POLITECNICO DI TORINO

Department of Mechanical, Aerospace, Automotive
and Production Engineering

Master of Science
in Automotive Engineering

Thesis

Competitive Landscape
Strategic Passenger Vehicles Architectures Benchmark

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1 Abstract

The topic examined in the present work has been developed at the department of Electrified Vehicles Product Planning of Fiat Chrysler Automobiles and deals with passenger vehicles architectures. The aim of this work is to provide a benchmark about the future strategies on vehicle architectures adopted by passenger cars manufacturers in the future challenging context due to more stringent carbon dioxide emissions reduction targets in 2025 and 2030 imposed by the European Union. The investigated timeframe extends up to 2024 in order to identify how car manufacturers will arrange to face the radical transformation in the European automotive market from 2025 onwards.

The work methodology has started from searching data and information about the car manufacturers architectures portfolio to evaluate past, present and future trends. The collected data and information have been validated by looking on car makers press releases and investors relationships. Afterwards, a detailed analysis about electrification technologies and vehicle architectures employed by each model has been performed. Consequently, the electrification technologies adopted by each vehicle platform have been obtained.

After that, the vehicle architectures have been clustered per typology: conventional platform, designed for internal combustion engines, modified conventional platform, designed for internal combustion engines and afterwards modified for electrified vehicles, multi-energy platform, flexibly designed for both internal combustion engine and electrified vehicles, and dedicated battery electric vehicle platform, designed from scratch just for battery electric vehicles. Then, an analysis by segments has been accomplished in order to recognize possible tendency in vehicle architectures cluster adoption in certain segments. Eventually, an analysis about volumes on each vehicle architecture has been performed in order to determine possible economies of scale bearing the investment for the development of a dedicated battery electric vehicle platform.

The key findings emerged from the present work are mainly three. Firstly, the modified conventional platforms are just transient and related to an adaptation period before the adoption of dedicated battery electric vehicle or multi-energy

platforms. Secondly, multi-energy platform will be adopted by the majority of car manufacturers. Thirdly, dedicated battery electric vehicle platforms will be present on larger and premium segments and in high sales volumes segments.

2 Introduction

This present thesis has been developed at the department of Electrified Vehicles Product Planning of Fiat Chrysler Automobiles. FCA designs, engineers, produces, delivers and sells vehicles under the Abarth, Alfa Romeo, Chrysler, Dodge, Fiat, Fiat Professional, Jeep, Lancia and Ram brand and luxury cars under Maserati brand. FCA also operates in the components sector through Teksid, in the production system (Comau) and in the after sale and spare parts services through Mopar. The product planning is a company function that aims to ensure the long-term vehicle planning and product life cycle management of all versions belonging to different brands. Product planning follows the entire product development process from the concept definition up to the commercial launch. This organizational function is mainly focused on the set-up phase of the product development. In fact, the main target is to define the product contents and the functional and performance objectives by considering the strategic competitive landscape and following the voice of customers. Market analysis and benchmark analysis of competitive models are performed to support the concept generation and definition and product setting. In addition, the product planning supports the product cost definition and profitability analysis, also checking the product targets achievement from both technical and commercial point of view.

The examined topic emerges from the more and more increasing complexity of the competitive landscape which the car manufacturers are forced to operate in. The carmakers have passed through several revolutions. The more recent challenges that the automotive industry has overcome are the globalization of the market, the uncertainty deriving from different sources of information and customers that are more aware and demanding in terms of costs, quality, technical and innovative contents. The more stringent environmental legislations constitute the last stumbling block that carmakers are called to afford. Since 2009 the European Union has imposed a path made of increasingly carbon dioxide reduction targets that in the 2025-2030 timeframe will determine a radical transformation in the automotive world, thus completely disrupting the vehicles market. In order to be compliant with the imposed standards, the only feasible option is to increasingly electrify the product range by offering hybrids and full electric vehicles. In the complexity of this context, the need of deep diving the future strategies adopted by the major industrial automotive groups in terms of vehicle architecture comes out in order to support the strategic decision making.

The present work is organized in seven chapters whose outline is given below.

After the abstract and the introduction, in the third chapter, a brief history of the electric vehicles is presented starting from their origin in the Nineteenth century, their decline around 1930s and their return in 1970s to seek a solution to solve air pollution.

The fourth chapter is aimed to make the reader aware about the existing electrification technologies that will spread in the European market in the closer future.

In the fourth chapter, an overview of the current electrified vehicles market is provided. Then, the discussion develops by presenting the past, present and future European legislation frame about stringent carbon dioxide reduction targets that will shape and determine the future automotive market. The last argument treated in this chapter regards a forecast about the electrified vehicles market evolution by 2024.

The following chapter deals with the analysis of the vehicle architecture. Firstly, the historical evolution of the vehicle chassis and platform is provided. Secondly, the typology of platforms that will be employed in the future are clustered and their pros and cons are evaluated. Thirdly, a benchmark about the future strategies on vehicle architectures adopted by the major passenger cars manufacturers is performed.

In the final chapter the strategic analysis of the vehicle platforms is summarized, and the main key finding are discussed.

3 Brief history of the electric vehicle

A battery electric vehicle (BEV) is a kind of electric vehicle that uses electric motor or motors as unique power source. The storage system is based on chemical energy stored in rechargeable battery packs.

Establishing who invented the first electric vehicle is not simple since several inventors have been indicated. In 1828, a Hungarian, Ányos Jedlik designed a small-scale model car powered by an electric motor. Between 1832 and 1839, but the precise year is unclear, a Scottish inventor, Robert Anderson, launched a crude electric-powered carriage using non-rechargeable battery. In 1834, Thomas Davenport from Vermouth developed a battery-powered electric motor that employed to run a small model electric vehicle. In 1835, Sibrandus Stratingh, professor of chemistry and technology of Groningen, designed a small-scaled electric vehicle which was constructed by his assistant Christopher Becker. [1] Around 1842, both Anderson and Davenport improved their electric car, making it more practical, but however based on non-rechargeable batteries. [2]

In 1859, the French physicist Gaston Planté invented the lead-acid battery that became the first rechargeable electric battery. Later, in 1881, the French chemical engineer Camille Alphonse Faure considerably improved the lead-acid battery by increasing its capacity and making it more reliable.

In 1884, a British electrical engineer and inventor, Thomas Parker manufactured in London the first practical electric vehicle. [3]

Figure 1: Thomas Parker electric vehicle [3]

In 1888, Andreas Flocken developed the Flocken Elektrowagen that is considered the first electric vehicle built in Germany.

In 1889, Thomas Edison developed an electric three-wheeled vehicle by employing two electric motor and nickel-alkaline batteries.

In 1891, William Morrison built a six-passenger electric car in US, able to reach up to 23 km/h.

In 1894, the mechanical engineer Henry G. Morris and the chemist Pedro G. Salom designed and manufactured the Electrobat, with steel tires to withstand the heavy frame and the large lead battery.

In 1899, Camille Jénatzy developed “La Jamais Contente”, an electric race car that is the first vehicle to reach 100 km/h. The vehicle was designed with a streamlined body with lightweight aluminum alloy and a large set of lead acid batteries: 100 lead acid battery made by Fulmen. The voltage was 200V, the short circuit current equal to 250A and power of 50kW. It was equipped with two separated electric motors, each driving rear wheels without any gearbox or differential. [4]

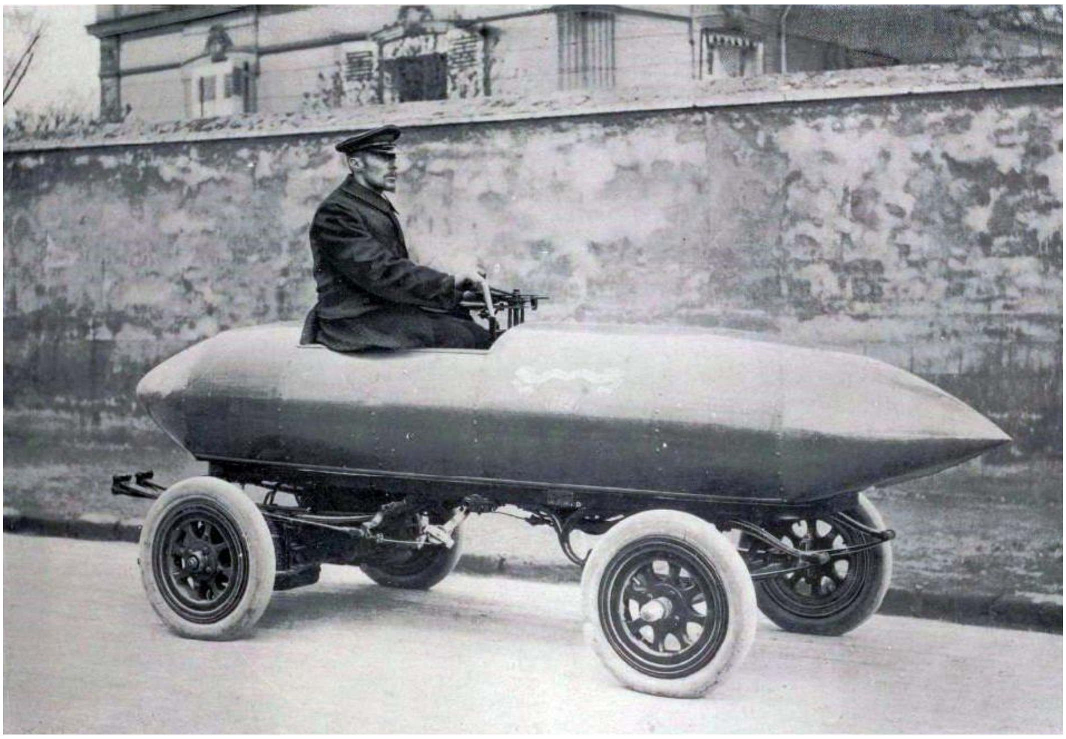


Figure 2: "La Jamais Contente", electric race car developed by Jénatzy [2]

In 1897, a fleet of electric battery-powered taxis was introduced in London based on the design of Walter C. Bersey.

In New York City the Samuel's Electric Carriage and Wagon Company established a cab system including service stations for repair work and fast battery sets change and started operating 12 electric cabs in 1897. In May of the same year it was acquired by Isaac Rice, founding the Electric Vehicle Company in September. [5]

Figure 3: New York City electric taxi cabs in 1897 [5]

Electric vehicles founded their maximum spread at the beginning of 20th century, with a peak in production around 1912. Their advantages with respect to the internal combustion engine were the absence of vibrations, smell, noise and no need of gear changing, that was the most problematic part of driving.

Electric vehicle was mostly diffused in US, rather than in Europe due to their intense use in urban environment and their spread among women, that were interested in driving vehicle without the complications of internal combustion car. The most famous electric vehicles manufactures were: Pope, Studebaker, Anderson Electric Car Co., Baker and Rauch & Lang. [6] In 1901 was developed the Pope model, which is an example of low-cost electric car where the engine is actuated directly on the rear axle through a couple of gears to decrease the size of the motor. In 1911 Rauch and Lang Brougham realized an example of luxury city car. [4] William C. Anderson was a Canadian who moved to Michigan and started building few automotive bodies for local manufacturers and began enjoying the idea of producing his own vehicle with an electric drivetrain. In 1907 the Anderson Carriage Company manufactured the first electric vehicle called “Detroit Electric”, with a total production of 125 units. According to advertising, it could reach a top speed of about 32 km/h and a range of 130 km between charges. It was endowed with fourteen 6V Edison batteries. In 1908, 400 Detroit Electric were sold, 650 in 1909 and 1500 in 1910. In order to ensure a constant electric components supply, Anderson Carriage Company acquired Elwell Parker Electric Company, manufacturer of electric motor and components and supplier of both Anderson Carriage Co. and its competitor, the Baker Electric. In 1911 Anderson Carriage Co. was rearranged into Anderson Electric Car Company. [7]

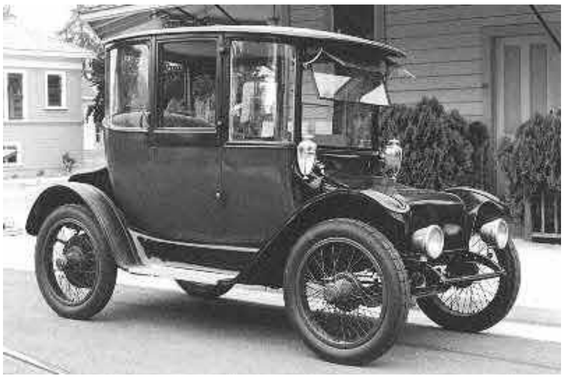


Figure 4: "Detroit Electric", electric vehicle manufactured by Anderson Carriage Company [7]

In 1896 Hartford Electric Light Company realized an exchangeable battery service early and provided between 1910 and 1924 to overcome the lack of charging infrastructure and the limited vehicle range: they solely sold the electricity through exchangeable batteries by paying a variable per-mile charge, while the truck was sold by General Vehicle Company. A monthly tariff provided the access to truck maintenance and storage service. From 1917, Milburn Wagon Company supplied a similar service in Chicago for their car’s owners. [5]

With regard to hybrid vehicle, William H. Patton designed a gasoline-electric hybrid rail-car in early 1889 and he developed a prototype in the same year.

In 1898, Justus Entz designed a vehicle with a gasoline combustion engine and an electric drive transmission for the Pope Manufacturing Company, but once tested, a spark ignited fuel inside the fuel tank destroyed the car. [6]

In 1897 Ferdinand Porsche patented the first hybrid vehicle that he realized at the beginning of 20th century called “Lohner-Porsche Mixte Hybrid”. The first prototypes were front wheel drive with electric motors mounted on the hub. The later version was a series hybrid four-wheel drive vehicle with motors mounted on the hub of each wheel. The electric motors were able to reach 2.5/3.5hp per motor with a peak power of 7hp. [8]

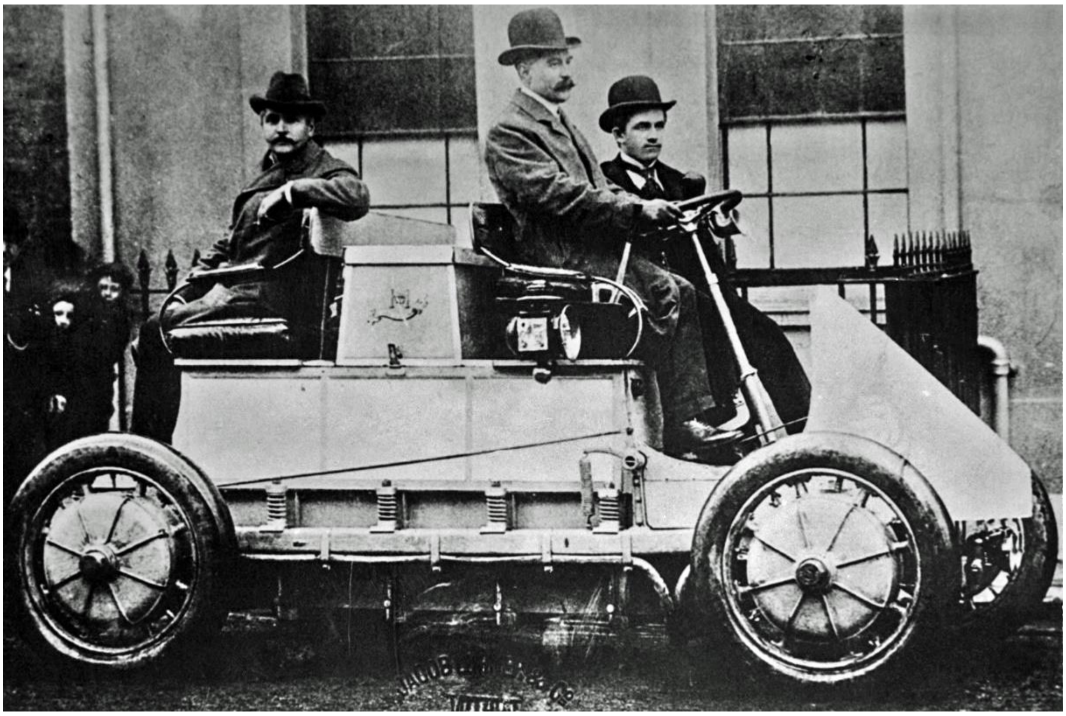


Figure 5: "Lohner-Porsche Mixte Hybrid", a series hybrid vehicle

In 1916 Woods Motor Vehicle Company of Chicago patented and produced the “Dual Power”, a hybrid vehicle powered by a four-cylinder internal combustion engine and an electric motor.

Since 1920 the interest towards electric vehicles has started declining and they completely disappeared around 1935. Several drivers can be addressed as determinants of the electric vehicle decline: firstly, a decrease in the gasoline price due to the discovers of petroleum reserves, secondly an improvement in the extra-urban road infrastructure, and the consequent need of vehicle capable of longer ranges, and lastly the elimination of the need of hand cranking for internal combustion engines thanks to the invention in 1912 of the electric starter by Charles Kettering. [9]

During the second world war, electric vehicles were employed for the delivery in countries where there were fuel-leakages, such as in England the Wilson Electric model LW milk delivery van.

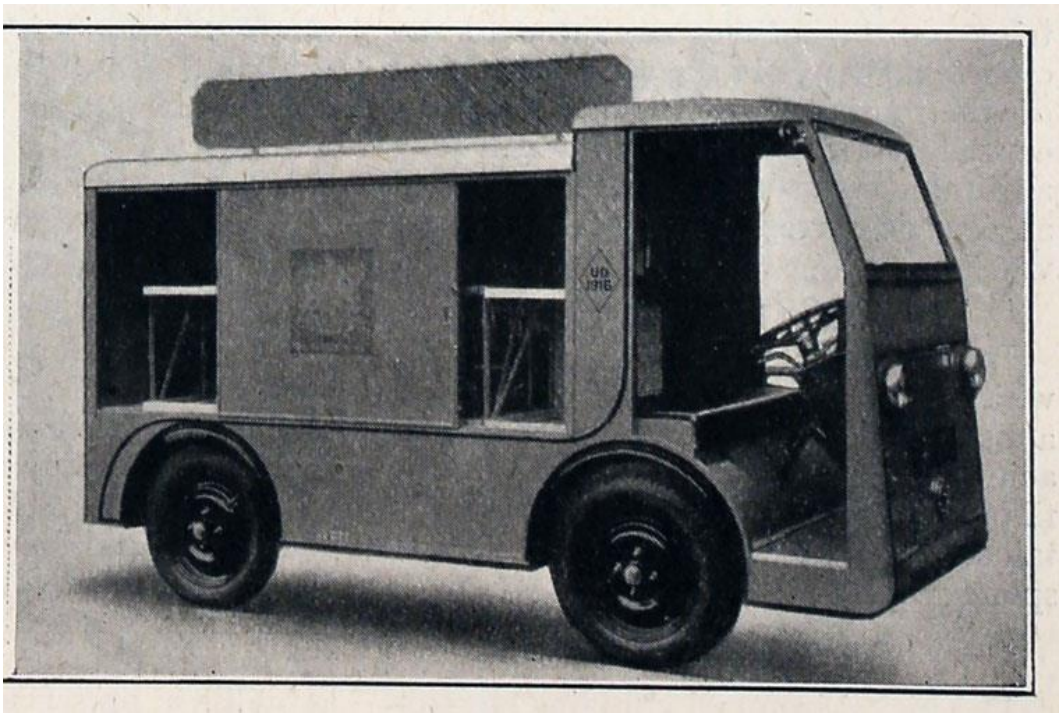


Figure 6: Wilson electric model LW milk delivery van [10]

In 1942, Peugeot developed an electric microcar called VLV (Voiture Légère de Ville), powered by four 12V Pb acid batteries and made of aluminum for a total weight of about 350 kg. The batteries account for about half the total weight. The vehicle maximum speed was 36 km/h while the range about 75 km. Only 377 units were produced.

The interest towards electric vehicle came back increasing in 1960s and 1970s, in order to try to find a solution to air pollution caused by exhaust emissions problems and diminish the dependency on imported foreign crude oil. The Clean Air Act is a United States federal law designed to control air pollution on a national level, firstly released in 1955.

In 1959 AMC (American Motor Company) declared a joint research with Sonotone Corporation in order to produce an electric vehicle powered by a self-charging battery.

In 1965 the Scottish Aviation designed a concept car, the Scottish Aviation Scamp for a total of 12 units for tests. It was endowed with four 48V batteries and two electric motors. This prototype had a range of 29 km and was able to reach a maximum speed of 58 km/h.

In 1966 another concept car was built by General Motors as the electric version of the gasoline Chevrolet Corvair. The Electrovair had an 86 kW electric motor and a silver-zinc battery located in trunk and engine compartment. The range was between 64 and 129 km. [11]

In the same year, the Enfield 8000 was a two-seater battery electric city car developed by Enfield Automotive and powered by 6 kW electric motor and lead-acid batteries. About 120 cars were produced in total. It was able to reach a maximum of 77 km/h. the range was about 64 km. [2]

Figure 7: Enfield 8000, an electric city car developed by Enfield Automotive in 1966[1]

[1] By Constantine Adraktas, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2738656

AMC created in 1967 a partnership with Gulton Industries to construct a lithium-based battery. In 1967, they developed an experimental electric subcompact car, the AMC Amitron, that included regenerative braking. It showed an advanced battery design, able to offer a range of 240 km. Due to high batteries costs and technological problems, the development was stopped. Based on this prototype, an updated concept car called Electron was developed in 1977. In 1969, AMC implemented a nickel-cadmium battery electric station wagon, the Rambler American. [12]

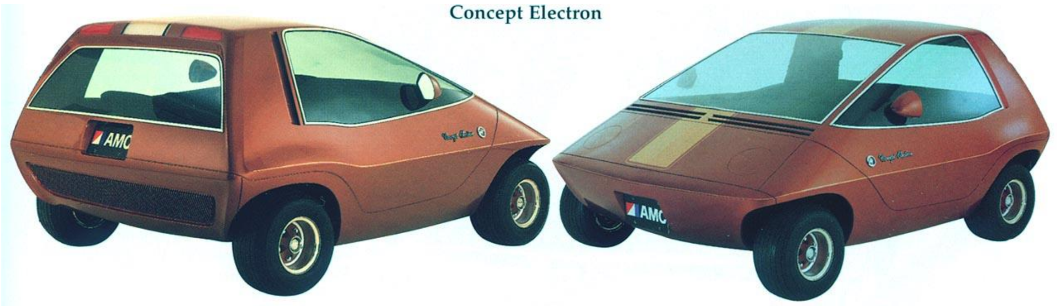


Figure 8: AMC Electron, 1977 concept car

In the 70s, General Motors designed the Electrovette, an electric concept car derived from the Chevette. It was endowed with an electric motor and lead-acid batteries. It was able to reach a top speed of 85 km/h. the range was about 80 km, evaluated at a speed of 48 km/h. [11]

At early 60s, Smith Delivery Vehicles engaged a partnership with Boyertown and Electric Storage Battery division of Exide Technologies to manufacture an electric delivery truck. The new company was arranged as the Battronic Truck Corporation. The first Battronic electric truck was released in 1964. It had a payload of 1,100 kg, a range of 100 km and it was able to achieve a top speed of 40 km/h. Between 1973 and 1983, about 175 utility vans were produced from the collaboration between Battronic and General Electric. [9]

In 1975, 350 electric delivers AMC jeeps were bought by US postal service for a test program. These vehicles were able to reach a top speed of about 80 km/h. The range was 65 km evaluated at a speed of 65 km/h. The recharging time was estimated to be around ten hours. [9]

An electric microcar was built by the Italian design company Zagato between 1974 and 1976. The Zagato Zele had a fiberglass body, while chassis and suspensions were derived from Fiat 500 and Fiat 124. There were three different electric motor power: 1 kW, 1.5 kW, 2 kW. The range was about 80 km. This vehicle was imported in US by Elcar Corporation.

Figure 9: Zagato Zele, an italian electric microcar (credit Zagato)

Between 1974 and 1977, Sebring-Vanguard, Inc. produced the CitiCar, a two-seats electric vehicle with flat diagonal front, a flat roof and a quite vertical back. The CitiCar was constructed in three models: the SV-36, with 1.9 kW electric motor and 36V battery pack, the SV-48, with 2.6 kW electric motor and a 48V battery pack, and the third model variant with an enhanced drivetrain of 4.5 kW. The 36V model was able to reach a maximum speed between 40 and 45 km/h, while 15 km/h more on the 48V model. The range was about 64 km.

In 1976, Fiat presented an electric version of the Fiat City Car X1/23 originally showed as concept car in 1972. The nickel-zinc batteries weighted 166 kg and were placed at the rear, while the electric motor had a 13.5 hp. The range was 50 km and the top speed was about 70 km/h. [13]

Figure 10: Fiat City Car (X1/23) [13]

In the 1990s there was a new enthusiastic wave towards electric vehicle thanks to the ZEV mandate released by CARB (California Air Resources Board), the clean air agency in the California government. The ZEV (Zero Emissions Vehicle) mandate was firstly launched in 1990 to assist California in reaching its emissions goal by requiring manufacturers to offer on the market a specific percentage of vehicle with the cleanest available technology. It required that 2 percent of light duty vehicle sold in California had no emissions by 1998, 5 percent by 2001 and 10 percent by 2003. This law was repeatedly weakened but the target of 1.5 million ZEVs by 2025 remains. As a consequence, a set of electric vehicles were launched to be produced during this decade. [2]

The Chrysler TEVan was produced between 1993 and 1995. It was equipped with nickel-iron or nickel-cadmium batteries. The top speed was about 110 km/h. Only 56 vehicles were built.

The GM EV1 was the first electric vehicle mass produced and leased by a major car manufacturer, counting 1,117 units between 1996 and 1999. [14] This vehicle is also the first purpose-designed electric vehicle from a major carmaker. it was a front wheel drive vehicle with a three phase AC induction electric motor able to deliver a maximum torque of 149 Nm and a 102 kW maximum power. It was equipped with a lead acid battery pack (16.5-18.7 kWh) and lately NiMH battery pack (26.4 kWh). The GM EV1 is the first and only passenger vehicle to be sold with the corporate name instead of using one of its division names. [15]

Figure 11: GM EV1, first mass produced electric vehicle[2]

[2] By EV1A014_(1).jpg: RightBrainPhotography (Rick Rowen)derivative work: Mariordo (talk) - EV1A014_(1).jpg, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=14727110

Between 1997 and 1998 a variant of the Chevrolet S-10 pickup truck was produced in a completely electric version called Chevrolet S-10 EV. It was supplied for leasing to utility fleet customer. It was endowed with an AC induction liquid-cooled motor and lead acid battery pack (16.2 kWh) or NiMH battery pack (29 kWh). The former had a range of 53 km (EPA), whereas the latter 116 km (EPA).

The Honda EV Plus was an electric vehicle manufactured and sold between 1997 and 1999 for a total of about 300 units. It employed a NiMH battery pack.

Figure 12: Honda EV Plus

The Toyota RAV4 EV was the electric vehicle derived from the Toyota RAV4 SUV. 1,484 vehicles were leased in California in order to meet ZEV mandate. [16] It was equipped with an electric motor able to deliver a 50 kW maximum power and a 190 Nm maximum torque. The NiMH batteries had a 27 kWh capacity. The range was about 153 km, while the maximum speed 126 km/h.

The Ford Ranger EV is an electric vehicle that was offered for leasing between 1998 and 2002.

The Nissan Altra is an electric vehicle using the Nissan R'nessa body style. It was mainly employed as fleet vehicle with only about 200 units between 1998 and 2002. It is the first production vehicle using a Li-Ion battery that allowed a maximum range of 190 km. [17]

Relatively to hybrid vehicles, they did not spread and were available until 1997, when the Toyota Prius was released in Japan becoming the first mass-produced gasoline electric hybrid car, followed in 1999 by Honda Insight. The Honda Insight had an aluminum structure with a 3-cylinders 1L gasoline engine able to provide

50 kW and supported by a 10 kW brushless electric motor mounted on the crankshaft, capable to deliver an electric torque of 49 Nm. The Honda Insight became the first hybrid vehicle available in US market from December 1999, followed seven months later by Toyota Prius. [18]

4 Available electrification technologies

Nowadays the offered percentage of electrified vehicles (hybrid or battery electric vehicles) is increasing more and more. The reason is linked neither to the aim from the carmakers for a more sustainable and greener environment nor to real wants and needs coming from customers, that on the contrary show themselves reluctant towards the pure battery electric vehicle adoption. The real cause driving this phenomenon is the increasingly stringent legislation to reduce pollutant and carbon-dioxide emissions established by the European Commission.

A hybrid vehicle is a vehicle that uses more distinct power sources to move the vehicle, a primary power source and one or more secondary power sources. At least one of the power sources is an electric motor. The system includes also a storage system.

A battery electric vehicle (BEV) is a kind of electric vehicle that uses electric motor or motors as unique power source. The storage system is based on chemical energy stored in rechargeable battery packs.

The technologies for the emissions reduction that are now available on the market can be divided according to their degree of electrification, according to batteries capacity, circuit voltage and electric motor power. From the lower to the higher, we can distinguish among micro-hybrid electric vehicles (µHEV), mild-hybrid electric vehicles (MHEV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), range extender electric vehicles (REEV) and battery electric vehicles (BEV).

Figure 13: Parallel hybrid vehicles layout: P0, P1, P2, P3, P4

Another aspect that allows to describe the electrification technologies is the layout of the parallel hybrid vehicles in terms of positions in which the electric motor can be located:

- P0: the electric motor is mounted on the front end accessory drive and connected to the internal combustion engine through a belt. This system is generally identified as belt integrated starter generator (BSG).

- P1: the electric motor is installed on the crankshaft between the engine and the transmission. This system is commonly identified as crankshaft integrated motor generator (CMG).

- P2: the electric machine is side-attached through a belt or integrated between the internal combustion engine and the transmission. The electric motor is decoupled from the internal combustion engine, having the same or a multiple speed than the internal combustion engine.

- P3: the electric motor is connected through a gear mesh to the transmission. The electric motor is decoupled from the internal combustion engine and its speed is a multiple of the wheels speed.

- P4: the electric motor is connected through a gear mesh on the rear axle. The electric motor is decoupled from the internal combustion engine and is located in the rear axle drive or in wheel hub. [19]

Table 1: Synthesis of electrification technologies with energy properties and electric control functions [20]

	µHEV	MHEV (BSG)	MHEV (TMG)	MHEV (CSG)	HEV	PHEV	BEV
Electric power [kW]	2-4	10-15	< 21	15-20	25-60	40-100	> 60
Operating Voltage [V]	12	48	48	< 160	150-350	< 400	< 450
Battery Capacity [kWh]	< 0.5	~ 1	~ 1	~ 1	1-2	10-15	>15
CO_2 Reduction	5-6 %	7-12 %	7-12 %	7-12 %	15-20 %	> 20 %	100 %
EV mode [km]	/	/	/	/	5-10	~ 50	> 100
Cold Engine Cranking	Yes	No	Yes	Yes	Yes	Yes	Yes
Idle Start/Stop	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Advanced Start/Stop	Maybe	Maybe	Yes	Yes	Yes	Yes	Yes
Engine Load Shift	Maybe	Yes	Yes	Yes	Yes	Yes	Yes
Torque Fill	No	Yes	Yes	Yes	Yes	Yes	Yes
Torque Boost	No	Yes	Yes	Yes	Yes	Yes	Yes
Sailing/Coasting	No	Yes	Yes	Yes	Yes	Yes	Yes
Regenerative Braking	No	Maybe	Yes	Yes	Yes	Yes	Yes
Creeping	No	No	Maybe	No	Yes	Yes	Yes
Plug-in Charging	No	No	No	No	No	Yes	Yes

The Table 1 summarizes the main electrification technologies that are described below. The MHEV can be subdivided according to the topology among BSG (Belt-integrated Starter Generator), TMG (Transmission-integrated Motor Generator) and CSG (Crankshaft-integrated Starter Generator).

4.1 Micro Hybrid Electric Vehicles (μHEV)

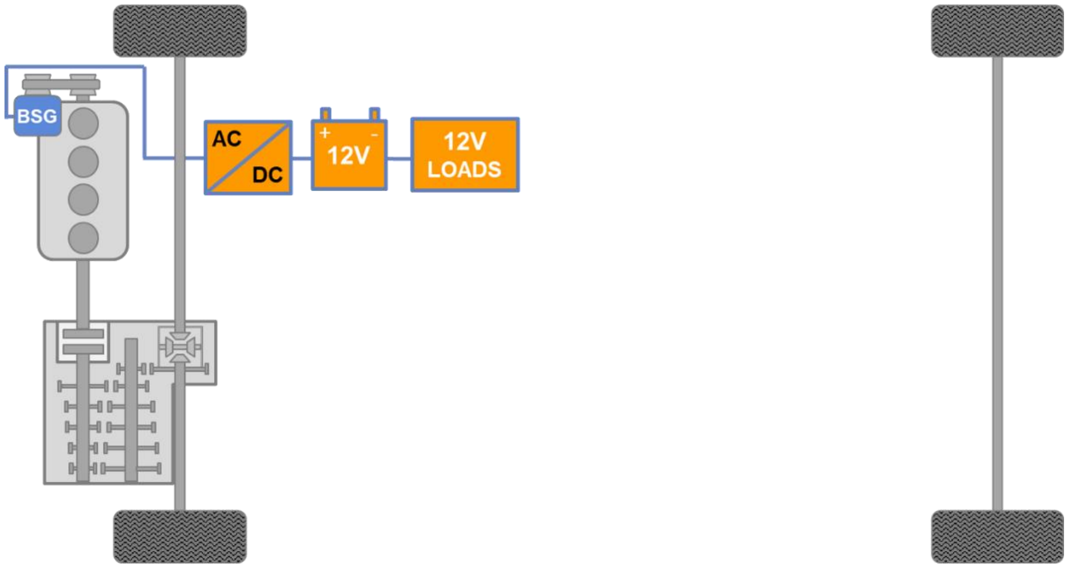


Figure 14: μHEV with Belt-integrated Starter Generator, inverter and 12V battery

Micro-hybrid electric vehicles (μHEV) are characterized by a battery and circuit voltage equal to 12V. The electric motor is capable of delivering a power of about 2-4 kW. The battery capacity value is generally below 0.5 kWh. The CO_2 estimated reduction is in the order of 5-6 percent. [21] The function that are enabled in μHEV throughout the installation of electric motor in parallel with respect to the internal combustion engine are the conventional start and stop (idle start and stop), that consists of switching off the internal combustion engine when the vehicle is stationary and then restarting it through the electric components. This electrification technology may even supports an extended start and stop, that intervenes when the driver brakes and the speed goes below a certain threshold, and the engine load shift in which the electric motor is able to provide and amount of the total torque required by the driver allowing to make the internal combustion engine in a more efficient part in the engine map. [22] The μHEV shows a parallel coupling with the internal combustion engine in which the electric motor is mounted on the front end accessory drive and connected to the internal combustion engine through a belt (P0) or on the crankshaft between the engine and the transmission (P1).

