Ca' Foscari
University
of Venice

Master's Degree in
International management

Final Thesis

The transition to electric mobility and its impact on the Italian automotive supply chain

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Academic Year
2017/ 2018

Abstract

Electric mobility is not a far future dream anymore. Due to the recent discussions on the topic of climate change, important decisions have been made regarding the future of the automotive industry. This dissertation went through several steps in order to finally address the issue of electric mobility in the Italian context and what does the shift to the battery electric vehicles (BEVs) mean for the local supply chain. A detailed analysis of all the alternatives of product architecture has been done in Chapter 2, resulting in a very descriptive summary of all the possibilities including other alternative energy vehicles such as flex-fuel vehicles (FFVs), liquefied petrol gas vehicles (LPGVs), and vehicles running on methane (CNGVs). Chapter 3 continued with a structural description of the global automotive industry by mapping the top 100 global auto suppliers (ranking provided by Automotive News), identifying the main drivers of innovation and the players who could potentially become the “bottlenecks” of the next automotive industry. Finally, Chapter 4 provided a detailed description of the methodology and processes that were followed in order to reach an accurate image of the Italian automotive supply chain. Furthermore, the conducted study finishes with some comments and conclusions based on the findings.

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Chapter 1: Introduction

1.1 History and evolution of the automobile

Across its more than a century history, the auto industry has passed through several evolutive steps essential to the creation of the industry as we know it. The very first step which led to the emergence of such a massive sector was the invention of the steam engine – the key component of the first automobiles. This happened in the late 18th and was definitely a breakthrough technology. With slow progress, the vehicle started getting more attention in the 19th century when, firstly, the electric motor, and later the internal combustion engine was invented and, as a result, the first cars running on electricity and then gasoline were made. Although it is clearly something unexpected to most consumers, electric mobility – the central theme of this dissertation - was available from the very beginning of the automotive industry. However, due to several factors among which was the small battery capacity, electric vehicles lost the competition for the dominant design to those internal combustion engine automobiles. According to Cowan, R., and Hulten, S. (1996), the competition for the dominant design was held in the late 19th century between electric, steam, and gasoline vehicles. During this period, the production process can be characterized as quite time-consuming and resource demanding. As a result, vehicles that were sometimes very different one from another as the production of parts and components was mostly manual. As the S-shaped evolution curve model says, at the very beginning, although a lot of research and experimenting is done, the number of consumers willing to early adopt the new technology is quite limited due to the high costs and limited knowledge.

As the time passed, in 1908, the automotive industry entered a new cycle: mass production. The first businessman to have achieved this in such a successful way was Henry Ford whose name remained engraved in the business terminology forever by the Fordist system. He was the first one to transform his factories in such a way that the vehicle was moving from the beginning till the end throughout the plant meanwhile being fully completed. The work has been simplified to such an extent that literally any person could perform it. Thanks to this system, Ford was the first able to standardize the production of cars to such a point that compared to earlier years, the car was being produced and assembled many times faster. Furthermore, Ford turned the automotive industry upside down by mass producing parts and components for vehicles which has never been done before because everything was being done hand-made and the pieces were not interchangeable. As a result, Henry Ford was able to bring the car into the masses.

After almost two decades of Ford dominance, the American market became so saturated by the Model T, that sales began to drop, and General Motors slowly became the new leader. Although GM was using a similar model to Ford, meaning that it was also mass producing, Alfred P. Sloan – General Motor's CEO – thought that the consumers had different preferences. This is why GM's slogan "a car for every purse and purpose" was oriented towards differentiation while still keeping the prices low where necessary. Offering different brands for different needs and the budget was quite innovative and profitable. While Chevrolet was a cheaper car for the everyday user, Cadillacs were more expensive and premium. Furthermore, Sloan decided to implement the "model year" system according to which every car model was cosmetically updated annually. Hounshell D.A. (1984) refers to this evolutionary stage of the automotive industry as "flexible mass production", which involved an improvement of the Fordist mass production system rather than a full substitution.

The next revolutionary step that once more shifted the structure of the auto industry is the introduction of the Toyota Production System (TPS). According to Holweg, M. (2008, p. 19), this new system introduced by Toyota represents an alternative to how the automobiles are manufactured and it is quite similar conceptually to the original Fordist system. Mainly, practices such as "synchronized processes, short changeovers that allowed for small-batch production, machines that stopped in the event of a defect, and a social system designed around workforce empowerment and continuous improvement" have inspired Taiichi Ohno and Saiichi Toyoda when developing the TPS. Operating under the Japanese model implies applying the "just-in-time" principle according to which the OEM must have only the necessary amount of parts in the deposit without keeping any if not specifically required at that same moment. Because this system requires the carmaker to have only the minimum required inventory and because of the highly productive task force, the Japanese companies were building a car in less than 17 h, whereas US and European companies needed 24.9 and 35.5 h respectively (Womack, J.P., Jones, D.T., and Roos, D., 1990). Above everything said, the Japanese system allowed OEMs to be also highly productive while keeping the quality on a very high level.

Lastly, the automotive industry entered a new technological cycle involving a partial or complete change of the powertrain system from a fossil-fueled to an electric one. As to what caused this change and what are the possible solutions to that, several points are presented and explained in the following sections of this chapter.

1.2 The factors pushing the change of the automotive industry

Although it might seem that the car is constantly changing, it is not quite true. Generally speaking, the structure of the products this industry is offering remained almost unchanged during its more than a century history. International Consulting companies such as McKinsey & Company and Goldman Sachs suggest that a new era in the automotive industry is arriving. Popular trends such as electric mobility, autonomous driving cars, highly-connected vehicles, reorganization of the supply chain, new market entrants and the shift to the emerging markets started to have importance only in the past decade. Many OEMs and suppliers are investing in green technologies and in transforming driving in a much safer activity while lowering the prices and keeping cars convenient.

So, what caused such a massive shift from the initial position in which the automotive industry was in? There are several answers to that, each corresponding to a trend listed above. Firstly, as Goldman Sachs (n.d.) reports that one of the reasons that pushed carmakers into developing electric vehicles are the regulations on fuel economy and emissions imposed by national and supranational governments. Special attention should be addressed to the climate change which has been an issue for a long time. However, in the past decades, it became of critical importance due to the fact that the carbon emissions have risen considerably comparing to the previous century. According to the IPCC’s Fifth Assessment Report “it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century” (IPCC 2014, p. 4). As a result, climate change reshaped the society on a core level. Both governments and consumers promote environmentally-friendly behavior on a day to day basis. The same regulations also encourage the diffusion of alternative technologies by setting price ceilings to car manufacturers to make Electrified Vehicles (xEVs) more affordable. One example is Japan who is planning to have FCEVs under 20 thousand US dollars by 2025.

Concerning self-driving cars, the main reason why this technological trend is getting its momentum is that both carmakers and suppliers are trying to enlarge the automotive market but in the same time, they are trying to improve traffic conditions and reduce accidents. With the arrival of autonomous vehicles, new classes of customers could benefit, including disabled people. Other reasons include the changes in consumers' preferences such as the willingness to share; the emergence of the middle class in developing countries such as China and India; and, in addition, the fewer barriers to enter the industry because many of the new entrants are already familiarized with electrics and electronics and have transferable competencies that prove to be quite useful in the auto industry.

