km of 13,6 (Fiat, 2024a).

In this case, the most efficient Kia has a range much closer to previously seen efficient EVs. However, in this market segment it still achieves more than double the range of its EV rival. As previously seen, performance is generally related as a compromise with the range of a vehicle and in this case, the 0-100km/h times of the Fiat are far superior to those of the Kia. The 24kWh Fiat 500e manages a 0-100km/h time of 9,5s while its long-range counterpart, the 42kWh, achieves it in 9s flat (Fiat, 2023a). The Kia Picanto on the other hand struggles, the five-speed manual transmission 67hp 1.0 MPi has a 0-100km/h time of 14,8 seconds while its least efficient counterpart, the five-speed automatic transmission 84hp 1.2 MPi, is much slower with a time of 15,7s (Kia, 2022b). Top speed wise the roles are reversed. The 24kWh 500e being software limited, is capable of 135km/h while the 42kWh variant achieves 150km/h (Fiat, 2023a). The 67hp variant of the Picanto with the five-speed manual transmission is capable of 160km/h, while its least efficient counterpart, the 84hp variant with the five-speed automatic achieves 172km/h (Kia, 2022a).

Once more in this pair of vehicles, the EV has the most usable performance of the two with respectable 0-100km/h times. The Kia by comparison manages a respectable top-speed for the market segment, although the 0-100km time of the 84hp performs poorly. Due to the automatic transmission, this variant offers inferior performance and inferior fuel economy when compared to the same exact variant with the five-speed manual.

The charging time of the Fiat 500e varies with the type of charging used. Charging the 24kWh variant with 2,3kW AC from a depleted battery to 100% it takes 8h:45min, in

11kW AC it takes 2h:30min and in 85Kw DC from depleted to 80% it takes 30 minutes. The 42Kw variant takes 15h:15min, 4h:15min and 35 minutes respectively (Fiat, 2024a).

The Fiat 500e has a weight of 1255kg in the 24kWh variant with a battery weight of 182kg and the 42kWh 1365kg with a battery weight of 294,3kg (Fiat, 2021). The Picanto 67hp 1.0 MPi five-speed manual has a weight of 935kg (Kia, 2019). The 84hp 1.2 MPi comes in with a weight figure of 976kg (Kia, 2022b). Once more, due to battery weight, the EV is heavier, and in this case, by a considerable margin considering the general weight of vehicles in this market segment.

For this market segment, although the figure for the EV is much lower, range is not critical. These are city vehicles, and in city conditions the range of an EV tends to be higher than the combined range, due to regenerative braking being used more often.

As such, in city traffic, while pure ICEVs will achieve lower range figures, the EVs gain from it. In the case of the Fiat 500e, the combined range increases, with the WLTP range for a city cycle in the 24kWh version being 257km versus the WLTP combined 190km, and in the 42kWh variant 449km-459km as opposed to the combined WLTP figure of 315km-320km (Fiat, 2021).

The Fiat 500e therefore outshines the Kia Picanto for city driving, working brilliantly in its designed role. The Picanto's advantage over the EV is the ability to be used for a broader purpose, whether it is city driving or longer trips. Therefore, the Kia Picanto is a good vehicle for families that only own one car, while the Fiat 500e, perfect and efficient for its purpose, is a great second vehicle.

Package Design

The Kia Picanto has a length of 3595mm, and the Fiat 500e a length of 3632mm. The package of the Fiat gives the appearance of a smaller vehicle in length even though it has the longer footprint of the two. The Kia has a wheelbase of 2400mm and a width of 1595mm, while the Fiat has a 2322mm wheelbase, and a width of 1683mm, both not accounting for the mirrors. The Kia Picanto has a height of 1485mm while the Fiat 500e 1527mm, substantially taller than its rival. Luggage space in the Kia is 255 litres with the Fiat having just 185 litres of available space. Lowering the rear seats increases the space to 1010 litres in the Kia Picanto and to 550 in the Fiat 500e (Fiat, 2021; Kia, 2022a; Kia, 2022b). To summarize, the Kia Picanto has a much more efficient use of space, from its exterior size to ability to carry five people in addition to a large luggage compartment, while the Fiat 500e is focused on retro design, compromising interior and exterior space to achieve it (fig. 71).

The proportions of both vehicles are distinctively different. The Fiat 500e has a much rounder profile, akin to that of the original icon that was the original Fiat 500 of 1957. It also appears to have a smaller footprint than the Kia Picanto even though it is the longer and wider vehicle of the two. The profile of the Kia Picanto is the traditional two box design FWD hatchback. Unlike the Fiat 500e, it comes as a four door, the roof line maintaining a consistent height until the rear of the vehicle where it sharply turns downwards, this increasing boot space substantially and giving it a boxy shape. The 5-door layout also means the rear side windows can be lowered, unlike in the Fiat 500e.

The Fiat 500e's form over function continues into its aerodynamic efficiency, achieving a Cd of 0,32, the worst so far for an EV. Kia on the other hand has not officially released the Cd figure of the third generation Picanto, and therefore the closest figure available is the Cd of the second generation of the same model with a Cd of 0.31, giving us an estimate (Joubert, 2024; Kia, 2015).

Figure 71: 2021 Kia Picanto profile (left) (Kia, 2020). 2021 Fiat 500 profile (right) (Fiat, 2023b).