The main actor using nowadays this technology is Suzuki in their models Swift, Ignis and Baleno.

4.2 Mild Hybrid Electric Vehicles (MHEV)

Mild-hybrid electric vehicles (MHEV) show a battery and circuit voltage of 48V. This voltage value is properly chosen in order to not exceed the electric shock limit resulting in possible hazard for human.

The electric motor is able to deliver 15-20 kW and a torque between 30-70 Nm. The battery capacity is generally around 1 kWh. [20]

This system presents the higher cost-benefit ratio. Indeed, the estimated CO_2 reduction is between 7 and 12 percent with considerably low cost of installation and no need of strong modifications for the integration. [21]

About the functions enabled by the MHEV technology, it allows to perform an extended start and stop, the electric torque assistance, the engine load shift, the regenerative braking (even if limited with respect to vehicle with higher electrification degree) and the coasting. The extended start and stop allows stopping the internal combustion engine when the driver brakes and the speed goes below a certain threshold and restarting it through the electric components when that threshold speed is overcome. The electric torque assistance can be split between torque filling and torque boost. The torque filling allows to cover the engine torque transient. An internal combustion engine has some delay in delivering the torque required by the driver. This is particularly evident in diesel engine in which the torque assist can be used to eliminate the turbo-lag caused by the compressor and turbine rotor inertia, determining an electric supercharging. The torque boost consists of increasing the maximum torque that can be delivered by the engine throughout the torque supplied by the electric motor. The engine load shift allows to make the engine work in its most efficient part in the engine map by supplying the missing torque with respect to the one required by the driver through the electric motor. The regenerative braking is allowed by the electric motor that is put in generator mode by opposing a negative torque that is overcome through the kinetic energy, thus generating electrical energy that is stored in the battery. The coasting is the function that allows to disengage the engine from the transmission while the vehicle is running at relatively high speed when the driver release slowly the accelerator pedal. In addition, the internal combustion engine can be downsized even maintaining the same performances since the torque and power gaps are covered by the electric motor. Another function that can be supported just in case P3 or P4 architecture is the vehicle creep, that is the electric vehicle mode for maneuvers at low speed. [22]

Another difference of MHEV with respect to μHEV is the need of a DC/DC converter in order to decrease 48V voltage into 12V voltage to feed the 12V circuit and loads.

The MHEV technology can be implemented in different ways according to the position of the electric motor.

4.2.1 48V P0 (BSG)

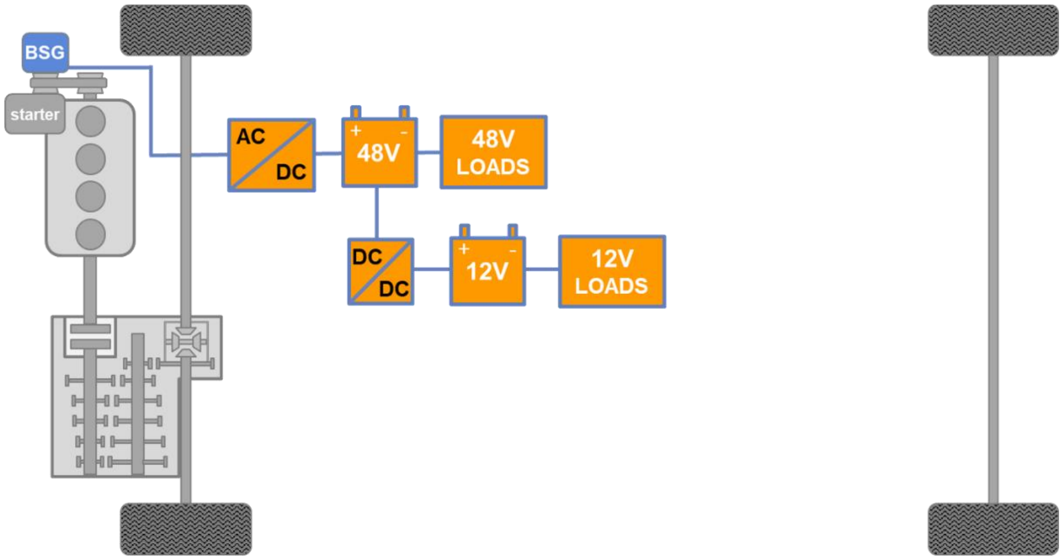


Figure 15: MHEV 48V with electric motor mounted on front end accessory drive (P0), inverter, 48V battery, converter and 12V battery

In this layout the electric motor is mounted on the front end accessory drive and connected to the internal combustion engine through a belt. It allows to perform the extended start and to reduce the CO_2 emissions by 5 percent on the World harmonized Light vehicle Test Cycle (WLTC). The drawback is that it shows a limited cold starting due to reduced power that can be generated by the electric motor. Therefore, the starter motor is needed to start the internal combustion engine when a higher power is required to overcome friction. [23]

4.2.2 48V P1 (ISG)

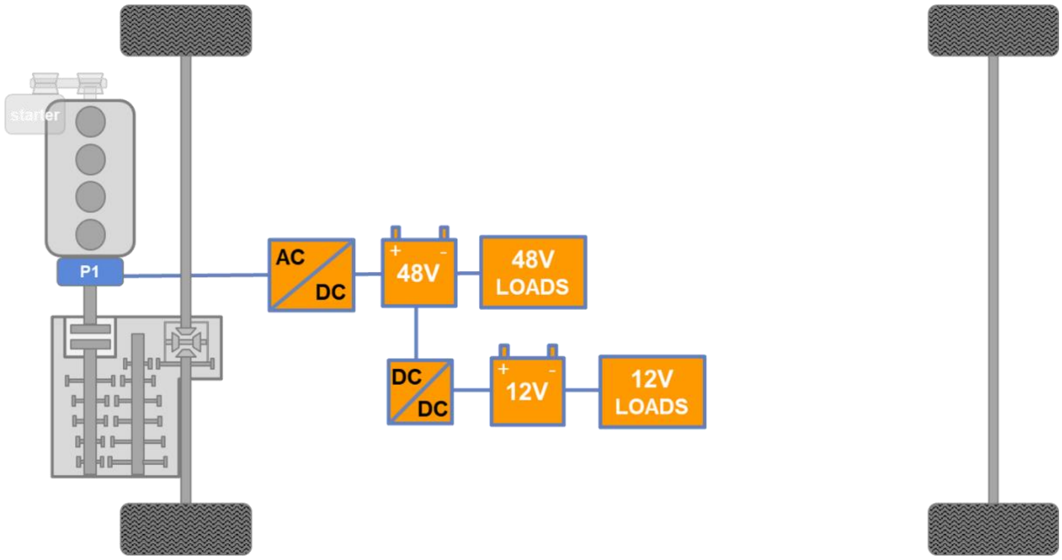


Figure 16: MHEV 48V with electric motor between clutch and ICE (P1), inverter, 48V battery, converter and 12V battery

In this layout the electric motor is located on the crankshaft between the engine and the transmission. It is called integrated starter motor (ISG). It allows a reduction of CO_2 emissions by 7 percent on the WLTC, a comfort start and stop and generation during standstill. [23]

4.2.3 48V P2 (ISG)

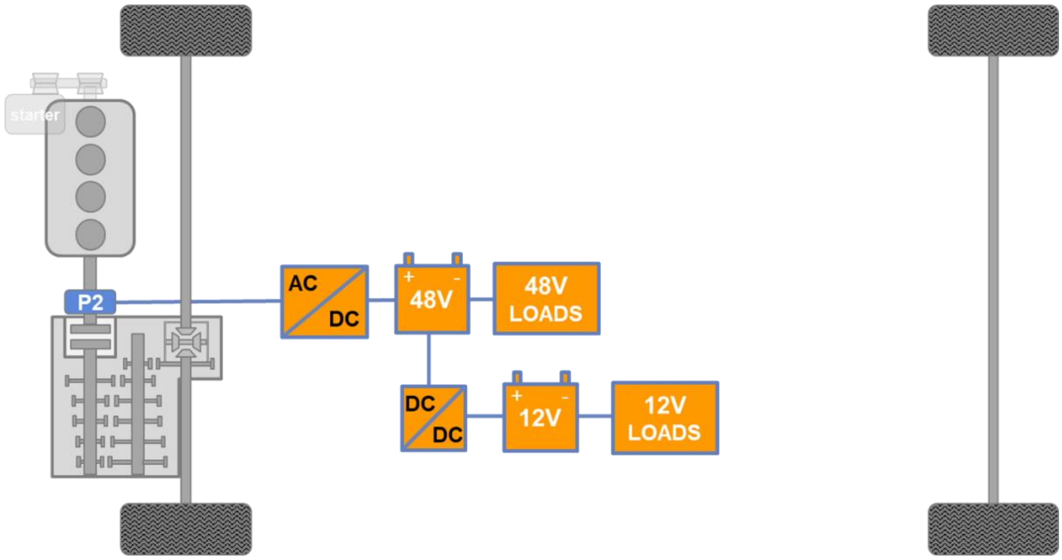


Figure 17: MHEV 48V with electric motor between internal combustion engine and transmission (P2), inverter, 48V battery, converter and 12V battery

This layout shows the electric motor located between the internal combustion engine and the transmission and can be integrated or side-attached. It allows a 10 percent reduction of CO_2 emissions on the WLTC. The main drawbacks are the need of modifications of transmission, cooling, clutch and internal combustion engine. On the other hand, the advantages are a comfort start and stop without noise and vibrations, an efficient coasting and the possibility of performing electric vehicle mode maneuvers at low speed. [23]

4.2.4 48V P3 (ISG)

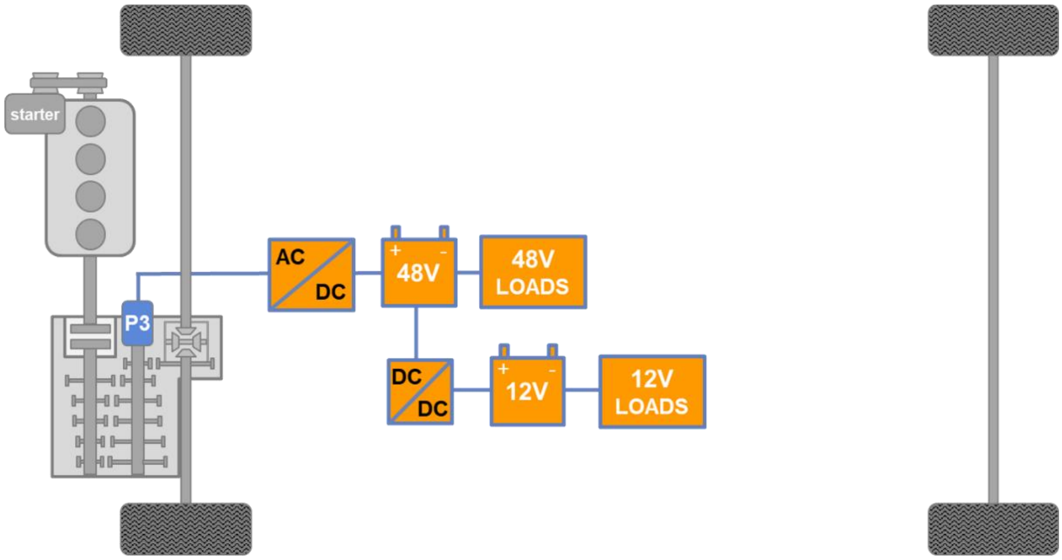


Figure 18: MHEV 48V with electric motor at transmission output (P3), inverter, 48V battery, converter and 12V battery

In this case, the electric motor is located at the transmission output. It allows a reduction in the CO_2 emissions by 9 percent but does not permit any start and stop function. Moreover, major transmission modifications are required. [23]

4.2.5 48V P4 (rear axle)

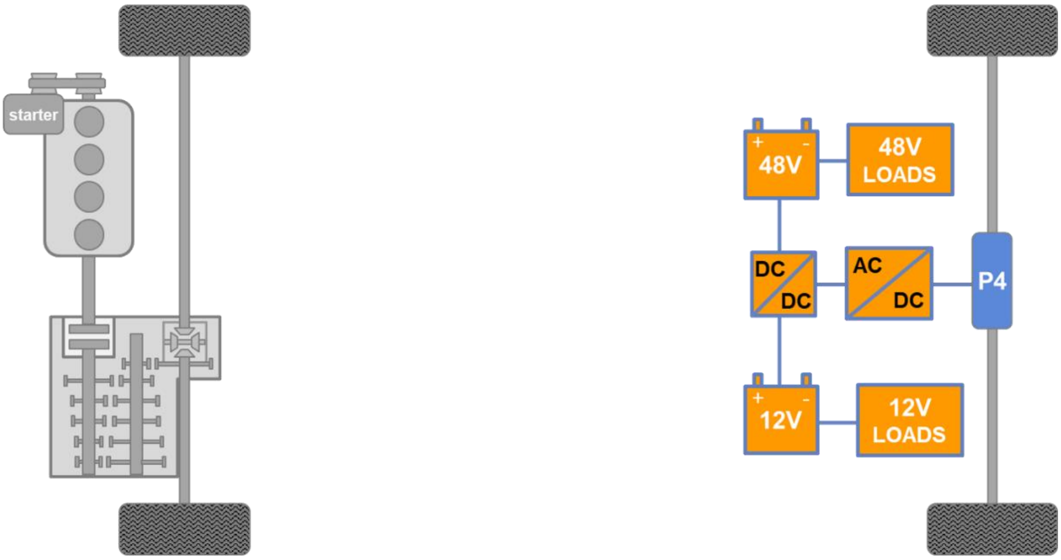


Figure 19: MHEV 48V with electric motor on rear axle (P4), inverter, 48V battery, converter and 12V battery

The electric motor is located at rear axle with an optional flywheel. The CO_2 reduction in the WLTC is between 5 and 7 percent. In this case, no modifications are required to the internal combustion engine, but the rear axle must be properly arranged in order to optimize the packaging. This system is independent from front wheel drive. [23]

4.3 Hybrid Electric Vehicles (HEV)

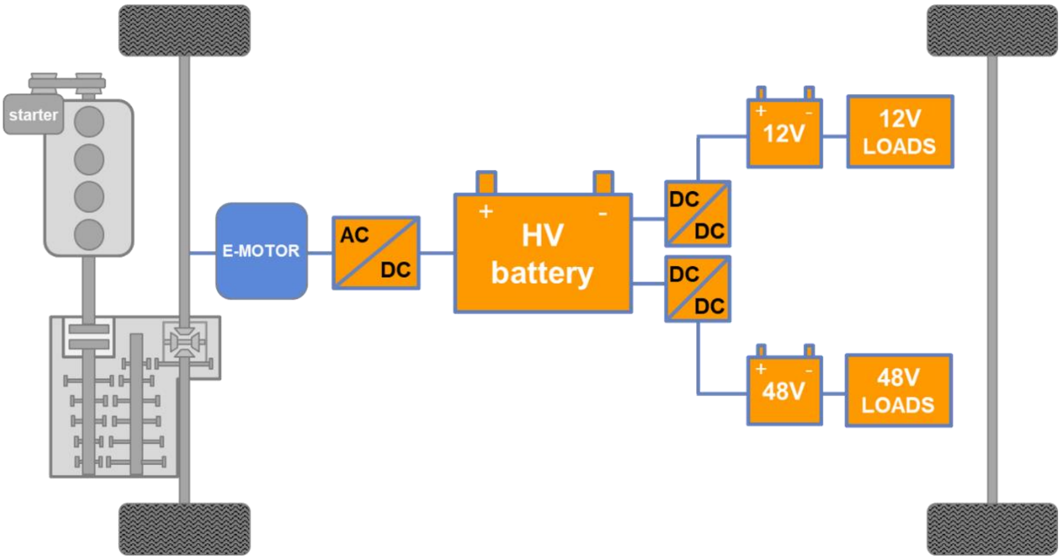


Figure 20: Hybrid Electric Vehicles schematic layout

Hybrid Electric Vehicles (HEV), also named full hybrid electric vehicles, have an electric motor power of about 25-60 kW. The operating voltage is generally bounded between 150V and 350V. The obtainable CO_2 reduction is about 15-20 percent. [20] The battery capacity is about 1-2 kWh, but what really matters is the minimum State of Charge (SOC) of the battery, that corresponds to the minimum level of discharge that can be achieved without incurring into permanent battery damages. Normally this value for the batteries employed in HEV is around 30-50 percent. All the functions previously described for MHEV are available. In particular, the Electric Vehicle driving mode has a range of about 5-10 km. [21]

The HEV can be classified according to the layout among series hybrid, parallel hybrid and series-parallel hybrid.

The series hybrid layout shows the internal combustion engine completely decoupled from the differential. It is employed in order to recharge only the battery. It is identified as Range Extender Electric Vehicle (REEV) and so it will be discussed afterwards in the following paragraphs.

Parallel hybrids can be schematized by two branches, one including the internal combustion engine and the other one containing the battery, the power converter and the electric machine. The internal combustion engine and the electric machine are mechanically coupled to the same shaft and the amount of power delivered by each can be adapted according to driver needs or for fuel economy optimization, by allowing the internal combustion engine operating in its most efficient part in the engine map. Furthermore, the internal combustion engine can be completely detached, thus enabling the complete electric vehicle driving mode. Parallel hybrids normally show a P2 configuration, with the electric machine is side-attached through a belt or integrated between the internal combustion engine and the transmission. This is the simpler solution that does not require strong modifications to the vehicle architecture. The parallel hybrid layout can be even combined with a P4 by locating a further electric motor on the rear axle. The most diffused layouts are P0/P4, showing a BSG in the front and an electric motor on the rear, and a P2/P4 in which an ISG high voltage is present in the front and an electric motor on the rear.

Series-parallel hybrids are more complex solutions that have both series and hybrid energy path, thus allowing to reach a total flexibility in terms of energy flow directions and obtaining an extremely efficient system. These can be divided among complex hybrids, spit parallel and power split. Power split hybrid is composed of one internal combustion engine and two electric machines, one of them acting as energy flows direction controller, all linked to a power split device. In the most famous implementation, the power split device is a planetary gear set. This system allows the vehicle to operate both as a parallel hybrid and as a series hybrid in which the internal combustion engine is independent from the car speed, so that the internal combustion engine can be operated in its more efficient part in the engine map to recharge the battery or to provide further power to the wheels. Indeed, the wheels can be moved just by the electric motor at low speed or by both internal combustion engine and electric motor at higher speeds. Further advantages offered by this solution are the elimination of the need of the starter and of the automatic transmission: the electric motor acting as generator can start the internal combustion engine, whereas the whole system works as Continuous Variable Transmission (CVT). Detailing the functioning of the planetary gear set, the internal combustion engine is connected to the planet carrier, the generator to the sun gear whereas the electric motor to the ring gear which is directly connected to differential and so to wheels. The speed of the ring gear depends on the contribution provided by each of the power source (internal combustion engine, electric motor and generator). At low speed, when accelerating, the power is completely delivered by the batteries and the electric motor. As a result, the ring gear starts to spin. On the contrary, the planet carrier is not rotating since the internal combustion engine is still not running, but the planetary gears that are engaged with both the ring gear and the sun gear, start to spin, thus causing the generator to move. In order to let the engine switched off, the generator spins at any speed. Then when the speed reaches 64 km/h, the generator suddenly modifies its speed producing the internal combustion engine to turn on consequently to the rotation of the planet carrier. Once the engine is on, the generator adjusts its speed to complement the output speed with the electric motor, whereas the internal combustion engine is set at constant speed so that it can operate in the most convenient part of the engine map, hence maximizing the fuel economy.

If the vehicle needs to be strongly accelerated, the required power is taken from the batteries and supplied by the electric motor. One possible drawback of the power split hybrid is the substantial impact on the existing architecture. [24]

4.4 Plug-in Hybrid Electric Vehicles (PHEV)

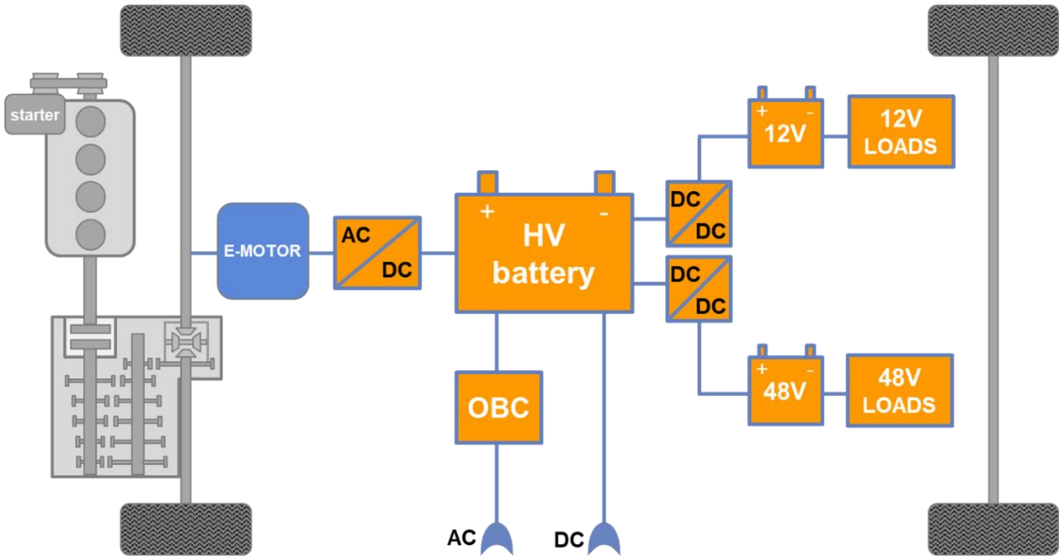


Figure 21: Plug-in Hybrid Vehicle schematic layout

Plug-in hybrid electric vehicles (PHEV) are equipped with an electric motor able to deliver a power of 60-100 kW. The voltage of the circuit is lower than 400V. The batteries are much larger than HEV with a value between 10-15 kWh, that allows a complete driving electric mode around 50 km. The achievable CO_2 reduction is more than 20 percent. [20] [21] The architecture of PHEV is very similar to HEV, but their battery can be recharged throughout an external power source. Indeed, they can be plugged to the grid through a socket to recharge the battery. Consequently, the PHEV is equipped with an On-Board Charger that converts the AC power from the wall into DC power to charge the vehicle battery. As regards the DC charging, there is no need of converting power that is therefore directly stored inside the battery from the plug.

4.5 Range Extender Electric Vehicles (REEV)

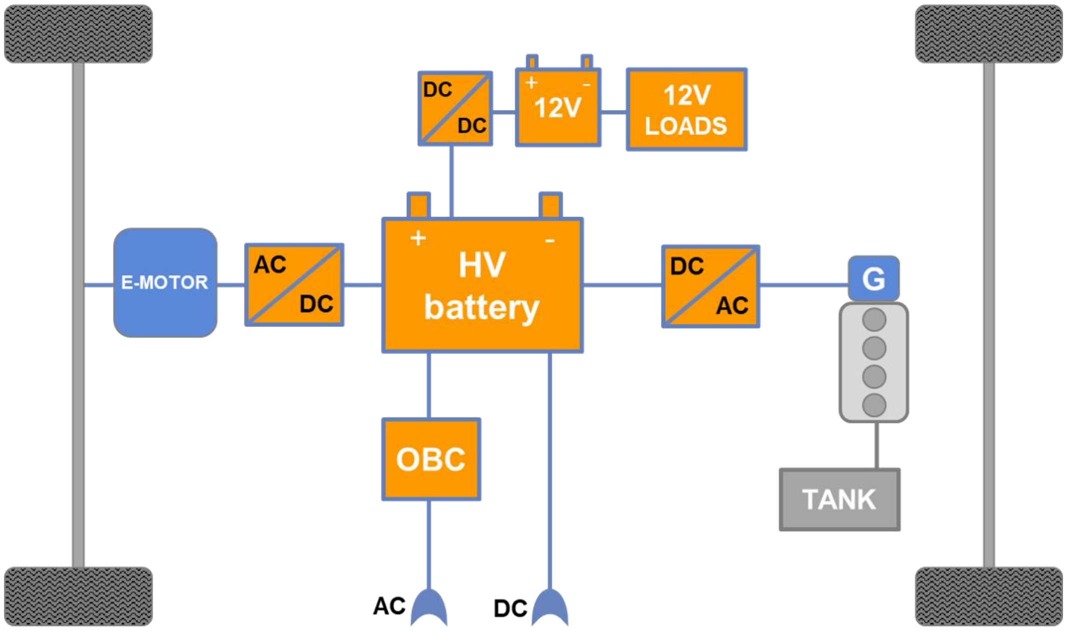


Figure 22: Range Extender Electric Vehicle, a series hybrid with a small internal combustion engine

Range Extender Electric Vehicles (REEV) can be identified as series hybrid electric vehicle. They show a series connection between the engine, the battery and the electric motor. The internal combustion engine is completely decoupled from the differential, thus allowing to always operate independently from driving conditions in its most efficient part of the engine map. Furthermore, the dimension of the internal combustion engine can be reduced a lot, since the energy generated by the internal combustion engine is only stored inside the battery through a generator, that is used to transform kinetic energy of the crankshaft into electric energy. The electric motor is the only component supplying the power for motion, drawing it from the battery. The main disadvantage of this solution is the overall energy efficiency that is reduced due to five energy conversions: from chemical into mechanical energy in the internal combustion engine, from mechanical into electric energy in the generator, from electrical into electrochemical in the battery, from electrical into mechanical energy in the electric motor. In addition, there is an increase in the complexity, weight and costs. Lastly, the presence of the internal combustion engine results in a non-zero pollutant and CO_2 emissions.

4.6 Battery Electric Vehicles (BEV)

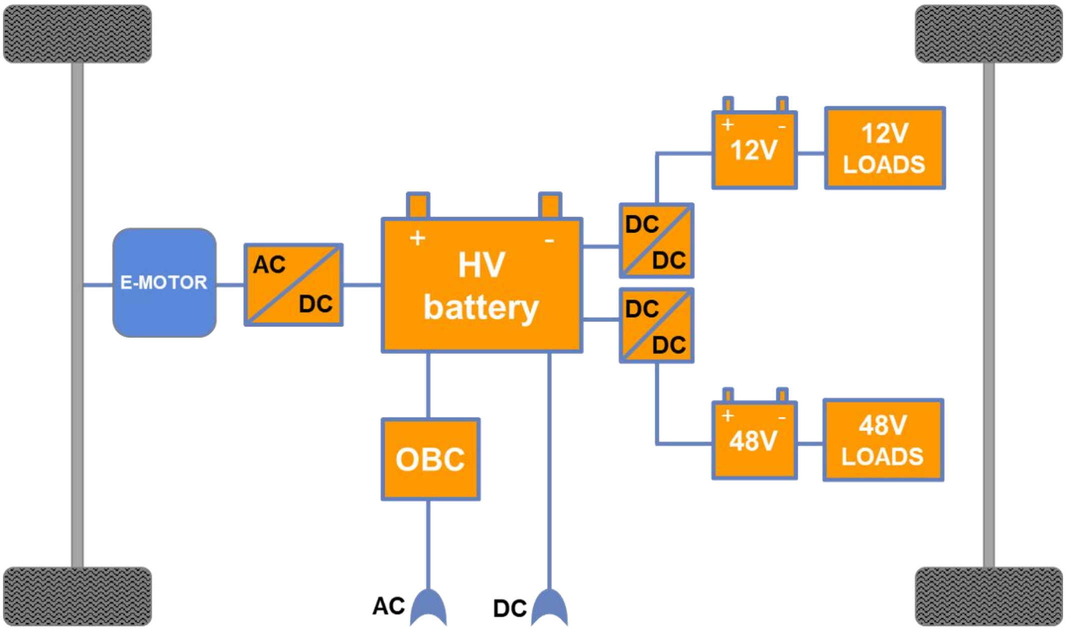


Figure 23: Battery electric Vehicles schematic layout

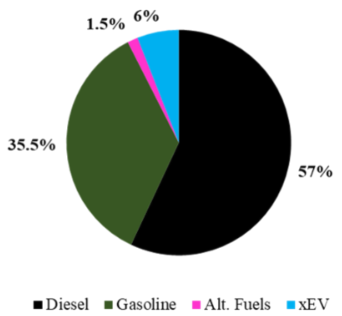
Battery electric vehicles (BEV) are a kind of electric vehicle that uses electric motor or motors as unique power source. The storage system is based on chemical energy stored in rechargeable battery packs. The power of the electric motor is above 60 kW. It can be located in the front or rear axle according to the desired traction, or on both axles in order to obtain an electric All-Wheel Drive (e-AWD). Another solution shows one electric motor per each wheel, providing a complete and independent wheel control, in terms of speed and torque. The circuit voltage is lower than 450V. The battery electric vehicle shows deep simplification in the vehicle layout and management with respect to conventional internal combustion engine layout. The packaging is simplified, and the power electronic components can be located so as to reduce the cables length.

5 European market evolution

5.1 *Current European market outlook*

According to ACEA data updated at Year To Date (YTD) Q3 2018, in EU28 and EFTA markets, the total number of vehicles sold is equal to 12.2 million units. The industry shows a growth by 2 percent with respect to YTD Q3 2017.

Germany is the first market for vehicles sold (23%), followed by United Kingdom with a share of 16 percent. The third major market is France (14%) followed by Italy and Spain with respectively a share of 13 and 9 percent.



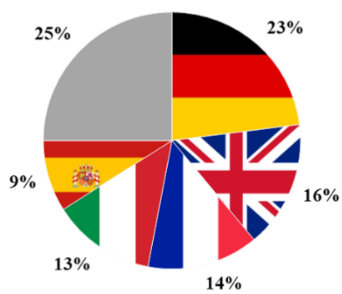


Figure 24: Left: the industry fuel mix at YTD Q3 2018. Right: Countries' shares (source: ACEA-JATO)

By looking at the fuel mix, conventional fuels accounts for 94 percent, while electrified vehicles for the remaining 6 percent. Among conventional fuels, the gasoline covers the higher portion with a share of 57 percent, whereas diesel counts for 35.5 percent. The remaining part is occupied by alternative fuels (LNG, CNG) with a percentage equal to 1.5. In the past the shares of diesel and gasoline were inverted. This change occurred between 2016 and 2017. In 2014, the diesel had a share of 52 percent, but in the period 2014-2018, it has displayed a decrease with a CAGR (Compounded Annual Growth Rate) of -9.4 percent. On the opposite, the gasoline counted in 2014 the 44 percent of the industry and in the period 2014-2018 it has increased with a CAGR of 6.7 percent. The alternative fuels have remained quite stable in the same period and their percentage in 2014 were equal to 2. The electrified vehicles in 2014 represented the 2 percent of the industry and they increased in the period 2014-2018 with a 28% CAGR. Examining the fuel mix in the major markets, it is possible to notice that Italy shows an abnormal behavior because at YTD Q3 2018 diesel (53%) has a higher share than gasoline (34%) and since 2014 it decreased by solely 2 pp (percentage points). In contrast, in the other major markets, the diesel mix is much smaller, counting 35 percent on average and showing a mean diminishment of 19 pp. Another contrasting aspect of Italy with respect to Germany, United Kingdom and France is the amount of alternative fuels that since 2014 has decreased of 5 percentage points and today (YTD Q3 2018) has a percentage of 9.

Analyzing the segments, diesel mix remains higher than gasoline in larger segments. Indeed, since 2014 diesel has been presenting the major decrease in I0, L0 and I1 segments (28 pp on average) in favor of gasoline. The larger share of electrified vehicles is present in larger SUV segments (about 13 percent in I2 segment and 16 percent in the I3 segment). In particular, in the I3 segment their mix is greater than gasoline one (13%).

Let's now focus on the electrified market. At YTD Q3 2018 in EU28 and EFTA market, according to ACEA data, the sales of electrified vehicles are equal to 734 thousand units, thus representing the 6 percent of the total industry. The electrified vehicles market has displayed a 35 percent increase with respect to YTD Q3 2017. The first market for the electrified vehicles is Germany with a share of 16.6 percent corresponding to 122 thousand units, the second one is United Kingdom, representing the 15.6 percent of the total industry and equal to 115 thousand units. The third electrified vehicles market is France (13.2 % and 97 thousand sales) followed by Italy that has a share of 9.2 percent and 67 thousand xEV sold and Norway showing an 8.9 percent on the total and 65 thousand of units. The sixth market for electrified vehicles is the Spain with a share of 8.7 percent and displaying one thousand units with respect to Norway

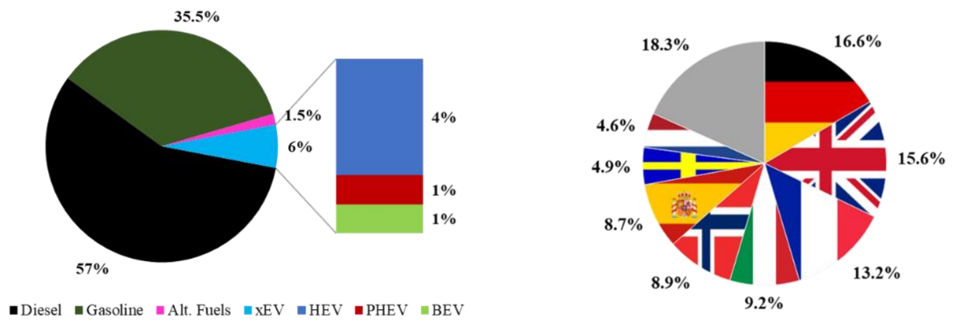


Figure 25: Left: the xEV focus at YTD Q3 2018. Right: Countries' shares on xEV (source: ACEA-JATO)

Among the 734 thousand of electrified vehicles sold in EU28 and EFTA market, the largest part is composed of HEV that count about 4 percent of the total industry, while the remaining part is constituted by BEV and PHEV, respectively 132 and 141 thousand units. HEV show an 35 % increase with respect to YTD Q3 2017. The most sold HEV is Toyota Yaris with about 93 thousand units and an increase of 33 percent with respect to the previous year at the same period (YTD Q3 2018 vs YTD Q3 2017). At YTD Q3 2018, the 61 percent of total Yaris sold are HEV. Toyota Group is leader of HEV technology, displaying a total of 334 thousand units sold equal to 89 percent of HEV sales. PHEV display a 34 percent growth with respect to YTD Q3 2017. Mitsubishi Outlander is the most sold PHEV (14 thousands of units), quite constant with respect to YTD Q3 2017. About half of the Mitsubishi Outlander sales are PHEV. Through a 37 percent growth, BEV is the technology that has more increased its sales at YTD Q3 2018 with respect to the previous year at the same period. Nissan Leaf is the BEV top seller counting 26 thousand units followed by Renault Zoe (23 thousands of units). They are offered just as BEV. Nissan Leaf displays an increase of 84 percent with respect to the previous year, whereas Renault Zoe has remained stable.