1.3 Possible solutions to the emissions problem

Increasing pressure is being put on the companies throughout the world to reduce the carbon emissions. Several paths have been considered and are being developed as solutions by the automotive industry to the carbon footprint issue. In fact, Wu, G., Zhang, X., and Dong, Z. (2014, p. 426) state that there are four possibilities for improving a vehicle's efficiency. Advancements can be made in order to improve the "engine, transmission, vehicle techniques and hybrid techniques". Considering the first out of 4 ways mentioned earlier, namely - improving engine efficiency, NHTSA (2012) suggests that this can be done by using lubricants with low friction for a better engine performance and by reducing the friction of the engine components. Moreover, it is suggested that deactivating the engine cylinders in certain situations, using variable valve timing (VVT) to reduce losses, increase power, and efficiently manage the gases left in the cylinder, apply variable valve lift (VVL) and variable valve actuation (VVA) will prove to reduce engine's loss of efficiency. Additionally, further changes to the injector could be made by using stoichiometric gasoline direct injection (SGDI).

Regarding the transmission, there are also several possibilities that, if applied, could improve a vehicle's fuel efficiency. One option is to improve the gearshift timing of the automatic transmission. As it is described in the second chapter of this dissertation, the automatic transmission offers more comfort to the driver but also is less efficient. In addition to that, gearboxes could also be improved by reducing the friction between the gearbox components, or by introducing up to 8-speed transmissions. This will allow the engine to operate more efficiently at high speed. NHTSA (2012) suggests that using Dual Clutch (DCT) and Automated Manual (AMT) Transmissions will also increase fuel efficiency.

The third possibility requires the use of lighter metals and materials to produce the vehicles. The reduction of the weight improves fuel efficiency. According to Goldman Sachs (2018), there are clear advantages when considering other metals than the normal steel. Although the conventional steel costs 1$/kg, it is quite heavy compared to aluminum, which is almost twice lighter but costs 3 times more. An intermediate alternative would be the use of high-tensile steel which is lighter than the normal steel but not as expensive as the aluminum. A further improvement would be to use an aluminum alloy which is much lighter, but it costs 6$/kg. Considering the prices that the industry offers now, it is unreasonable to think that carbon fiber will become a commonly used material in the automotive industry. Although it is very light, durable and impact resistant, the price barrier is yet to be overcome.

The last possibility is highly related to the topic of this thesis, namely electric mobility. National Highway Traffic Safety Administration (2012) along with multiple researchers suggest that further improvement of fuel utilization can be done by electrifying the vehicle either by making it fully electrical or simply transforming it into a hybrid. In order to do that, NHTSA argues that carmakers could possibly reduce the fuel consumption by applying electric power steering and electro-hydraulic power steering instead of the conventional hydraulic power steering. Moreover, as car accessories such as the alternator and oil pumps are mechanical parts, changing them to electrically-driven components could further improve the efficiency. Another option, as described in chapter 2 of this dissertation, is the use of micro and mild hybrids by applying such technologies as stop-start and integrated motor assist (IMA). Obviously, by using vehicle designs such as strong hybrid (SHEV), plug-in hybrid (PHEV), extended-range electric vehicle (ER-EV), battery electric vehicle (BEV) and fuel cell electric vehicle (FCEV) fuel consumption level will lower significantly, whereas in certain situations the emissions are totally avoided while using the vehicle (this does not apply to the production of such vehicles though). One crucial point to be made is that although partial electrification (i.e. HEV technology) and the solutions from 1 to 3 presented earlier are improving vehicle fuel efficiency, they still do not overcome the issue of emissions. No matter how improved the technology is, as long as it uses fossil fuel emissions will still be a problem.

1.4 Overview

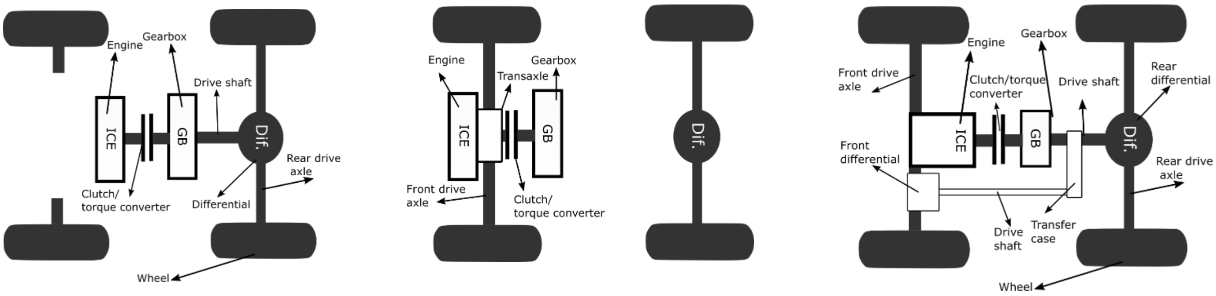
This dissertation is divided into 3 main parts. To have a better understanding of the architecture and dynamics of the automotive industry, it is crucial to have a detailed understanding of the product it is offering, namely the car. However, as complex as the car might be, the transition to electric mobility does not have an impact on the whole product but mostly only on its powertrain. This being said, Chapter 2 will look in detail at the most valuable components of each type of powertrain and describe in detail the different powertrain architectures. Moreover, it will compare them for a complete comprehension of the matter. After having identified all the possibilities of organizing the powertrain, Chapter 3 will move forward to describing the current situation of the global automotive industry. As a starting point, the most important auto players will be identified in order to understand who does what. Secondly, an analysis of the value chain will be done for a better comprehension of how the value is created and most importantly which players get to appropriate it, meaning who is the industry's "bottleneck". This analysis will cover the different types of supply chains corresponding to every variety of powertrain. A great reference framework for this part has been developed by Jacobides, M.G., Knudsen, T., and Augier, M. (2006) in "Benefiting from innovation: Value creation, value appropriation and the role of industry architectures". The third part, which represents the core contribution of this thesis to the academic world, will be developed in Chapter 4. It will involve, at first, a description of the current situation of the Italian automotive supply chain. Afterward, a qualitative analysis of the main Italian suppliers will be developed and based upon that information, hypothetical future predictions will be made followed up by conclusions and final remarks.

Chapter 2: Product architecture

This chapter focuses on the technical details of the product the automotive industry offers, namely the car. It aims to expand the reader's knowledge regarding conventional, hybrid, electric vehicles, and some other possibilities and to summarize the literature concerning all the technological alternatives mentioned earlier. All vehicle typologies mentioned above will be analyzed and described in detail using graphical representations where necessary. The information presented goes beyond the classical description of the archetypes. A lot of emphases is put on the different configurations even inside the categories of the ICE and xEV archetype. The aim of this decision is not, however, to confuse the reader but to simply illustrate all the possibilities. Next chapters will consider using only the archetypes nomenclature without any technical details about the arrangement of the components.

2.1 Internal Combustion Engine Vehicle (ICEV) powertrain architectures

A conventional automotive powertrain has several important components which can be organized in several ways. A schematic representation of conventional powertrains with rear-wheel drive (RWD), front wheel drive (FWD), and all-wheel drive (AWD) is illustrated in Fig. 2.1. The first component is the power converter device. In the case of ICEVs, this device is called the engine or the Internal Combustion Engine (ICE).