At the front the same general trend continues. The Fiat 500e pulls design cues from previous models, including its headlight arrangement and light signature, non-functional two stripe chrome grill and clamshell hood with integrated day running lights. Meanwhile, the Kia Picanto has large and bold headlights with the Kia grille in between. The Fiat 500e has a functional grill lower in the bumper for its cooling system and the Kia Picanto has the traditional two, one above and one below. The upper grill varies in functionality depending on the model and the lower grill is split into two: a larger lower half, interrupted by the licence plate area in the middle and a smaller airway above it. It is also accompanied by two airways on each side which house the fog lights. The Fiat 500e by contrast has only one grill, with two aesthetic covered “airways” on each side and no fog lights in the lower bumper area (fig. 72).

Figure 72: 2021 Kia Picanto front end (left) (Kia, 2020). 2021 Fiat 500 front end (right) (Fiat, 2023b).

At the rear the Fiat 500e keeps it simple with a smooth bumper and the licence plate in the truck. The Kia Picanto has a large flat surface in the form of its trunk, with just the opening and a busy bumper with lights and reflectors on each side, a large plastic panel in the middle and the license plate within. The exhaust in the Kia Picanto is hidden and neither vehicle has design cues alluding to fake exhaust exits. The taillight of the Fiat 500e is connect to older versions of the vehicle in shape and size. Both vehicles have a small roof spoiler above the rear glass, although much more pronounced in the Fiat 500e (fig. 73).

Figure 73: 2021 Kia Picanto front end (left) (Kia, 2020). 2021 Fiat 500 front end (right) (Fiat, 2023b).

Safety

The 2021 Fiat 500e received a EURO NCAP safety rating of four-stars, reviewed for that year alone. The 2017 Kia Picanto achieved a EURO NCAP three-star safety rating being reviewed from September 2017 until September 2021 and currently expired. Both vehicles offer the worst safety ratings so far, with the Kia being the least safe of the two.

The Kia Picanto is also the only vehicle reviewed that is currently expired due to being more than 6 years old (European New Car Assessment Programme, 2024). The Fiat 500e receives a "Adult Occupant" rating of 76%, while the Picanto received a score of 79%. For "Child Occupant" the Fiat managed an 80% score while the Kia only got 64%. For "Vulnerable Road Users" the 500e achieved 67% while the Picanto underperformed once more with 54%. The Fiat 500e performs worse in impact protections with a "Head Impact" score of 12.8 points versus the Picanto's 13.8 and a "Pelvis Impact" score of 2.1 points versus the 3.0 of the Picanto. Where the Fiat 500e gains advantage is by having Autonomous Emergency Braking (AEB) which can mitigate or avoid collisions all together. The Kia Picanto on the other hand is not equipped with this technology as standard, resulting in an inferior overall score even though the impact score was higher. Finally, for "Safety Assist" the Fiat 500e managed 67% while the Kia Picanto only a 25%, again due to the limited technology available as standard in the Kia Picanto (European New Car Assessment Programme, 2017a; European New Car Assessment Programme, 2021a). It is also relevant to mention that the Kia Picanto has a "Safety pack" option that when assessed achieved an overall EURO NCAP score to four-stars (European New Car Assessment Programme, 2017b). However, as every vehicle compared here has the "Standard Equipment," this safer version was not analysed. In the author's opinion, the "Safety pack" option should simply be standard equipment.

Overall, the Fiat 500e offers an overall much safer experience and is the obvious choice safety wise, with the only inferior score being the "Adult occupant" with a difference of just 3% when compared to the Kia Picanto.

Sustainability

Kia has a percentage of 2% of recycled plastics in finished vehicles. In some of its vehicles, such as the EV9 Kia uses recycled PC, recycled PET, bio-PE among others and in 2023 it

achieved an end-of-life recycling rate of 82,4% (Kia, 2023). Regarding the Picanto however, there is no mention by Kia of this model in regard to its sustainability.
The WLTP emissions data provided for the Kia Picanto show 127 g/km of CO2 for the least polluting 66bhp manual 1.0 MPI, and 152 g/km of CO2 for the most polluting version, the 83bhp automatic 1.25 MPI (Kia, 2022b).

The reduced battery size of the Fiat 500e means less use of rare materials per vehicle, resulting in a lower environmental footprint (Stellantis, 2024). The "SEAQUAL" seats are manufactured with recycled materials, using "Upcycled Marine Plastic", 10% retrieved from the sea and 90% from land, to create SEAQUAL YARN, then used to create the SEAQUAL seats (Fiat, 2024b; SEAQUAL, 2020). In addition, Stellantis, Fiat's parent company, recycled 72% of all waste produced in 2023, with another 11% going for energy recovery. It also recycled 100% of all metal waste produced that same year (Stellantis, 2023).

Costs

As in the previous benchmarks, the used metric to compare de costs of both vehicles are the previously stated European cost average of €1,64/L for gasoline, €1,56/L for diesel as of May 6th, 2024, and 0,17/kWh for electricity through the first half of 2024, which promotes a fair comparison the two platforms through the WLTP consumption for each variant. Of the benchmarked models, the Kia Picanto 1.0 MPi and the Fiat 500e 24kWh are the more cost efficient. Assuming the average combined WLTP consumption, the Kia 1.0 MPi costs between €7,87 and €8,69 every 100km, while the Fiat with the smaller 24kWh battery costs around €2,21 every 100km. By contrast, the Kia 1.2 MPi costs around €9,18 every 100km while the Fiat with the larger 42kWh battery costs around €2,31 every 100km. These figures confirm what is expected of an EV based on previous comparisons, with a minor increase for the ICE. It is interesting to note that the Kia 1.2 MPi is more expensive to run than the larger and heavier benchmarked Golf, equipped with the 2.0 diesel engine. The Kia Picanto is available from €11,720, while the Fiat 500e begins at €28,137 (Gomes, 2017a; Pinto, 2022). This entry cost difference of €16,417 must be taken into consideration along with the fuel/energy costs, maintenance costs and vehicle depreciation.