ACEA includes REEV into PHEV and MHEV into HEV. Therefore, in order to deal with the current MHEV market we must refer to data provided by JATO and updated at YTD Q3 2018. The MHEV corresponds to 4 percent of total xEV registered. The MHEV market leader is Suzuki Swift with about 12 thousand units. The 12 percent of total Swift sales corresponds to a MHEV. Other MHEV sold by Suzuki are Ignis and Baleno. Suzuki is leader for the 12V MHEV. Other vehicles that are registered as MHEV are the Mercedes C-Class, Mercedes CLS, Mercedes E-Class and Mercedes S-Class for a total of about 8,500 MHEV. In Italy Audi homologates 12V and 48V system as MHEV. The vehicles registered by Audi as MHEV are: A3, A4, A5, A6, A7, A8, Q7 and Q8, counting a total of about 1,200 units.

Table 2: Top seller per technology at YTD Q3 2018. µHEV included in MHEV. (source: JATO)

	BEV	Nissan Leaf	26,000 units
	PHEV	Mitsubishi Outlander	14,000 units
	HEV	Toyota Yaris	93,000 units
	MHEV	Suzuki Swift	12,000 units

The electrified vehicles in the A segment represent about the 2 percent of total vehicles sold in this segment. The technologies present in the A segment are MHEV and BEV with the former composing the major portion. At YTD Q3 2018, the BEV top seller in A segment is Smart Fortwo (about 6 thousand units), while the most sold MHEV is Suzuki Ignis with 5,300 units.

B segment electrified vehicles are the 6,5 percent with respect to the total sales in the segment. The major portion (about 4%) is composed of HEV with Toyota Yaris as unique player. About 1.6 percent of this 6.5 percent is related to BEV, with Renault Zoe, BMW i3 and Opel Ampera-e. The remaining part corresponds to REEV (BMW i3) and MHEV represented by Suzuki Swift and Baleno. PHEV are completely absent from B segment.

About 7.7 percent of the vehicles sold in the C segment are xEV, with HEV dominating with a share of about 4.5 percent thanks to Asian carmakers (Toyota Auris and Prius, Lexus CT and Hyundai Ioniq). BEV follow with Nissan Leaf, Volkswagen eGolf, Hyundai Ioniq for a total share of 2.2 percent. The residual part is occupied by PHEV. PHEV offered in the C segment are Volkswagen Golf, Hyundai Ioniq, Audi A3 and Toyota Prius.

The prevalent technology in the D segment is PHEV, with a 3.2 percent of sales. Volkswagen Passat, BMW Series 3, Mercedes C-Class, Kia Optima and Volvo V60 are the D segment PHEV. The Remaining portion is constituted by HEV, with Ford Mondeo and Lexus IS as main players, and MHEV represented by Mercedes C-Class. The mix of xEV over the total vehicles in this segment is equal to 5.2 percent.

The E segment displays all the electrification technologies with BEV and PHEV representing the majority of xEV with a share of respectively 4.1 and 4.5 percent over a total of 9.2 percent mix on the segment. The only player offering a BEV in this segment is Tesla with the Model S (12,500 units). BMW Series 5, Mercedes E-Class and Volvo V90 are the PHEV offered.

Analyzing the SUV segments, the I0 segment shows a lower xEV share on the segment equal to 0.6 percent, constituted mainly by Mini Countryman PHEV and in smaller part by the Hyundai Kona BEV that has been recently introduced into the market.

The I1 segment is mainly dominated by HEV thanks to Toyota C-HR and Kia Niro. They account for the 6.2 percent of the 6.7 percent of xEV mix on the segment. The remaining percentage (0.5%) is constituted by Kia Niro that is also offered in the PHEV version. From the third trimester of 2018, Kia started offering its Sportage as MHEV.

I2 segment is characterized by a xEV share on the segment by about 13 percent. Two third is represented by HEV thanks to Toyota Group (Toyota RAV4 and Lexus NX), while about one third by PHEV, leaded by Mitsubishi Outlander, Volvo XC60 and Mercedes GLC. The recently introduced Jaguar I-Pace is the first BEV in the I2 segment.

The I3 segment displays the larger xEV share on the segment (about 16%). About half of the electrified vehicles sold in this segment are PHEV. The reason is that there are a lot of nameplates offering PHEV technology: Volvo XC90, BMW X5, Porsche Cayenne, Audi Q7, Land Rover Range Rover Sport, Land Rover Range Rover and Mercedes GLE-Class for a total of about 16 thousand units. One fourth of xEV sold in this segment are BEV, with Tesla Model X as unique offered BEV model. The remaining one fourth is represented by HEV with Lexus RX.

The unique electrified vehicle offered in the L0 segment is the BEV Kia Soul, that shows a share on the segment of about 2 percent.

Relatively to L1 segment, all electrification technologies are currently present, but BEV. The xEV share on the segment is equal to 3.5 percent. Of this share, about half corresponds to the PHEV BMW Series 2 Active Tourer, whereas 1.5 percent is represented by the HEV Toyota Prius+. The remaining portion corresponds to Renault Scenic that is offered as MHEV.

Hereafter, the analysis is now deepened by evaluating the current electrified vehicle situation in the major markets.

5.1.1 Germany

In Germany, in the period 2014-2018 the diesel mix displayed a decline of about 15 pp, with the strongest decrease since 2016. The gasoline presents a mirrored trend. Since 2014 when it had a mix of 51 percent, it shows a slight increase up to 2016 when there is a sharp increase up to 64 percent (YTD Q3 2018). On the same period the alternative fuels have remained quite constant, while the electrified vehicles have passed from 1 percent in 2014 up to about 3 percent of mix at YTD Q3 2018. The number of electrified vehicles has nearly triplicated between 2014 and 2017 and in particular it showed a positive year over year growth by 79 percent. The CAGR evaluated in the period 2014-2017 is equal to 43 percent. By making a rough estimation of the FY 2018 xEV registrations, the CAGR in 2014-2018 period should be equal to 38 percent. At YTD Q3 2018, HEV are the 42 percent of total xEV sold, followed by 26 percent of PHEV and 25 percent of BEV. The MHEV percentage is equal to 6, whereas the remaining one percent is composed of REEV.

5.1.2 United Kingdom

United Kingdom fuel mix shows a trend very similar to Germany. The mix of diesel and gasoline are both closer to 50 percent with gasoline slightly increasing and diesel slightly increasing up to 2016, whereas since 2016 there has been a strong decrease of diesel mix and almost mirrored sharp increase of gasoline mix. At YTD 2018, the gasoline and the fuel mix are equal respectively to 62 and 32 percent. In United Kingdom there are no alternative fuels vehicles sold. In fact, the remaining 6 percent is constituted by electrified vehicles, that have showed an increase of 4 pp from 2014. The electrified vehicles number is more than doubled in the 2014-2017 period, presenting a 32 percent CAGR. By making a rough estimation of the FY 2018 xEV registrations, the CAGR on the 2014-2018 period has increased by 44 percent, thus highlighting last year as a positive year for electrified vehicles sales in UK. At YTD Q3 2018, more than half of xEV sold corresponds to HEV (55%), while PHEV are equal to 29 percent and BEV to 10 percent. The remaining 6 percent is occupied by MHEV and REEV, respectively 5 and 1 percent.

5.1.3 France

In France, in the period between 2014 and 2018 the diesel mix showed a continuous decline of about 24 pp reaching 40 percent, while gasoline mix displayed an opposite increasing trend passing from about 33 percent in 2014 to 54.5 percent in 2018. Electrified vehicles mix nearly doubled in the same period with a 18% CAGR. The number of xEV has triplicated in the period 2014-2017, with a CAGR of about 27%. By making a rough estimation of the FY 2018 sales, it is possible to notice that the CAGR decreases and becomes equal to 25%. HEV represents the 62 percent of total xEV sold in France, followed by BEV (21%). The PHEV counts for the 10 percent showing an increase of about 7 pp from 2014. The remaining percentage of xEV sold are MHEV and REEV that are respectively equal to 6 and 1 percent.

5.1.4 Italy

Italy shows an abnormal situation with respect to other major markets. The diesel mix has remained quite stable and has lost only 2 pp from 2014 when it was equal to 55 percent. The gasoline mix has slightly increased passing from 29% in 2014 to 34% at YTD Q3 2018. The mix of alternative fuels is another atypical phenomenon with respect to other major countries, where it presents shares equal or lower than one percent. The alternative fuels mix was equal to 14 percent in 2014 and has decreased by 5 pp in the period 2014-2018. The number of xEV registered between 2014 and 2017 has triplicated, showing a 44% CAGR. The most relevant increase has occurred in 2017. Indeed, the year over year variation is equal to 71 percent. By making a rough estimation of the total xEV sold in the FY 2018, the CAGR becomes equal to 41 percent. The electrified vehicles mix has displayed an increasing trend by about 2 pp, today representing 4 percent share. Most electrified vehicles sold are HEV that dominate with a share of 81 percent, followed by MHEV (9%). The remaining portion is composed of PHEV and BEV, that has the same 5% share.

5.1.5 Norway, Spain, Sweden and The Netherlands

Norway displays a remarkable situation: the electrified vehicles represent the 58 percent of total vehicles registered. Among these, about half are BEV (49%), while PHEV corresponds to 31 percent and HEV to 19 percent. The remaining one percent is occupied by MHEV. The number of xEV sold has passed from 30 thousand units in 2014 up to 81 thousand units in 2017, with a 39% CAGR. By making a rough estimation of the xEV sold at FY 2018, the CAGR decreased to 30 percent, highlighting that the Norwegian xEV market is slowing down. Norway was the third market per volume of xEV sold in 2016 and the fourth one in 2017, nowadays it has been overcome by Italy.

The share of xEV in Spain is 6 percent over the total Spanish car industry. About more spread electrification technologies sold, Spain displays a situation very similar to Italy: most of xEV registrations correspond to HEV, showing a share of 88 percent. The most relevant difference is the share of MHEV that is very low (little higher than zero percent). The other electrification technologies that are sold in Spain are BEV and PHEV, both presenting a share of 6 percent. The volume of electrified vehicles sold has passed from 13 thousand units in 2014 up to 62 thousand units in 2017, with a 70% CAGR. The most relevant increase occurred in 2017, showing an YoY increase by 81 percent. The Spanish xEV market keeps growing and the volume at YTD Q3 2018 is higher than the FY 2017.

In Sweden, the electrified vehicles share is about 13 percent over the total vehicles sold. The major share of xEV is occupied by PHEV and HEV, respectively 45 and 43 percent. BEV counts for the 11 percent, while the remaining 1 percent is covered by both MHEV and REEV. The electrified markets keep growing at constant rate with a CAGR in the 2014-2017 period equal to 49 percent. If the CAGR is evaluated over the period from 2014 to 2018, by making a rough estimation of the FY 2018 xEV sales volume, it is possible to obtain a value equal to 43 percent.

In Netherlands, 9 percent of vehicles sold are represented by xEV. Of these, half are constituted by HEV. The second sold electrification technology is BEV with a share equal to 40 percent. The remaining 10 percent is occupied by PHEV and MHEV, respectively 7 and 3 percent. The electrified vehicles trend shows a particular trend with a peak in the 2015 with 59 thousand xEV sold. In 2015, the YoY variation was +93%, but in the 2015-2017 period the sales volumes have decreased with a negative CAGR equal to 30 percent. The xEV sold at YTD Q3 2018 are more than FY 2017xEV sales volume.

5.2 Legislative evolution on carbon dioxide emissions

We are witnessing a continuous increase of the variety and quantity of electrified vehicles offered by car manufacturers on the market, thus accompanying a consequent rise of the sales volume, that in the period 2014-2018 has grown with a CAGR of 28 percent. The actual reasons beyond the proliferation of electrified vehicles lie in the more and more stringent carbon dioxide emissions target on passenger cars imposed by European legislation.

5.2.1 2015 targets

In 2007, the fleet average CO_2 emissions were equal to 158.7 g/km. In 2009, mandatory carbon dioxide standards were introduced in Europe for passenger cars. The target for fleet average CO_2 emissions was set for the 2015 with a value equal to 130 g/km. The target fixed a compulsory reduction in carbon dioxide percentage by 18 percent with respect to 2007. A phase-in period from 2012 to 2015 was established. The phase-in period consists of setting intermediate target in order to help carmakers in achieving the 2015 standard. The intermediate 2012 target was placed at 65 percent of final one, 75 for 2013, and 80 for 2014. 130g/km of carbon dioxide is just an average target for the European fleet of new vehicles sold, while the specific target value is tailored according to the vehicle mass by using a limit value curve. The limit value curve allows heavier cars to emit more CO_2 than lighter vehicles, so that the legislation does not affect the European market diversity by penalizing heavier automobiles.

$$Specific\ CO_2\ emissions = 130 + 0.0457\ (M - M_0) \qquad [g/km]$$

The specific carbon dioxide emissions target depends on M (specific vehicle mass), on M_0 (average yearly vehicle mass) and on the correction factor 0.0457. It means that a vehicle with the same mass of the average fleet mass is allowed to emit 130 g/km of CO_2, while a heavier vehicle can emit 4.57 g more each 100 kg it additionally has. For car manufacturers failing in reaching the targets from 2012 onwards, an excess emissions premium was instituted. If the average carbon dioxide emissions value of the sold vehicle fleet of a manufacturer's fleet is overcome, the premium to be paid is equal to 5€ for the first gram of exceedance, 15€ for the second one, 25€ for the third one and 95€ for each further additional gram. The total has to be multiplied by the number of vehicles sold in the out-of-compliance year.

Another further incentive is recognized for vehicles with extremely low emissions below 50 g of carbon dioxide per kilometer. The incentive mechanism is identified as super credits: in the determination of the total amount of CO_2 emissions of the manufacturer's fleet, each car below the set emissions threshold is counted 3.5 times in 2012 and 2013, 2.5 times in 2014, 1.5 times in 2015.

Eco-innovations, that will be discussed in the following paragraph, are another incentive mechanism that was introduced with the first set of legislation for emissions reduction. [25]

5.2.2 2021 targets

In 2014 a second collection of regulations was instituted. The target for fleet average CO_2 emissions was set for the 2021 with a value equal to 95 g/km, with 2020 as a phase in year with 95 percent with respect to the final target. As for the previous legislation, the provided target value is referred to the fleet average carbon dioxide emissions, whereas the specific vehicle emissions must comply with the value obtained through the value limit curve, in order to account of specific weight differences. The correction factor has been modified and set at 0.0333, thus allowing 3.33 g/km of CO_2 for each 100 kg more. The reference mass vehicle for the year 2017 was 1,372 kg. Therefore, a vehicle whose mass is equal to the reference mass is allowed to emit 95g of carbon dioxide per kilometer.

$$speific\ CO_2\ emissions\ target = 95 + 0.0333\,(M - M_0) \qquad [g/km]$$

From 2019 for car manufacturers failing in reaching the target, the previous excess emissions premium is modified and set equal to 95€ from the first gram onwards above the standards.

Table 3: Passenger vehicles manufacturer group market shares, vehicle mass, CO_2 emissions, 2015 and 2021 CO_2 targets and share of PHEV and BEV referred to 2017. All CO_2 values in NEDC. (Credit ICCT) [26]

Manufacturer group	EU market share 2017	Average mass (kg) 2017	Average CO_2 (g/km) 2017	CO_2 target (g/km) 2015	CO_2 target (g/km) 2021	Electric vehicle share 2017
Toyota	5%	1,359	103	127	94	0.3%
PSA	16%	1,273	112	125	91	0.1%
Renault-Nissan	15%	1,310	112	126	93	2.5%
Average		**1,390**	**119**	**130**	**95**	**1.4%**
FCA	6%	1,259	120	124	91	0.0%
Ford	7%	1,393	121	128	95	0.0%
BMW	7%	1,570	122	139	101	5.0%
Hyundai	6%	1,348	122	129	94	1.4%
Volkswagen	23%	1,420	122	132	96	1.2%
Daimler	6%	1,607	127	139	103	2.6%

Niche manufacturers have to comply with different targets according to their sales volumes. Carmakers selling between 300 and 10 thousand vehicles can apply a less stringent target: 25 percent CO_2 reduction for the 2012-2019 period and 45 percent from 2020 with respect to their 2007 average emissions. Car manufacturers selling between 10 and 1 thousand vehicles can make a proposal about their carbon dioxide emissions reduction target that needs the European commission approval. Vehicle producers selling less than 1,000 units or special purpose vehicles (such as the ones endowed with wheel chair access) are out of the legislation scope.

Manufacturers can decide to jointly group forming pools in order to jointly meet carbon dioxide emissions target. The only constraint is that they must respect competition law rules, by exchanging information just relatively to their specific emissions targets and total volumes of registered vehicles.

Innovative technologies can further assist in the carbon dioxide emissions reduction. Innovative technologies that allow manufacturer in saving CO_2 emission but whose influence is not displayed in the official test validation procedure are identified as eco-innovation technologies. In order to promote research, development and installation of these technologies on vehicles, eco-innovations technologies bringing to real world carbon dioxide emissions reduction of at least 1g/km can be granted by both components suppliers or car manufacturers allowing to obtain emissions credits on automobiles where they are mounted on. The cap of emissions credits attainable through the eco-innovations installation was fixed at 7g of carbon dioxide per kilometer. The eco-innovations have to be validated throughout verifiable, repeatable and comparable measurements. In order to not avoid that eco-innovations erode the benefits of the carbon dioxide regulations, correctly account the real world reduction of emissions is fundamental. Indeed, the risk is to overestimate the CO_2 reduction or to have a double-count due to assigned credits relatively to the vehicle approval test. The procedure for calculating the CO_2 savings associated to the eco-innovations during real world driving consists of the following steps. First, the test is performed under modified conditions both with and without the eco-innovation technology in order to trigger its activation. The difference in terms of CO_2 emissions is evaluated. Secondly, the test is executed under standard condition in order to avoid a double count. The difference between the subtraction obtained under modified and normal testing conditions is then computed. Eventually the result got from the previous subtraction is multiplied by the percentage of time the technology is switched on during the real-world driving.

The technologies that can be granted as eco-innovation must fulfill some further requirements. They may not be currently included into the strategy of the European Commission related to CO_2 emissions reduction: hence, the air conditioning system, the tire pressure monitoring system (TPMS), the tire rolling resistance measures, gear shift indicators and bio fuel cannot be classified as eco-innovations. The technology has not to overcome a market penetration share of 3 percent with respect to 2009. The eco-innovations must provide enhanced safety and performances. The produced advantages should be independent from the driver behavior (unless demonstrating the statistical evidence about average driver behavior).

If eco-innovations technologies are not able by themselves to achieve the granting threshold of 1 g/km of carbon dioxide reduction, they may be grouped in functionally similar technologies packages. [25]

Nowadays 25 technologies have been granted as eco-innovations, as listed in the table below. 16 of them have been developed by components supplier and 9 by vehicles manufacturers.

Table 4: List of approved eco-innovations [27]

ID	Company	Description
01	Audi	LED lights
02	Valeo	Efficient alternator
03	Daimler	Engine compartment encapsulation system
04	Bosch	Adaptive state of charge control in hybrids
05	Automotive Lighting Reutlingen	LED lights
06	DENSO	Efficient alternator
07	Webasto Roof & Components	Solar roof
08	Bosch	Efficient alternator
09	Bosch	Efficient alternator
10	Daimler	LED lights
11	Asola Technologies	Solar roof
12	Mitsubishi Electric Corporation	Efficient alternator
13	Porsche	Coasting function
14	DENSO	Efficient alternator
15	Toyota	LED lights
16	Mitsubishi Electric Corporation	Efficient alternator
17	Bosch	Efficient alternator
18	Valeo	Efficient alternator
19	MAHLE Behr	Enthalpy storage tank
20	Honda	LED lights
21	Mazda	LED lights
22	Toyota	LED lights
23	a2solar	Solar roof
24	Valeo	Efficient alternator
25	BMW	Coasting function

The super credits method is also present in this second set of carbon dioxide emissions reduction legislations for the 2020-2022 timeline. Each low emitting vehicles below 50 g/km of CO_2 is counted twice in 2020, 1.67 times in 2021, and 1.33 times in 2022. The cap on the super credits incentives is set to a maximum reduction 7.5 g/km of carbon dioxide.

The most significant setting up is the introduction of a new reference vehicle test validation cycle. All the carbon dioxide emissions reduction targets introduced up to this point relies on the New European Driving Cycles (NEDC). NEDC has been criticized since it provides results that are considered not representative of the real-world driving. The new cycle for the vehicle test validation is called Worldwide harmonized Light vehicles Testing Procedure (WLTP) and was introduced in 2017. The transition from NEDC to WLTP began in September 2017 when all the new car models had to be validated employing the new reference cycle, while the starting date for the validation of all vehicles with WLTP was set by September 2018. Starting from 2021, the CO_2 emissions reduction target will be expressed according to the new reference cycle WLTP. [25]

5.2.3 2025-2030 targets

In November 2017 the proposal related the carbon dioxide regulation after 2020 was presented by the European Commission. They set a 15 percent reduction for 2025 and a 30 percent reduction for 2030, percentages referring to 2021 as baseline. On October 3, 2018 the European Parliament chose to pose stringent targets: 20 percent for 2025 and 40 percent for 2030. On the 10th of October the European Council agreed with the European Commission about the target for 2025, while voted for a more severe reduction (40%) for 2030. On the 17th December, the European Commission, the European Council and the European Parliament met to discuss the reduction targets in the "trilogue meeting" where they agreed a trade-off: 15 percent for 2025 and 37.5 percent for 2030 with 2021 baseline. The formal adoption of these new regulations about post 2020 is expected to happen before the summer 2019. The reason why the carbon dioxide emissions target is set as a percentage referred to 2021 and not as absolute value lies in the uncertainty deriving from the introduction of the WLTP.

By looking at the approved set of new regulations more in details, the key aspects are discussed below.

The correction factor in the limit value curve remains equal to 0.0333 up to 2024. From 2025 onwards, the slope employed for computing the annual specific carmaker target will be based on Least-Square fit through CO_2 data versus mass of all vehicles registered in 2021.

About eco-innovation technologies, from 2025 the efficiency improvements deriving from air conditioning system will be qualified as eco-innovations, contrarily with previous legislations that prevented it. Furthermore, a review on the 7 g/km of CO_2 cap on eco-innovations will be taken over by the European Commission.

The exemption from complying the carbon dioxide emissions targets for niche manufacturers whose sales volume is lower than 300 thousand will be phased out by 2028.

The third set of carbon dioxide emissions standards introduces incentives for selling zero and low emissions vehicles (ZLEV). The ZLEV incentive awards carmakers overdoing the set target but does not penalize vehicles manufacturers that are not capable of achieving it. The ZLEV incentive is based on the share of vehicle sold with less than 50 g of CO_2 per kilometer. Each ZEV sold counts a CO_2 emissions value equal to one (as a full vehicle), cars above 50 g/km of CO_2 correspond to a value of zero, while LEV (cars between 0 and 50 g/km) weight as a value between 1 and 0.3 according to a linear function that depends on the CO_2 emissions. Moreover, in order to promote sales of ZLEV in member countries where they have low shares, a further benefit is foreseen. ZLEV that are registered in member countries where their share in 2017 was 60 percent lower than the European average and where less than 1,000 new ZLEV registrations occurred in 2017 are counted by multiplying the value obtained by 1.85, until 2030 or as long as the value of ZLEV share remains below 5 percent in the considered Member State. The ZLEV target is 15 percent for 2025 and 35 percent for 2030, percentage that is calculated on weighted ZLEV share and based on the previously explained mechanism. Car manufacturer failing or matching the target obtain a ZLEV factor equal to 1, whereas a ZLEV factor higher than 1 is assigned to carmakers overcoming the target up to a maximum of 1.05 corresponding to 5 percent or more than the target. The intermediate values between 1 and 1.05 are assigned proportionally to the achieved ZLEV target share. By multiplying the ZLEV factor to the specific CO_2 emissions target, the corrected and less stringent target is found, thus awarding manufacturers that encourage the transition towards cleaner vehicles. [26]

The mechanism for the ZLEV factor and related incentive that have been described above is better clarified throughout the support of the figure 26.

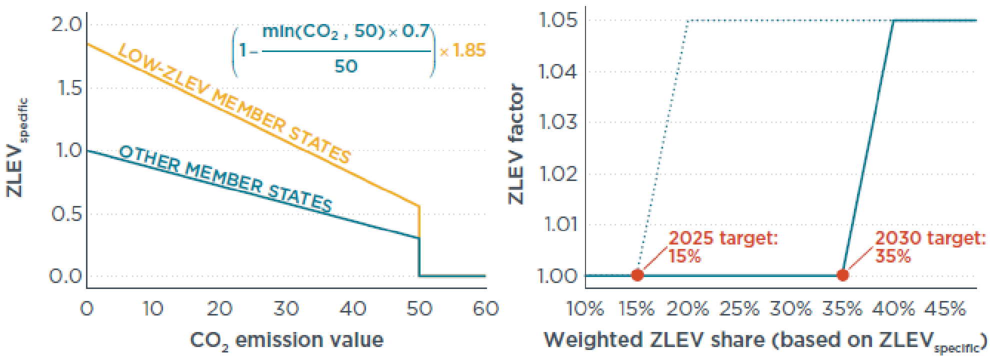


Figure 26: Left: Weight used to count each vehicle in calculation of ZLEV shares. Right: ZLEV factor used to adjust manufacturer CO_2 emission targets. (Credit ICCT) [26]

The 2025 and 2030 CO_2 emissions reduction targets are set as percentages due to the introduction of WLTP instead of NEDC. This modification led to an uncertainty relatively to the results achieved in the CO_2 emissions reduction process. In fact, the target for 2025 and 2030 are percentages that will be based on the manufacturers fleet average WLTP value in 2021 and not on the current 2021 target that is equal to 95 g/km of CO_2 on the NEDC. More specifically, the reference 2021 starting point will be based on a correction factor according to the fleet average CO_2 emissions for each single manufacturer. Nevertheless, the European commission has established that this reference target will rely on directly measured emissions value and not on the declared one, in order to avoid carmakers from exaggerating the declared WLTP CO_2 emissions value.

In addition, the European Commission has defined more detailed conditions and parameters to prevent the alteration of the results of CO_2 tests and has proposed more transparency on CO_2 emissions value to carmakers by reporting them both declared and measured value. [26]

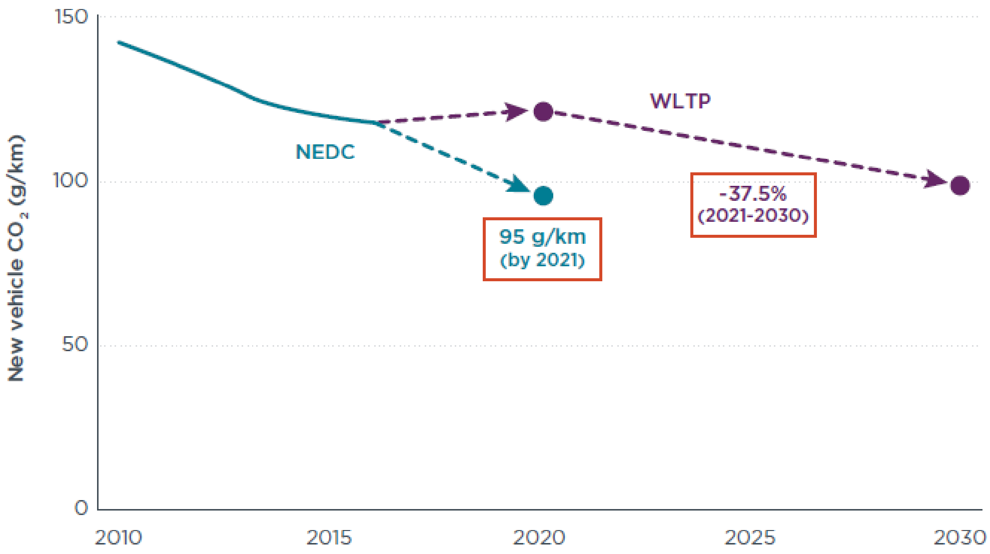


Figure 27: Schematic illustration showing how the CO_2 target for 2021 will still be based on NEDC, while after 2021 a percentage CO_2 reduction applies, relative to the 2021 starting point in WLTP. (Credit ICCT) [26]

Further key elements in the third set of CO_2 emissions reduction target for the 2025-2030 period aim to prevent the gap between real world and declared CO_2 emissions from increasing and to evaluate by considering the whole life cycle emissions of vehicles, the feasibility of developing future CO_2 legislations and a real-world emissions test procedure. Coherently to this scope, an OBFCM (on-board fuel/energy consumption values monitoring) device must be installed on new vehicle model from 2020 and on all vehicles from 2021 to systematically check and track real world carbon dioxide emissions. The data collected in the 2021-2026 timeline will be exploited to try to prevent the gap between real world and declared carbon dioxide emission from rising.

Eventually, the figure 28 shows how European targets compare with other worldwide carbon dioxide emissions standards. All the regulatory plans are provided in NEDC value in order to make them comparable. For 2025, the European target is somehow like the Canadian and US standards (99 g/km of CO_2). [26]

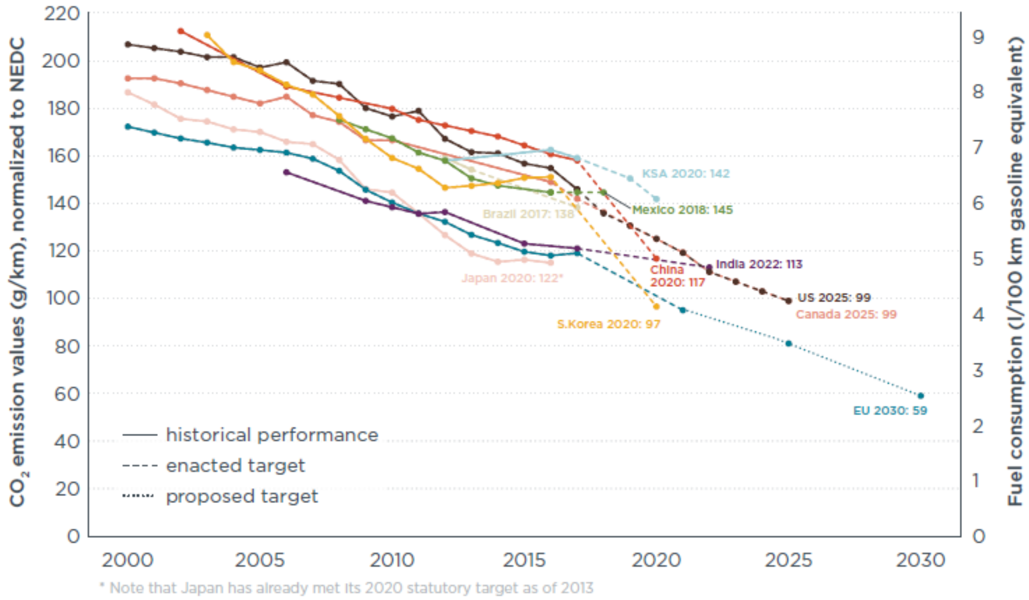


Figure 28: Comparison of global CO_2 regulations for new passenger cars. (Credit ICCT) [26]

5.3 Future European market projection

Due to more and more stringent carbon dioxide emissions reduction targets, the automotive market will undergo a radical transformation.

According to J.P. Morgan, the electric vehicles market will represent the 30 percent of the global automotive industry in 2025. The PHEV and BEV will jointly cover the 7.7 percent of the market. The internal combustion engine will decrease by about 70 percent of share. J.P. Morgan foresees that the BEV and PHEV will correspond to 9 percent of the overall European industry in 2025, but this projection was released before that more stringent carbon dioxide emissions reduction targets were proposed and voted by European parliament. [28]

According to Bloomberg NEF, a massive electrified vehicles adoption would be required as a consequence of more stringent proposed European carbon dioxide reduction targets for 2025 and 2030. The new vehicles fleet would be represented by a share between 18 and 26 percent of BEV and PHEV in 2025 and 32 and 47 percent in 2030 considering the scenario in which each carmaker will be compliant with European targets and no premium for exceedance of CO_2 emissions will be paid. [29]

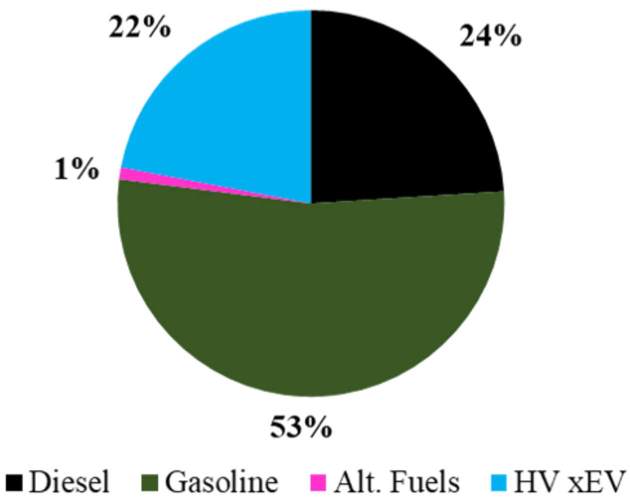


Figure 29: 2024 market fuel mix forecast (Source IHS)

According to IHS, in 2024 there will be a high voltage electrified vehicle each five new vehicle sold. Furthermore, one fourth of new vehicles will be a MHEV. The remaining portion that corresponds to half the new cars fleet will be powered by just internal combustion engine with about 70 percent of gasoline and 30 percent of diesel. Therefore, the diesel is expected to lose about 10 pp between 2018 and 2024 with a CAGR of -6%. The diminishment will be even more accentuated if we consider just pure diesel cars by excluding MHEV fueled by diesel and the CAGR will be -16 percent. As regards gasoline, it will slightly decline in the same period by losing just 5 pp. As for diesel, the gasoline mix decrease is sharper without considering MHEV portion and the CAGR is equal to -8 percent. The gasoline and diesel share will move to high voltage electrified vehicles that in the period 2018-2024 will gain about 16 percent of share on the total industry. As far as segments are concerned, I0, L0 and I3 are the segments where diesel is expected to have the most significant reduction in its share. The first two listed segment are particularly relevant since the drop is respectively about 40 percent and 50 percent. The segments expected to receive the higher electrification are larger SUV segments, with about 30 percent of high voltage electrified vehicles on the I2 segment and 40 percent on the I3 segment.