(a) (b) (c)

Fig. 2.1: Conventional powertrain architecture. (a) RWD, (b) FWD, and (c) AWD

Thanks to it, the vehicle is able to convert chemical energy (gas or diesel) into mechanical. The succeeding important element of the powertrain is the transmission represented by a gearbox. Generally, there are several gear ratios available to the driver. However, later in this chapter, examples of vehicles with no transmission (fixed gear ratio) will be presented. Depending on the type of transmission, the powertrain has either a clutch (if the transmission is manual) or a torque converter (if the transmission is automatic). The clutch is used as a coupling device in order to keep the engine and the gearbox connected or not. On the other hand, the torque converter, although having a similar function to the clutch, it functions uninterrupted because it has a continuously variable gear ratio. Moving next towards the wheels the final drive can be identified. The 5th component is the differential. Its function is to regulate the wheel rotation speed in case the vehicle is performing a curve. It has an important element but as it will be explained later, it can be substituted in more advanced powertrain architectures. The last components are the drive shaft and the wheels. Generally speaking, the driving process goes the following way: the engine transforms chemical energy into mechanical; this energy is transmitted to the wheels through the clutch or torque converter to the gearbox, final drive, differential and, finally, the drive shaft. In the following subsections, a description of the engine and the transmission is given as these components are the most complex and important in the ICEV powertrain.

From a statistics perspective, Eurostat (2018) provides data regarding the total number of registered passenger cars. According to it, the European countries with the most registered ICEVs running on petrol fuel is Italy and UK with a total of over 18 million vehicles each in 2016 (data for developed countries such as Germany is not available). The runners-up are Poland, France, and Spain with numbers around 10 million vehicles. On the other hand, when it comes to passenger cars running on diesel, the situation changes a bit. France is the leader with over 22 million cars registered in 2016. It is followed by Italy, Spain, and the UK with 16 million, 13 million, and 12 million respectively. As a general observation, there is a slight decrease in the number of ICEVs running on petrol compared to the previous years in the countries mentioned earlier, whereas diesel ICEVs seem to become more popular in the late years, with exception of France.

2.1.1 Internal Combustion Engine

ICE is classified as a piston engine. It is a powertrain component that, according to Basshuysen, R., and Schäfer, F. (2016), transform chemical energy into mechanical energy by combusting a combination of air and fuel. As stated by the same authors, ICEs can be classified into different groups depending on the criteria. For instance, if one decides to consider the pistons, there are two types of engines: those with reciprocating pistons and the others with rotary pistons. On the other hand, engines could also be classified by looking at the fuel they use, which, considering the area of interest of this thesis, can be gas or diesel engines. The first type uses compressed gasoline and air and needs an external source of ignition (the sparks) to start the combustion. On the other hand, diesel engines use a similar but, in the same time, different principle: instead of using an external ignition device to start the combustion, it brings the mix of fuel and air to such a high pressure that the combustion starts without a spark. Fig. 2.2 illustrates the layout of an engine and its main parts.

The ICE functions according to the 4-stroke principle. As stated by Basshuysen, R. and Schäfer, F. (2016), there are 4 operation cycles at the end of which the engine is able to transform the fuel into mechanical power. The process starts with the intake cycle. During this, the engine receives the mix of air and fuel. In the compression cycle, the piston starts putting pressure over the fuel mix and in doing so, it diminishes the volume of the engine chamber where this process takes place. During the third cycle, thanks to an external source of ignition, the fuel mix is inflamed and as a result of this, the piston is sent downward from the spark. As we move to the last cycle, the exhaust stroke, the piston moves upward and releases the energy. When this cycle finishes, it reaches the intake valve which opens again and lets in the mixture of atmospheric air and fuel. The 4 strokes are described graphically in Fig. 2.3. Diesel engines also use the 4-stroke principle. However, during the intake cycle, only air is entering the engine chamber. During the compression cycle, the piston compresses the air to a very high level. The third cycle is the power stroke. During this cycle, a fuel injector adds fuel to the compressed air and as a result, it ignites and bounces back the piston. Both types of engines have a similar 4th cycle.

2.1.2 Transmission

The transmission is a very important element of the powertrain. Its main functions are: helping the initial movement and, also, adjusting the power with which the engine