3.3 – The Impact of Electric Propulsion in Automotive Design

3.3.1 – Challenges in EV adoption: costs, infrastructure, and accessibility

The recent electrification of the automobile, a means of transportation which has been shaped by more than a century of ICE development, creates a variety of tremendous challenges but also opportunities. These span various domains, including the vehicle itself, meaning its packaging, architecture, brand identity, infrastructure, energy citizenship, manufacturing among others (Calhamar, Monteiro, & Londrim, 2024).

The entry cost of both EVs and ICEVs presents the first challenge in the form of a substantial disparity between the two as on average, EVs are still more expensive than the equivalent ICEVs alternatives. The lack of a mature second-hand EV market also limits consumers who opt for a cheaper alternative in some markets, with high prices being the norm. On other markets the opposite is true, with large depreciation plaguing the used EV market, which leads to a reduction in consumer interest in purchasing EVs from new (Calhamar, Monteiro, & Londrim, 2024).

Potential battery replacement costs also present an additional challenge, as older used EVs are equipped with older technology and out of warranty. This puts pressure of an eventual battery replacement on the consumer. The cost of a new battery may be over the value of the vehicle, leaving the owner in a difficult situation (Barry, 2024). The evolution of EV technology may have improved battery longevity, but time is needed to confirm that optimistic forecast (Calhamar, Monteiro, & Londrim, 2024).

The support infrastructure strongly dictates how viable a vehicle is, as without one its rendered useless. Traditional fuel stations are abundant and easily accessible, making ICEVs easy to operate on a day-to-day basis. The EV charging infrastructure on the other hand is severely lacking, not only through a lower density of charging stations but also the number of charging posts at those charging stations. The average EV charging time, which takes much longer than refuelling a traditional ICEV, exacerbates this issue. While a fuel post is in use for just a couple of minutes to fill a fuel tank, a charging post may take tens of minutes at best to charge an EV, which severely diminishes vehicle rotation at a station and prolongs waiting times (Calhamar, Monteiro, & Londrim, 2024).

Additionally, a gasoline fuel pump fits all gasoline vehicles the same way a diesel one does for diesel vehicles, but the same cannot be said about EVs. In total, nine different connector types exist, meaning that without the proper one available, it is not physically possible to use the charger. Each region (China, Japan, Europe, and North America) has its own specific connector type for AC and DC electricity, and this in addition to Tesla's own proprietary North America Charging Standard (NACS) connector (Evesco, 2023).

On some regions, public chargers require access cards to function, and depending on the card, their use may be exclusive to certain chargers. This forces users to carry multiple cards to charge their vehicle and it may prevent them from using the chargers completely. Mobile apps or even the vehicle's map function may present charging stations with an outdated status, leading to wasting the remaining valuable range to reach a station that may not be operational. During longer trips, fast chargers are the most desirable, but that desirability usually means longer waiting lines, particularly during holidays. The alternative are low speed chargers, which take much longer to charge, increasing severely the duration of the trip (Calhamar, Monteiro, & Londrim, 2024).

The low density of chargers is most prevalent in some regions, usually further away from metropolitan areas. Traveling with an EV under these circumstances may generate range anxiety and usually requires careful planning. The already inferior range of EVs when compared to ICEVs complicates this even further, with the scenario of running out of charge being much more complicated to resolve than an ICEV out of fuel (Calhamar, Monteiro, & Londrim, 2024).

While a jerry can full of fuel is all it takes to get a gasoline vehicle safely to a fuel station, the EV requires either a specialised vehicle equipped with a generator and charging equipment, or a tow vehicle to carry the EV to either the owner's home or the closest charging station (YOUR PARKING SPACE., 2022).

These "charging deserts" represent the government's inability to keep up with infrastructures, to the same degree they have placed pressure on manufacturers invest on EVs (Field, 2024).

3.3.2 – Innovations and considerations in EV design and charging solutions

Charging at home presents a variety of benefits, from peace of mind to cheaper electricity rates, but unfortunately a limiting set of conditions are required to access it. The user needs a place to install a charging station, whether it be in a garage or a designated personal parking space. Additionally, the allocated place may require updating to the electrical power lines or even may lack electricity altogether. The costs involved must be considered to grasp the viability of the investment (Calhamar, Monteiro, & Londrim, 2024).

Housing scenarios where public parking is the only possibility hinder this option even further. Possible mitigating strategies exist, such as proposed by the EV charging startup Voltpost, that in collaboration with AT&T, has a pilot project taking place in New York and Detroit where chargers are being installed in existing streetlights. These chargers are equipped with either two or four retractable cables and allow EV users to access the existing lighting grid to charge their EVs. Charging speeds will be low but so will be the electricity prices. This offers an alternative to conventional charging stations while also giving some the ability to charge their EVs close to home (Dnistran, 2024).