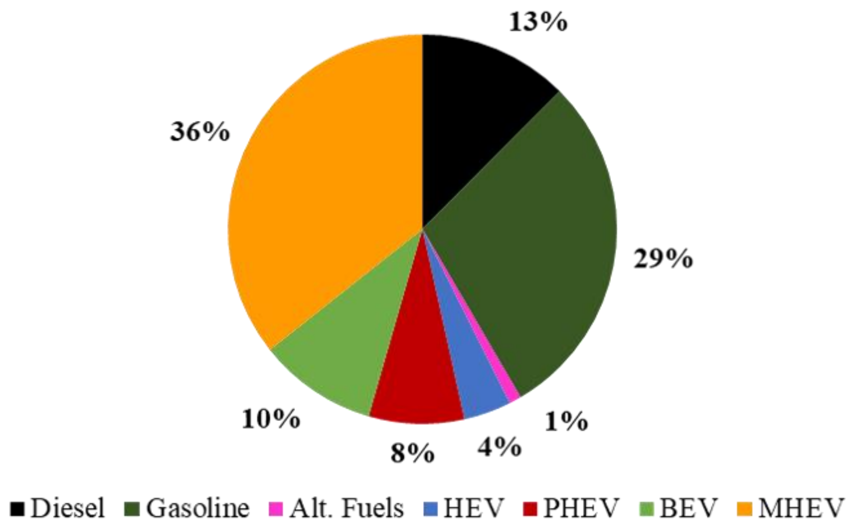


Figure 30: 2024 market forecast with focus on xEV. µHEV included in MHEV (Source IHS)

By analyzing the future electrification of the European car industry more in detail, the xEV are expected to be about 58 percent of the passenger cars sales in 2024. MHEV are projected to guide the electrification market with a share of 36 percent on the overall industry. BEV and PHEV are forecasted to occupy half the MHEV quota, with respectively 10 and 8 percent. The HEV will cover the remaining fraction among xEV with a share of 4 percent on the total market. Starting from a mix of 5 percent in 2019, MHEV will grow by 36% up to 2024 with a CAGR of 48 percent. In the same period the PHEV quota will move from 2 to 8 percent (32 % CAGR). Starting from a mix of 1 percent on the overall industry in 2019, the BEV technology is foreseen to mostly grow with a CAGR of 58 percent. On the contrary, HEV mix will remains quite constant during the analyzed period.

PHEV will have the higher shares in D and SUV segment (I0, I1, I2, I3). In each of these segments, about 20 PHEV applications are expected to enter the market by 2024. Some of these PHEV have already been announced by OEMs and are awaited to enter the market in 2019: BMW 3 Series, Peugeot 508 and Skoda Superb, Volvo S60 in D segment; BMW X1, Peugeot 3008, Range Rover Evoque and Volkswagen Tiguan GTE in segment I1; Audi Q5, BMW X3, Chery Exceed, DS7 Crossback, Jaguar F-Pace and Range Rover Discovery Sport in I2 segment; Bentley Bentayga, BMW X7 and Porsche Cayenne Coupé in segment I3.

BEV will represent about half of future electrified vehicles in A segment and one over five electrified cars in B and I3 segment. In A and B segments more or less 30 vehicles are expected to be powered only by the energy stored inside batteries. In these segments, the models that have been announced to be offered in 2019 as BEV are: Honda Urban, Mini Cooper, Peugeot 208, Skoda Citigo. The BEV I3 segment today is represented by just Tesla Model X, but in 2019 Audi E-Tron and E-tron Sportback will also be available, while most new BEV applications are awaited around 2021.

In 2024 the HEV will have higher mix in B, C and I0 segments. In the C segment, Toyota Corolla and Honda Insight have been announced to be offer in 2019 the HEV technology, while Renault Clio in B segment.

In general, the segments that are projected to offer the highest number of new xEV applications are C and I1 segments with about 50 electrified vehicles strongly massed in the 2020-2021 timeframe.

By looking at the OEMs in terms of fuel mix and adopted technologies, we can see that there isn’t a single approach to comply with stringent carbon dioxide reductions targets and thus generally the strategies undertaken differs. Nevertheless, it comes out that every car manufacturer will adopt Low Voltage Hybrid Electric Vehicles (MHEV), except Toyota Group that will continue investing in High Voltage Full Hybrid Vehicles (HEV). Toyota Group announced they would have removed diesel version from passenger cars offer as of 2018 and indeed forecasts about 2024 indicate that their sales volumes are composed of gasoline by more than 90 percent, divided between pure ICE, HEV and PHEV, and of BEV for the remaining portion. On the contrary, the players that will keep diesel in their product line up will strive heavily on MHEV. That’s is the example of BMW Group and Daimler. BMW Group sales volumes forecasts display that half of the sold vehicles will be fueled by diesel and about the 70 percent of total sales will be MHEV. About Daimler the 2024 picture is quite similar presenting the same share of diesel mix, but a lower percentage of MHEV. The share of BEV sold by BMW Group is expected to be smaller than the Daimler ones, respectively 7 percent versus 17 percent. In fact, Daimler announced that from 2020 the Smart brand will be completely electric.

This difference in BEV mix in 2024 clarifies the higher share of internal combustion engines in Daimler since they are compensated by zero emissions pure electric vehicles and on the other hand the need of BMW Group of selling more MHEV. As far as other carmakers are concerned, the lower mix of MHEV (about one fourth) will be present in PSA, Volkswagen Group and in the Renault-Nissan-Mitsubishi Alliance. As regards all of them, more than half of total sales volume will correspond to gasoline internal combustion engine vehicles. About fuels strategy, both Volkswagen Group and Renault-Nissan-Mitsubishi Alliance will also bet on Alternative fuels (LNG, CNG), but however their mixes will remain very low. Among big automotive industry actors, the Renault-Nissan-Mitsubishi Alliance is the only one which will strive on REEV technology. The Hyundai Motor Group will adopt a strategy in between: in 2024 about half of the sales volumes will be composed of internal combustion engine vehicles and another 40 percent of MHEV. The remaining slice will be occupied by BEV and a lower share of PHEV and HEV. A completely different strategy from the previous ones will be adopted by Geely Group: in 2024 the higher quota will be represented by MHEV (about 55 percent), followed by PHEV with a mix of about 30 percent and then a 10 percent share of BEV thanks to Polestar that is pure electric vehicle brand. The distinctive aspect in the Geely Group strategy is the very low amount of pure internal combustion engine vehicles that are forecasted to be marketed on the overall sales volumes and lower than 5 percent.

6 Platforms analysis

In the literature a unique definition of vehicle platform is not possible to be found. From a technical point of view, the underbody and the axles with suspensions compose the vehicle architecture. By deploying the basic already mentioned mechanical components, the underbody is constituted of frame, underfloor, front floor and engine compartment that is distinctive according to the engine layout (transverse or longitudinal). The axles define the wheelbase according to their relative distance. Another mechanical module that is included in some vehicle platform definition is the steering mechanism. [30]

Originally the platform was a previously-employed chassis that underwent a carry-over process, thus being reused as base for the development and manufacturing of one or more different models. The definition of vehicle platform currently employed in the automotive sector is linked to a long-term strategy of product development to reduce product complexity by sharing the elementary mechanical components, such as underbody, axles and suspensions, among different future models.

6.1 Vehicle architectures history

Before looking at the historical evolution of the vehicle architecture, an overview of the evolution over time of the basic component constituting the car platform, the automotive frame, is presented below. The main load-bearing structure of a motor vehicle is the frame or chassis whose purposes are to carry dynamic and static loads and to allow the body and the mechanical components to be joint.

The first cars were derived from carriages and coaches; thus, they employed the same body on frame construction method. The frame and the body were produced by different manufacturers and were normally assembled together by the body maker. The body on frame is a production method in which the body is separated from the chassis and is mounted on the frame that is the rigid load-carrying element. The chassis originally employed and derived from carriages was a ladder frame, characterized by two longitudinal beams running throughout all the vehicle length and several welded cross beams. At the end of 19th century, the frame and the body were both made of wood and the former reinforced with metal pieces in order to increase its stiffness. [31] Afterwards, in the early 20th century, steel ladder frames started spreading and, in the Twenties, the entire vehicle was made of steel thanks to Budd Company that employed mass production method to shape the body, supplying Ford, Dodge, Buick and Citroen. [32] [33] The Budd Company was an American company that had a crucial part in the development of the unibody, thanks to Joseph Ledwinka that in 1930 designed a full unitary constructed prototype of a vehicle. In 1934 the full unibody design was purchased by Citroen that produced the Citroen Traction Avant. This vehicle was the first high volume application of modern integration of body and frame in a unitized body by means of deep stamped steel sheets that were welded to compose a load-carrying structure. [33] [34] Nevertheless, the first endeavor of designing a unibody was the Lancia Lambda in 1922. The Lancia Lambda showed a body with riveted panels in order to create boxed parts that were also reinforced by side beams, thus increasing the total stiffness. [4] [31]

Figure 31: Lancia Lambda, first endeavor of unibody chassis

The unibody or unitized body is a "type of body/frame construction in which the body of the vehicle, its floor plan and chassis form a single structure. Such a design is generally lighter and more rigid than a vehicle having a separate body and frame". [35] The advantages provided by the unibody are the increased structural stiffness, the weight reduction and the decrease of the total vehicle height that is the main drawback of the body on frame where the floor is located above the frame rather than inside it. In 1935 Opel developed Olympia, the first German vehicle with unibody structure. In 1936 the Lincoln Zephyr was built with a unibody structure, while in 1941 Nash Motors manufactured the first unibody vehicle mass produced in United States, the Nash 600. [36] From 1930s onwards, unibody became the most employed frame in Europe for passenger cars. On the contrary, in the United States the body on frame with ladder frame at first, and perimeter frame or platform frame later, remained the most utilized design as it made possible to offer frequent changes and improvements in body and interiors in short time and with limited costs by maintaining the chassis.

The perimeter frame is the prevalent design for body on frame cars in US and it is similar to the ladder frame, but it is different in the central part between the axles in order to allow lowering the floor pan and therefore the vehicle height. The platform frame is a modified perimeter frame in which the floor pan is also employed to carry load as longitudinal and transverse beams. Volkswagen Beetle is a famous example of model based on a platform frame. Other kinds of developed chassis are the backbone frame, composed of a strong tubular rectangular or circular cross section beam between the axles, and the X-frame in which the side beams enlarge in correspondence of the axles in order to provide suspensions connection whereas they tighten in the central section, thus forming an x-shape. GM developed several full-size American models on an X-frame at the end of 50s and at the beginning of 60s.

Since 1960 the unibody had been employed on Ford Falcon, Plymouth Valiant and Chevrolet Corvair and Chrysler jumped most of its passenger vehicles to the same frame. In the late Seventies, American motors, instead of persevering with the body on frame construction method, opted for unibody for the design of the XJ platform which the Jeep Cherokee was built on. [37] In United Kingdom Triumph Herald was the last mass-produced passenger cars to be built with the body on frame principle. Since 2014, after that Ford Panther platform had phased out, there are no more passenger vehicle based on perimeter frame. Nowadays the unibody is the chassis typology used on the majority of passenger vehicles, while the ladder frame is largely employed for trucks, buses and pick-ups chassis. Some SUV manufactured by Toyota Group are presently employing body on frame construction method, such as Toyota 4runner, Toyota Sequoia, Toyota Land Cruiser, Lexus GX and Lexus LX. The same hold for Nissan Patrol and Nissan Amanda. An interesting example of modern body on frame design is the BEV

BMW i3. The BMW platform is called LifeDrive and is composed of two separate parts: the Life module is the body, made of Carbon Fiber Reinforced Polymer (CFRP), while the Drive structure is the chassis, made of aluminum. The selected materials provide high strength and are very light in order to compensate the weight added by the high voltage lithium-ion battery. [38]

Figure 32: BMW i3 LifeDrive architecture, a modern body on frame design

As previously stated, from a technical point of view, the frame is load-carrying structure composing the vehicle platform. Originally the platform was a previously-employed chassis that underwent a carry-over process, thus being reused as base for the development and manufacturing of different models. Carry-over consists of the procedure of reusing existing parts rather than developing new ones. It allows to cut development costs and investments for new tooling, but it has a negative effect on the product personality and distinctiveness if excessively utilized, especially for the interiors and the body. Nevertheless, nowadays in the automotive field the concept of platform has evolved beyond pure carry-over of the chassis and it is generally associated to the product development long-term strategy of sharing the elementary mechanical components, such as underbody, axles and suspensions among different future models in order to reduce the product complexity, whenever it is not recognized by the final customer or not justified by an enhancement of benefits with respect to costs. The product complexity is related to the number of variants that needs to be managed throughout the product development and during their assembly processes.

At the beginning, each new model was designed separately without any synergy with other cars in the product portfolio of a carmaker. Later on, in order to face the increasing costs related to the proliferation of variants, the platform sharing strategy was initiated but at this embryonic stage it involved just a simple carry-over of the chassis from previously manufactured vehicles, and not a long-term plan strategy. That's the example of the Citroen 2CV whose platform chassis was also employed in the Citroen Ami and Dyane or of the Volkswagen Beetle chassis which was reused for the Volkswagen Karmann Ghia.

Figure 33: From left to right: Citroen 2CV[3], Dyane and Ami[4]

The following step was the development of synergies inside a single segment, thus allowing the development of a single platform above which to construct different future models. One of the first example of platform sharing strategy was applied around 1960 in United States by GM for the design of Pontiac Lemans, Buick Skylark, Chevrolet Chevelle and Oldsmobile Cutlass under the same platform. In the late 70s, Ford developed the Fox platform which remained in production from 1978 to 1993 and was the base for rear-wheel drive Ford, Mercury and Lincoln vehicles with unibody chassis. [39] In the 80s, after the guideline suggested by the Chrysler CEO Lee Iacocca that blamed the product complexity for low margins and related losses, the K platform was designed to suit Dodge Aries, Plymouth Reliant, Chrysler LeBaron, Dodge 400 and Dodge Dart. [40] The K platform could host

[3] By allen watkin from London, UK - 2CV, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=32038907
[4] By allen watkin from London, UK - Ami, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=32033943

front-wheel drive transverse engine vehicles and had independent front suspensions and semi-independent rear suspensions.

Figure 34: examples of vehicle based on the Chrysler K-platform. On top from left to right: Dodge Aries (1987), Chrysler LeBaron (1986). On bottom from left to right: Dodge 400 (1982), Plymouth Reliant (1983).

GM applied an equivalent strategy in the development of the J platform which had been used since 1981 to suit the vehicles of the four GM divisions (Buick, Cadillac, Chevrolet and Oldsmobile). Some examples of J platform-based vehicles are Opel Ascona C in 1986, Daewoo Espero in 1987, Pontiac Sunbird and Cadillac Cimarron in 1988. A further step was the creation of vertical synergies among different segments in addition to the horizontal interactions formerly generated inside each single segment. This last described step corresponds to the design of a modular platform that can be stretched in its fundamental dimensions, such as wheelbase, track, front and rear overhang, so that the use of a single platform for more than one segment is achievable.

Figure 35: examples of vehicle based on the GM J-platform. On top from left to right: Opel Ascona C[5], Pontiac Sunbird. On bottom from left to right: Cadillac Cimarron, Daewoo Espero[6].

The advantages of the platform sharing strategy are firstly a cost and time reduction in the product development and thus in time to market; secondly, a diminishment of the investments for tooling; thirdly, an easier inventory management and a reduction of related costs. Clearly, there are also some drawbacks. The development of several models with a similar external appearance over a single platform leads to product cannibalization. [41] The cannibalization is *"the negative impact a company's new product has on the sales performance of its related products. In this situation a new product "eats" up the demand for the current product, potentially reducing overall sales. This downward pressure can negatively affect both the sales volume and market share of the existing product"* [42]. The other disadvantage is the product dilution occurring if luxury vehicles and mass-produced cars built on the same platform are too similar in interiors or body. The result is a damage of luxury vehicle positioning and image in the customer mind. [41] Generally the platform sharing strategy, and more specifically the platform modularization provides the increase of the economy of scope, economy of scale and operational flexibility as benefits. Economies of scope are *"efficiencies formed by variety, not volume"* [43]. Economy of scale refers to the decrease in the production costs linked to production volumes increase. Operational flexibility is connected to the possibility of moving product manufacturing among different plants. Nevertheless,

[5] CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=335740
[6] CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=675571

these three aspects are directly inherent to the specific car manufacturers. The economy of scope is directly linked to the carmaker product portfolio. The larger the product range in one segment, the higher the returns obtainable through the platform sharing strategy. On the contrary, in case of smaller product portfolio inside one segment, in order to include a proper number of vehicles, the development of a platform with higher degree of modularity will be needed to extend the synergies to closer segments, even if the higher design complexity will require higher efforts and investments are necessary. The economy of scale is associated to the production volumes and to the markets' size. Eventually, the operational flexibility is connected to the manufacturing network dimension and to the number of manufacturing plants producing vehicles based on the same platform. The higher the platform degree of modularity, the larger the number of plants inside the platform manufacturing network, thus operational flexibility.

The future stage in the evolution of the platform strategy approach is correlated to the radical transformation that the market is experiencing. In order to comply with stringent carbon dioxide emissions reduction targets, car manufacturers have started offering electrified vehicles. These vehicles require a certain level of modifications that has a higher impact on the vehicle architecture proportionally to the degree of electrification. Indeed, even if a BEV is much simpler from the layout complexity point of view thanks to the reduced size and number of components, a conventional architecture will require more modifications in order to suit the high voltage traction battery, the electric motor and the power electronics. As a result, some native dedicated battery electric vehicle platforms have been designed by some car manufacturers to suit only BEVs by obtaining an optimized platform. In contrast, some other car manufacturers prefer developing flexible architectures that are designed to suit both internal combustion engine vehicles and electrified vehicles in order to be optimized whichever the kind of powertrain is. Selecting the most appropriate vehicle architecture strategy could be one of the business key success factors in the future transforming automotive market.

6.2 *Vehicle architectures classification*

The vehicle architectures employed by car manufacturers in the automotive sector can be clustered according to their typology: conventional platform, designed for internal combustion engines, modified conventional platform, designed for internal combustion engines and afterwards modified for electrified vehicles, multi-energy platform, flexibly designed for both internal combustion engine and electrified vehicles, and dedicated battery electric vehicle platform, designed from scratch just for battery electric vehicles.

6.2.1 Conventional platforms

Internal combustion engines are the most widely employed power-generating device used for traction in automotive history. Therefore, the vehicles architectures are specifically designed and developed to suit internal combustion engines. this kind of architectures can be defined as conventional platforms. The conventional platform shows two longitudinal rails that are two stiff beams running throughout all the vehicle length. They are not straight but shaped into a particular contour in order to provide some functions. Looking at them from the top, they are wider in the central part to increase the torsional stiffness, whereas they start getting closer in correspondence of the front and rear axles, thus surrounding the wheels in order to provide attachment points for the suspensions and then extend straightly widening a little in both the frontal and rear part, to provide the frontal and rear crash protection. The frontal portion of the longitudinal rails must be shaped in order to enclose the internal combustion engine and to provide connection points for the engine mounts. Hence, it is evident the need of different platform according to the engine layout (longitudinal or transverse). By looking at the vehicle from the side view, in the central section, the longitudinal rails are lower to reduce the floor height and increase the internal roominess, while in the frontal and rear part in correspondence of the axles, they start rising in order to reach the impact force height, so that they are axially loaded as much as possible. In addition, two transverse beams cross the central underbody portion between the axles, one running below the front seat and the other one below the rear seats. The component that divides the engine compartment from the passenger compartment is the firewall. It provides acoustic and heat insulation. One of the most important safety requirements is that the engine has not to break the firewall entering the passenger compartment in the event of a crash. As a consequence, the longitudinal rails must be stiff enough and their length together with the energy absorbing unit behind the bumper needs being designed properly. Therefore, due to the internal combustion engine, the front overhang length cannot be reduced beyond a certain limit. Another distinctive element of a conventional platform is the tunnel. It runs throughout all the central portion between axles. In front-engine front-wheel drive vehicle, the tunnel is used to accommodate the exhaust system going rearward, while in the front engine rear wheel drive engine is also employed to locate the transmission shaft in the floor. Due to their topology, the conventional platform can be exploited to develop pure internal combustion engine or electrified vehicles that have small batteries, thus having a very small impact on the platform, such as MHEV or HEV.

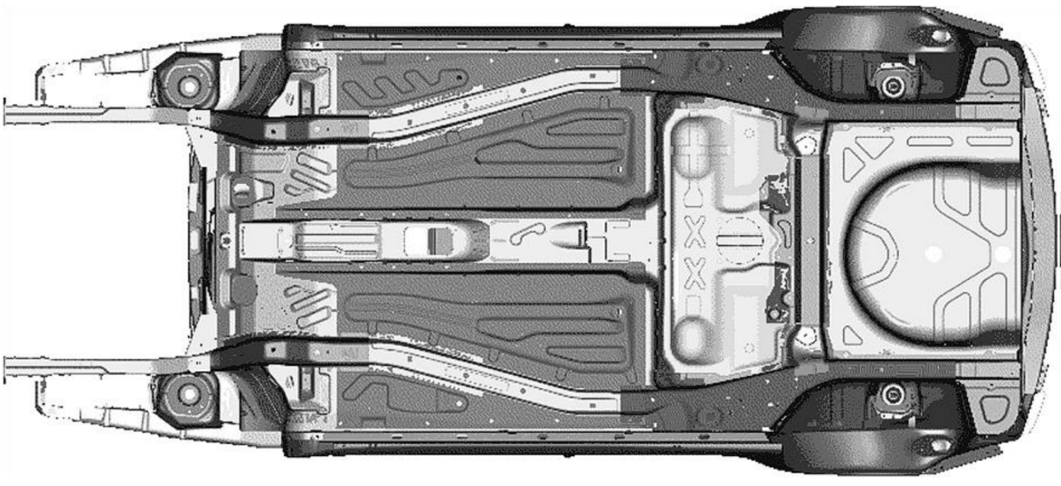


Figure 36: example of the underbody of a conventional platform [31]

The modified conventional platforms are architectures designed for internal combustion engines but modified in order to suit electrified vehicles, overall BEV and PHEV. The needed modifications are aimed to generate room for locating the high voltage traction battery. The development of PHEV starting from a conventional platform may be quite complex since the available space is already optimized and there is no free space to locate the battery and the power electronics, therefore the modifications are obviously required. On the contrary, the BEV case is somewhat simpler, since neither the internal combustion engine nor the fuel tank is yet present. So, the tunnel can be removed, thus obtaining a flat floor where to put the battery. If compared to the realization of a new platform designed from BEV from the beginning, the costs and investments savings are the main advantage. Nevertheless, there are some drawbacks because the use of a conventional platform that is belated modified, leads to limitations and trade-off. First of all, due to longitudinal rails and transverse beams, the battery size will be irregular in shape and smaller compared to those of a BEV on a dedicated platform, thus resulting in a limited range. Secondly, the battery is located above the floor and not inside it. A reduced internal roominess and compromised vehicle dynamic may follow. Even the vehicle weight is worse than the one of a dedicated BEV platform car since the battery is not substituting the steel platform portion and furthermore some steel plates may be added with respect to the conventional one. An example is the electric motor. It is still located in engine compartment. However, its dimension is smaller than the one of an internal combustion engine and so the original points for fixing the engine to the chassis are further. An additional steel supporting structure will be needed.

BEV and PHEV are high voltage electrified vehicles. The cable used to connect the traction battery with the power electronics and the electric motor have a larger cross section. The cables packaging inside the vehicle is more complicated. Therefore, some platform modifications to accommodate and to let the wires passing may be necessary. In addition, during its normal use, the high voltage traction battery may incur into overheating. A proper aeration cooling system must be provided, and vehicle architecture modifications are needed.

6.2.2 Multi-energy platforms

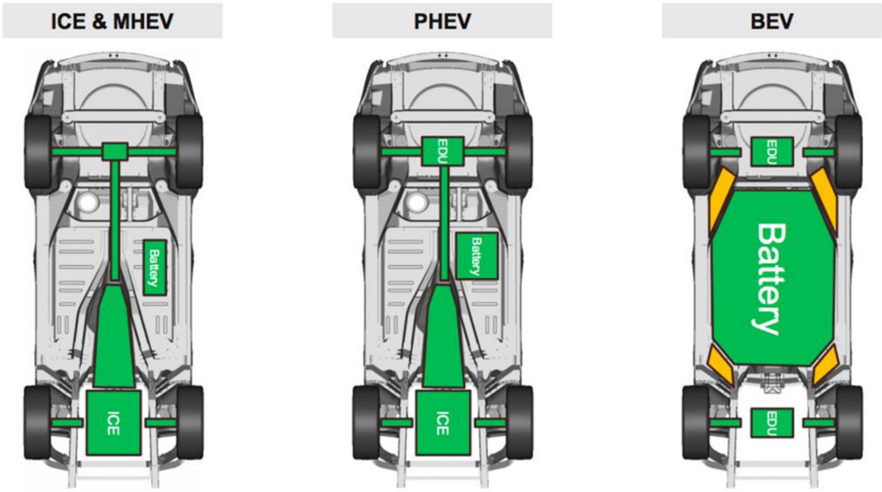


Figure 37: Modular Longitudinal Architecture (MLA), an example of multi-energy platform under development by Land Rover and Jaguar that will be available by 2020 (Credit JLR)

Nowadays car manufacturers are offering both internal combustion engine powered vehicles and electrified vehicles. Therefore, the need of developing a car platform that is capable of efficiently integrating any kind of powertrain in order to meet the variety of global customer wants comes out. That's the reason why it is called "multi-energy". Nevertheless, this is a very complex technical solution that requires an ingenious design. Although there are few vehicles built upon this kind of vehicle platform, it is expected to become the most adopted architectural alternative in the automotive future. While a conventional platform is optimized in its design to host internal combustion engine, the peculiarity of a multi-energy platform is its ability in optimizing each relevant factor such as packaging, roominess and costs for every powertrain type. The technical flexibility deriving from the clever design of multi-energy platforms leads to technological flexibility. Indeed, the main technological benefit provided by a multi-energy platform is the possibility of manufacturing and assembling both conventional and electrified vehicles on a single production line. As a result, it is not yet required to separate electrified dedicated plants from conventional ones, thus reducing associated investments. The distinctive element of a multi-energy platform is the central portion of the underbody between axles that must be designed to suit both the traction high voltage battery and the exhaust system or the transmission shaft for rear wheel drive front engine vehicles. In some cases, the platform underbody is engineered with the floor tunnel able to accommodate both. Other manufactures prefer developing two different interchangeable central floors, one of which is flat in order to install a regular shaped battery pack. Anyway, both the front and rear portion of the platform remain standardized for the two alternatives.

6.2.3 Dedicated battery electric vehicle platforms

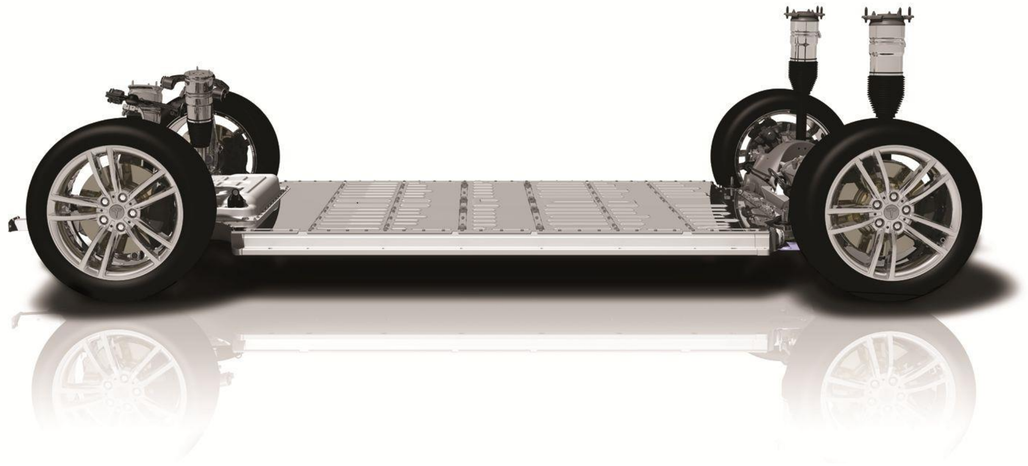


Figure 38: Tesla dedicated BEV platform (Credit Tesla)

Some car manufacturers are designing and developing dedicated BEV platforms. These vehicle architectures are platforms designed from scratch to suit only BEV. BEV offers simplification in the packaging thanks to a reduced complexity with respect to internal combustion engine powered vehicles and to smaller dimensions of the modules. A dedicated BEV platform is designed with batteries completely integrated inside the underfloor between the axles. As a consequence, several advantages come out. The battery capacity can be maximized by widening the longitudinal rails, so that the battery area compared to the footprint of the central portion offers the larger ratio with respect to conventional modified or multi-energy platform. Therefore, dedicated BEV platforms allow to achieve higher ranges between two consecutive charges. Additionally, the battery pack is flat, thus reducing the costs with respect to special battery pack shape employed in conventional modified and certain multi-energy platform. A flat battery packs permits also to better exploit the interior roominess since the vertical distance between the floor and the roof is reduced. In a near future, the battery pack will be even integrated in the vehicle architecture as a structural element to improve the torsional stiffness of the chassis, leading to a reduction in the vehicle weight and so improving the efficiency in terms of range. A dedicated BEV platform displays improved vehicle dynamics. In a conventional vehicle, the main element affecting the weight distribution is the internal combustion engine. For example, a front engine front wheel drive vehicle has 60% of the vehicle weight on the front axle. The battery is the most weighting element among BEV components. Hence, a dedicated BEV platform has a lower center of gravity that is closer to the ground through the battery integrated in the underbody and an equal weight distribution between the axles thanks to the flat energy storage element and higher flexibility in locating electric engines and power electronics. Because of the simpler layout, the flexibility in locating these components allows to maximize the interior roominess. The possibility of locating the electric motors on both axles leads to drivetrain flexibility since front, rear or all-wheel drive configurations can be obtained on the same platform. Another benefit is linked to a dedicated BEV platform is the overhang length reduction. The purpose of front longitudinal rails is to take the frontal crash load and to prevent the internal combustion engine from being pushed against the firewall and entering the passenger compartment. Therefore, their length is equal to the internal combustion longitudinal length plus a portion that in case of crash even when deformed avoid the engine from being pushed backwards. Since the electric motors is smaller and can be placed both in the front or rear axle, the length of the front overhang is the minimum needed to protect from the frontal crash, thus improving the vehicle exterior style. Lastly, the longitudinal rails height from ground can be reduced with respect to both conventional and multi-energy platforms by employing just one load lines passing through the rails. On the contrary, in conventional and multi-energy platforms, the vertical dimension of the internal combustion engine determines the need of raising more the longitudinal rails in order to provide attachment points for the engine mounts.

There are obviously some drawbacks associated to a dedicated BEV platform. First, a dedicated BEV platform cannot be manufactured on the same production line or production plant. It requires a dedicated plant that means dedicated investments for the conversion or the retooling of the production lines. Furthermore, a dedicated BEV platform involves high initial investments for the design and the development of the vehicle architecture and the specific unique components that suit on this platform. Secondly, a dedicated BEV platform needs the development of new top hats and new dedicated nameplates, thus strongly impacting on the car manufacturer commercial strategy. The last disadvantage is the market risk deriving from the future demand uncertainty and connected to the strategical rigidity of a dedicated BEV platform. This vehicle architecture is designed to suit only BEV. So, in case of large changes in the BEV market demand with respect to forecasted volumes, this platform would result in a huge investment that cannot be repaid through high volume BEV sales and it cannot even be converted into a vehicle architecture able to host internal combustion engine.

6.3 Platform strategy benchmark

6.3.1 BMW Group

The BMW Group defines itself as a "pioneer" of the electric mobility and its purpose is to develop a holistic integrated system. In 2013 the BMW Group launched on the market two electrified vehicles based on two bespoke platforms, the BMW i3 and the BMW i8, respectively a BEV and a PHEV. The platforms are called "LifeDrive" since they are composed of two separate parts: the Life module is the body, made of Carbon Fiber Reinforced Polymer (CFRP), whereas the Drive structure is the chassis, made of aluminum.

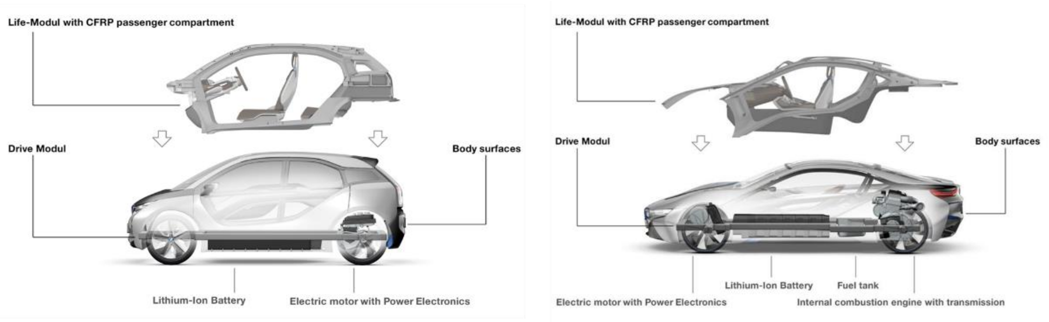


Figure 39: LifeDrive, the platform principle design of the BMW i3 and BMW i8 (Credit BMW Group)

Nevertheless, BMW Group has changed its mind about vehicle architecture strategy, passing from "born electric" to "one platform serves all". The German Group foresees the global demand for BEV and PHEV in 2025 between 15 and 25 percent but is not able to project the exact proportion between the two electrified vehicles. In addition, due to different legislative, infrastructure and customer demand in the global market, the BMW Group believes that the key success factor is the flexibility. Therefore, in order to promptly fulfill the different customer preferences, the BMW Group strives on flexibility in fuel, maintaining both diesel and gasoline engines, in powertrain, offering both internal combustion engine and electrified vehicles, in concept, developing both cars and SUV, and in platform, through the development of two multi-energy vehicle architectures that allows to fit all powertrain derivatives.