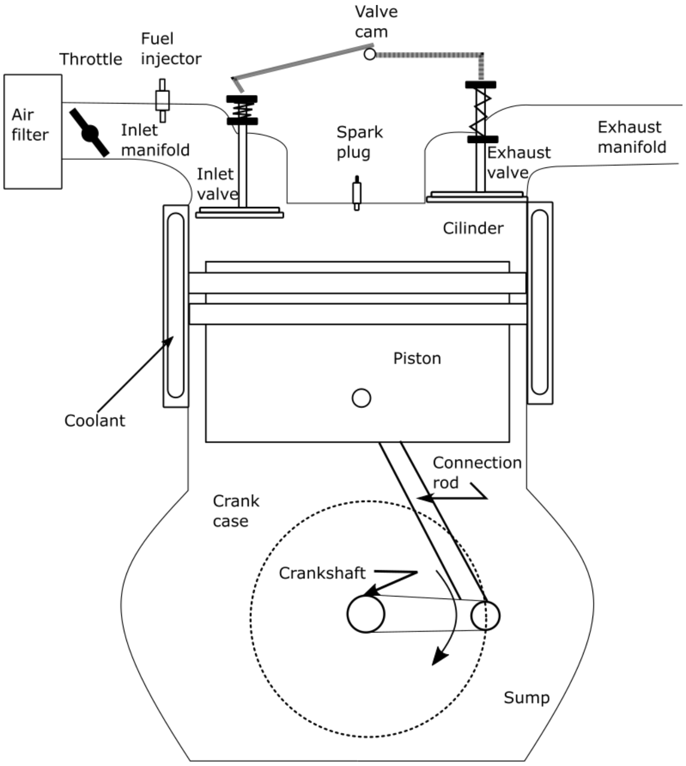


Fig. 2.2: The structure of a 4-stroke Spark-Ignition gasoline engine

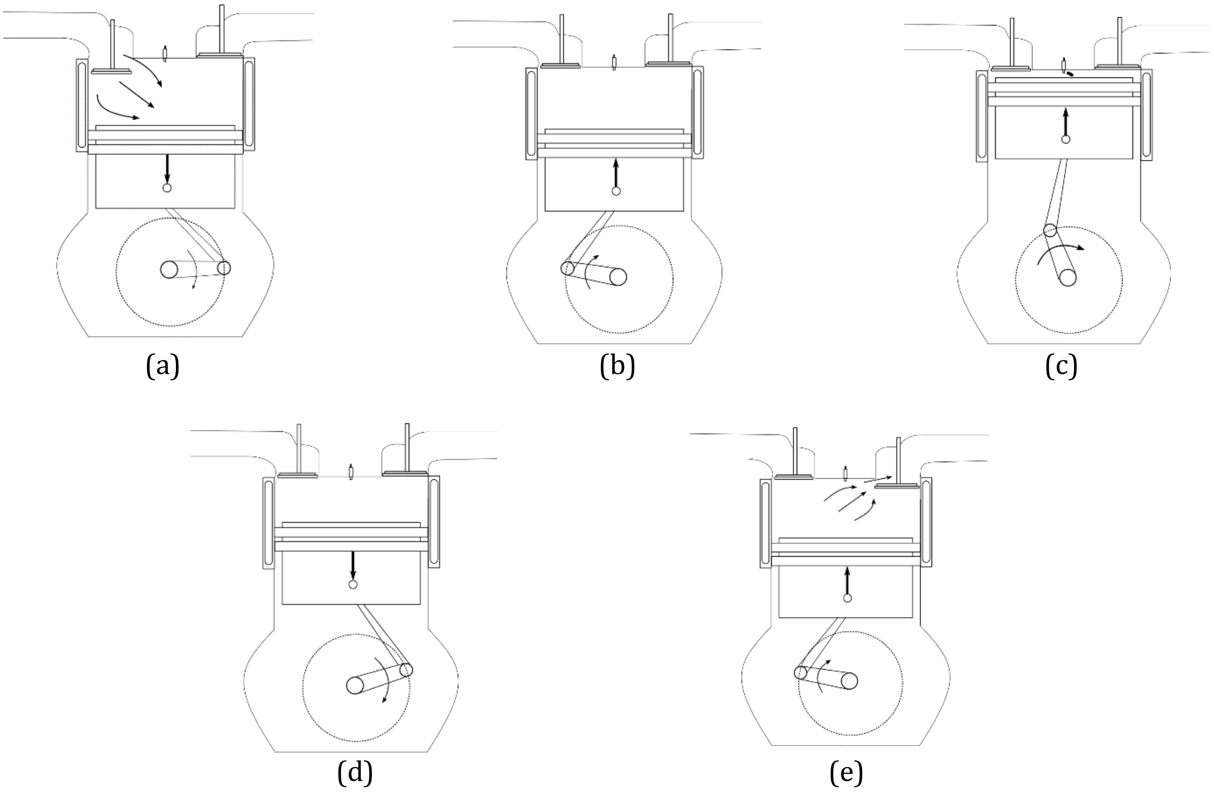


Fig. 2.3: 4-stroke principle. (a) Intake stroke, (b) Compression stroke, (c) Ignition, (d) Power stroke, and (e) Exhaust stroke

operates. It is irreplaceable in the ICEV powertrain because the ICE can generate torque and power in a restricted engine speed-range. In order for the ICEV to accelerate, it needs multi-speed transmissions. Such transmissions are able to keep the engine operating in its power range by changing the gear ratios. As stated by Bosch (2012), multi-speed gearboxes are so popular because of high efficiency, easy-to-use mechanism and adaptiveness to the traction hyperbola. However, in some situations, such as electrified powertrains, the gearbox can be omitted due to the fact that the electric motors are better able to manage the torque. More details on this matter are discussed in the next sections.

There are several possibilities of transmission systems on an ICEV powertrain. The type of transmission used on a vehicle depends on the characteristics of the power converter. They can be either grouped by the way in which they are operating, by the way the elements are organized and by the level of automation. By grouping according to the first criteria, there are multistage transmissions and continuously variable transmissions. The first ones, as stated by Basshuysen, R. and Schäfer, F. (2016, p. 696), “are based on geometrically locking transmission elements”. On the other hand, the second type transmissions are based on friction-locking functioning. While the vehicle is being driven, this type of transmission allows the gear ratio to constantly change within a certain range. Ideally, because of this feature, any engine speed is matched with a perfect torque-speed ratio. Usually, the continuously variable transmissions (CVTs) use a pulley and a belt assembly. The engine and the output shafts are connected each to a pulley while the belt links the pulleys (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. 2005). Due to the fact that CVT requires additional energy to constantly change, it is not as efficient as the first type. When looking at the level of automation, a general tendency could be observed in Europe vs. United States and Asia. Generally speaking, the European consumers use more vehicles with manual transmission, whereas the US and Asian consumers prefer the electro-hydraulically actuated automatic transmissions. Manual transmission usually has a 5-speed gearbox for passenger vehicles and even more speed gearboxes for commercial vehicles. The smallest gear ratio is achieved by using the highest gear. Using this gear, the vehicle is able to perform at high speed. On the other hand, with a big gear ratio, the vehicle uses the lowest gear and is able to have more tractive effort by increasing the torque. The gears between the two extremes are used

Transmission type	Ratio	Weight	Noise	Consumption
Manual transmission (5-speed) - 5MT	Dual-shaft transmission	Low	Low	-10%
Manual transmission (6-speed) - 6MT	Dual-shaft transmission	Low	Low	-12%
Automatic multistage transmission (5-speed) - 5AT	Set of planetary gears	Medium	Low	-0%
Automatic multistage transmission (6-speed) - 6AT	Set of planetary gears	Medium	Low	-3%
Continuously variable transmission - S-CVT	Flexible transmission mechanism (push belt)	High	Medium	-5%
Continuously variable transmission - K-CVT	Flexible transmission mechanism (chain basis)	High	Medium	-5%
Toroidal drive - T-CVT	Friction wheel transmission	Very high	Low	-7%
Automated manual transmission - E-AMT	Dual-shaft transmission with electromechanical actuation	Low	Low	-15%
Automated manual transmission - H-AMT	Dual-shaft transmission with electrohydraulic actuation	Low	Low	-14%
Dual-clutch transmission - DCT	Dual-shaft transmission with electrohydraulic actuation	Medium	Low	-8%

Table 2.1: Transmission types and their characteristics

depending on the requirements of the vehicle. The hydrodynamic transmission, compared to the manual type, uses fluids to send torque and speed. Its main elements are the torque converter and the automatic gearbox. As opposed to the manual transmission, hydrodynamic transmission, if well designed, will not allow the engine to stop running and could potentially provide nearly- ideal torque-speed characteristics. Moreover, the coupling between the ICE and the wheels are connected in a flexible manner. However, it could prove to be less efficient than the manual transmission (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A., 2005). Moving further, by using the second criteria for grouping the transmissions, there are dual-shaft and inline transmissions. In the table above (Table 2.1), different transmission types are presented and shortly described by Basshuysen, R. and Schäfer, F. (2016).

2.2 Hybrid Electric Vehicle (HEV) powertrain architectures

2.2.1 Classification of HEVs depending on the electrification level

Depending on the level of electrification, there are several types of HEVs. This section will deal with all of them in detail by describing what is the difference between each of them and what are the possible powertrain architectures. But before going further, a definition of Hybrid Vehicle (HV) is needed: "A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle. A hybrid vehicle with an electrical power train (energy source energy converters) is called an HEV." (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. 2005, p. 118).

According to Wu, G., Zhang, X., and Dong, Z. (2014) there are mainly 5 types of HEVs which differentiate themselves depending on some functions they might have or not such as the idle-stop and power assist, regenerative braking (RB), BEV driving, charger, voltage, and effectiveness. A summary of this information is presented in Table 2.2.