Once able to use a charger, discipline is needed to prolong the usable life of the battery as much as possible. Using fast charging frequently and leaving the battery fully charged for long periods of time are two habits that greatly diminish the useful battery life. Instead, opting for slower charging during the night and keeping the battery in a state of charge between 20% and 80% maximizes battery life. Additionally, maintaining the vehicle in a garage, or even a climatized garage where temperature can be controlled also plays an important role, as sharp changes in temperature or even extremely high or low temperatures tend to degrade the battery faster. Finally, keeping the vehicle updated with the latest battery management software is also important (Calhamar, Monteiro, & Londrim, 2024).

The combination of the heavy propulsion battery with the proportionally light drivetrain results in the battery having a pivotal role in the weight distribution and handling characteristics of the automobile. Thus, positioning the battery low in the chassis, beneath the passenger compartment and between the axles drastically reduces the center of gravity of the vehicle and allows for a balanced weight distribution. Safety in vehicle geometries more prone to tipping such as SUVs is drastically increased due to the low center of gravity allowed by the battery placement, which the ICEVs cannot match within the same vehicle class (Calhamar, Monteiro, & Londrim, 2024).

The low position of the battery also means it is susceptible to being hit by road debris or pavement irregularities, and as such requires large amounts of protection to prevent it from being compromised. This extra protection adds additional weight to an already heavy component, but this additional weight reinforces the already low position of the center of gravity (Calhamar, Monteiro, & Londrim, 2024).

The combination of a low center of gravity with large amounts of weigh results in a vehicle that cannot be stopped by conventional guard rails, as tested by the University of Nebraska. While a traditional ICEV hits the guardrail and bounces back into the road, the comparable EV sedan goes under the guard rail, slowing down but still defeating its purpose. Larger and heavier EVs on the other hand, don't even lose much speed, managing to go through the guardrail with ease, which puts the occupants and others at risk (Vogel, 2024).

The high voltage present in batteries also presents a risk factor for those that come in contact with the vehicle, thus a high level of failsafe systems and safety measures are required to keep not only the occupants safe, but also others. A variety of layers of automated and manual disconnection are essential for crash scenarios and general maintenance. Dense isolation reduces the chance of additional complications in case of an accident, such as fires which are harder to extinguish in EVs than ICEVs (Calhamar, Monteiro, & Londrim, 2024).

These challenges reduce potential design freedom, but compared to an ICEV, the EV still has much more of it. The difference in number of components between the two is stark. As previously mentioned, while the drivetrain of a ICEV has around 2000 parts, the drivetrain of an EV is merely around 20, this translating to a much greater simplicity, which then results in higher reliability (Raftery, 2018). Most importantly however, it provides greater design flexibility, enabling innovative alternatives in vehicle shape and layout, while fostering new solutions for mechanical systems, interior configurations, and storage options (Calhamar, Monteiro, & Londrim, 2024).

3.3.3 – Revolutionizing EV architecture: space, efficiency and sustainability potential

The electric motor allows large amounts of power while having much smaller dimensions than a traditional ICE. The lack of a gearbox or clutch mean it is also lighter and more compact, increasing available space within the vehicle. Its size and nature also mean it can be placed low in the chassis, lowering the center of gravity and freeing space for the passengers and storage. Additionally, most large and high-performance vehicles use

RWD or AWD configurations to improve grip during acceleration. Many vehicles also feature AWD to improve traction on slippery roads, which traditionally requires long rotating shafts to connect a front-mounted engine to the rear axle. However, EVs eliminate the need for these shafts by directly connecting compact electric motors to the axles. This feature not only increase interior space for greater usability and comfort but also retains the vehicle's functionality and performance. In either of these two layouts, RWD or AWD, backseat foot space is maintained and there is no longer a need for a transmission tunnel unlike in ICEVs (Calhamar, Monteiro, & Londrim, 2024).

As previously mentioned, the battery requires a strong casing to uphold its structural integrity, which has the added benefit of increasing the structural rigidity of the passenger's compartment, reducing the likelihood of deformation in a crash (Calhamar, Monteiro, & Londrim, 2024). New developments have led to the possibility of having the battery as structural element itself, no longer being placed on the chassis, but instead being part of it. This reduces overall weight of the vehicle and increases the chassis torsional rigidity, further improving the vehicles handling characteristics (Calhamar, Monteiro, & Londrim, 2024).

EVs are also much more efficient than ICEVs, as such they produce less heat during use, which means the amount of thermal insulation can be reduced. The lack of noise produced by the electric motor also results in a reduction of the acoustic insulation needed (Calhamar, Monteiro, & Londrim, 2024).

The higher level of energy efficiency of EVs translates into fewer heat dissipation needs and, as such, fewer cooling intakes and outlets. Therefore, a less convoluted front end is possible, which can be optimised for greater aerodynamic optimization, reducing the Cd. The absence of an exhaust means the vehicle's underside is free from obstacles, further decreasing the Cd (Calhamar, Monteiro, & Londrim, 2024).