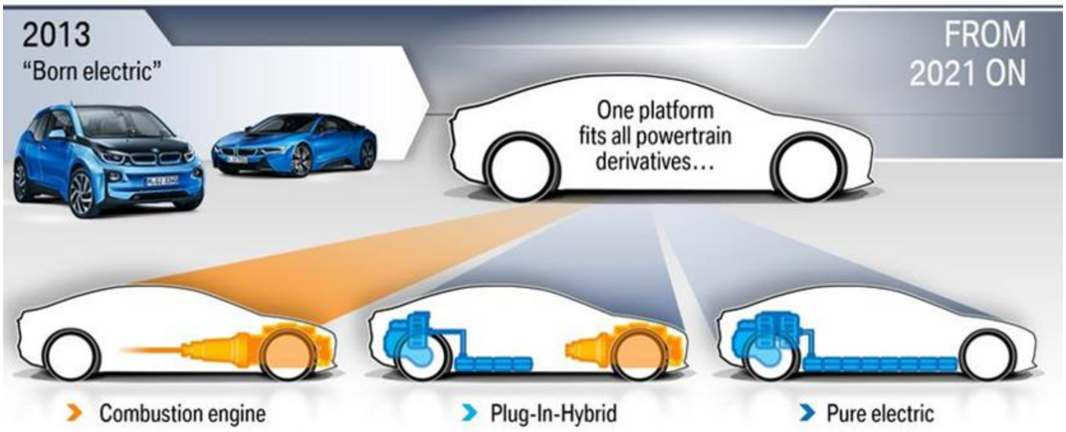


Figure 40: BMW from "Born Electric" to multi-energy platforms [44]

These two multi-energy platforms are the FAAR (Front Antriebs Architektur) and the CLAR (Cluster Architecture). The FAAR is the evolution of the UKL (Untere Klasse Linien) and is a modular platform employed for front-wheel drive vehicles. The CLAR is a modular platform employed for rear-wheel drive vehicles made of steel, aluminum and carbon fiber, in order to provide strength and lightness to the automobile. Among the different electrified vehicle versions, the only platforms components that are not common are the central portion of the underfloor that for BEV is tailored in order to accommodate a flat battery pack and the rear underbody part that for PHEV displays some bespoke pieces around the fuel tank in order to host the battery. The other components constituting the vehicle architectures are shared. About electric modules, BMW Group opts for scalability to fulfill customer demand by providing a complete range of performances. The two multi-energy platforms allow to produce both electrified vehicles and conventional vehicles on the same production line, thus enabling the plants for all types of powertrains. This results in lower investment costs and less dependence on the market development throughout higher flexibility and utilization.

BMW Group has set a target of 500 thousand BEV and PHEV on the road by the end of 2019 and has declared they will launch 12 BEV and 13 PHEV by 2025 globally. [44]

The FAAR platform is dedicated to B, C, I0, I1 segment, whereas vehicles belonging to higher segments are built on the CLAR platform. The LifeDrive platform will be phased out around 2023.

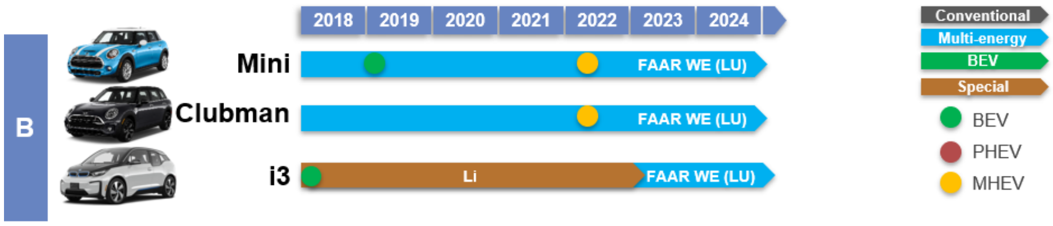


Figure 41: BMW Group B segment

In the B segment there are Mini Cooper, Mini Clubman and BMW i3. The Mini Cooper is built on the FAAR platform and the BEV version was announced to be launched for late 2019. In 2022 a MHEV version is expected. The Mini Clubman is based on the FAAR platform and in 2022 is forecasted to be available as MHEV. The BMW i3 was launched in 2013 on the LifeDrive platform. This vehicle architecture is a modern example of body on frame design and is composed of two separate parts: the Life module is the body, made of Carbon Fiber Reinforced Polymer (CFRP), while the Drive structure is the chassis, made of aluminum. The selected materials provide high strength and are very light in order to compensate the weight added by the high voltage lithium-ion battery. As a result, the platform is 250-230 kg lighter than a usual one. From the structural point of view, the load of a frontal impact is optimally distributed between the Life and the Drive module, whereas the rear impact load is mainly absorbed by the Drive module. In order to protect the battery from the side impact with a pole, the sill is filled with honey-comb elements that absorb the load and distribute it in the Drive module. Around 2023, the BMW i3 is expected to shift on the FAAR platform.

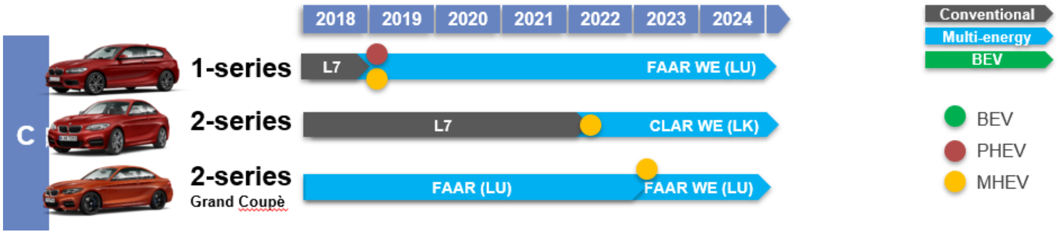


Figure 42: BMW Group C segment

In the C segment BMW offers the 1-Series, the 2-Series and the 2-Series Grand Coupé. The BMW 1-Series is currently based on the L7 platform but is expected around 2019 to pass on the FAAR platform. Together with the platform shift, the PHEV and MHEV versions are awaited. The BMW 2-Series MHEV version is forecasted to arrive in 2022 when the car will pass from the L7 to the CLAR platform. The BMW 2-Series Grand Coupé is already based on the FAAR platform and the MHEV version is expected in 2023.

Figure 43: BMW Group D segment

The BMW vehicles that are nowadays in the D segment are the 3-Series, the 4-Series and the 4-Series Grand Coupé. A BEV native vehicle has been announced to be launched in 2021 on the CLAR platform. The BMW 3-Series is built on the L7 platform but in 2019 it will shift on the CLAR together with the offer of MHEV and PHEV versions. BMW 4-Series and 4-Series Grand Coupé are currently on the L7 platform, but they will pass on the CLAR when the MHEV version will probably be offered respectively in 2020 and 2021.

Figure 44: BMW Group E segment

In the E segment the BMW 5-series and the 6-Series GT are based on the CLAR platform. The former is already available in the PHEV version and a BEV version is forecasted in 2024. From 2020 the two vehicles will probably be offered as MHEV.

Figure 45: BMW Group G segment

The G segment shows the BMW 7-series and the BMW i8. The former is expected to be launched on the CLAR platform in 2019 with a PHEV version, while the MHEV technology is expected to be mounted in 2023. The BMW i8 is a PHEV presented in 2015 on the LifeDrive platform. This vehicle architecture is a modern example of body on frame design and is composed of two separate parts: the Life module is the body, made of Carbon Fiber Reinforced Polymer (CFRP), while the Drive structure is the chassis, made of aluminum. The name is the same of the BMW i3 platform but what is identical is just the concept. In fact, the dimensions are obviously different and none of the two can be derived from the other since they are bespoke for the specific vehicle. The BMW i8 is expected to be phased out in 2023.

Figure 46: BMW Group H segment

In the H segment BMW offers the 8-Series, the 8-Series Grand Coupé and the Z4. The 8-Series Grand Coupé will probably be launched in 2020 on the CLAR platform, the same of the 8-Series. The two vehicles are expected to be offered as MHEV from 2021. The BMW Z4 is currently on the L4 platform but will shift in the CLAR around 2019-2020, while the MHEV version is forecasted for 2023.

Figure 47: BMW Group I0 segment

The Mini Countryman is the vehicle that is offered by the BMW Group in the I0 segment. It is built on the FAAR platform and is today available as PHEV. The MHEV and BEV versions are forecasted respectively in 2023 and 2024.

Figure 48: BMW Group I1 segment

In the segment I1 the German Group offers the BMW X1 on the CLAR platform and the BMW X2 from about 2019 on the same vehicle architecture. Their PHEV version is expected in 2019. The BEV X1 is projected for 2024. The MHEV version of both X1 and X2 is foreseen respectively in 2022 and 2023.

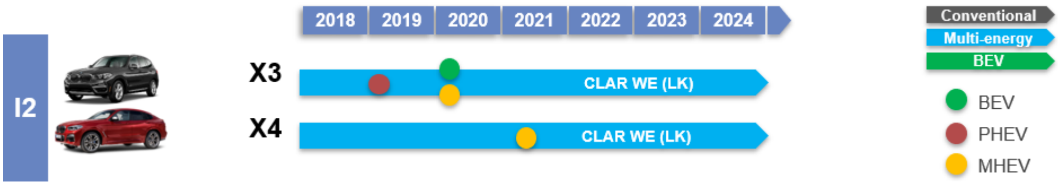


Figure 49: BMW Group I2 segment

The BMW Group I2 segment is composed of BMW X3 and BMW X4, both on the CLAR platform. The former has been announced to be offered as PHEV from 2019 and BEV from 2020. The pure electric version will be called iX3. In the same year also a MHEV version is likely to be presented. The MHEV version of the BMW X4 will probably be available from 2021.

Figure 50: BMW Group I3 segment

The vehicle composing the I3 segment of the BMW Group (X5 and X6) are today based on the L4 platform. The X5 is already present in its PHEV version. The passage to the CLAR platform is expected in the 2019 when also the BMW X6 is likely to be available as PHEV. In the same year, the BMW X7 will be launched directly on the CLAR platform and probably offered as PHEV. These three vehicles are awaited as MHEV in 2020. The BMW iNext has been announced to enter the market in 2021 only as BEV version.

To summarize, the BMW Group in 2024 will have just two multi-energy platforms (FAAR and CLAR) that will accommodate 25 vehicles.

By looking at the sales volumes that are foreseen by 2024 and grouping them by platform, 590 thousand vehicles based on FAAR are expected to be sold, while the ones on CLAR correspond to 390 thousand units.

6.3.2 PSA Groupe

The PSA Group is composed of Citroen, DS, Opel/Vauxhall and Peugeot.

The PSA Group vehicle architecture strategy aims to reduce the number of platforms through the development of two multi-energy platform: the CMP (Common Modular Platform) and the EMP2 (Efficient Modular Platform 2). All the passenger cars will be built on these two multi-energy platforms that are highly flexible in order to promptly adjust the products offer to the global customer needs and market trends. The multi-energy platforms allow to fit all powertrain types (ICE, PHEV, BEV) on the same vehicle architecture that is manufactured on the same production line, thus reducing the technological investment costs.

The CMP has made its debut on the DS3 Crossback and is employed for city cars, entry level and mid-range sedans and compact SUV. The CMP replaces the PF1 platform. From 2019 onwards, a variant of the CMP commonly named eCMP will be available for BEV and 7 new full electric vehicles are expected to be based on it by 2021. The EMP2 was launched in 2013 with the Peugeot 308 and Citroen C4 Picasso and is used for mid and high-end body styles. It replaces the PF2 and PF3 platform. 8 new PHEV are expected to be launched by 2021. The PSA Groupe has announced that the whole range will be electrified by 2025.

In 2017 PSA acquired Opel/Vauxhall from GM. Nowadays the Opel/Vauxhall vehicles are still based on GM platform but they are expected to shift on the two PSA multi-energy platforms in the future in order to increase the number of vehicles inside the CMP and EMP2 manufacturing network, thus increasing the economy of scale.

The CMP have been developed in France through a partnership with Dongfeng Motors. The reason behind the partnership are the splitting of Resources and Development costs, the opportunity to access international suppliers and to improve the knowledge of the Chinese market.

Figure 51: PSA CMP platform for the BEV Peugeot e208 (Credit PSA Groupe)

The CMP is a modular multi-energy platform which allows 2 track widths, 3 wheelbases, 3 rear modules and several wheel dimensions, thus providing stylistic freedom in order to maintain the unique distinctive brand identity. In addition, the front overhang can be varied from 800 mm to about 890 mm, whereas the body width from 1700 mm to 1800 mm. The CMP was designed in order to reduce the carbon dioxide emissions by acting on weight reduction using better materials (up to 1.2 g/km CO2), aerodynamics improvement (up to 1.5 g/km CO2) and rolling resistance reduction (up to 2.5 g/km CO2). The total platform weight has been reduced by about 40 kg using Advanced High Strength Steel (AHSS), Ultra High Strength Steel (UHSS), press hardened steel, composite materials and aluminum. The aerodynamics has been enhanced by a smoother underbody and by controlling the air intake system in the front. The rolling resistance has been improved by reducing the axles mechanical friction. The battery does not occupy all the central portion of the underbody, but it is located below the front and rear seats in order to not compromise habitability, comfort and interior roominess. [45] [46]

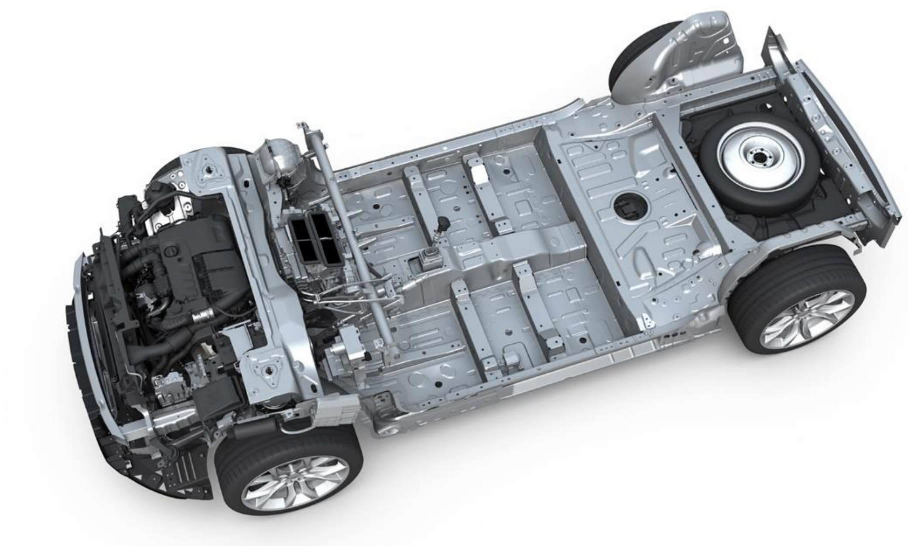


Figure 52: PSA EMP2 multi-energy platform (Credit PSA Groupe)

The EMP2 is a modular multi-energy platform which allows 4 track widths, 5 wheelbases, 2 cockpit architectures, 2 rear axle architectures, several rear vehicle modules to develop various versions and 6 rear vehicle assemblies. In addition, the front overhang can be varied from 850 mm to about 940 mm, whereas the body width from 1800 mm to about 1880 mm. Furthermore, the floor has been lowered by 20 mm with respect to previous platforms. The EMP2 was designed to reduce the overall weight with respect to previous platform by 70 kg. This was achieved by employing more advanced materials in the platform design: the UHSS and AHSS passed from 18 percent in previous platforms to 76 percent, while standard HSS passed from 82 percent to 22 percent. The remaining 2 percent is composed of composite material. A further weight reduction has been possible through the use of advanced technologies, such as hydroforming and laser welding that allows also to have better surface quality. The EMP2 allows to develop PHEV with both front wheel drive and all-wheel drive through a common rear architecture in terms of train, tank and battery that is located under rear seats. [46] [47]

Speculations about a new dedicated BEV platform developed by PSA have recently started to spread. This new platform should be called "EVMP" and should be a complement to the EMP2 in order to develop full electric vehicle in larger SUV segments. This vehicle architecture is expected to be launched in the Chinese market from 2023 and will be employed to develop one BEV under each PSA brand by about 2024 in the European market.

The CMP is employed on the automobiles belonging to B and I0 segment and on smaller vehicles of the C and I1 segment. The EMP2 is the platform used for D and I2 segment and on larger vehicles of the C and I1 segment. Therefore, the two platforms are able to cover all the segments where PSA Group offers its vehicles.

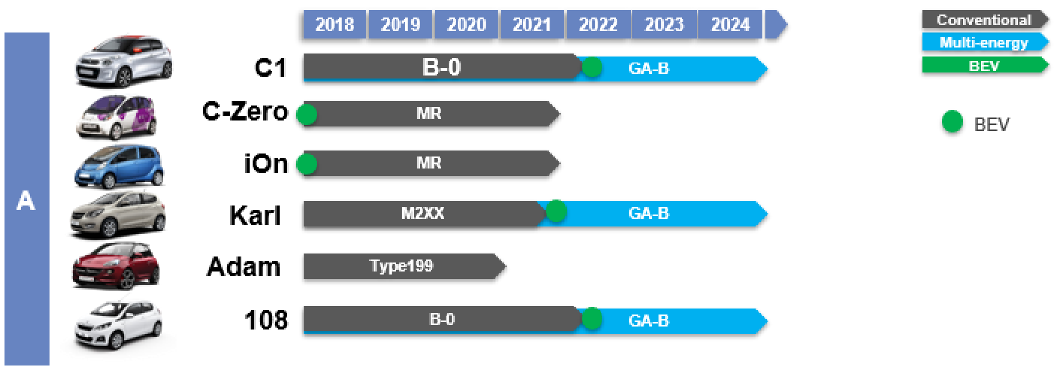


Figure 53: PSA A segment

In the A segment, PSA offers the Citroen C1 and C-Zero, the Opel Karl and Adam, the Peugeot 108 and iOn. Citroen C-Zero and Peugeot iOn derive from a rebadging operation of the Mitsubishi i-MiEV undertaken through a joint venture between PSA and Mitsubishi. They were launched on the market in 2010, one year after the i-MiEV. The three cars have the same top hat and a common architecture, MR, that is the Mitsubishi Mid-engine Rear-wheel drive platform. The two full electric vehicles are forecasted to be phased out around 2021. As a replacement, from 2022 the BEV version of the Peugeot 108 and Citroen C1 are expected to be available. The two city-car are based on the B-0 platform, that is a Toyota vehicle architecture used for the Toyota Aygo. The three vehicles were developed making a badge engineering operation subsequent to the partnership between Toyota and PSA. The joint venture provides for the sharing of the PSA light commercial vehicle architectures with the Japanese group and of the Toyota city-car platform with the French group. Recently the two automotive industrial groups have renewed the partnership. Therefore, a shift in the vehicle architecture is forecasted to happen together with the new electrification of the powertrain in 2022. The new platform should be GA-B, the smaller version of TNGA (Toyota New Global Architecture). Opel Karl is currently based on the GM M2XX platform but after the entrance in PSA is expected to move on the GA-B platform around 2022, when the BEV version will be launched. Opel Adam is based on a GM architecture (Type199) but it is forecasted to be phased out around the beginning of 2021.

The Opel vehicles are obviously based on GM architectures. The GM platforms are identified by a four-digit code. The first digit categorizes the platform among Delta (D for compact and crossover vehicles), Gamma (G for subcompact/crossover vehicles), Epsilon (E for mid-size and full-size vehicles) and Microgamma (M for micro vehicles). The second digit is a number that identifies the platform generation. The last two digits determine in which markets the platform is employed. For instance, "XX" refers to a global vehicle architecture.

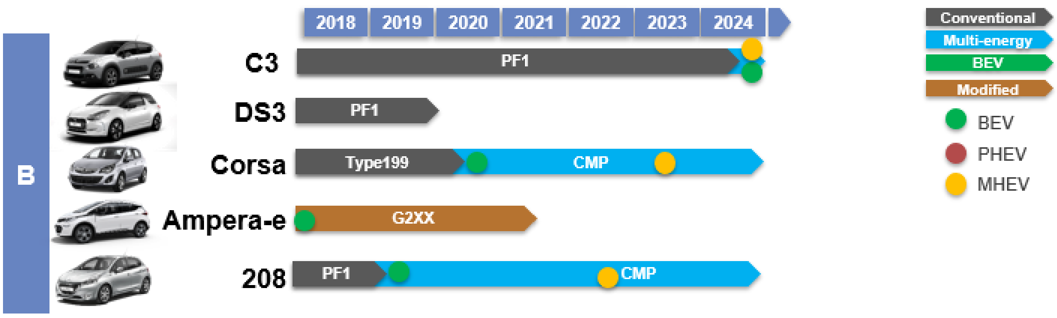


Figure 54: PSA B segment

Citroen C3, DS DS3, Opel Corsa, Opel Ampera-e and Peugeot 208 are the B segment cars of the PSA Group. The Citroen C3 will remain on the PF1 platform up to 2024, when the BEV and MHEV version will be available and the vehicle will move on the CMP platform. The DS3 is currently based on the PF1 platform but it won't move on the new modular platform since it is expected to be phased out in 2020. The Opel Corsa BEV has been announced for 2020. As a consequence, it will move from the Type199 platform to the CMP. The MHEV variant will be available from 2023. The Opel Ampera-e is a BEV constructed on the G2XX, but it is no longer available in certain European countries and it will be completely phased out by 2021. The new BEV version of the Peugeot 208 will be delivered to customers by the end of 2019. It is based on the CMP, whereas the previous vehicle architecture was the PF1.

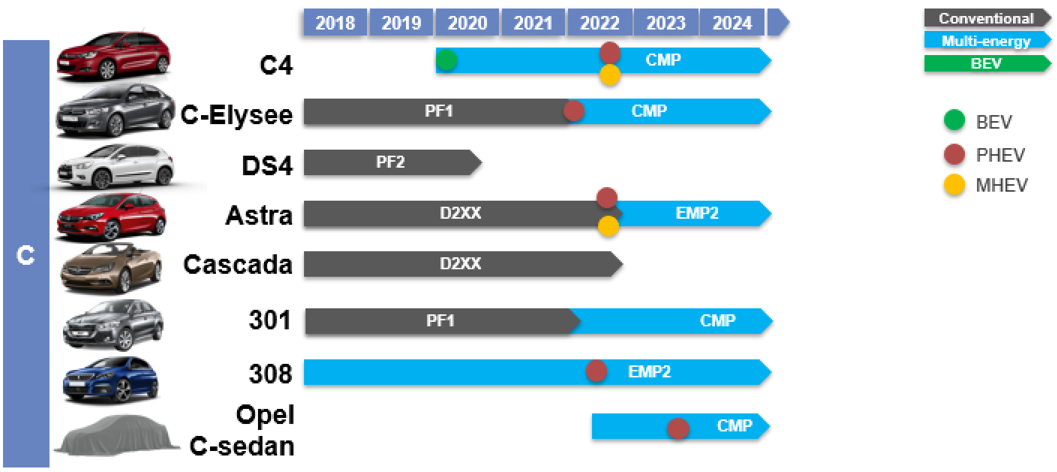


Figure 55: PSA C segment

In the C segment, the PSA group currently offers Citroen C-Elysee, DS DS4, Opel Astra, Opel Cascada, Peugeot 301, Peugeot 308. The Citroen C-Elysee is nowadays based on the PF1 platform but it will move on CMP from around 2022 when the powertrain will be electrified and offered as PHEV. The DS4 is constructed upon the PF2 platform but it won't be moved on the new multi-energy platform since it will be phased out from about 2020. D2XX is the platform used by Opel Astra and Cascada. This vehicle architecture will be dropped by 2022. The Opel Cascada will be phased out, whereas the Opel Astra will move on the EMP2. Together with the platform shift, the PHEV and MHEV variants will be launched. The Peugeot 301 will probably move from the current PF1 platform to CMP from 2022 and the

PHEV variant will be available from the following year. The Peugeot 308 is already on the multi-energy EMP2 platform. The 308 will be offered as PHEV from 2023.

In addition, Citroen C4 will be probably launched in 2020 as BEV, while in 2022 also as PHEV and MHEV. In the same segment, a new car under the Opel brand is expected to be launched in 2022 and available as PHEV from 2023. Both vehicles will be built on CMP.

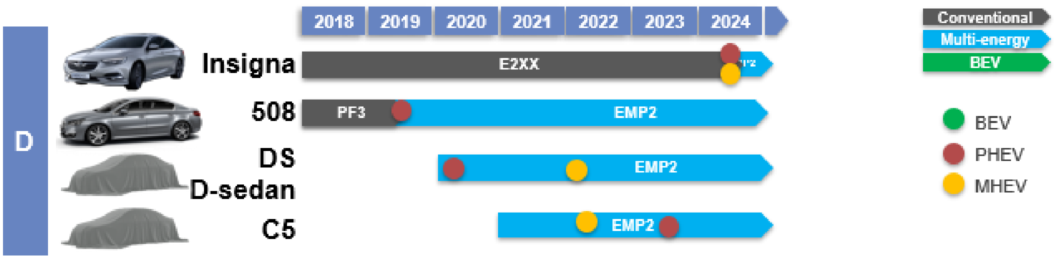


Figure 56: PSA D segment

The vehicles currently offered in the D segment by PSA are Opel Insigna and Peugeot 508. The two vehicles are based on conventional platform, respectively the E2XX and the PF3. The Opel Insigna will shift to EMP2 platform when the PHEV and MHEV variants will be launched around 2024. However, the platform shift would be anticipated due to the end of the agreed period in which PSA is authorized by GM to employ their platforms. The Peugeot 508 will move to the multi-energy platform (EMP2) around the end of 2019, when it will be also available as PHEV. Two further D-segment vehicles, Citroen C5 and a DS sedan, are expected to be launched respectively in 2020 and 2021. The PHEV version of the DS sedan will be offered from the launch and in 2022 the MHEV version will be added. The Citroen C5 will be electrified as MHEV and PHEV respectively one and two years after the launch.

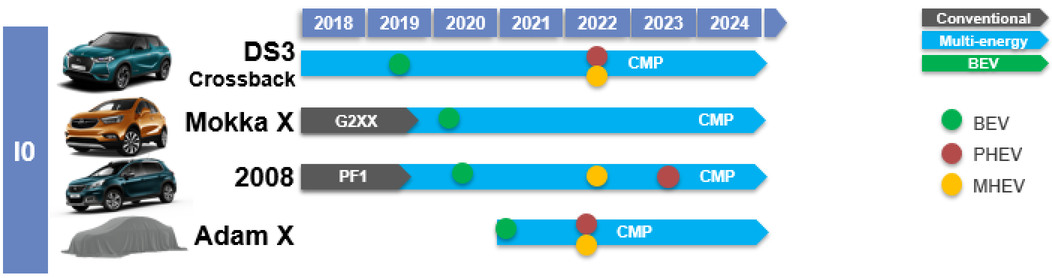


Figure 57: PSA I0 platform

PSA offers in the I0 segment displays the DS3 Crossback, the Opel Mokka X and the Peugeot 2008. The DS3 Crossback will be offered as BEV from 2019. The PHEV and MHEV versions are forecasted to arrive in 2022. The DS3 Crossback is built on the CMP in the Poissy plant, near Paris. The Opel Mokka X is currently upon the G2XX platform. As a result of the platform shift towards CMP, the Opel Mokka X production site will be moved to Poissy and produced together with the DS3 Crossback as BEV from 2020. The Peugeot is now constructed on the PF1 platform, but it will Move on CMP in 2019. The BEV will arrive the following year, whereas the MHEV and PHEV variants will be available respectively from 2022 and 2023. A SUV version of the Opel Adam that is nowadays offered as car will be launched in 2021 on CMP as BEV, while the PHEV and MHEV versions are expected for the following year.

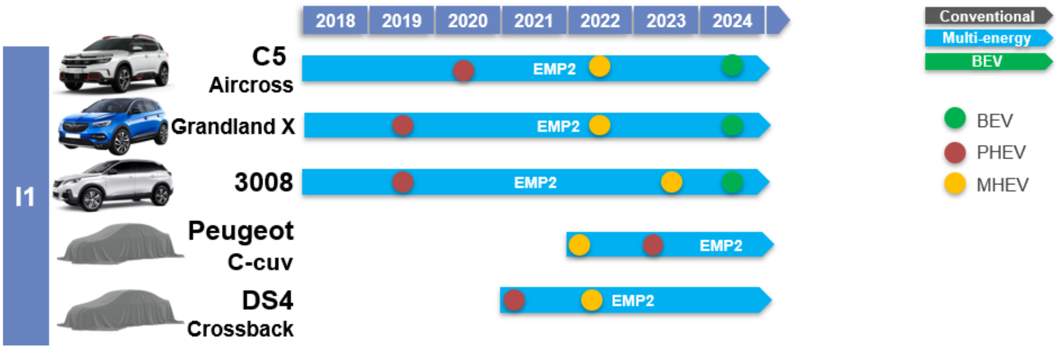


Figure 58: PSA I1 segment

The PSA I1 segment is composed of Citroen C5 Aircross, Opel Grandland X and Peugeot 3008. EMP2 is the platform on which all these vehicles are currently based. Their PHEV version are expected around 2019 and 2020. About three years later, the MHEV variants will be offered. The BEV versions are forecasted to arrive in 2024. Recently, some speculations about a new dedicated BEV platform called “EVMP” and developed by PSA to host these BEV versions have started circulating. In addition to the previous I1 segment vehicles, the DS4 Crossback is forecasted to be launched from 2021 as PHEV and the following year as MHEV. A new Peugeot C-CUV is expected for 2022 as PHEV and the following year as MHEV. Both vehicles will be based on EMP2.

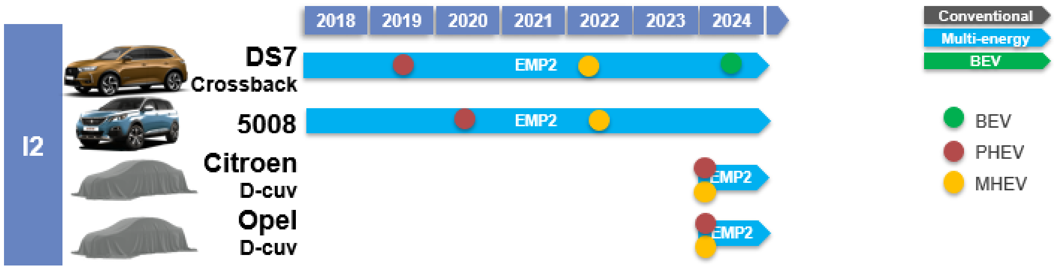


Figure 59: PSA I2 segment

In I2 segment, The Peugeot 5008 and the DS7 Crossback are currently offered. They are built on EMP2. They will be electrified: the 5008 will offered as PHEV from 2020 and as MHEV from 2022, while the DS7 Crossback as PHEV from 2019, MHEV from 2022 and BEV from 2024. The BEV version of the DS7 Crossback would be produced upon the new EVMP platform. On the EMP2, two new models are expected to be launched in this segment from 2024 and immediately available as PHEV and MHEV.

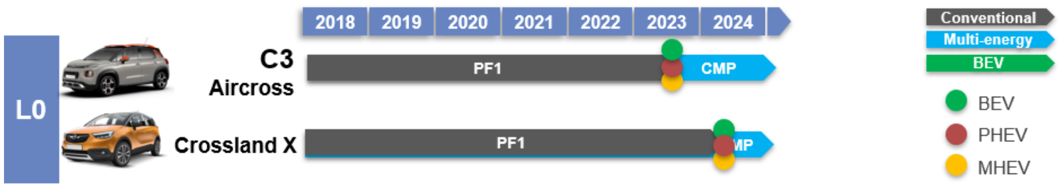


Figure 60: PSA L0 segment

The L0 segment presents two PSA models: the Citroen C3 Aircross and the Opel Crossland X. Both are built on PF1. The electrification of the powertrain will occur respectively in 2023 and 2024 when BEV, PHEV and MHEV variants will be added to the product line up. The new electrified version will be followed by the shift towards the multi-energy CMP platform.

Summing up, in 2024 the PSA group will probably have just two multi-energy platforms that will be the base of 28 vehicles. The three A-segment vehicles will be constructed on the GA-B platform. Some of the 2024 sales volume will be related to the last conventional platform (PF1) before that the Citroen C3 will move to CMP in the same year. If the speculations about the new dedicated BEV platform reveal as real, in 2024 it will count four BEV constructed upon.

By looking at the sales volumes that are foreseen by 2024 and grouping them by platform, the vehicles based on the CMP platform will be about 1.2 million units, 1.03 million units on the EMP2, 160 thousand units on the GA-B and 55 thousand on the PF1 platform.

6.3.3 Hyundai Motor Group

The Hyundai Motor Group is composed of Hyundai, Kia and Genesis brands. Genesis is a recently introduced global luxury brand in order to penetrate the premium market that is rapidly growing by exploiting the related profit opportunity and to elevate the whole group.

The strategy of the Hyundai Motor Group relatively to vehicle architectures started in 2005 and it is aimed to reduce the development costs to achieve a greater economy of scale. In 2005 the Korean Group started the commonization of platform by sharing 10 platforms between Kia and Hyundai. In 2008 the number of vehicle architectures was reduced by 6 through first generation integrated platforms. In 2013 the basic performances provided by the vehicle architecture were strengthened and the level of standardization was increased, thus obtaining the second generation of advanced integrated platforms. Around 2019 the third generation of integrated platform is expected. This new vehicle architectures have been developed to be modular and adaptable, in order to increase commonization but allowing to develop different type of vehicle on the same vehicle architecture to be able to reflect worldwide market trends and environmental regulations and to fulfill different customers' needs. The new vehicle architectures have been improved in terms of safety since they exploit multi-load path allowing to spread the impact load. About the performances provided by the platforms, the ones for front engine front-wheel drive vehicles have got a better geometry, thus optimizing the structure, whereas the ones for front engine rear-wheel drive vehicles have been strengthened from the structural point of view of the platform frame. The improvements performed on the new platforms are meant to enhance the fuel efficiency. The new vehicle architectures have been designed with more lightweight material, such as aluminum and foamed plastics, and an increased portion of AHSS that has switched from a percentage between 33 and 52 in 2014 to a percentage between 48 and 62 to make the vehicle safer and lighter. Furthermore, Hyundai Motor Group has announced that a new dedicated BEV platform will be available from about 2020. The development of a platform designed just for BEV is in line with their electrification strategy which is aimed to be in the global top 3 group in the green car market. The Hyundai Motor group has set a global sales target of 1.67 million electrified vehicles in 2025. So as to achieve this target, the Korean group will launch worldwide 44 new electrified models by 2025: 20 under the Hyundai brand, 18 under the Kia brand and 6 under the Genesis brand. The electrified vehicles of the premium brand will be launched on the market starting from 2021. [48] [49]

The Hyundai Motor Group is expected to have in 2025 a total of 6 vehicle architectures: 5 multi-energy, obtained through ingenious modifications of components variants and one dedicated only to BEV. The KP1 platform is employed for A and L0 segments, the KP2 platform for B and I0 segments, the KP3 platform for C and I1 segments, the N and M platforms as the base of vehicles in D, E, G, I2 and I3 segments. The new dedicated BEV platform is likely to be called EP1 and will be the base for SUV, especially for the I1 segment.