Starting with the micro HEV, it is a quite simple technology. The main feature that differentiates it from the ICEV is the fact that in order to improve efficiency, it turns off the engine when the driver stops the car, say in front of the traffic lights, and turns the engine on when the Vehicle Central Controller (VCC) determines that the driver is willing to move the vehicle. The same feature is held by the Mild HEVs. However, as shown in Table 2.2, it can also partially administer the power assistance and RB. Overall, it is more effective than the micro HEV (8-11% compared to the 2-4%) and has a higher voltage (48+ vs. 12). Moving next to the strong or full HEVs, the main feature that differentiates it from the previously mentioned HEVs is that at low or medium speed, it can use only electric energy, so it behaves as a Battery Electric Vehicle (BEV). Considering that compared to the mild HEVs it has fully functional RB and power assistance capabilities, this type of vehicle doubles or even triples the effectiveness. By reducing the size and the weight of the engine, both mild and full HEVs are able to be more fuel and emissions-efficient.

Criteria	**Micro**	**Mild**	**Strong/Full**	**PHEV**	**ER-EFV**
Idle-stop	◉	◉	--	--	--
Power assist		◎	◉	◉	◉
RB		◎	◉	◉	◉
BEV driving			◎	◉	◉
Charger				◉	◉
Voltage	12	48+	300+	300+	300+
Effectiveness (%)	2-4	8-11	20-35	50-60	>60
Legend: 1. ◉ -> full capacity; 2.◎ -> partial capacity; 3. -- ->inapplicable.					

Table 2.2: Comparison of hybrid electric vehicles based on the level of electrification

The next 2 types of HEV must be highlighted due to the fact that as compared to the previous 3 configurations (micro, mild, and strong HEV), they have a charger, meaning that they are quite similar to the Plug-in Electric Vehicle (PEV) and can travel a bigger distance on solely electric power. This is possible because they are equipped with larger and more powerful batteries (more than 300 V). Wu, G., Zhang, X., and Dong, Z. (2014) argue that Plug-in Hybrid Electric Vehicles (PHEVs) are able to drive fully electrical approximately 20 km. Even though PHEVs have a great potential to pollute less, they have the disadvantage that they turn on the ICE under certain circumstances such as strong acceleration and climbing even when the battery has power. As a PHEV counterpart, GM introduced the concept of Extended Range Electric Vehicle (ER-EV). This powertrain architecture and functionality is very close to the BEV. One might see it as an intermediate step between the PHEV and the BEV. Similar to the PHEV, the ER-EV has two energy converters (EM(s) and ICE) but the ICE is more of a backup plan rather than an essential element of the driving process. Petrol is used only when the electric power is over. Considering this feature, ER-EV can further diminish the consumption of fossil fuels and the emissions.

Up to this point, this chapter described several types of HEVs depending on the level of electrification. In the next sections, however, HEVs are classified from a different perspective: how the powertrain components interact and how they are arranged. Most papers which discuss HEVs agree that there are mainly 3 archetypes of HEVs: series, parallel, and power-split. Each of them has its advantages and disadvantages and each of them has a different level of complexity.

2.2.2 Series HEV powertrain architectures

This powertrain architecture includes an ICE, an electric generator (EM1) which is connected to the ICE through a mechanical link, an electric motor (EM2) which is connected to the generator and the battery through an electrical link, an Energy Storage System (ESS), a Vehicle Central Controller (VCC), transmission system, and other elements. A detailed representation of such an HEV can be found in Fig. 2.4. Citing Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005, p. 121) “A series hybrid drive train is a drive train where two power sources feed a single powerplant (electric motor) that propels the vehicle”. The specificity of this type of layout is that in the series hybrid the ICE does not have a mechanical link with the wheels. The purpose of the ICE is to transform fossil fuel into energy which then is passed next to the EM1. The purpose of the latter is to transform the energy produced by burning the fossil fuel into electric power. This energy is then sent to the motor (EM2) which, in turn, is responsible to send the energy to the wheels and move the car. There are different ways that a carmaker can arrange these components. Fig. 2.5 (a) is a graphic representation of a series HEV with the ICE and EM1 being positioned in the front, while the EM2 and the ESS are located in the rear part of the car.

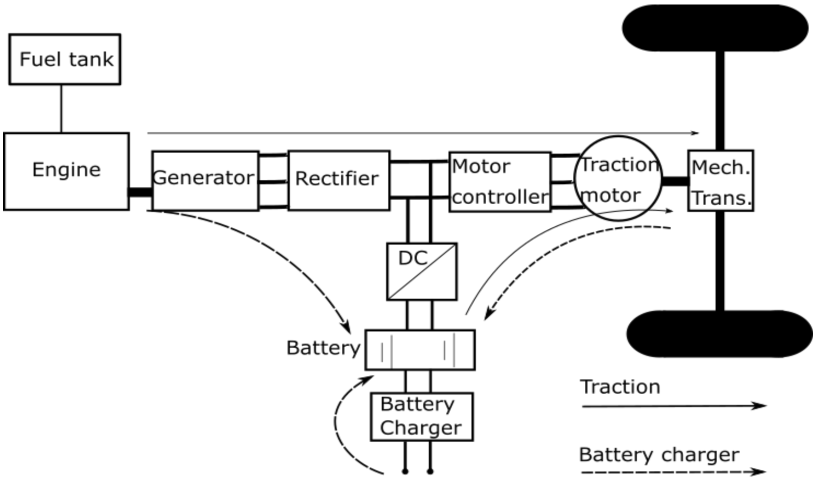
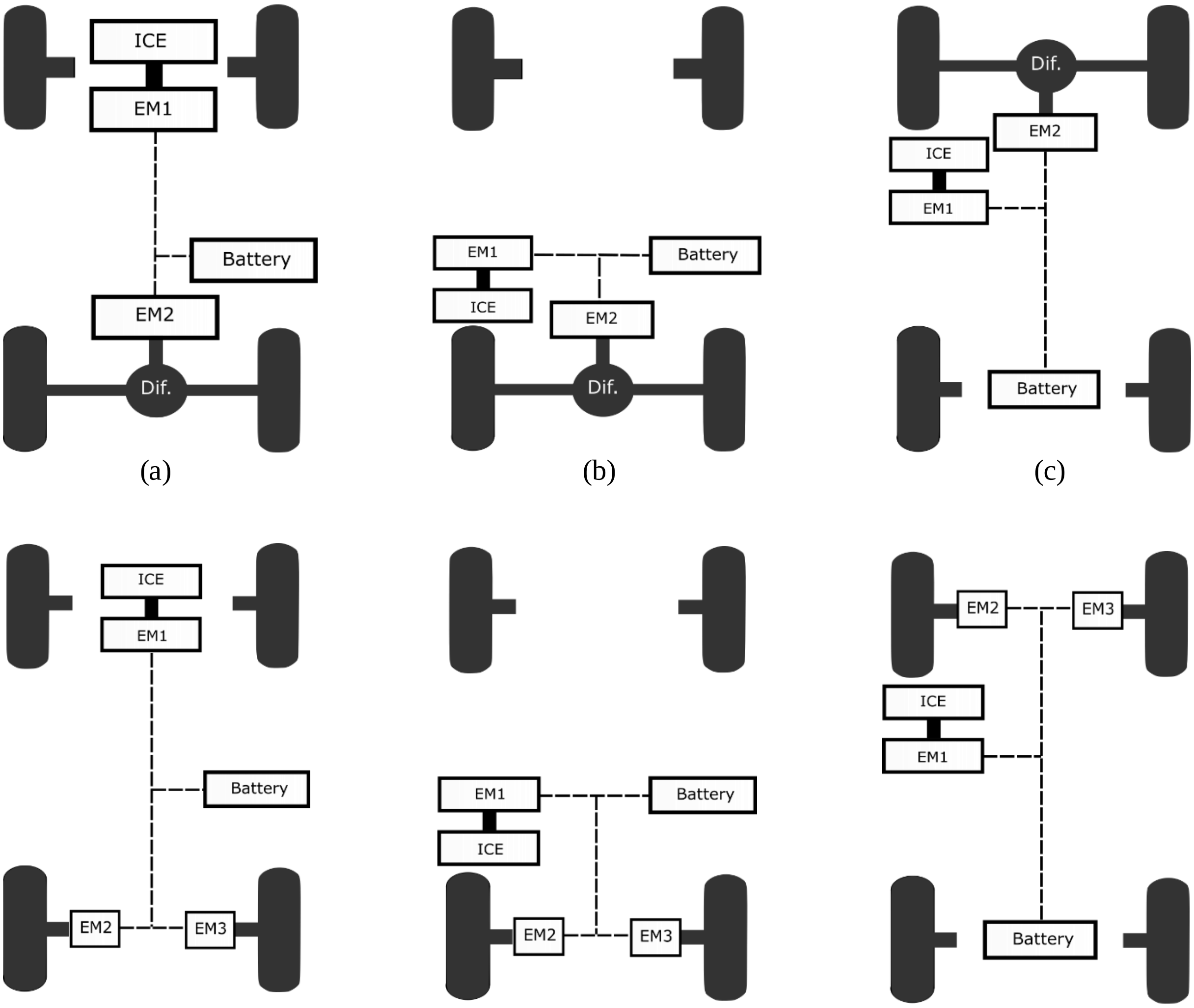