The potential optimisation of aerodynamics comes with added risks, not regarding the functional aspects of the vehicle, but public interest instead. The previously mentioned Nissan Leaf, released in 2010, was part of the first lot of mass produced EVs which were criticized by their appearance, in similar fashion to the 1930s Chrysler Airflow. Unlike the Airflow however, these designs were not strictly functional, but instead a way for manufacturers to show how these vehicles were built from the ground up to be electric, unlike the ICEV platforms turned electric from other attempts in recent history. Unfortunately for these manufacturers, most potential buyers were merely looking for an eco-friendly means of transportation, resulting in the average consumer reacting negatively to these radical designs. Tesla took advantage of the situation and released in 2013 the model S, equipped with a black trim piece at the front resembling the grill on a traditional ICEV. This design appealed to consumers uncertain about unconventional aesthetics but interested in EVs. Tesla managed to create a completely new EV with a new design language, able to blend in well among contemporary ICEVs. As both the market and model matured, Tesla removed the black trim piece, replacing it with an elegant line. Manufacturers nowadays reach a wide range of the market by offering a variety of EV models, ranging from more progressive designs to contemporary ones, thus offering something to every consumer (Calhamar, Monteiro, & Londrim, 2024).

The electric drivetrain offers a variety of possibilities, and one of them is the skateboard architecture. In similar fashion to body on frame construction, the skateboard sees every drivetrain component be placed within, such as the drive train itself, propulsion battery, wheels and suspension, while the body is placed on top of it. The result is a streamlined design approach, facilitating platform sharing between different models and even between several manufacturers, substantially reducing manufacturing costs (Calhamar, Monteiro, & Londrim, 2024).

The EV has a lot of potential, not only in reducing pollution levels but also in its usefulness to the user. It is imperative citizens obtain a well-informed environmental conscience, to understand the risks Humankind faces involving global warming, as a consequence of greenhouse gasses (GHG) to which ICEVs contribute significantly. Opportunities in energy citizenship, such as the installation of solar panels and/or wind turbines at home can help significantly reduce the true environmental footprint of the vehicle while reducing running costs. Surplus energy produced at home can even be sold back into the grid, increasing the percentage of green energy on it and further contributing to offset the initial investment (Calhamar, Monteiro, & Londrim, 2024).

Regarding functionality, an EV can be used as a home power supply. If equipped with bidirectional charging, this functionality allows for the battery of the vehicle to power another system, achieving a Vehicle-to-House (V2H) connection. The relatively recent nature of this technology means the electrical power output is relatively limited in the few EVs that presently support this function. Currently, the highest value in this regard belongs to the Ford F-150 Lightning at 9.6 kW (Nedelea, 2024a).

Small weekend habitations or camping are other scenarios where using an EV as a home battery can also be forecast. The 2020 Honda E came equipped with a traditional 220 V power outlet in its interior, granting the ability to power home appliances (Calhamar, Monteiro, & Londrim, 2024; Honda, 2020).

3.3.4 – Evolving design, technology, and commitment for a sustainable automotive future

The visual perception of traditional sports cars and sports models are marked to a large degree by their needs of larger amounts of air flowing to the ICE, resulting in larger and usually more angular openings with larger exhaust exits at the rear. As sporty EVs do not have the same needs, alternative functional methods will need to be utilized to create the same visual effect (Calhamar, Monteiro, & Londrim, 2024).

Adapting brand identity to these changes has led manufacturers to choose one of three options. The first is maintaining established brand identity elements, even if their main function ceases to exist. The example of this is BMW, which has maintained its hallmark “kidney grill” in all its models, including those strictly electric. The second is covering the grill with a painted panel piece, essentially reducing its visual significance. An example of this is Hyundai with its Kona model, in which the ICE variant has a large black grill, and the electric variant has the grill covered with a textured and body coloured painted piece. The third strategy is to create a new and separate model line with a new design language, strictly for EVs. VW is an example of this third option, developing its ID. line which includes models such as the previously benchmarked ID.3 and ID.5. These vehicles lack the traditional front grill, having a single opening below the licence plate area. Even though the VW ID.4 belongs to the same market segment as the VW Tiguan, its design language is much smoother than the more traditional sharp lines and large air openings seen in the Tiguan (Calhamar, Monteiro, & Londrim, 2024).

The inferior energy density of batteries compared to gasoline or diesel, leads manufacturers in search of higher aerodynamic efficiency to foster the range of their EVs. One such example is Audi, which now includes in their most aero efficient model the option of having camera wing mirrors. This option available in the new A6 e-tron replaces the traditional wing mirrors with cameras, the result being is a Cd of 0,21, with the new optional camera wing mirrors adding 7km of range in every charge (Gomes, 2024b).

New EVs are also proving their ability with new range records being broken frequently, the most recent being a Ford Mustang Mach-E which achieved a record 916,74km on a single charge (Bridgestone, 2024). At the same time, a Toyota Prius Plug-in recently broke another record, achieving the lowest fuel consumption recorded across a 5,168km trip. It managed 2,51L/100km, proving the levels of efficiency newer hybrids are achieving (Dias, 2024). Manufacturers are duplicating the battery capacity of plug-in hybrids, with new models generally having an electric range of over 100km. This is due to a multitude of reasons, one being a revision by the European Commission on how CO2 emissions are calculated for these vehicles (Teles, 2024a).