Figure 61: Hyundai Motor Group A segment

The Hyundai Motor Group offers the Hyundai i10 and the Kia Picanto in the A segment. The First one is today based on the SA platform and will shift to KP1 platform in 2021, coherently with the group policy of reduction of the total number of platforms. The Kia Picanto is built on KP1 and it is expected to be offered as BEV from 2020.

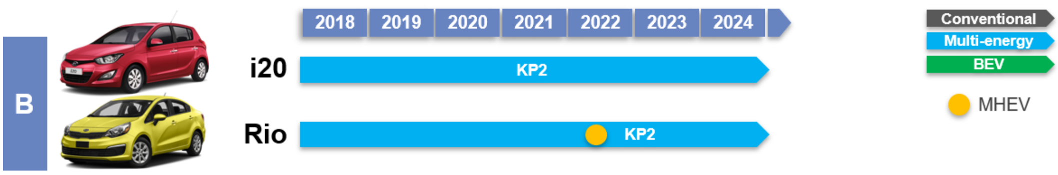


Figure 62: Hyundai Motor Group B segment

The B segment of the Korean group displays the Hyundai i20 and the Kia Rio, both based on the KP2 platform. The Kia Rio is expected to be available as MHEV from 2022.

Figure 63: Hyundai Motor Group C segment

Hyundai i30, Elantra, Ioniq and Kia Ceed are the group models that belong to the C segment. All of them are constructed above the KP3. The Hyundai Ioniq is offered as BEV, PHEV, HEV and the version powered only by the internal combustion engine has not ever been available. The other three previously listed vehicles belonging to this segment will probably offer a MHEV version starting in 2020.

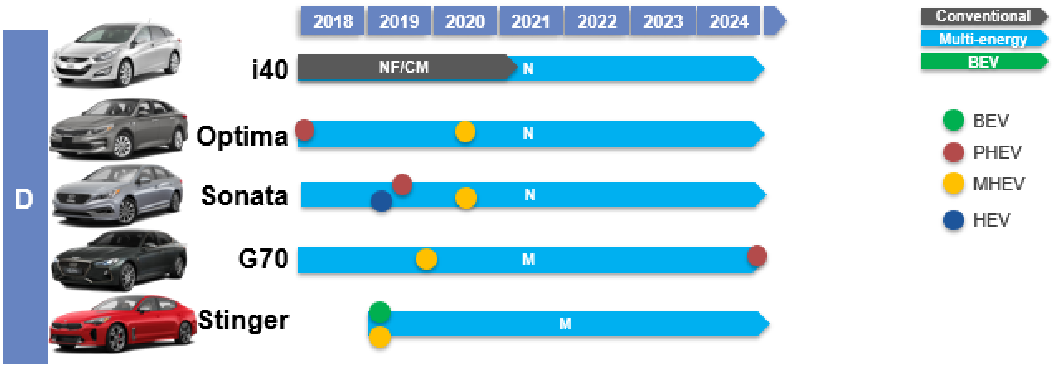


Figure 64: Hyundai Motor Group D segment

The models belonging to the D segment that are offered by the Korean group are the Hyundai i40 and Sonata, the Kia Optima and the Genesis G70. The Kia stinger is projected to enter the European market in 2019 both with the BEV and MHEV version. The Kia Stinger and the Genesis G70 are both based on the M platform. The Genesis G70 will probably be available as MHEV from the beginning of 2020, while the PHEV version is forecasted for 2024. The i40 is currently based on the NF/CM platform that will be phased out in 2021 in favor of the N platform. The only electrified vehicle that is nowadays offered by the Korean group in this segment is the Kia Optima, that is based on the N platform and will be available as MHEV from 2020. The Hyundai Sonata that is now built on the N platform has been announced to be electrified from 2019 when both PHEV and HEV variants will be available. In addition, the MHEV version should be offered from 2020.

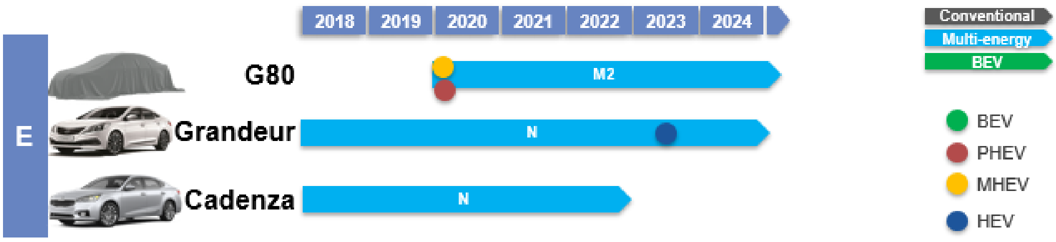


Figure 65: Hyundai Motor Group E segment

The E segment of Hyundai Motor Group offers the Grandeur and the Cadenza. Both are constructed on the N platform. The former will be offered as HEV from 2023, whereas the latter is expected to be phased out around the end of 2022. From 2020, the Genesis G80 will be added to the product line-up of the Korean group. It will be based on an improved version of the M platform. The MHEV and PHEV variants are expected to be offered from the commercial launch.

Figure 66: Hyundai Motor Group G segment

The G segment of the Group is only composed by the Genesis G90 that is already available on the marker above the M platform.

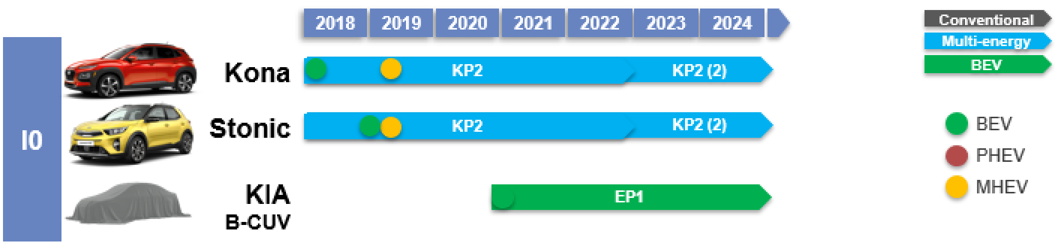


Figure 67: Hyundai Motor Group I0 segment

The Kia Stonic and the Hyundai Kona are offered by the Korean group in the I0 segment. Both vehicles are built on the KP2 platform. The Kia Stonic will be available as BEV from 2019 and probably also as MHEV. The Hyundai Kona is already offered as BEV, while the MHEV version is forecasted from 2019. The Hyundai Kona platform is based on a multi-energy platform that has been designed starting from the conventional platform. In particular, the internal combustion engine powered version has the central portion of the underfloor presenting the tunnel in order to accommodate the exhaust system, whereas in the BEV version it has been redesigned by enlarging the longitudinal rails and removing the tunnel in order to be completely flat and accommodate a rectangular shaped battery pack. A new Kia B-CUV is expected to be added to the product line-up from 2021. This small SUV is forecasted to be a full electric vehicle built above the new dedicated BEV architecture (EP1) that will be available from 2020.

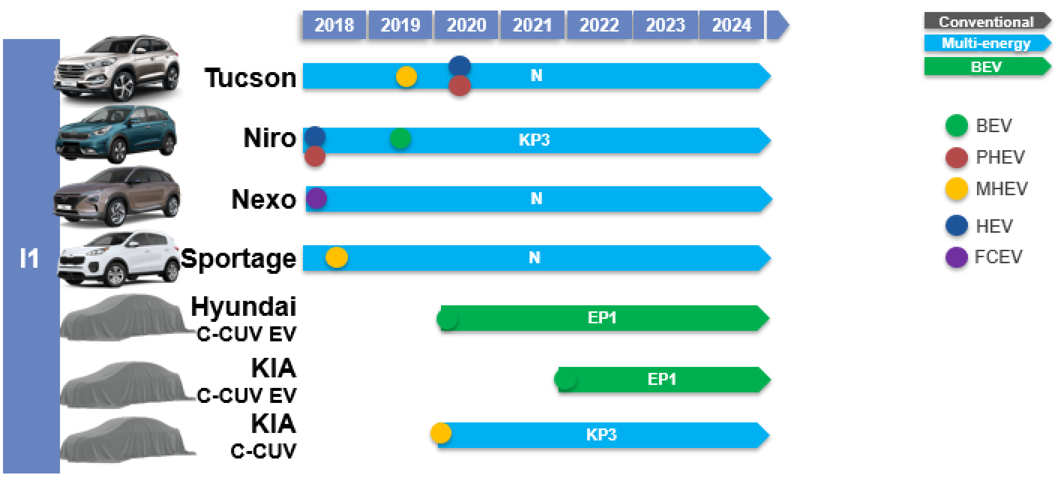


Figure 68: Hyundai Motor Group I1 segment

The Hyundai Motor Group offers four models in the I1 segment: the Hyundai Tucson and Nexo and the Kia Niro and Sportage. All of them are based on the N platform, except the Kia Niro. Actually, it is constructed on the KP3 vehicle architecture and is offered as HEV and PHEV, whereas the BEV version has been announced to be available as from 2019. The MHEV variant of the Kia Sportage has been offered on the market since about mid-2018. The Hyundai Nexo is one of the few models on the European market already offering the fuel cell technology. The Hyundai Tucson is expected to be available as MHEV from 2019 and has been announced to be offered as PHEV and HEV from 2020. In addition to the previously listed vehicles in this segment, the Hyundai Motor Group will probably launch three SUV: two full electric vehicles based on the new BEV dedicated platform (EP1) from 2020 and 2022 and branded respectively under Hyundai and Kia and one further Kia C-CUV that will be launched in 2020 on the KP3 platform and will be available as MHEV.

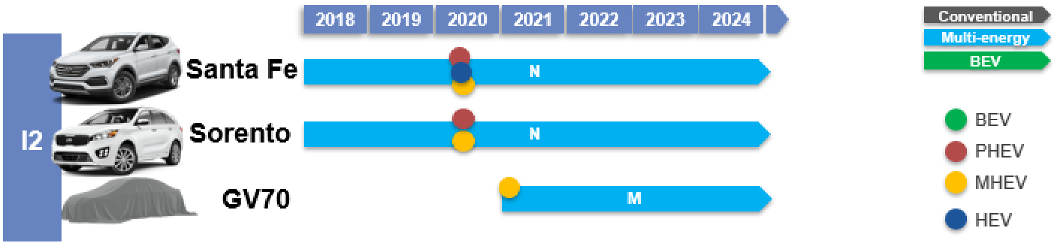


Figure 69: Hyundai Motor Group I2 segment

In the I2 segment, The Hyundai Santa Fe and the Kia Sorento are the vehicles offered by the Korean group. Both are based on the N platform. The Hyundai Santa Fe has been declared to be available in the HEV and PHEV variants from 2020. In the same year also the MHEV version will be probably available. The Kia Sorento is forecasted to be electrified from 2020 when PHEV and MHEV will be on the market. In 2021 a further model branded Genesis, called GV70, will be launched on the market. It is expected to be based on the M platform and be offered as MHEV.

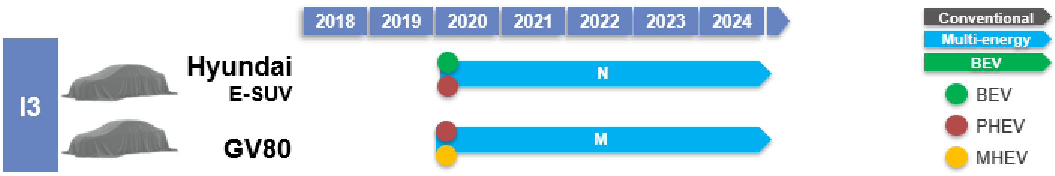


Figure 70: Hyundai Motor Group I3 segment

Nowadays the Hyundai Motor Group is not offering any SUV in the I3 segment. Nevertheless, a Hyundai E-SUV and a Genesis GV80 are expected to arrive on the market in 2020. They will also be available in the electrified variant: the former will be offered both as BEV and PHEV, whereas the latter as MHEV and PHEV. They will be based respectively on the N and M platform.

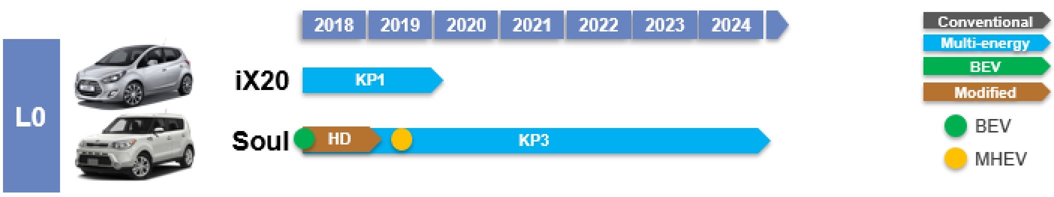


Figure 71: Hyundai Motor Group L0 segment

The L0 segment of the Hyundai Motor Group shows two vehicles: the Hyundai iX20 and the Kia Soul. The former that is built on the KP1 platform will be phased out by 2020. The latter has been offered as BEV since 2015. It is based on the HD platform, but this vehicle architecture will be phased out from 2019 in favor of the KP3 platform. As a consequence, it is expected to be increased in its dimensions. Around late 2019, The MHEV variant is expected to be offered on the market.

To summarize, in the European market, about 29 vehicles are expected to be constructed on the 5 multi-energy platforms, while the dedicated BEV platform is currently forecasted to host about 3 SUV, even if a larger number of nameplated should be expected to be based on this platform.

Considering the sales volumes foreseen in 2024 and grouping them by platform, the vehicles sold that are based on the KP1 platform correspond to 130 thousand units, 350 thousand units on the KP2 platform, 280 thousand of units on the KP3 platform, 325 thousand on the N platform and 10 thousand on the N platform. 15 thousand of the BEV sold will be constructed on the dedicated BEV platform of the Hyundai Motor Group (EP1).

6.3.4 Renault Nissan Mitsubishi Alliance

Renault Nissan Mitsubishi Alliance is an automotive industrial group composed of 5 main brands: Dacia, Infiniti, Mitsubishi, Nissan and Renault.

In 1999 Renault and Nissan created the Alliance to share the strategy and to develop synergies. In 2016 Mitsubishi joined the Alliance.

In 2017 the Alliance developed a six-year plan called “Alliance 2022” to strengthen the cooperation and accelerate the use of common platforms, powertrains and new technologies. The alliance has declared that the 50 percent of the range will be electrified by 2022 and that 9 million vehicles will be based on the four common platforms. To support the Alliance plan, Nissan has settled a strategy called MOVE that is the acronym of Mobility, Operational excellence, Value to customers and Electrification. The Renault Group aims to become the leader in electric vehicles through a strategy named “Drive the Future” with the launch of 8 BEV (5 new models and 3 renewals) and 12 electrified vehicles. The new Renault and Nissan PHEV models will adopt the Mitsubishi technology. Infiniti is expected to offer only electrified vehicles from 2021. [49] [50]

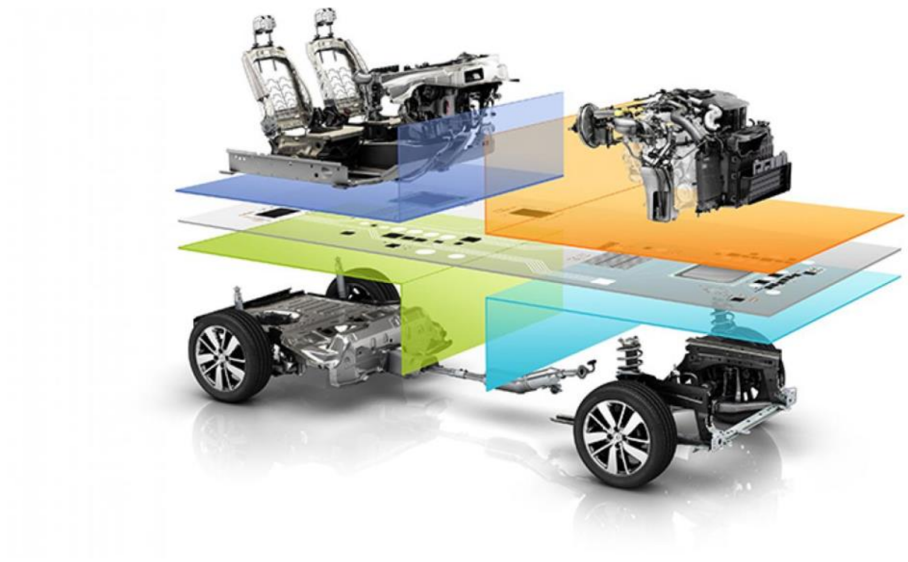


Figure 72: The fundamental areas of CMF are the engine compartment, the cockpit, the front underbody, the rear underbody and the electrical and electronical architecture (Credit Renault Groupe) [50]

To achieve the set targets, the Alliance members will globally increase the use of the common platforms. The common scalable platform of the Alliance is the CMF (Common Modular Family) that allows to create a scale, thus reducing the resources and development costs by 40 percent and the production costs by 30 percent thanks to a simplified manufacturing. The CMF is a platform, but it can involve several platforms. In fact, the CMF divides the vehicle into 5 fundamental areas composed of 5 common parts that can be mixed and matched to create a large variety of vehicles ranging from small vehicles up to executive sedans and crossovers, thus allowing to develop MPV, SUV, sedan and hatchback. The 5 common parts are the engine compartment, the cockpit, the front underbody, the rear underbody and the electrical and electronical architecture. Thanks to CMF platform, lower costs and higher quality are achievable. The cost reduction allows to insert additional content inside the vehicle, thus making the car more attractive and increasing possible sales volumes. Through higher sales volumes is possible to further reduce costs and add extra contents, generating a virtuous circle. To reduce carbon dioxide emissions, since 2018 CMF has been employing a higher content of UHSS on more than 25 percent of vehicle parts and especially on SUV. [50]

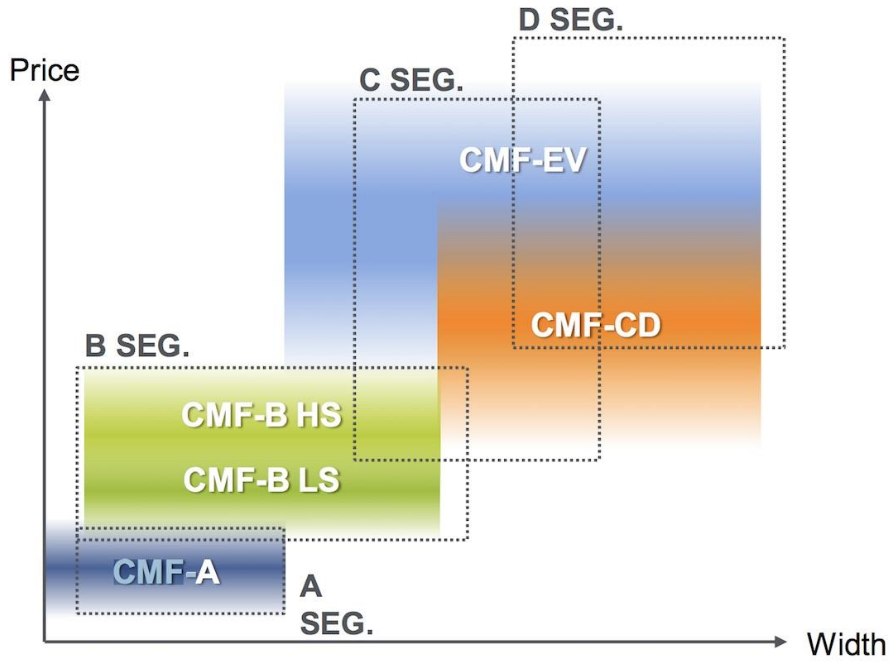


Figure 73: Common Module Family across segments. LS is the acronym of low specifications that is employed mainly by the Dacia brand, while HS means high specifications (Credit Renault Groupe) [50]

CMF can be seen as composed of 4 common platforms: CMF-A, CMF-B, CMF-CD and CMF-EV. The CMF-A is the base of A-SUV that are not already present in the European market. 8 new models are expected to be built on the CMF-B by 2021 and they will count one third of the overall CMF sales. The first of the previously mentioned platforms that arrived on the market was the CMF-CD in 2013. It was firstly employed by Nissan for Rogue in the USA and for Qashqai in Europe. In 2015 the CMF-CD debuted on the Renault Group with the Renault Espace. The CMF-EV is the dedicated BEV platform developed by the Alliance. The benefit provided by this flat floor platform is the increased interior roominess that is comparable to the one of one class above vehicle. All the BEV launched after 2020 will be constructed on the CMF-EV. The Alliance is foreseen to launch 12 new BEV. Among them, 70 percent of the sales volume will be on the CMF-EV. [50] [51]

The Infiniti vehicles won’t be based on the CMF. Today the platform employed by the Infiniti brand is the FR-L stands for Front engine Rear wheel drive Large. In the future a dedicated BEV platform (EV-L) is expected.

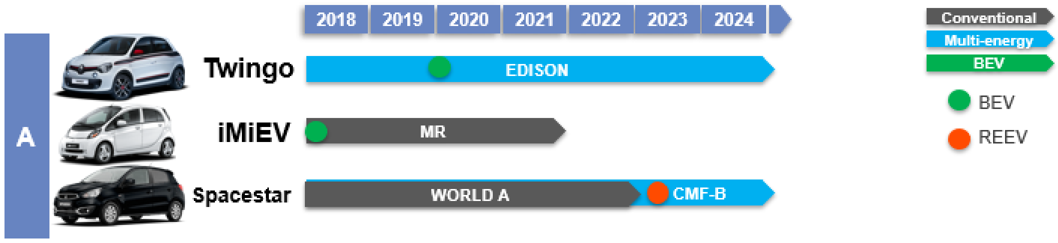


Figure 74: A segment of Renault-Nissan-Mitsubishi Alliance

The A segment of the Alliance is composed by Renault Twingo, Mitsubishi i-MiEV and Mitsubishi Spacestar. The Renault Twingo is built on the Edison platform that derives from a partnership with Daimler to develop and share a vehicle architecture for city cars. The BEV version of the Twingo is expected to be available from 2020. The Mitsubishi i-MiEV is a full electric city car built on MR, that is the Mitsubishi Mid-engine Rear-wheel drive platform. Mitsubishi i-MiEV was launched on the market in 2009 and is forecasted to be phased out around 2021. The Mitsubishi Spacestar is constructed on the World A platform, that will be phased out in 2023 in favor of the CMF-B. Together with the platform shift, the vehicle will probably be offered as REEV.

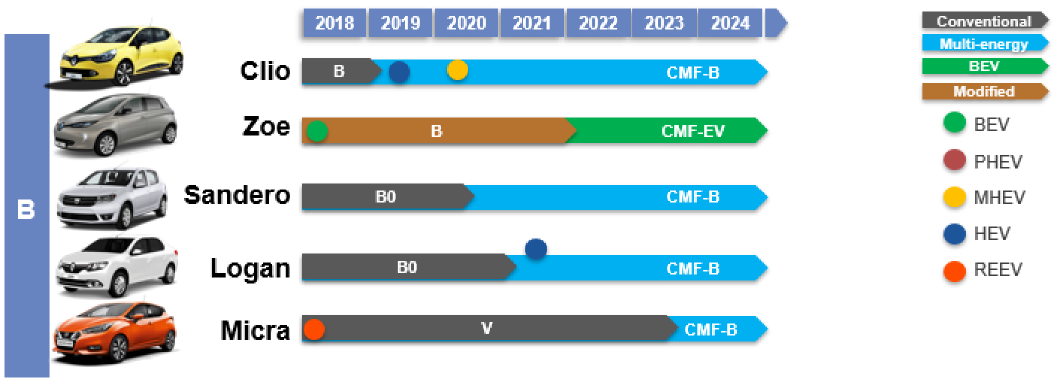


Figure 75: B segment of Renault-Nissan-Mitsubishi Alliance

Renault Clio and Zoe, Dacia Sandero and Logan and Nissan Micra are the models belonging to the B segment. The Renault Clio is currently based on the B platform. The B platform was developed in 2002 jointly by Renault and Nissan consequently to the creation of the Alliance in 1999. Renault Clio is expected to be moved on the CMF-B platform from 2019, when it will be available as HEV. The following year, the MHEV variant will probably be added to the products offer. The Renault Zoe is a BEV launched on the market in 2012. It is constructed on a modified version of the B platform in order to fit the battery pack and the power electronics. Around

2022 it is expected to move on the CMF-EV platform. Dacia Sandero and Logan are both based to the B0 platform that is a platform with a stretched wheelbase. Both of them will shift to the new CMF-B platform, respectively in 2020 and 2021. The Dacia Logan will be offered as HEV when it will move on the new platform. The Nissan Micra is available as REEV and is constructed on the V platform, that is an updated version of the B platform. Nissan Micra is expected to move on the new CMF-B platform around 2023.

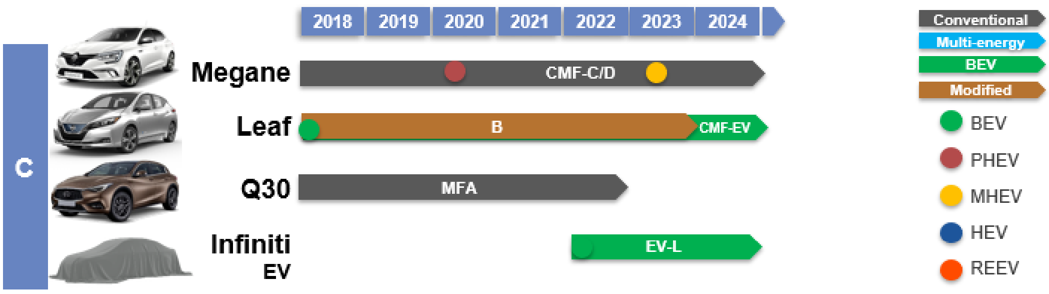


Figure 76: C segment of Renault-Nissan-Mitsubishi Alliance

In the C segment, the Alliance offers Renault Megane, Nissan Leaf and Infiniti Q30. The Renault model is built on the CMF-C/D platform. Its powertrain is expected to be electrified from 2020 when the PHEV version will be offered. The MHEV variant is projected to arrive by 2023. The Nissan Leaf is a BEV launched on the market in 2010 on the modified version of the B platform in order accommodate all the BEV related components. Around 2023 it is expected to move on the dedicated BEV platform of the Alliance (CMF-EV). The Infiniti Q30 is a compact vehicle that shares the platform with the Mercedes A-Class and GLA (MFA platform). Nevertheless, this side of the partnership between the Alliance and Daimler has stopped and the Q30 will be phased out around 2021-2022. A compact BEV branded Infiniti will be launched by 2022 on the new dedicated BEV platform that the premium brand is developing (EV-L). The model is expected to be named Infiniti EV.

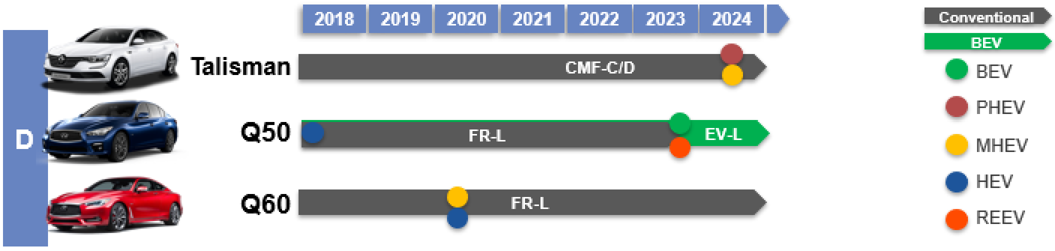


Figure 77: D segment of Renault-Nissan-Mitsubishi Alliance

Renault Talisman, Infiniti Q50 and Q60 are the vehicles composing the D segment of the Alliance. The Talisman is based on the CMF-C/D platform. it is expected to be offered as PHEV and MHEV from 2024. The Infiniti Q50 and Q60 are both based on the FR-L platform. The former is presently available on the market also as HEV and is expected to be offered as BEV and REEV by 2023 when it will shift on EV-L. The latter will probably be offered as HEV and MHEV from 2020.

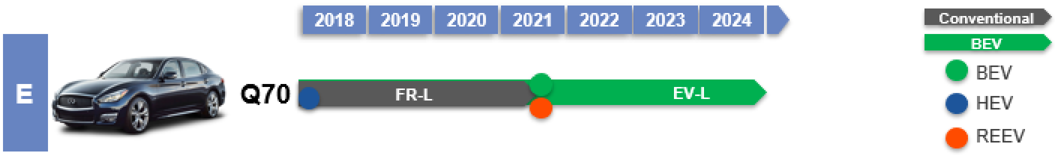


Figure 78: E segment of Renault-Nissan-Mitsubishi Alliance

The Infiniti Q70 is the premium vehicle offered by the Alliance in the E segment. Nowadays it is also available as HEV. By 2021 a platform shift in favor of the EV-L is expected together with the offer of BEV and REEV versions.

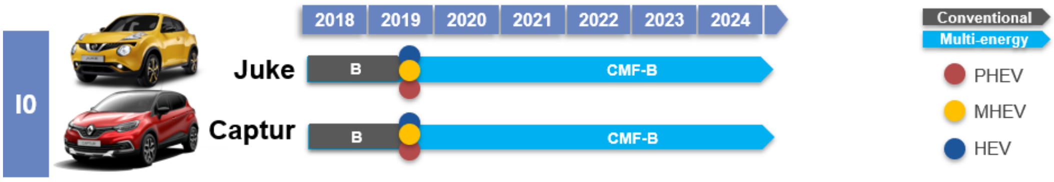


Figure 79: I0 segment of Renault-Nissan-Mitsubishi Alliance

Nissan Juke and Renault Captur are the models of the alliance corresponding to the I0 segment. Both of them are today based on the B platform. They will move to the CMF-B platform by 2019 when PHEV, HEV and MHEV variants will be offered on the market.

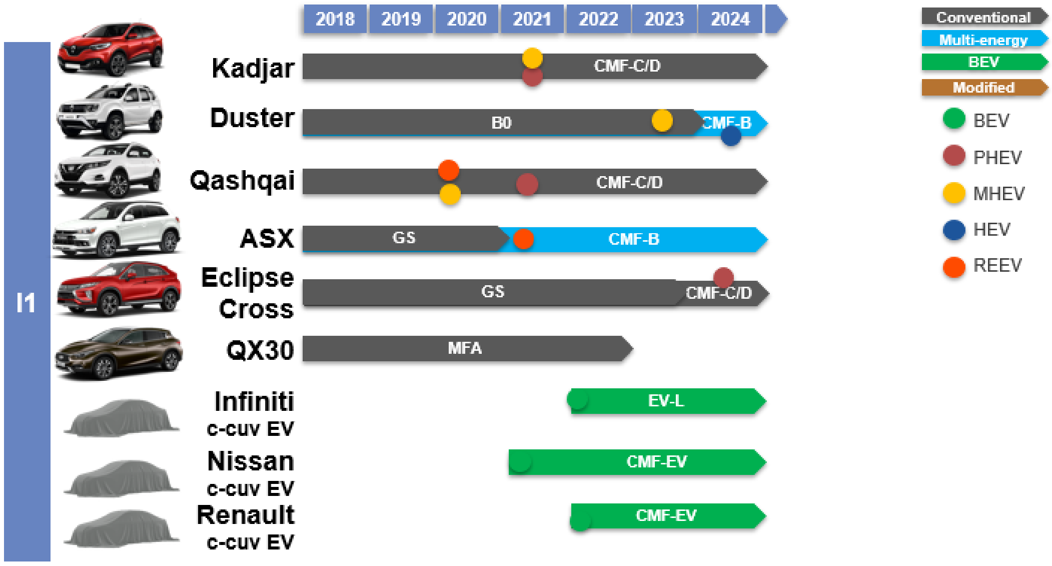


Figure 80: I1 segment of Renault-Nissan-Mitsubishi Alliance

The segment I1 of the alliance is the one with the larger number of models. The Renault Kadjar is built on the CMF-C/D platform. The electrified versions are expected to arrive from 2021 with MHEV and PHEV variants. The Dacia Duster is based on the B0 platform. The MHEV technology is expected to be mounted in 2023 whereas the HEV variants will probably be available from 2024. In between, a platform shift in favor of the CMF-B is projected. The Nissan Qashqai was the first Nissan vehicle sold in Europe based on the CMF-C/D. From 2020 the REEV and MHEV variants will probably be offered, while the PHEV technology will be available from the following year. The Mitsubishi ASX and Eclipse Cross are currently based on the GS platform. This vehicle architecture has been developed jointly by Mitsubishi and Daimler. The Mitsubishi ASX will move to CMF-B from 2021 when it will be also available the REEV version. The Mitsubishi Eclipse Cross will move to the CMF-C/D platform around 2023. With the new vehicle architecture, the PHEV variant will be offered. As the Infiniti Q30, also the Infiniti QX30 is presently based on the Mercedes MFA on which GLA is constructed. Therefore, it will be phased out around 2021-2022. In the I1 segment, three BEV are expected to be launched on the market by the Alliance: the CMF-EV will be the base of a Nissan and Renault SUV, respectively from 2021 and 2022, whereas the other full electric SUV will be branded Infiniti and available from 2022.