Fig. 2.4: Schematic representation of a series hybrid

Another possibility is to position all the elements in the back of the car such as the configuration in Fig. 2.5 (b). A third possibility would be to have a similar layout as the one in Fig. 2.5 (b) but instead of putting everything on the rear side of the car, the powertrain components are placed in the front of the vehicle.

As an alternative to the previously mentioned layouts, Wu, G., Zhang, X., and Dong, Z. (2014) and Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005) state that the same configurations are possible without a differential by adding 2 or 4 EMs instead of one next to the wheels. Fig. 2.5 (d), (e), and (f) depict graphic representations of such possibility.

There are 7 operation modes that the series HEVs can have. The first one is working only with electric power. Under this scenario, the ICE is turned off and the batteries become the only source of energy. The second mode is the opposite of the first one, meaning that it is only the ICE that works, and the battery is turned off, meaning that it does not give or receive any energy. The next operation mode is the hybrid one which uses both energy sources. When the vehicle is operating under the fourth mode - the battery charging mode while the ICE is working, the engine-generator tandem produces energy both to propel the vehicle and to recharge the battery. The fifth mode involves the electric motor and the batteries. Under this scenario, the engine-generator does not function, and the power generated by the motor is sent to the batteries. The sixth mode turns off the motor and uses the engine-generator to recharge the battery. The last one involves a hybrid combination of all the elements to recharge the batteries.



(a) (b) (c)

(d) (e) (f)

Fig. 2.5: Series hybrid powertrain architectures. (a) Front-engine rear-drive with differential; (b) Rear-engine rear-drive with differential; (c) Front-engine front-drive with differential; (d) Front-engine rear-drive 3 EMs; (e) Rear-engine rear-drive 3 EMs; (f) Front-engine front-drive 3 EMs.

As with any technology, the series HEVs have their advantages and disadvantages. Starting with advantages, it is important to mention that due to the fact that the engine is mechanically independent of the wheels, it is able to function highly-efficient and so to reduce both the fuel consumption and the emissions amount. Moreover, taking into account that the electric motors have great traction torque, series HEVs do not need multi-gear transmissions. This simplifies the layout and the cost quite significantly (Wu, G., Zhang, X., and Dong, Z. (2014); Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005); Chan, C.C., Bouscayrol, A., and Chen, K. (2010)). Going further, another advantage that this type of hybrid has is that because it is only the electric motor that launches the vehicle and it has outstanding torque-speed characteristics, this type of vehicle is great for low-speed and heavy vehicles which is in fact confirmed by the fact that it is frequently used in busses or locomotives. Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005) suggest that for an even bigger improvement, the differential and the motor could be substituted by two or four motors attached close to the wheels.

On the other hand, this technology is not flawless. The first thing to notice is the potential of losing some energy when being converted from mechanical to electrical by the engine-generator and from electrical to mechanical by the electric motor and the wheel drive. If poorly designed, there might be substantial energy losses. Furthermore, the price also rises with the additional components being added to the powertrain. It is no secret that HEVs cost more than the conventional ICEVs. A third point to be made is that since the electric motor is the only one propelling the vehicle, it is crucial to perfectly design it to meet the requirements of the vehicle. Adding to this, in case the electric motor fails, there is no other system that could substitute it such as in the parallel HEVs which will be described later.

2.2.3 Parallel HEV powertrain architectures

The feature that differentiates the parallel HEVs from the series ones is that both the engine and the electric motor can drive torque directly to the wheels, individually or jointly. Wu, G., Zhang, X., and Dong, Z. (2014) argue that the motor can as a booster for the ICE or as a generator in order to improve ICE's efficiency. The parallel HEV powertrain is composed of an engine, electric motor, transmission system, a coupling device, a battery and a vehicle central controller. Referring to the work of Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005), in most of the situations, the electric motor and the engine are coupled together by mechanical coupling. Fig. 2.6 describes the layout of a parallel hybrid. The mechanical coupling in Fig. 2.6 can be either torque-coupling or speed-coupling or sometimes a combination of both. Depending on the requirements, one or the other could be a better option for the vehicle. For instance, torque-coupling allows the vehicle to add the ICE torque and the EM torque keeping the speed constant and work better when