The recent decline in EV sales has led some manufacturers to back paddle previous claims of going EV only. Mercedes-Benz revealed its plans to delay becoming an EV only manufacturer by 2030, adding it aims to continue producing and developing new ICEV and hybrids (Lyon, 2024). Both Audi and Volvo have also abandoned their targets of becoming EV only by 2030, expecting to continue selling hybrids beyond that date (Davies, 2024; Silva, 2024). Porsche has backtracked its EV plans, continuing instead with the production of hybrids and perhaps prolonging the life of ICEs models which were meant to be discontinued (Nedelea, 2024b). Lotus has also abandoned its EV only plans, announcing a new hybrid drivetrain is in development entitled “Hyper Hybrid EV Technology” (Mendes, 2024b). Additionally, Fiat has backtracked their comments regarding the 500 being strictly an EV. Seeing the fall of sales due to the higher price has led the brand to change their plans and bring back a hybrid drivetrain option of the model. According to Fiat, this move was a response to the abrupt cancelation of incentives by both Germany and Italy, leading the brand to bring back the hybrid 500 in hope of saving the EV 500, by putting it on sale at around half the price of the EV variant (Lago, 2024).

As a result, ICE development is continuing. Mercedes Benz is developing the mild hybrid M 252 engine, which is a gasoline engine said to achieve fuel efficiency levels of a diesel engine (Gomes, 2024a). In similar fashion, Porsche has patented a complex 6-stroke engine in the hope of staying ahead of new emission regulations (Costa, 2024).

At the same time, brands such as Jaguar, Abarth and Alpine proved to be committed to going EV only, with Jaguar becoming an EV brand by early 2025 (Fitzgerald, 2024; M., 2024; Overland, 2024). Volkswagen and Rivian have just begun a joint venture to mutually develop and improve EV offerings of both brands, showing a deep commitment to this technology (Mendes, 2024a).

New developments in battery technology are being made, such as the creation of batteries without critical raw materials. The largest battery manufacturer in Europe, Swedish manufacturer Northvolt, has developed a battery free of lithium, nickel, graphite or cobalt (Expresso, 2023). Mercedes-Benz has announced the development of a solar paint which would allow vehicles exposed to sunny environments to be charged by sun exposure. This technology would allow every painted panel to essentially be turned into a solar panel, increasing the efficiency and ease of use of the vehicle (Tingwall, 2024). More importantly, Toyota has announced its plans to begin mass-producing solid-state batteries between 2026 and 2027. According to the manufacturer, the use of this technology will result in range figures of up to 1000km and the capacity to be charged from 10% to 80% in 20 minutes or less, all this combined with inferior costs. As solid-state technology evolves and improvements to the efficiency of vehicles are made, Toyota predicts a potential 50% increase in range, meaning a projected figure of around 1500km (Mendes, 2023). Honda has also announced its plans to begin producing solid state batteries with hopes of testing and analysing it to begin mass production. Additional, Honda has also reported the lower cost of this technology and the same 1000km range figure (Teles, 2024c).

In essence, a commitment on a variety of fronts is required for the transition to a greener future to continue and governments must ensure incentives to both citizens and manufacturers alike. These could be through financial incentives, subsidies in the purchase of EVs and the creation of a dependable charging infrastructure. The eventual reduction of subsidies once EVs are well established should be gradual and made to reflect market maturity as prices decrease. Manufacturers must also commit to having efficient, attractive and affordable EVs, which hopefully will lead to an increase in sales, not only as a testament of their qualities as vehicles, but also their greener footprint (Calhamar, Monteiro, & Londrim, 2024).

The financial importance of a vehicle rests on the fact that on average it represents the second largest investment on a person’s lifetime after housing (One Main, 2023). As such, the reduced purchasing power of a percentage of the population means a limit to their ability to obtain newer and more efficient vehicles. Thus, inflicting penalties on those who continue to use ICEVs will not suddenly change this fact, the answer being instead to incentivise those who do have that ability. The result would be the increase of new EV sales, increasing market share at the cost of a reduction in ICEV sales. This would then lead to a flood of EVs onto the used market which would increase variety and decrease the price of second hand EVs, allowing those with reduced purchasing power to obtain this type of vehicle (Calhamar, Monteiro, & Londrim, 2024).

Air pollution in metropolitan areas must be reduced through the limited use of the more polluting ICEVs in predetermined areas. Mobility to these areas must be ensured by other means such as by green public transportation. As to not harm low-income households, these limitations should take engine displacement and fuel type into consideration, as to limit older vehicles with large polluting engines while continuing to allow older, but efficient ICEVs (Calhamar, Monteiro, & Londrim, 2024).

As the technical challenges of EVs have been mostly overcome by now, three key fundamentals are required for a successful green transition: 1) citizens must be taught through the education system and awareness campaigns the climate emergency, and internalize the need for a responsible energy citizenship; 2) EV prices must be brought down to values comparable to those of equivalent ICEV; 3) A widespread and fully functional charging infrastructure must be implemented (Calhamar, Monteiro, & Londrim, 2024).

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4 - Conclusion

In summary, with the advantages and disadvantages of the varying means of propulsion identified, it is possible to understand how they fit into the day-to-day life of the average consumer. Additionally, with the advancements in technology in recent years it is also possible to predict a path which sees the EV overcoming the remaining challenges it currently has, to become the obvious choice as a tool for transportation.

The substantially larger dimensions of an ICE drive train over the corresponding EV drivetrain are striking. The increased size is not only due to the larger size of the ICE itself, but also by the need for a gearbox, a clutch and in many cases long drive shafts. This need for physical connection between components in an ICE powertrain not only increases its dimensions and weight but also diminishes design and packaging freedom. The bulky drivetrain also affects heavily the weight distribution of the vehicle, which will naturally be front biased if the engine is at the front, or rear biased if the engine is at the rear.