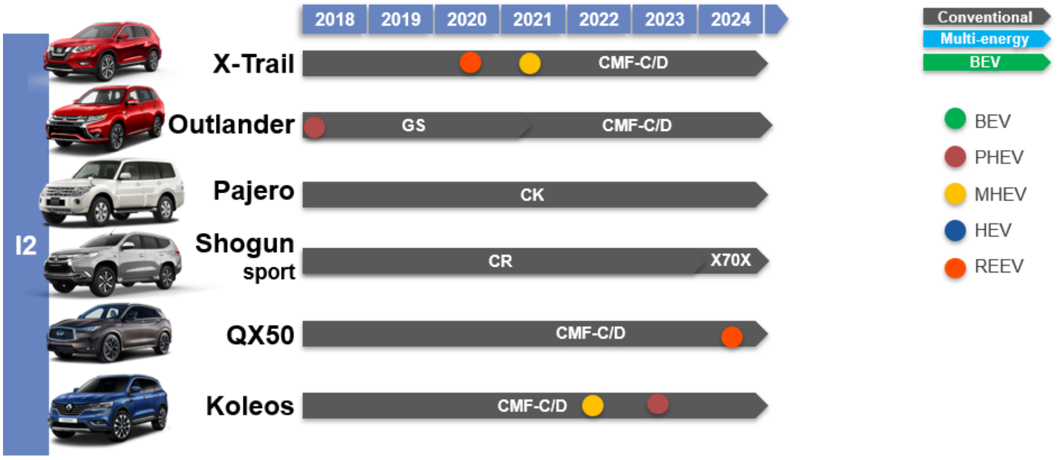


Figure 81: I2 segment of Renault-Nissan-Mitsubishi Alliance

The I2 segment of the Alliance is composed of six different models. Nissan X-Trail, Infiniti QX50 and Renault Koleos are nowadays sharing the CMF-C/D platform. The Mitsubishi Outlander will move on the same platform from the GS vehicle architecture by 2021. Mitsubishi Outlander is the best seller PHEV in the European market. Nissan X-trail and Infiniti QX50 will probably be available as REEV from respectively 2020 and 2024. The Nissan SUV will also be offered as MHEV from 2021. MHEV and PHEV variants of the Renault Koleos are expected to arrive for sale from respectively 2022 and 2023. Other two additional vehicles in this segment are the Mitsubishi Pajero and the Shogun Sport. The former is based on the CK platform, whereas the latter on the CR vehicle architecture but it is expected to move to the X70X platform from 2024.

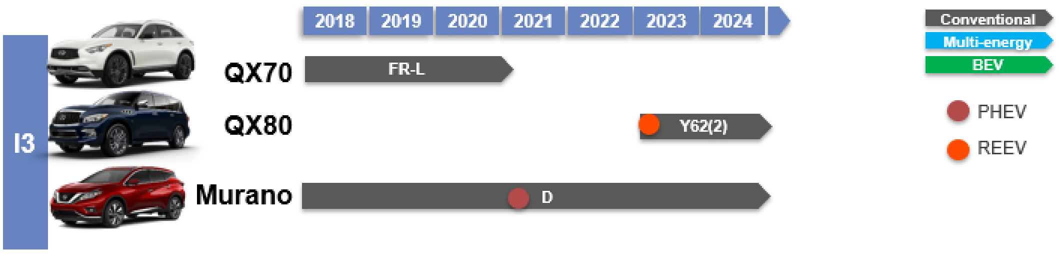


Figure 82: I3 segment of Renault-Nissan-Mitsubishi Alliance

The Infiniti QX70 and Nissan Murano are the Alliance SUV belonging to the I3 segment. The Infiniti SUV is built on the FR-L platform, but it is expected to be phased out by 2021. It will be replaced by QX80 that will be launched on the market by 2023 also as REEV and based on the Y62 platform. The Nissan Murano is constructed on the D platform and the PHEV variant is expected to be offered from 2021.

Summing up, Edison and CMF-B can be identified as multi-energy platforms. By 2024 they will be the base of 10 models. The main conventional platforms are CMF-C/D and FR-L. The vehicles that will be based on conventional platform by 2024 will be 14. The remaining vehicles that are BEV constructed on dedicated platform (CMF-EV and EV-L) are in total 8.

By looking at the sales volumes that are foreseen by 2024 and grouping them by platform, the Renault Twingo (Edison) will sell about 50 thousand units. The vehicles sold and based on the CMF-B platform will be equal to 855 thousand units, 790 thousand units on the CMF-C/D, 115 thousand units on the CMF-EV, four thousand on the EV-L, 2 thousand on the FR-L platform, 135 thousand units on the B0 platform. GS and B platforms will count about 10 thousand vehicles sold in total.

6.3.5 Volkswagen Group

The main brands composing the Volkswagen Group are Audi, Porsche, Seat, Skoda and Volkswagen.

“Transform 2025+” is the German group strategy with 2015-2030 timeframe to become the world-leading volume manufacturer. The strategy is made of three phases: the first one up to 2020 is named “SUV offensive”, “electric offensive” is the second one going up to 2025 while the third one is focused on autonomous driving and related services. The “SUV offensive” will increase the SUV models in the product portfolio from the current 11 up to 30 by 2025, so that one over two vehicles sold will probably be a SUV. [52]

Figure 83: The ID family is an emissions free group of Volkswagen vehicles based on the MEB platform expected between 2019 and 2022 (Credit Volkswagen) [53]

The “electric offensive” is meant to support the group in becoming the global market electric leader. Volkswagen set the target of being the first car manufacturer to sell more than one million of electric vehicles within 2025. The Group will launch on the market about 50 BEV and 30 PHEV. In 2030, at least one electrified version for each of the group models will be offered on the market. The German group will invest 9 billion in the expansion of e-mobility in order to make the electric vehicle accessible to everyone. To sell electric vehicles at affordable prices, the Volkswagen Group will expand the platform orientation. The MEB (Modular Elektro Baukasten, modular electric toolkit) is a dedicated BEV platform that has been developed by Volkswagen and that will be extended on the entire group. The MEB will be produced in 8 locations on 3 continents. The first Volkswagen model based on the MEB will be produced in Zwickau and will be launched in 2020. Emdem and Hannover will manufacture MEB-based vehicles from 2022. [53] [54]

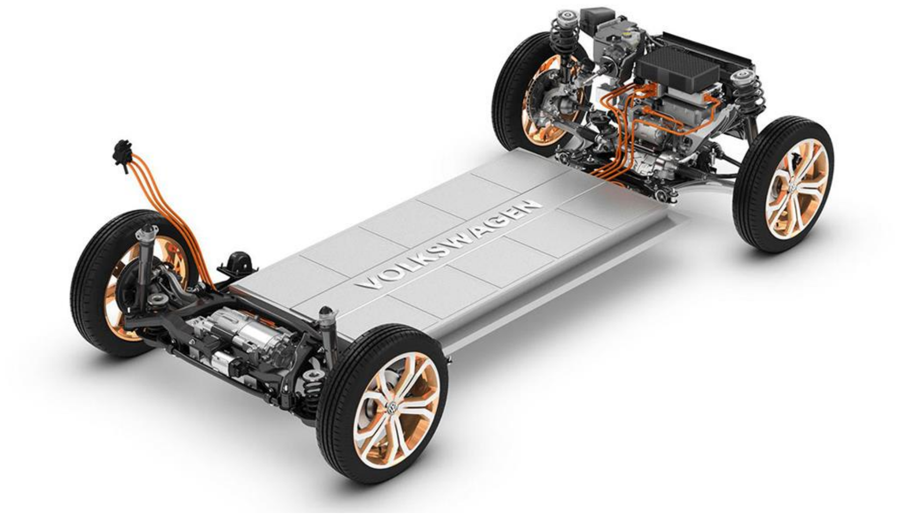


Figure 84: MEB (modular electric toolkit), the dedicated BEV platform developed by Volkswagen (Credit Volkswagen)

Producing vehicles based on the same platform at multi-brand plants will allow to achieve global economies of scale, thus reducing material and delivery costs. The further benefits provided by the MEB are a significant increased interior roominess and the possibility to design vehicles with new proportions. For instance, the front overhang can be reduced with respect to the wheelbase. The platform orientation will enable valuable synergies. In the past, the MLB (Modular Langs Baukasten, modular longitudinal toolkit) was developed transversally on the entire group. MLB is used on longitudinal engine vehicles, hence especially on Audi and some Porsche cars. In 2007 Audi A5 was the first vehicle based on the MLB. Meanwhile, a new dedicated BEV platform is under jointly development by Audi and Porsche brands. PPE (Premium Platform Electric) will be a scalable flexible vehicle architecture for premium BEV. It will generate a scale effect since composed of common modules, thus reducing the development costs by 30 percent with respect to the case in which it was developed by only one brand. [53] [54]

Figure 85: MQB platform for transverse engine vehicle (Credit Volkswagen)

Another platform that allowed to exploit valuable synergies is the MQB (Modular Quer Baukasten, modular transverse toolkit). The MQB is a platform for transverse engine vehicle that was employed for the first time on the Audi A3 in 2012 and then on Volkswagen Golf since 2013. In 2015, MQB was the base of 20 percent of Volkswagen models. This value has increased by 60 percent in 2018 and is expected to reach 80 percent in 2020. The MQB is a modular platform that is described as a "toolkit" and not as a platform per se. In fact, speaking of "toolkit" means that the architecture is intended to support the development of a specific vehicle platform by matching and mixing together a set number of pre-made and mutually compatible parts. The MQB is scalable in all longitudinal dimensions except the distance between the wheel center and the pedals. With respect to previous platforms, the MQB has a reduction in weight by 37 kg that was achievable throughout the use of UHSS with an overall proportion equal to 30 percent. Therefore, thinner metal sheets are employed. In particular, 18 kg reduction was obtained through the 85 percent of the underbody made of UHSS. According to "Transform 2025+" strategy, the MQB does not require any kind of modifications, thus minimizing the expenditures. The MQB replaces some previous PQ platform (PQ25, PQ35 and PQ46). This PQ family platforms (except PQ12) won't be updated and will be discontinued. In PQ platforms, the letter P means "Passenger", the letter Q stays for "Quer" that means transverse, while the following two numbers indicate the size or class for which the platform is employed and the generation or the evolution of the vehicle architecture. [54]

Figure 86: New Small Family (NSF) PQ12 platform (Credit Volkswagen)

The PQ12 platform is employed for the vehicles in the A segment. The MQB A0 is used for the entire B segment and some of the cars in I0 segments, the MQB A/B in C, D, I0, I1, I2, L1 segments. Some vehicles in the D, E, I2 and I3 are based on the MLB C/D. The MEB will be used mainly in C, D, I1 and I2 segment, while the PPE in I2 and I3 segments.

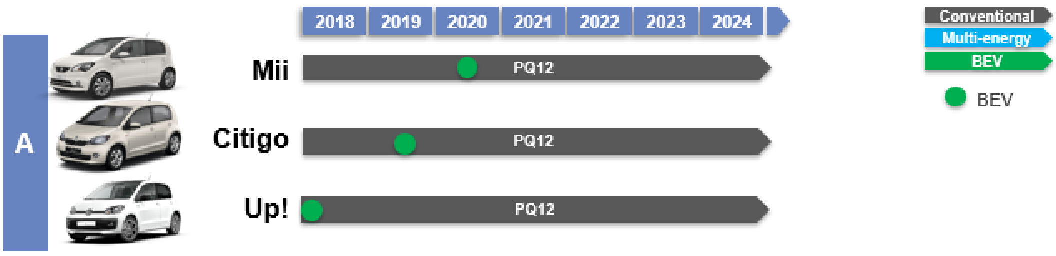


Figure 87: Volkswagen group A segment

The Volkswagen Group offers Volkswagen Up, Seat Mii and Skoda Citigo as city-car in the A segment. All of them are based on the PQ12 platform, that is also called NSF platform (New Small Family platform). In fact, Seat Mii and Skoda Citigo are rebadged version of the Volkswagen Up. The BEV version of the Volkswagen Up called "e-Up!" is offered on the market since 2013. The electric version of the Skoda Citigo and of the Seat Mii has been announced to arrive respectively by 2019 and 2020.

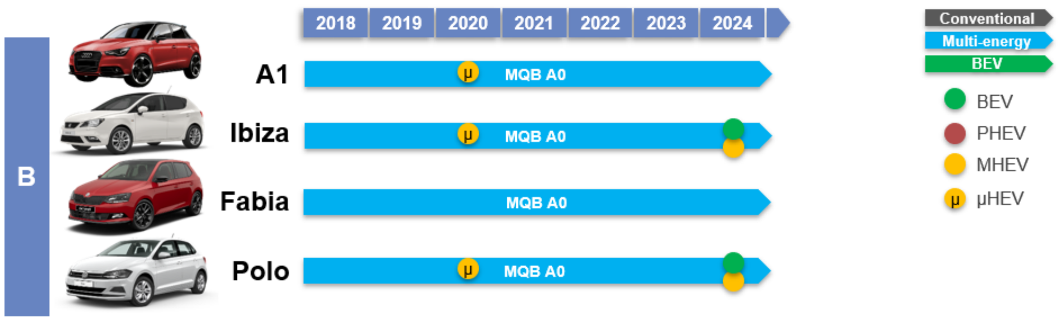


Figure 88: Volkswagen group B segment

The B segment of the Volkswagen Group is composed by Audi A1, Seat Ibiza, Skoda Fabia and Volkswagen Polo. In the electrification of these vehicles (except Skoda Fabia) is forecasted to occur by 2020 through a µHEV technology. The BEV variant of the Polo and Ibiza is expected to be offered from 2024. In the same year, both vehicles are projected to pass from a 12V to a 48V system, thus becoming a MHEV.

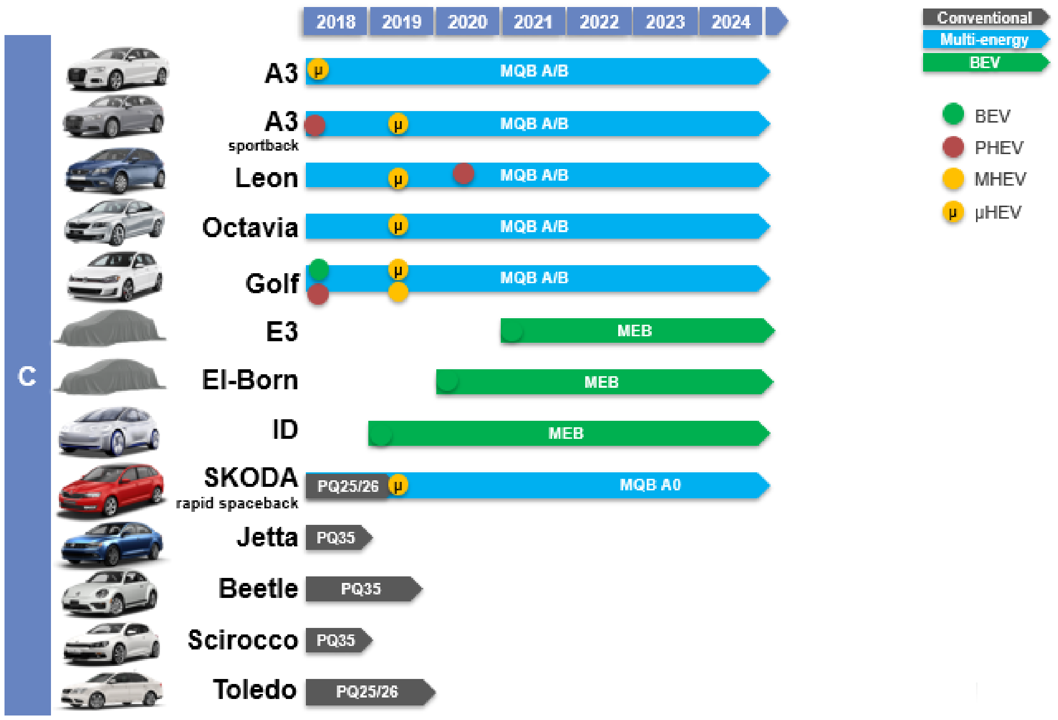


Figure 89: Volkswagen group C segment

A huge number of models composes the C segment of the Volkswagen Group since each brand offers at least about two vehicles. Nevertheless, there are some vehicles that are in phase out and they will be removed from the product line-up, as the platforms on which they are built (PQ35 and PQ35). These vehicles are the

Volkswagen Jetta, Beetle and Scirocco and the Seat Toledo. The Skoda Rapid Spaceback is nowadays constructed on the PQ25 platform but it will shift on the MQB A0 by 2019 and the µHEV will be also available. All the other models in this segment that are currently on the market are based on the MQB A/B platform. The most famous is the Volkswagen Golf that can be presently ordered in its PHEV and BEV variants. In 2019 the eighth generation of the Golf will be on the market and the µHEV version will be probably available. Nevertheless, the BEV version that has been introduced since 2015 could be removed and no longer possible to be ordered. This action could be done in order to not cannibalize the sales volume of the new Volkswagen ID 3, that will be delivered to customer by the end of 2019. The Volkswagen ID 3 will be the first full electric vehicle built on the new MEB platform. On the same platform, other two BEV are expected to be launched in about three years: Seat El-Born from 2020 and the full electric variant of the Audi A3, that should be named E3. The Audi A3 is nowadays available as µHEV. The Audi A3 Sportback is instead offered as PHEV and the µHEV version should be added by 2019. In the same year, also the µHEV variants of the Seat Leon and Skoda Octavia are awaited. The following year, the Seat Leon should be offered as PHEV.

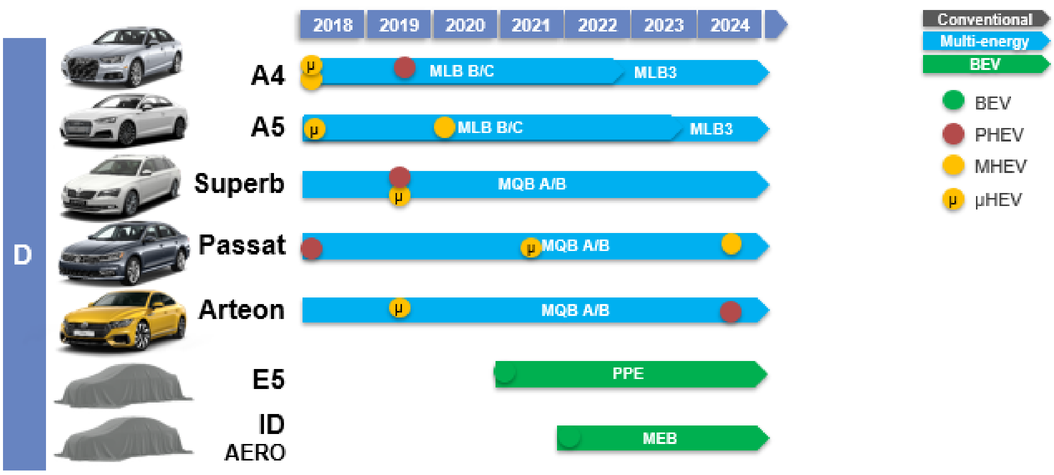


Figure 90: Volkswagen group D segment

The Audi A4 and A5, the Skoda Superb, the Volkswagen Passat and Arteon are the vehicle of the group that are categorized in the D segment. Both A4 and A5 are currently available as µHEV. These two models are based on the MLB B/C platform since they have longitudinal layout of the engine. An update of these platforms is awaited to happen around 2023. The PHEV version of the A4 will probably be available from 2019, whereas the A5 should be available in a BEV variant called E5 from about 2021. It is not clear whether it will be constructed on the MEB platform or on the PPE platform, developed by Audi jointly with Porsche. In addition, the Audi A5 is expected to be offered also as MHEV from 2020. Skoda Superb, Volkswagen Passat and Arteon are constructed on the MQB A/B vehicle architecture. The Skoda Superb has been announced to be available in the PHEV variant from 2019. In the same year, a µHEV version could also be offered. The Volkswagen Passat is now on the market also in its PHEV variant. The µHEV version is expected to be offered from 2021, whereas from 2024 the MHEV one. The µHEV of the Volkswagen Arteon should be on the market from 2019. Customers need to wait until 2024 for the PHEV variant. Volkswagen has announced another BEV to be added in this segment. It will be marketed under the sub-brand ID from 2022 and will be called ID Aero.

Figure 91: Volkswagen group D segment

The Audi A6 and A7 are the models composing the E segment of the German group. Nowadays they are offered also in the µHEV version and have been announced to be available from 2019 as PHEV. they are both based on the MLB B/C platform.

Figure 92: Volkswagen group G segment

Audi A8, Porsche Panamera and Audi R8 are the models offered by the Volkswagen group in the G segment. The Audi A8 is built on the MLB D platform and it is available as MHEV. The PHEV version is expected to be offered from 2019, whereas the full electric model will arrive by 2024 on the PPE platform. It should be named E8. The Panamera is currently built on the MSB platform (Modularer Standardantrebs Baukasten, Modular Standard Toolkit). It is also offered in the PHEV variant. The MHEV version will probably arrive in 2019, whereas the BEV of the Panamera is projected to be launched by 2023 on PPE. The Audi R8 is on Lamborghini platform. The MHEV variant is expected to be available from about 2019.

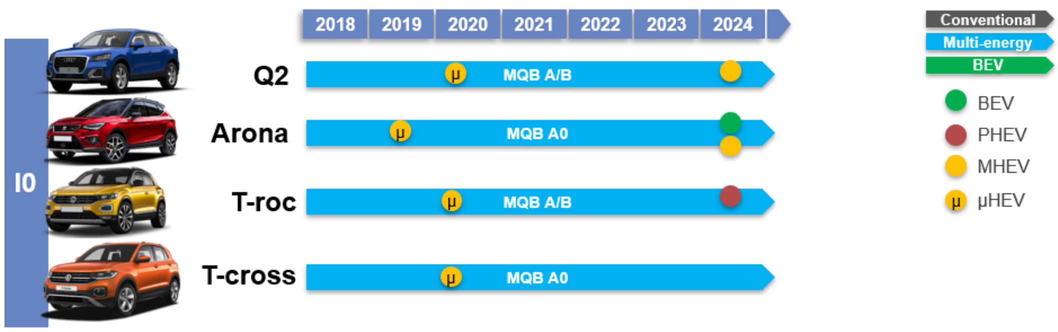


Figure 93: Volkswagen group I0 segment

The models composing the I0 segment of the Volkswagen Group are Audi Q2, Seat Arona, Volkswagen T-Roc and T-Cross. All of them are constructed on the MQB. Seat Arona and Volkswagen T-Cross are based on the smaller version, MQB A0. The µHEV variant of these four models is expected around 2019-2020. The seat Arona is also expected to be offered as BEV and MHEV from 2024. In the same year, the PHEV variant of the T-Roc and the MHEV version of the Q2 should be available from 2024. A new model branded by Seat will be launched in 2020.

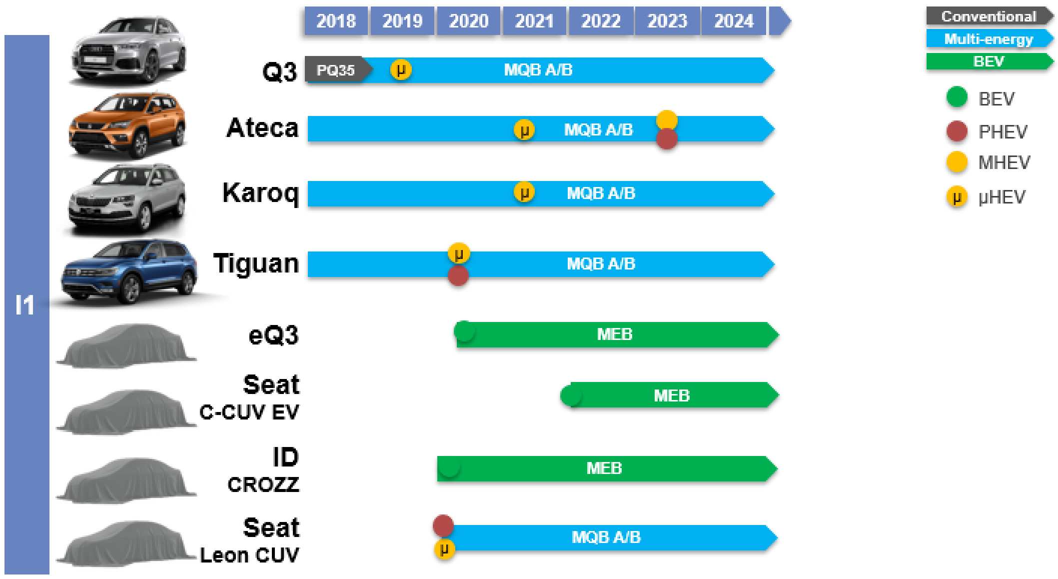


Figure 94: Volkswagen group I1 segment

In the I1 segment of the Volkswagen Group, Audi Q3, seat Ateca, Skoda Karoq and Volkswagen Tiguan are currently offered on the market. They are all built on the MQB A/B platform, except Audi Q3 that is expected to present the new model by moving on the modular platform for transverse engines from the current PQ35 by 2019. In the same year, the µHEV version of the Audi SUV should be available. From 2020 the Volkswagen Tiguan is expected to be offered both as PHEV and µHEV. The 12V system should be mounted on the Seat Ateca and Skoda Karoq from 2021. The Seat Ateca is also expected to present its MHEV and PHEV variants from 2023. From 2020, a Seat SUV deriving from the compact car Seat Leon should be launched on the Market on the MQB A/B platform. It should be immediately available as both µHEV and PHEV. In this segment, three new vehicles are forecasted to be launched under the MEB platform by 2022. The first two should be the eQ3, the BEV variant of the Audi SUV, and the Volkswagen ID Crozz, that has been announced to be available from 2020. It will be the second model under the ID brand. Eventually, a Seat full electric SUV is awaited to enter the market in 2022.

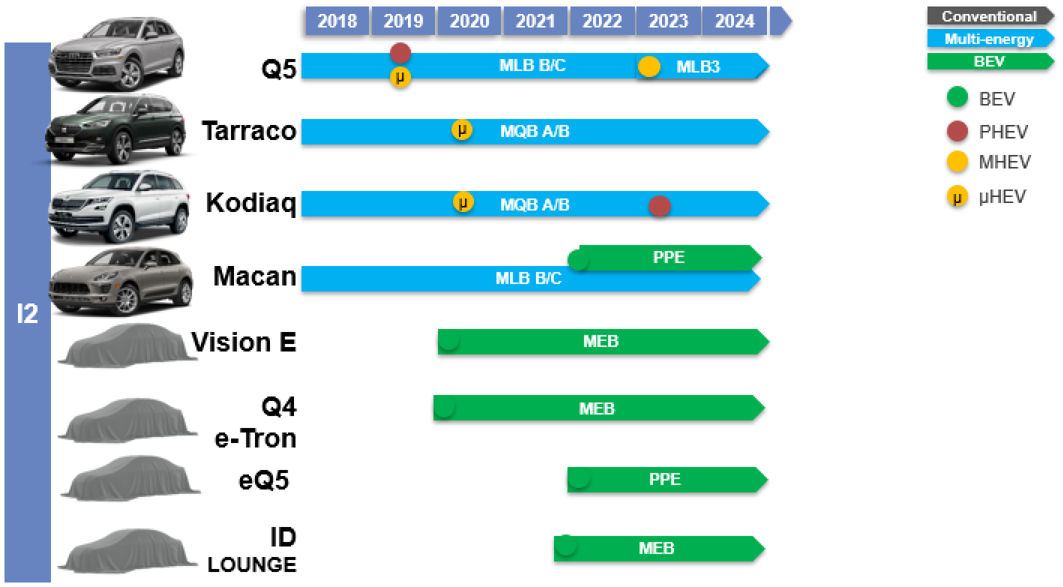


Figure 95: Volkswagen group I2 segment

The vehicles currently composing the I2 segment of the Volkswagen group are Audi Q5, Seat Tarraco, Skoda Kodiaq and Porsche Macan. The Audi Q5 is based on the MLB B/C platform and is expected to be available as µHEV and PHEV from 2019. The MHEV variant is projected to arrive by 2023 together with a platform update. The BEV version of this Audi SUV should be called eQ5 and available from 2022 on the PPE platform. Another Audi full electric SUV has been announced to be launched on the market by 2020 on the MEB platform: the Audi Q4 E-Tron. In the same year, the Skoda Vision E is expected to enter the market. This will be a BEV SUV based on MEB. Other BEV models in this segment will be the ID Lounge and the Porsche Macan that will be available from 2022. The former will be a SUV larger than the ID Crozz badged under the new full electric brand and constructed on the MEB platform. The latter has been announced to be offered as BEV and be constructed on the new PPE platform. The remaining two previously listed models in this segment are the Seat Tarraco and the Skoda Kodiaq. They are both on the MQB A/B platform and they will probably be electrified by 2020 by offering the µHEV variant.

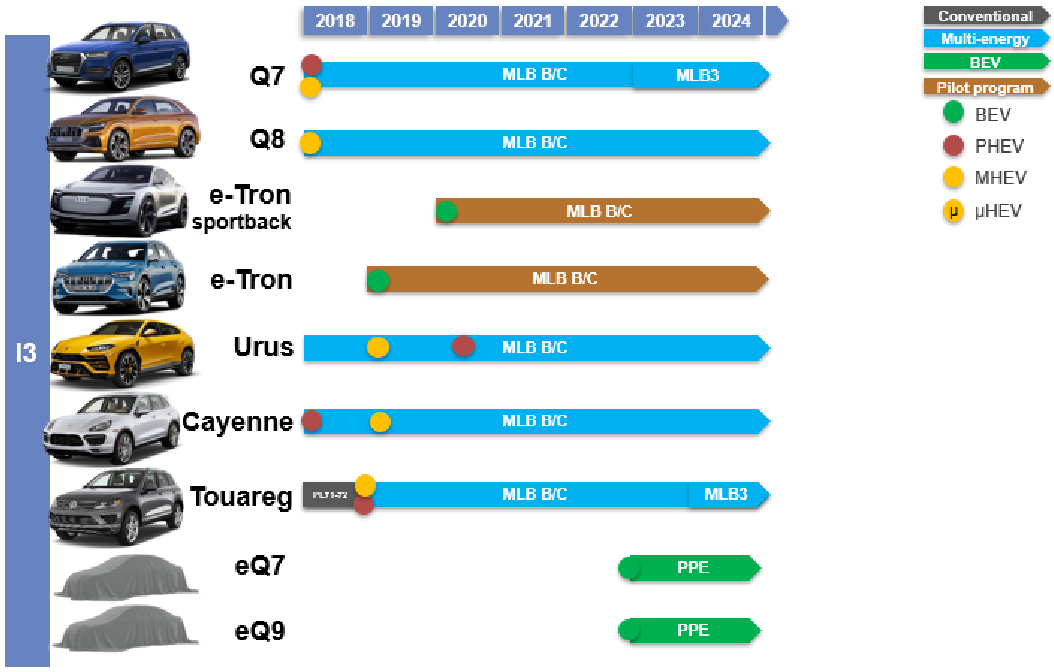


Figure 96: Volkswagen group I3 segment

Volkswagen Touareg, Audi Q7 and Q8, Lamborghini Urus, Porsche Cayenne are the models belonging to the German group that correspond to the I3 segment. They have a longitudinal layout of the engine. Consequently, they are all based on the MLB B/C platform. The only one that is still manufactured above an old generation platform is the Volkswagen Touareg. The new model will be presented by 2019, thus passing from the PL71 platform to the modular MLB B/C. The new model will probably be offered with the MHEV and PHEV electrification technology as well. The Audi Q7 and Q8 are currently offered as MHEV. This electrification technology will be mounted on Lamborghini Urus and Porsche Cayenne from 2019. The Lamborghini SUV is expected to be offered as PHEV by 2020. The models that are currently available on the market as PHEV are Audi Q7 and Porsche Cayenne. About the BEV in this segment, the Volkswagen Group has already presented the Audi E-Tron that will be delivered to customers from 2019. The following year, the Audi E-Tron Sportback will enter the market. These BEV vehicles are both based on a modified version of the MLB B/C platform. The modifications involve mainly the central portion of the underbody where the tunnel is taken out in order to accommodate a flat rectangular-shaped battery pack, thus increasing the range. Other two BEV Audi SUV models are expected to enter the market from 2023. They are projected to be called eQ7 and eQ9 and will be based on the PPE platform.

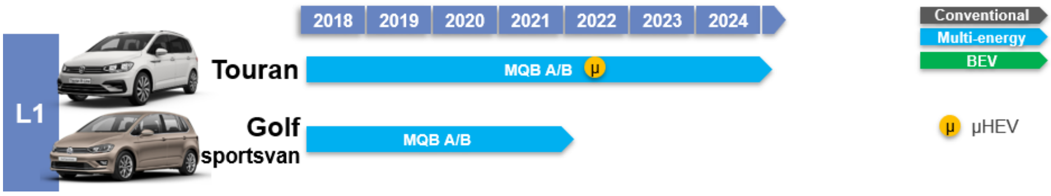


Figure 97: Volkswagen group L1 segment

Volkswagen Touran and Golf Sportsvan are two L1 segment models offered by the German group. These two MPV are both based on the MQB A/B platform. The former is expected to be offered as µHEV around 2022, whereas the latter will probably be divested in the same year.

Another BEV model that will be launched on the market under the electric brand ID will be the Volkswagen ID Buzz. It will be based on the MEB platform and it has been announced to be offered from 2021. It will correspond to a L3 segment vehicle.

Nowadays, the vehicles with both gasoline and diesel engine with four cylinders are equipped with a 12V battery and therefore they are classified as µHEV. Currently offered MHEV are offered with V6 or V8 engine and a 48V battery.

To Summarize, the Volkswagen Group will have a total of five platform by 2024. The PQ12, a conventional modified platform to accommodate traction battery and power electronics, will host three vehicles. The MQB and the MLB can be classified as multi-energy platform since they are so flexible to accommodate all kind of electrification technologies. Respectively 25 and 14 models will be based on these two multi-energy platforms. The remaining two vehicle architecture are the dedicated BEV platforms: 18 models will be built above them.

By looking at the sales volumes that are foreseen by 2024 and grouping them by platform, 2.9 million vehicles built on the MQB platform will be sold, 210 thousand on the MEB, 355 on the MLB, 60 on the PPE and 115 on the PQ12.

6.3.6 Daimler

The Daimler AG is an automotive industrial group mainly composed by two brands: Mercedes-Benz and Smart. Daimler-Benz was created in 1926 when Benz & Cie merged with Daimler Motoren Gesellschaft. In 1998 it was renamed Daimler Chrysler after the acquisition of Chrysler Corporation. The current name was given after the divestment of Chrysler in 2007.