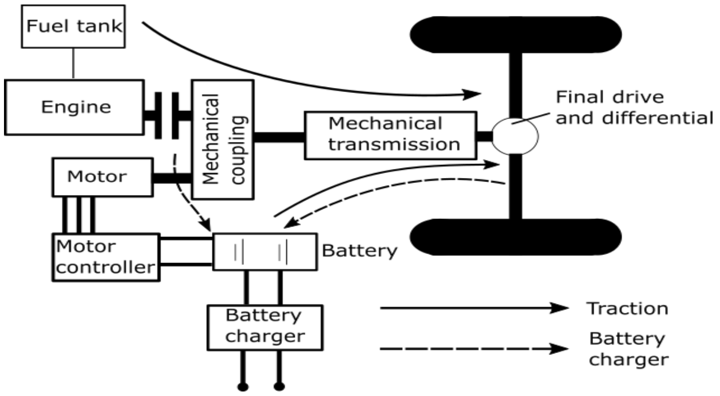
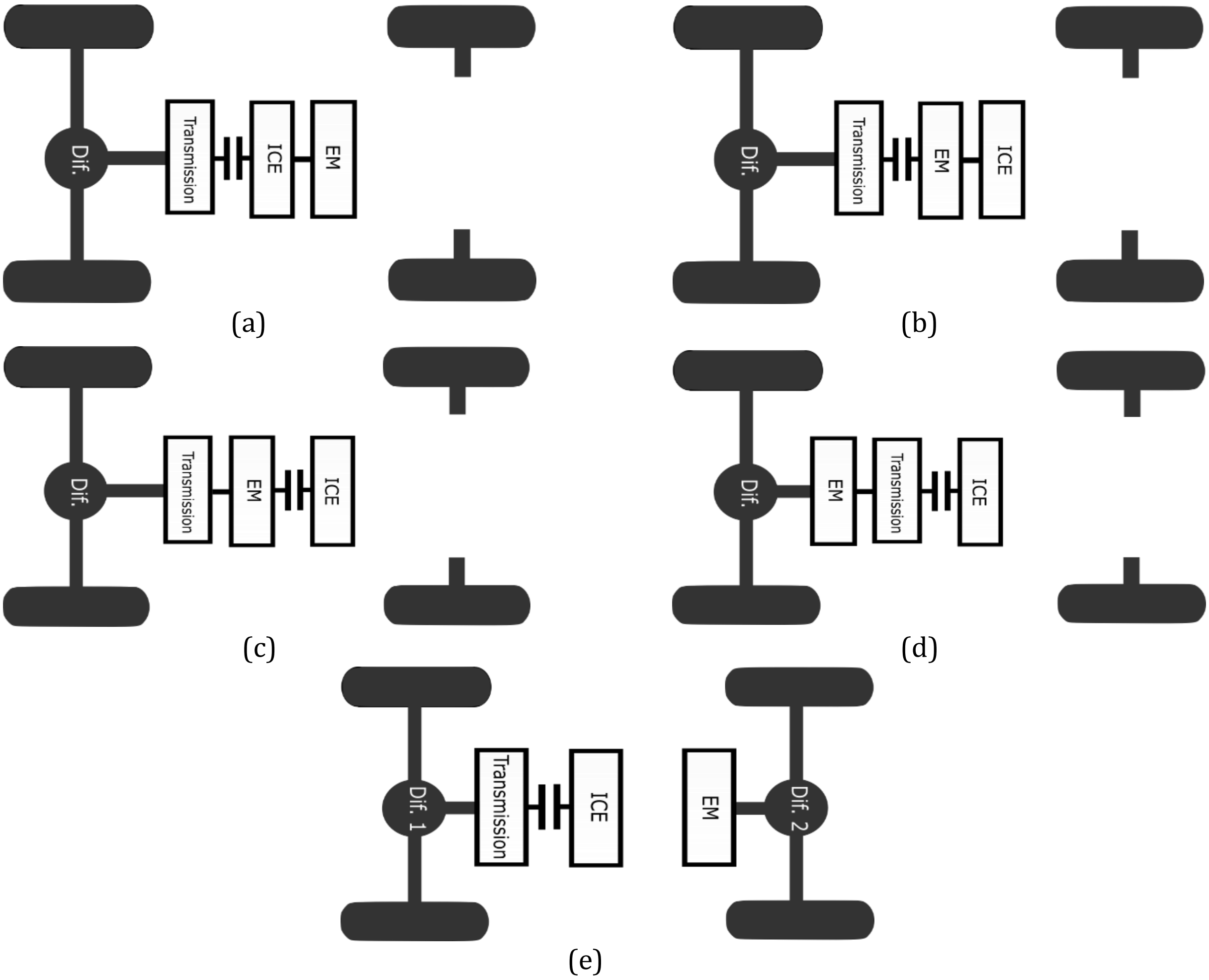


Fig. 2.6: Configuration of a one-shaft parallel hybrid drivetrain



(a) (b) (c) (d) (e)

Fig. 2.7: Parallel hybrid designs. (a) type-a parallel architecture; (b) type-b parallel architecture; (c) type-c parallel architecture; (d) type-d parallel architecture; (e) type-e parallel architecture

climbing a hill. On the other hand, at high speed, a better fit is the speed-coupling which adds up the speed of the engine and the motor keeping the torque constant (Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005). Depending on some of the components, there are several layouts possible. For instance, the position of the EM is variable. Fig. 2.7 shows 5 possible ways of rearranging the powertrain depending on how the motor is placed. Furthermore, transmission type is also to be selected. Carmakers could decide to use a conventional manual transmission (MT), a dual-clutch transmission (DCT), an automatic transmission (AT) or a continuously variable transmission (CVT). The presence of the clutch in the powertrain depends upon choosing the type of transmission system is being used (i.e. if MT or DCT is used the clutch is needed, otherwise it can be changed to a torque converter). Comparing to the series HEVs, parallel hybrids have less energy conversion, meaning that they do not risk losing too much energy in the process.

By taking as a reference framework the work of Wu, G., Zhang, X., and Dong, Z. (2014) and using other scientific papers and books throughout, in the next paragraphs a more detailed description of the 5 configurations depicted in Fig. 2.7 will be given.

2.2.3.1 Type-a parallel architecture

Looking back at the types of hybrid vehicles grouped by the level of electrification, this configuration of the parallel HEV is clearly quite simple and allows the electric motor to be an efficiency improvement component rather than a second energy propulsion system. Considering this, it can only be applied to micro and mild HEVs. By comparing this architecture to the one of a conventional vehicle, it is rather easy to notice that the differences are minimal, making it a cost-effective solution for an efficiency improvement. In the case of micro HEVs, the starter is replaced with a 3-5 kW EM and some additional components such as the engine control unit (ECU), pedal sensors and control algorithms. Thanks to these changes, the car is able to become more fuel efficient in urban areas due to the fact that it is able to stop and launch the engine smoothly when the driver's intentions are such. On the other hand, the role of the motor increases in the case of mild HEVs. First of all, its power is increased up to 12 kW which allows it to do the same functions of a micro HEV but with additional features such as partial RB. Secondly, it is able to improve the engine efficiency by adding or extracting some energy from the battery in certain situations.

2.2.3.2 Type-b parallel architecture

As shown in Fig. 2.4 (b), this configuration requires the electric motor to be placed in between the engine and the transmission-clutch tandem. It is quite similar to the type-a configuration, however, taking into consideration the fact that there is not much space in between the two components mentioned earlier, the EM must be well designed in terms of volume. Comparing to the previously described type-a architecture, type-b is not as cost-efficient and is not compatible with micro HEVs. Taking into account these factors, it is not a very popular solution, which is confirmed by the fact that it is only Honda who is using this technology.

2.2.3.3 Type-c parallel architecture

Starting with this architecture and the next two, these configurations are able to work in battery electric vehicle (BEV) mode (i.e. the ICE can be turned off). Type-c hybrid is frequently called pre-transmission parallel hybrid because the electric motor is located between the coupling device and the transmission. Such architecture can be applied to all the types of hybrids starting with the mild one (i.e. mild, strong/full, PHEV, and ER-EV). It can operate in full electric mode if the power demand is low for several dozens of kilometers. However, when the power demand exceeds the limit of the electric motor, the ICE is put into work. When this happens, the EM can function as a substitute for the starter or a traction motor and also strongly contribute to RB. Under this layout, it is the transmission who is modifying the torque of the ICE and the EM. Both have to have similar speed range (Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005).