An EV drivetrain by contrast is much simpler and occupies much less space. Even though the EV drivetrain is lighter, its energy storage device, the battery, is much heavier than the conventional fuel tank, which results in EVs being substantially heavier than comparable ICEVs. When directly comparing EVs and ICEVs, their proportions and available interior space also differ. The ICEV has more traditional lines such as a flatter and longer bonnet, larger overhangs, longer boot and a lower profile. The EV on the other hand appears rounder, this is due to the sloped bonnet which leads to a rounder front end and the shorter boot at the rear, resulting in a much lower Cd and thus higher efficiency. The longer wheelbase of a typical EV is coupled with shorter overhangs, resulting in similar proportions with the exception of its height, usually increased due to the presence of the battery under the floor. The result is added interior space due to the now possible flat but higher floor, combined with the added interior space benefit of the increased wheelbase and shorter overhangs, merely coming at a cost of perhaps narrower boot space as a result of that very same change. However, the lack of a drivetrain at the front means potential available space, resulting in some EVs offering additional front storage space (fig. 74).

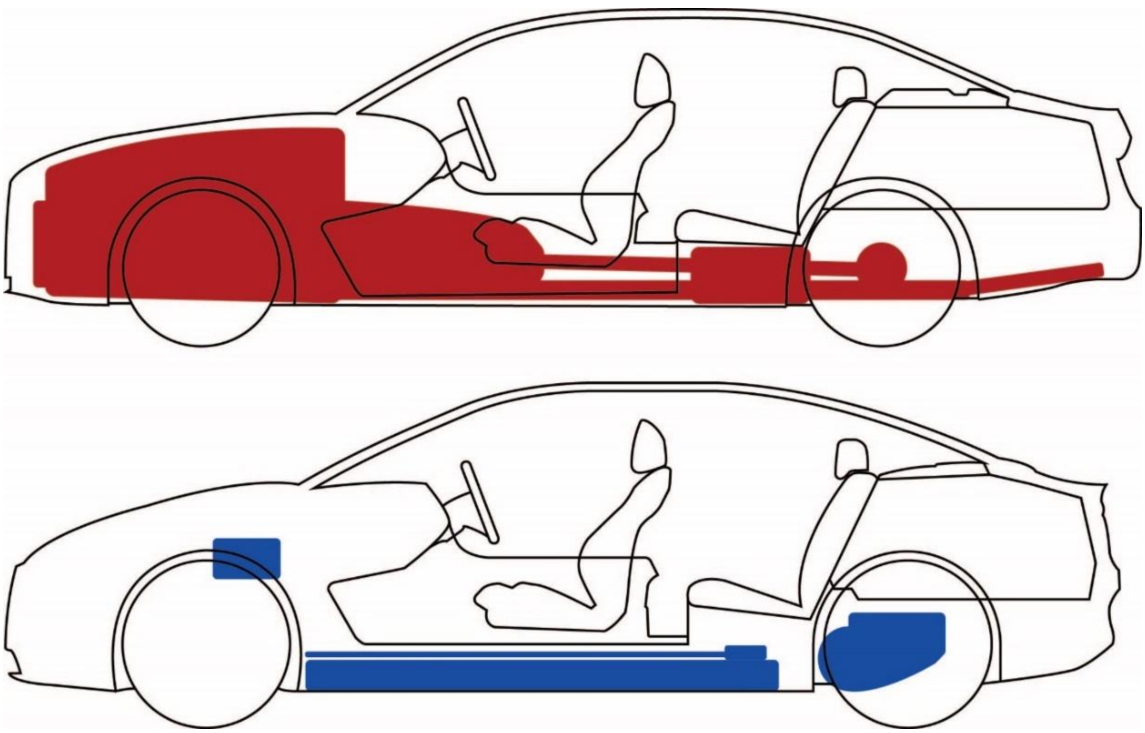

Figure 74: Traditional ICE sedan (above) and its ICE drivetrain (red) contrasting with an EV sedan (below) with its much simpler electric drivetrain (blue).

The ICEV on the other hand suffers from a reduced interior space by comparison, due to the shorter wheelbase which takes a percentage of interior volume in the front foot area and at the rear, in the form of less distance between front and rear seats, thus resulting in inferior rear leg space. The lack of a battery means a lower floor, but the frequent presence of a transmission tunnel immensely reduces available foot space, particularly to the rear passengers. Finally, headspace is similar in both, with the advantage of a higher seating position in the EV. In fact, in order to maintain comparable interior space, the EV is taller, increasing the cabin's distance to the ground and giving the driver a better view of the road, along with a deeper boot (fig. 75).