Daimler Group strategies aim to maintain the image and the position of Mercedes-Benz as first premium car brand. The automotive industry is experiencing the most drastic transformation in its history. In order to remain aligned and updated with new trends, the German group has designed a strategic business called CASE that stands for Connected, Autonomous, Shared and services, Electric. One of the most important pillars in this strategic plan is the electric vehicle offensive. The Daimler group has created EQ, a new brand for the electric mobility. New electrified products and technologies are branded under EQ. The high technology internal combustion engines will be identified by “EQ Boost”, the PHEV by “EQ Power”, the performance hybrids by “EQ Power +” and 10 BEV will be launched on the market under “EQ”. The first of these 10 full electric vehicles, the Mercedes EQC, will be available at the end of 2019. Furthermore, from 2020 the Smart brand will offer only BEV in the US and European market. The Group foresees that BEV volume share will be bounded between 15 and 25 percent until 2025. These electrification actions are meant to reduce the carbon dioxide emissions of the whole group to comply with future stringent standards. By 2022, at least one electrified version in each series of Mercedes will be available for a total of 130 electrified variants. Therefore, the products range of Mercedes-Benz and Smart will be entirely electrified by 2022. In addition, the Group will invest more than one billion of euro in the global battery production network in order to improve the production flexibility. The investment will involve Kamenz and Unterturkheim in Germany, Tuscaloosa in USA, Beijing in China that are the production sites of the batteries. Other plants producing energy storage devices are expected to be located in Poland and Thailand. The Smart is manufactured in Hambach in France, where the conventional and the electric versions are manufactured on the same production line, whereas the competence center of the EQ production will be Rastatt, Sindelfingen and Bremen in Germany, Tuscaloosa in USA, Beijing in China. More specifically, the Mercedes EQC will be produced in Bremen and in Beijing from 2019. [54]

Figure 98: EQ vehicles and batteries manufacturing network (Credit Daimler) [54]

Daimler strategy related to vehicle architectures strive on the modularity in order to increase the efficiency in terms of costs, time and flexibility. The Mercedes-Benz passenger vehicles are nowadays based on four platforms: MFA, MRA, MHA, and MSA. MFA (Modular Front-wheel drive Architecture) is used for transverse engine front-wheel drive vehicles that has a fixed wheelbase. MRA (Modular Rear-wheel drive Architecture) is employed in longitudinal Rear-wheel drive vehicles that has a higher degree of modularity with respect to MFA since it allows different wheelbases and different body widths. MRA has an intensive use of aluminum in order to strongly reduce the vehicles weight, thus obtaining benefits in terms of carbon dioxide emissions. MHA (Modular High Architecture) is a platform to accommodate mainly SUV. MSA (Modular Sport Architecture) is an architecture developed for sports cars.

The modularity concept is also extended to the electric drive train technologies, thus allowing a variety of derivatives in order to better fulfill the different customer needs. The battery packs will be available in three sizes: small, medium and large. The electric motor modularity will improve the drivetrain flexibility: small electric motor will be located on the front axle while the larger one on the rear axle. [54] In addition to the currently available platforms, Daimler is developing a new dedicated

BEV platform from scratch that will arrive around 2021 and will be probably called EVA2 (Electric Vehicle Architecture). The platform of the Mercedes EQC is a modification of the MRA platform with a flat floor to fit battery packs between axles.

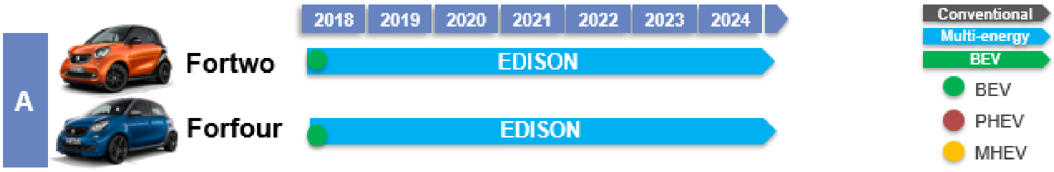


Figure 99: Daimler A segment

Smart is the brand inside the Daimler group offering city cars in the A segment: Smart fortwo and Smart Forfour. Today both the internal combustion engine and the electric version are available and produced on the same production line in the plant of Hambach in France. Nevertheless, from 2020 the conventional version will no longer be offered. These two vehicles are based on the Edison platform that derives from a partnership with Renault to develop and share a vehicle architecture for city car. In fact, Edison platform is also employed by Renault Twingo.

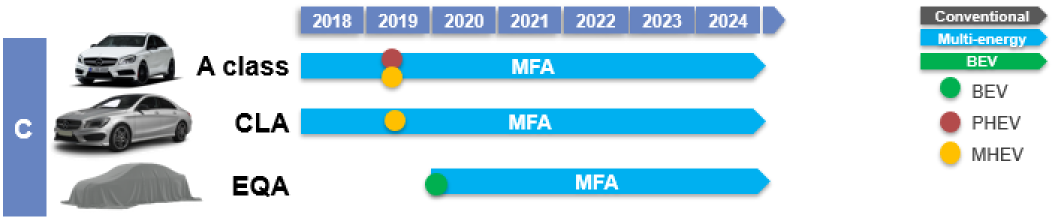


Figure 100: Daimler C segment

The vehicles offered by the Daimler group in the C segment are Mercedes C-Class and CLA. The former is expected to be offered as MHEV and PHEV from 2019, whereas MHEV version of the latter will probably be available from the same year. These two vehicles are both based on the MFA platform. In addition, a compact BEV named Mercedes EQA is expected to be launched on the market from 2020 on MFA.

Figure 101: Daimler D segment

The Mercedes C-Class belongs to the D segment and is based on the MRA midsize platform. It is also offered on the market in the MHEV and PHEV variants. The commercial launch of a new Mercedes EQ-D sedan is expected to happen by 2021. This BEV will be based on the new dedicated BEV platform called EVA2.

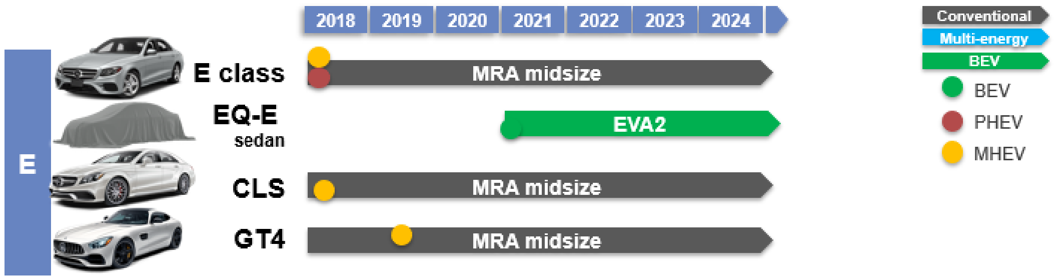


Figure 102: Daimler E segment

In the E segment, the German group offers the Mercedes E-Class, CLS and AMG GT4. All of them are built on the MRA midsize. The first two are already available as MHEV. The PHEV version of the E-Class is on the market too. The MHEV variant of the Mercedes AMG GT4 will probably be launched from 2019. A BEV Mercedes EQ-E sedan is expected to be launched from 2021 on the EVA2 platform.

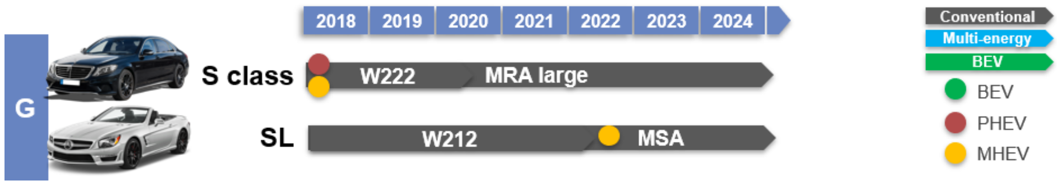


Figure 103: Daimler G segment

Mercedes S-Class and SL are the vehicles that Daimler has in its product line-up for the G segment. The former is already available in the PHEV and MHEV variants and is based on the W222 platform but is expected to move on the MRA large platform from around 2020. The latter is built on the W212 platform that will be phased out by around 2022 in favor of the MSA. Together with the platform shift, the MHEV version will be added.

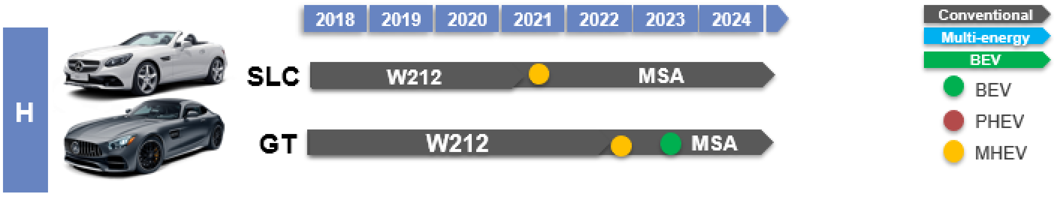


Figure 104: Daimler H segment

The sport cars belonging to the H segment are Mercedes SLC and GT. Nowadays they are both constructed on the W212 platform and they are expected to move on the MSA platform respectively from 2021 and 2022. The MHEV variants will enter the market with the new vehicle architecture. A BEV version of the Mercedes GT will be probably launched by around 2023.

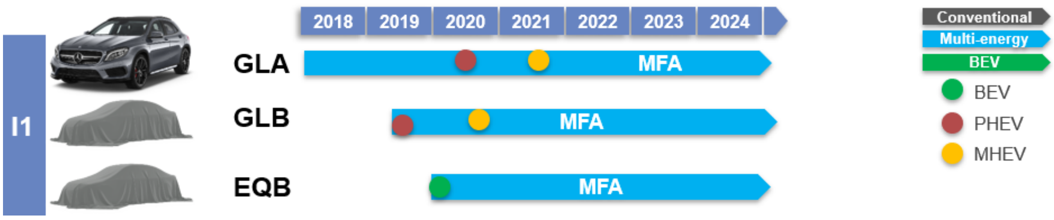


Figure 105: Daimler I1 segment

The I1 segment displays the Mercedes GLA. It is based on the MFA platform. A new model called Mercedes GLB will probably be launched by 2019 also as PHEV and as MHEV by the end of 2020. The GLA is forecasted to show the same electrification plan but delayed by one year. Mercedes is expected to launch a BEV variant of the Mercedes GLB from 2020 that will be marketed under the name EQB.

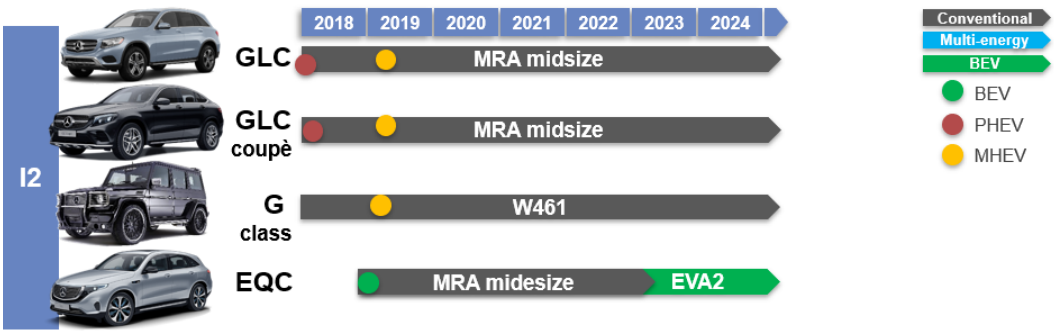


Figure 106: Daimler I2 segment

Mercedes GLC, GLC Coupé and G-Class are the SUV that Daimler sell in the I2 segments. GLC and GLC Coupé are nowadays constructed on the MRA midsize platform and available on the market also as PHEV. W461 is the vehicle architecture which the Mercedes G-Class is based on. No change of platform is expected by 2024. The MHEV variant of this three SUV are expected by 2019.

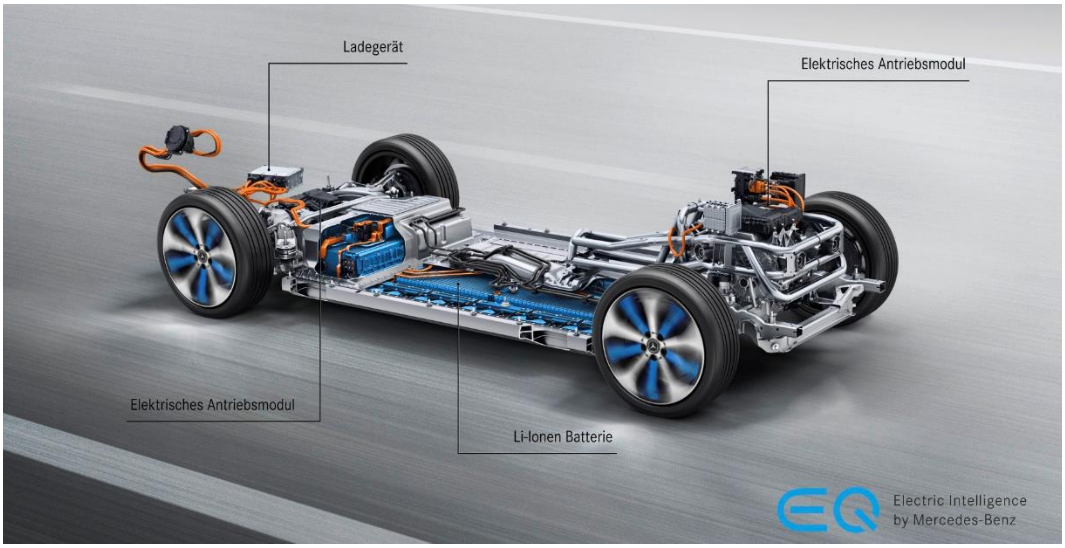


Figure 107: Mercedes EQC platform is a modified conventional platform to accommodate electric drive modules and battery pack between axles (Credit Daimler)

Mercedes EQC has been announced to be delivered to customer by the end of 2019. Mercedes EQC will be the first full electric vehicle launched on the market under EQ, the new product and technology brand of Mercedes. It is based on a modified version of the MRA midsize. The central portion of the platform between the axles has been modified by widening longitudinal rails in order to accommodate a flat rectangular-shaped battery pack. When the new dedicated BEV platform (EVA2) will be available, it could be possible a platform shift around 2023.

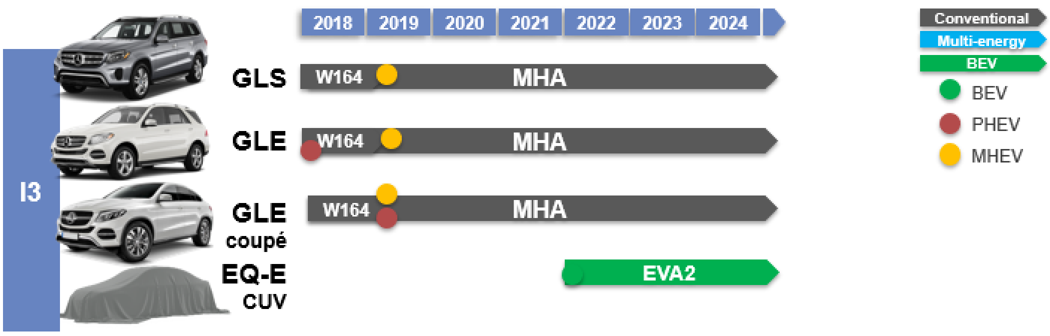


Figure 108: Daimler I3 segment

In the I3 segment, the Daimler group offers the Mercedes GLS, GLE, GLE Coupé. These three SUV are nowadays sharing the W164 platform that will be phased out from 2019 in favor of MHA, when also the MHEV variant will be marketed. The

Mercedes GLE is already available in the PHEV variant. The GLE Coupé PHEV will be offered from 2019. From 2022 the BEV Mercedes EQE will be launched on the market on the EVA2, the dedicated BEV platform of the Daimler group.

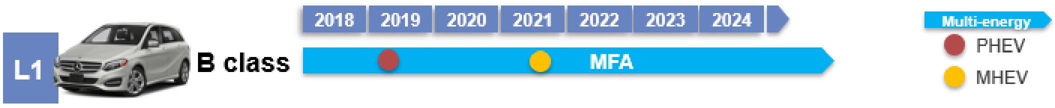


Figure 109: Daimler L1 segment

The Mercedes B-Class is the compact executive MPV composing the L1 segment of the German group. It is built on the MFA. Mercedes had been offering the B-Class as BEV until 2018. The PHEV version is expected to be available from 2019, whereas the MHEV variant from about the end of 2021.

Summing up, by 2024 the Daimler group will have six vehicle architectures: two multi-energy (Edison and MFA) that will be the base of 9 vehicles, 3 conventional (MRA, MSA, MHA) with a total of 14 vehicles above and one dedicated BEV platform (EVA2) that will accommodate four BEV vehicles in the higher segment that are covered by the conventional vehicle architectures, thus complementing them.

By looking at the sales volumes that are foreseen by 2024 and grouping them by platform, the total sales of Smart (Edison platform) will be equal to 70 thousand units. MFA will count 385 thousand units of vehicles sold. The BEV sold that are based on the EVA2 platform will be equal to 40 thousand units. The quantity of vehicles on conventional platform that will be sold by 2024 will be equal to 395 thousand units slit among MHA (30 thousand), MRA (360 thousand) and MSA (5 thousand).

7 Conclusions

The analysis performed in this thesis aims to determine possible common trends among major automotive industrial groups in the development and adoption of different passenger vehicle platform typologies. After the evaluation of the vehicle architectures evolution among single models and of the electrification technologies mounted above, the platforms have been categorized in three cluster: conventional, multi-energy and dedicated BEV. Modified conventional platforms are included in the conventional architectures category.

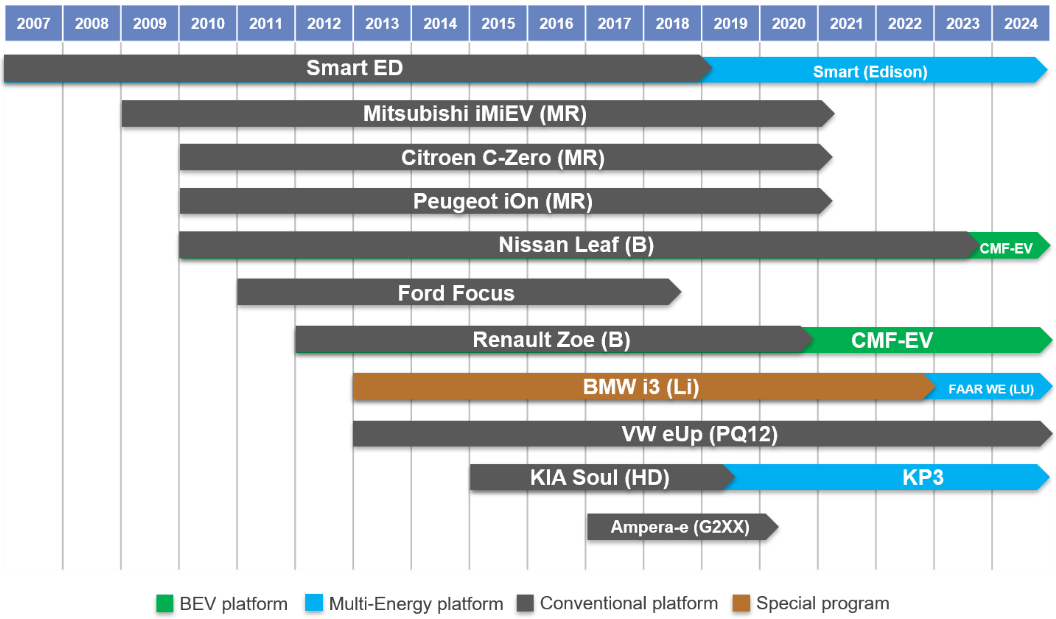


Figure 110: Evolution of modified conventional and bespoke platforms

From the analysis of the models evolution from a platform towards a new one, it is possible to note that most of electric vehicles built on modified conventional platforms will be phased out around the 2020-2021. Some of them will move on dedicated BEV platform (such as Renault Zoe), whereas others will shift their vehicle architecture in favor of multi-energy platforms (such as Kia Soul or Smart). It is quite evident that the modified conventional platforms are just provisional and related to an adaptation period before the adoption of multi-energy or dedicated BEV platforms. The development of a new platform requires massive economical resources. Indeed, the vehicle architectures are often developed through partnership, in order to reduce the investment costs.

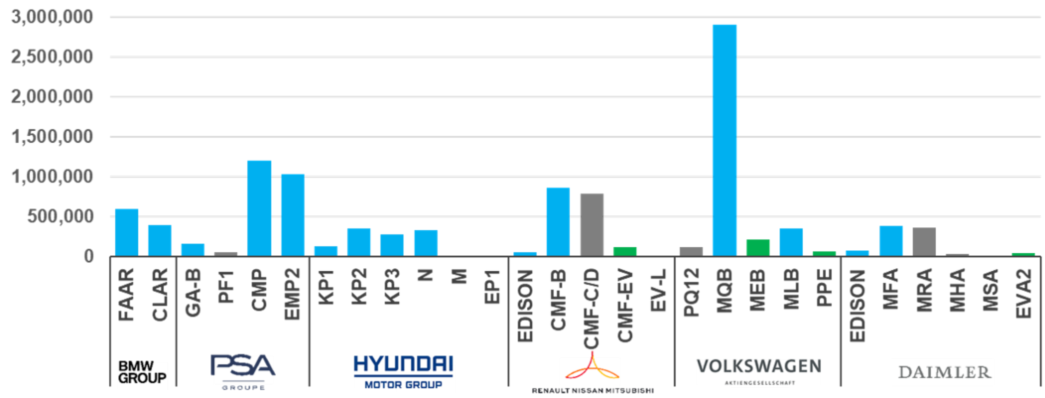


Figure 111: Volumes forecasted per platform in 2024

Through an analysis of sales volumes forecasted in 2024, it is possible to determine the weight of each different platform typology on the overall volumes of each automotive group. As a matter of fact, the results indicate that BMW Group will only have vehicles on multi-energy platforms, the PSA group 98 percent of volumes on multi-energy and 2 percent on conventional, Hyundai Motor Group 99 percent on multi-energy and 1 percent on dedicated BEV, the Renault-Nissan-Mitsubishi Alliance 46 percent on multi-energy, 6 percent on dedicated BEV and 48 percent on conventional, the Volkswagen group 89 percent on multi-energy, 8 percent on dedicated BEV and 3 percent on conventional and finally Daimler 51 percent on multi-energy, 5 percent on dedicated BEV and 44 percent on conventional.

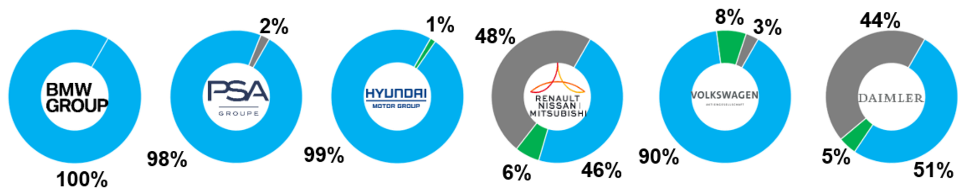


Figure 112: Volume mix per platform typology in 2024

This analysis carried out per volume mix of vehicle architectures aims also to understand which automotive groups have the potentiality of implementing economies of scale on dedicated BEV platform, thus amortizing the undertaken investment in a shorter time. Volkswagen group and the Alliance are the only ones, since they have respectively 8 and 6 percent of volume share on dedicated BEV platforms.

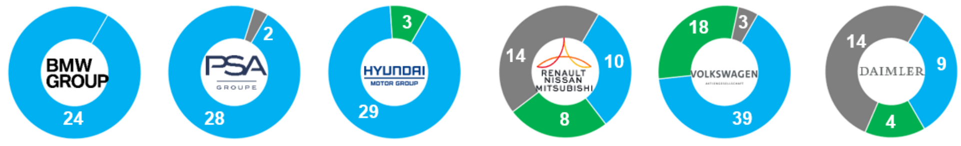


Figure 113: nameplates per platform typology in 2024

Furthermore, it is interesting to analyze the number of nameplates on each platform typology. In particular, Volkswagen group has 18 models that are equal to the 30 percent of total nameplates on dedicated BEV platforms, whereas the Alliance has 8 models corresponding to the 25 percent of offered nameplates on the same platform typology. Therefore, it is possible to state that the Volkswagen group is setting up the BEV nameplates in order to be prepared to afford the challenges in the 2025-2030 period. Furthermore, it is possible to note that most of models offered by the industry will be based on multi-energy platforms and that the vehicles above these architecture typologies will constitute most of sale volumes.

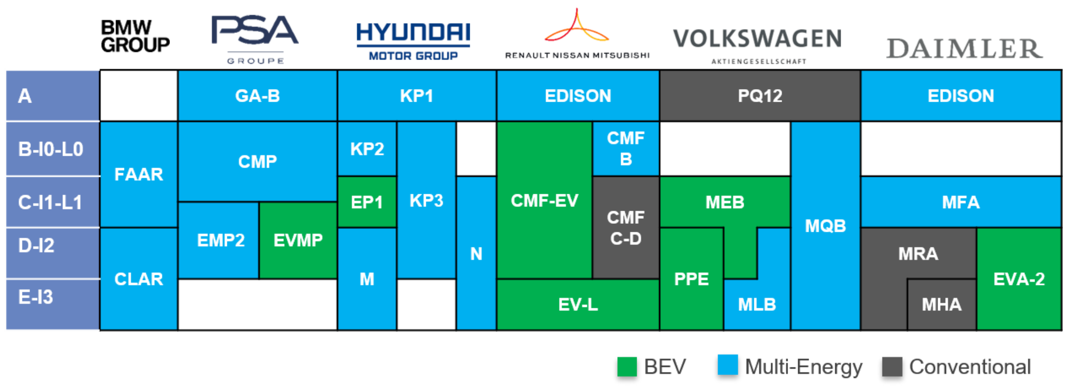


Figure 114: Platform typology adopted by major automotive industrial group in 2024

At this point, from the analysis of the platforms on each single model, the available vehicle architecture in 2024 are summed up per segment (figure 114). Analyzing the sales volumes of Daimler in 2024 (figure 115), the 43 percent of sales is forecasted to correspond to the C segment, while the D and E segments will respectively count 30 and 18 percent. Therefore, Daimler could develop a modular multi-energy platform able to cover C and D segments, thus potentially involving the 73 percent of overall sales. Nevertheless, this percentage correspond to just about 850 thousand of vehicles, thus not allowing to implement such a broad mechanism of scale economy.

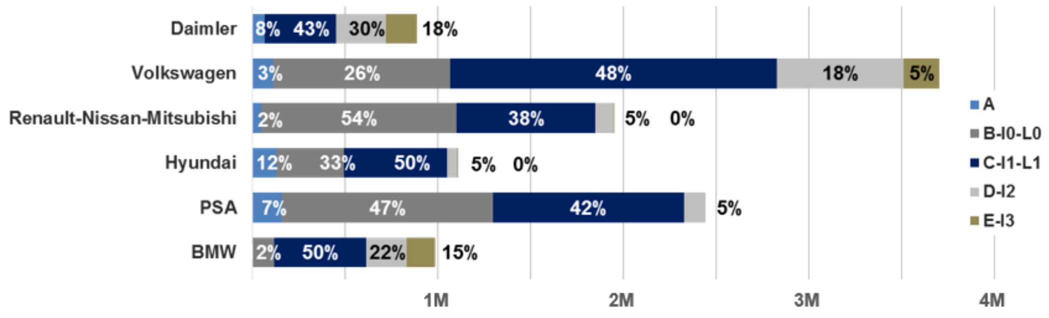


Figure 115: Segments shares per automotive group in 2024

As a consequence, Daimler strategy is oriented towards striving on premium segments, thus developing a dedicated BEV platform able to cover D and E segments. It is clear that this strategy aims to exploit the larger profit margin of premium vehicles to amortize the investment for the dedicated BEV platform. This is not a singular event, but a trend noticeable by observing the figure 114. The Volkswagen group is developing the PPE platform on these premium segments that will be used by Audi and Porsche. Renault Nissan Mitsubishi Alliance is also expected to develop a dedicated BEV platform (EV-L) on the E segment that will be employed by Infiniti. Volkswagen group and Renault-Nissan-Mitsubishi Alliance are the only automotive groups that have developed dedicated BEV platform on non-premium segment (MEB and CMF-EV vehicle architecture). The reasons behind this strategy have to be sought in the total sales volumes that allow to enable scale economies. Looking at the sales volume in 2024 and their mix per segment, the C segment of the Volkswagen group counts 48 percent of volumes, whereas the D segment is equal to 18 percent. These two segments correspond to about 2.2 million of vehicles. It is evident the choice of the German group to develop a BEV platform able to cover these two segments. The same logic can be used to assess Renault-Nissan-Mitsubishi Alliance where the B and C segments are equal to 92 percent of 2024 sales volumes. In fact, the CMF-EV platform has been developed to cover exactly the above mentioned segments. Looking at Hyundai Motor Group, the dedicated BEV platform shows low volumes by 2024. It corresponds to only one percent of volume share of the group. Nevertheless, the nameplates that are forecasted to be based on this EP1 platform are not many with respect to the ones that could potentially be constructed on it. The reason may be related to a planning presenting platform changes in favor of the dedicated BEV after 2024.

It is possible to conclude by listing some of the main key findings. The modified conventional platforms are just transitional and related to an adaptation period before the adoption of multi-energy or dedicated BEV vehicle architectures. The multi-energy platforms will be adopted by most of carmakers in the European market and will show the highest sales volumes overall. The dedicated BEV platforms will be adopted on the larger and premium segments, thus exploiting the greater profit margin or on mainstream segments with significant sales volumes, supported by the triggering of scale economy mechanisms.

8 Definitions and Glossary

μHEV: micro Hybrid Electric Vehicle

A segment is a category in the passenger car classification system defined by the FCA that identifies micro car or city cars

AC: Alternating Current

ACEA: Association des Constructeurs Européens d'Automobiles is the main lobbying and standards group of the automobile industry in the European Union

AHSS: Advanced High Strength Steel

AMC: American motor Company

AWD: All Wheel Drive

B segment is a category in the passenger car classification system defined by the FCA that identifies small cars

BEV: Battery Electric Vehicle

BSG: Belt Starter Generator

C segment is a category in the passenger car classification system defined by the FCA that identifies compact cars

CAGR: Compounded Annual Growth Rate

CARB: California Air Resources Board

CLAR: Cluster Architecture is a modular multi-energy BMW platform for rear wheel drive vehicles

CMF: Common Modular Family is a platform of the Renault-Nissan-Mitsubishi Alliance

CMG: Crankshaft Motor Generator

CMP: Common Modular Platform is a modular multi-energy PSA platform

CNG: Compressed Natural Gas

CUV: Crossover Utility Vehicle

D segment is a category in the passenger car classification system defined by the FCA that identifies mid-size cars

DC: Direct Current

E segment is a category in the passenger car classification system defined by the FCA that identifies full-size cars

EFTA: European Free Trade Association is a regional trade organization and free trade area consisting of four European states: Iceland, Liechtenstein, Norway, and Switzerland

EMP2: Efficient Modular Platform 2 is a modular multi-energy PSA platform

EPA: Environmental Protection Agency

EU28: Twenty-eight members state of the European Union

EVA2: Electric Vehicle Architecture is a dedicated BEV platform

EV-L: Electric Vehicle Large is a dedicated BEV platform under development by Infiniti

FAAR: Front Antriebs Architektur is a modular multi-energy BMW platform for front wheel drive vehicles

FCEV: Fuel Cell Electric Vehicle

FR-L: Front engine Rear wheel drive Large is a platform used by Infiniti

FWD: Front Wheel Drive

FY: Full Year

G segment is a category in the passenger car classification system defined by the FCA that identifies luxury cars

H segment is a category in the passenger car classification system defined by the FCA that identifies specialty cars

HEV: Hybrid Electric Vehicle

HV: High Voltage

I0 segment is a category in the passenger car classification system defined by the FCA that identifies small SUV

I1 segment is a category in the passenger car classification system defined by the FCA that identifies compact SUV

I2 segment is a category in the passenger car classification system defined by the FCA that identifies mid-size SUV

I3 segment is a category in the passenger car classification system defined by the FCA that identifies full-size SUV

ICE: Internal Combustion Engine

IHS: Information Handling Services Markit Ltd is a London-based global information provider

ISG: Integrated Starter Generator

JATO: JATO Dynamics Ltd is a global supplier of automotive business intelligence

L0 segment is a category in the passenger car classification system defined by the FCA that identifies small-MPV

L1 segment is a category in the passenger car classification system defined by the FCA that identifies compact MPV

L2 segment is a category in the passenger car classification system defined by the FCA that identifies mid-full size MPV

LNG: Liquid Natural Gas

MEB: Modular Elektro Baukasten (modular electric toolkit) is a dedicated BEV platform that has been developed by Volkswagen

MFA: Modular Front wheel drive Architecture is a Daimler platform

MHA: Modular High Architecture is a Daimler platform

MHEV: Mild Hybrid Electric Vehicle

MLB: Modular Langs Baukasten (modular longitudinal toolkit) is a Volkswagen group platform for longitudinal engine vehicles

MPV: Multi-Purpose Vehicle

MQB: Modular Quer Baukasten (modular transverse toolkit) is a Volkswagen group platform for transverse engine vehicles

MRA: Modular Rear wheel drive Architecture is a Daimler platform

MSA: Modular Sport Architecture is a Daimler platform

NEDC: New European Driving Cycle

NSF: New Small Family

OBC: On Board Charger

OEM: Original Equipment Manufacturer

PHEV: Plug-in Hybrid Electric Vehicle

PP: Percentage Points

PPE: Premium Platform Electric is a dedicated BEV architecture under development by Audi and Porsche

PQ: Passagier Quer (Passenger Transverse) identifies a group of Volkswagen platforms for passenger car with transverse engine

PSA: Peugeot Société Anonyme is an automotive group composed of Citroen, DS, Opel/Vauxhall and Peugeot

REEV: Range Extender Electric Vehicle

RWD: Rear Wheel Drive

SUV: Sport Utility Vehicle

TMG: Transmission Motor Generator

TNGA: Toyota New Global Architecture

UHSS: Ultra High Strength Steel

UKL: Untere Klasse Linien is a modular platform employed for front-wheel drive vehicles

WLTC: World harmonized Light vehicle Test Cycle xEV: Electrified Vehicles

YTD: Year To Date

ZEV: Zero Emissions Vehicle

ZLEV: Zero Low Emissions Vehicles

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