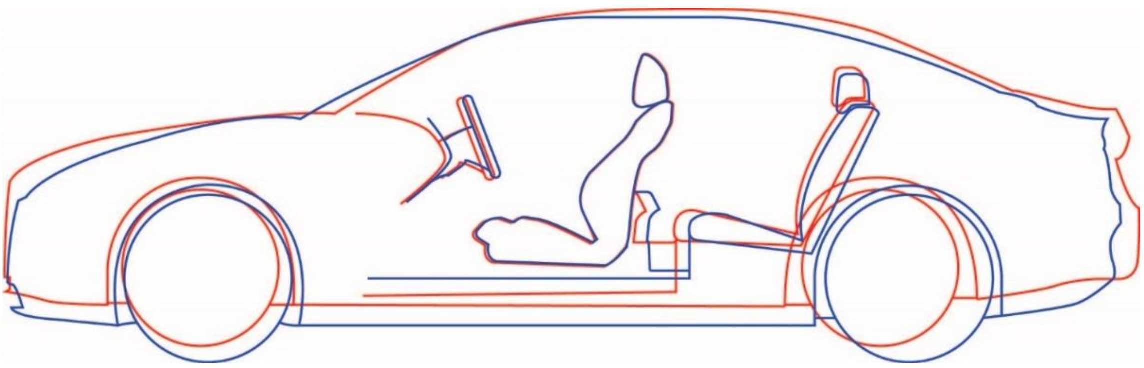

Figure 75: Traditional ICE sedan (red) and EV sedan (blue) overlapping, aligned at the H-point.

Compiling the figures of each of the benchmark vehicles and comparing the average between EV and ICEV, it is possible to observe some discrepancies between the two, such as presented in table 2.

Table 2.
Assessment of the average drivetrain related values collected from the benchmarked vehicles, based on method of propulsion

	Power (Hp)	Torque (Nm)	Range (km)	Efficiency (kWh/100km-L/100km)	Acceleration (0-100km/h)	Top speed (km/h)	tailpipe emissions (g/km)
EVs	269	396	481	14,61	7,05	169	0
ICEVs	122	247	921	5,39	10,75	196	133

Power and torque figures are overwhelmingly higher in EVs, resulting in much quicker acceleration. With range and top speed however, the inverse in true, the ICEVs achieve a substantially higher average top speed along with almost double the average range. Albeit the top speed in EVs is artificially restricted by software due to the detriment it would otherwise have to its range. Regarding energy/fuel efficiency and running costs, assuming the previously energy and fuel prices of €1,56/L for diesel, €1,64/L for gasoline and €0,17/kWh for energy and considering an average of 4,85L/100k for the diesel ICEVs and an average of 5,93L/100k for the gasoline ICEVs, it is possible to conclude an average of €8,65/100km for ICEVs and an average of €2,48/100km for EVs. This equates to a price increase of over three times in the ICEVs over the EVs. As previously mentioned, manufacturing emissions play an impactful role in sustainability but remain mostly undisclosed by manufacturers. Tailpipe emissions are the most contrasting differences as EVs produce a total of 0g/km while ICEVs average a figure of 133g/km, as can be seen in table 2.

Table 3.
Assessment of the average physical and price values collected from the benchmarked vehicles, based on method of propulsion

	Wheelbase (mm)	Length (mm)	Height (mm)	Width (mm)	Weight (Kg)	Boot space (litres)	Cd	Price (€)
EVs	2685	4305	1537	1799	2012	450	0,27	40,644
ICEVs	2638	4273	1495	1764	1362	412	0,31	33,131

The average figures regarding dimensions are close between the two vehicle types (table 3). The wheelbase is longer in EVs by 47mm, in length by 32mm, in width by 35mm and in height by 42mm. A larger difference exists weight wise, with EVs being heavier on average by 650kg. Boot space is also higher in EVs, and the difference of 38 litres is a result of not only larger overall space, but also the ability to have front storage space as can be seen in the Tesla, something impossible in front engine ICEVs. The EVs efficiency is also demonstrated by the lower average Cd figure of 0,27 when compared to the ICEVs

0,31. Finally in what concerns price, EVs cost on average an additional €7,533. When running costs are considered, this figure may be justifiable to many individuals who spend a significant amount of time driving, but for EVs to become truly competitive it must be reduced to more closely match ICEV prices.

In conclusion, EVs bring a plethora of design possibilities previously not possible. The simplicity and adaptability of the drivetrain translates into not only greater use of space for both occupants and luggage, giving greater potential in interior design, packaging and safety, but also improved driving dynamics through a lower center of gravity. The decreased drivetrain cooling needs and physical restrictions also free the exterior for greater aerodynamic potential as well as to provide possibility of innovative shapes and general styling. However, Arnaud Belloni, Renaults global marketing director, has been quoted saying that EVs look like fish (Grassi, 2024). This is a result of the current need for absolute efficiency. As technology evolves and obstacles with the energy density of batteries begin to decrease, this demand for peak efficiency will begin to diminish, allowing designs and shapes never before seen.

Usability is the greatest obstacle of current EVs. For city driving the EV is unbeatable. Regenerative braking means lower brake use and increased range. Substantially lower costs per 100Km and lower maintenance needs means EVs are exceptionally attractive for city use and small distance voyages. The inferior range however, coupled with complex and time-consuming charging means designated parking and a home charger are a necessity. For scenarios with transportation needs in “charging deserts” or those who require large distances to be covered, the ideal vehicle is a mild hybrid. It does not require plugging the vehicle, thus offering a traditional ICEV experience with the advantages of slight electrification to achieve greater efficiency. Thus, the current global landscape is not yet ready for full electrification, with exiting vehicles and drivetrains still having their part to play. As such, alternative means of propulsion and fuels such as hybrids, mild hybrids, ICEVs, hydrogen fuel cell vehicles, biofuels and so on should continue to be developed in the hope of a greener and diverse future, with a solution for every user.

None the less, it is clear that EV technological advancements will soon shape the EV into the greatest solution for most scenarios, hopefully accompanied by an equally advanced charging infrastructure, offering never before seen design freedom to automotive design.

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