Comparing this architecture to the other ones, it is well balanced in the costs, dimensions, fuel-efficiency, and flexibility. The main developments in this field are done through the hybridization of the transmission system and the electric motor. Examples given by Wu, G., Zhang, X., and Dong, Z. (2014) are Volkswagen Jetta Hybrid, Nissan Pathfinder Hybrid, and Acura RLX Sport Hybrid. On the contrary to all the advantages, it is not a flawless configuration. For instance, it goes further from the ICEVs and increases its complexity. It needs bigger batteries compared to type-a and type-b architectures and it requires the manufacturer to have excellent design skills in order to be able to fit the motor into the hybrid transmission. Furthermore, some non-powertrain related components such as the air conditioning must also be modified because their usage during the BEV mode will drain up the battery too fast as the engine is not rotating.

2.2.3.4 Type-d parallel architecture

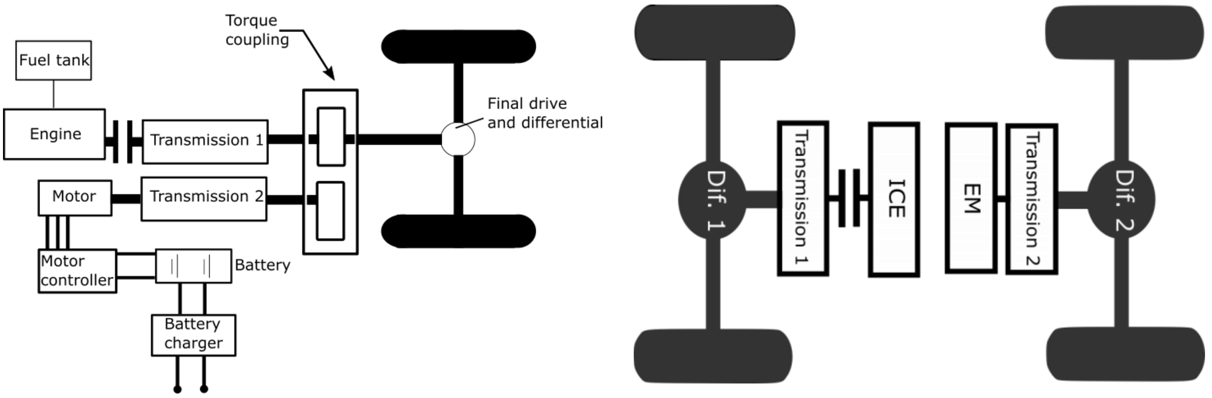
As compared to type-c hybrid architecture which is called pre-transmission parallel HEV, type-d is frequently named post-transmission parallel architecture for the same reasons mentioned earlier (i.e. the position of the EM is placed after the transmission). In this situation, the transmission modifies only the ICE torque whereas the motor is able to deliver torque directly to the wheel drive. The transmission is used only to improve the efficiency and performance of the engine. Using this configuration requires a bigger EM compared to the pre-transmission design (Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005). Similarly to type-c architecture, BEV operation mode is also possible if the power demand does not exceed the limits of the EM. There is one important difference, however: the motor is mechanically connected to the wheels through a fixed gear, meaning that there is no actual transmission between the wheels and the motor. This, in turn, allows the vehicle to use the automated manual transmission AMT more efficiently. In simple words, when the gear shift is happening, there is usually a torque-gap. The motor helps by providing torque while the gear shift is done. In order for this technology to be nearly-perfect, it needs to have a motor which has a wide speed range. Furthermore, because how the EM operates is determined by the speed of the car, it could be rather fuel inefficient in certain situations when being in BEV mode.

2.2.3.5 Type-e parallel architecture

This parallel architecture is very similar to type-a and type-b. The difference is that the motor is placed to the opposite wheel drive making it an all-wheel-drive (AWD) vehicle. In the same time, it is very similar to the conventional ICEV powertrain. It differentiates itself only by having the EM system.

2.2.3.6 Dual transmission parallel architectures

As noticed in Fig. 2.7, all the parallel hybrid powertrain architectures described earlier use a single transmission for both the propulsion systems. However, there is the possibility of installing 2 transmissions (i.e. each propulsion system has one). In Fig. 2.8(a), for instance, transmission 1 could be multi-gear and transmission 2 could be single-gear. According to Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005, p. 125), "The use of a single-gear transmission takes inherent advantage of the high torque characteristics of electric machines at low speeds". On the other hand, the multi-gear transmission is the best fit for the ICE since it improves its efficiency and diminishes the consumption of the battery energy by lowering the speed range of the automobile. They are quite similar to the type-d and type-d architectures. As stated by Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005), the two multi-gear transmissions layout is more performant and efficient than other configurations because two multi-gear transmissions allow for more opportunities for the ICE and EM to work under optimum conditions. Moreover, this design creates a lot of space for flexibility when the ICE and the EM are designed. Another possible design is illustrated in Fig. 2.8(b). As one might notice, the design uses two separated axles, each having its own transmission and an independent propulsion system (the motor on one side and the engine on the other). The main advantage of such a design is that the conventional powertrain architecture is changed only by adding an extra motor and transmission on the other axle keeping it rather simple and that, in addition to the RWD or FWD, AWD is possible. This improves the



(a) (b)

Fig. 2.8: Parallel architecture with a two-shaft design. (a) two-shaft design connected to a single wheel drive; (b) two-axle design, each wheel drive has its own propulsion system

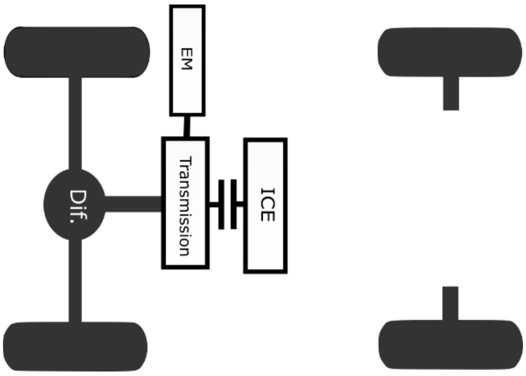


Fig. 2.9: Parallel hybrid architecture with three-port transmission

traction on icy roads and decreases the grip on a single wheel. On the other hand, this architecture requires more installation space. This issue could be overcome by using two small motors placed next to the wheels instead of one big EM (Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005). Furthermore, as an improvement to the dual transmission system, Wu, G., Zhang, X., and Dong, Z. (2014) state that there is the possibility to fuse them into a hybrid one called three-port transmission due to the fact that it is connected to the EM, ICE, and the wheel drive simultaneously. An example of a powertrain with such transmission is presented in Fig. 2.9.

Concluding this section, Table 2.3 summarizes to what type of hybrid can the previously discussed configurations be applied.

	Micro	Mild	Strong/full	PHEV	ER-EV
Type-a	◉	◉			
Type-b		◉			
Type-c		◉	◉	◉	◉
Type-d		◉	◉	◉	◉
Type-e		◉	◉	◉	◉

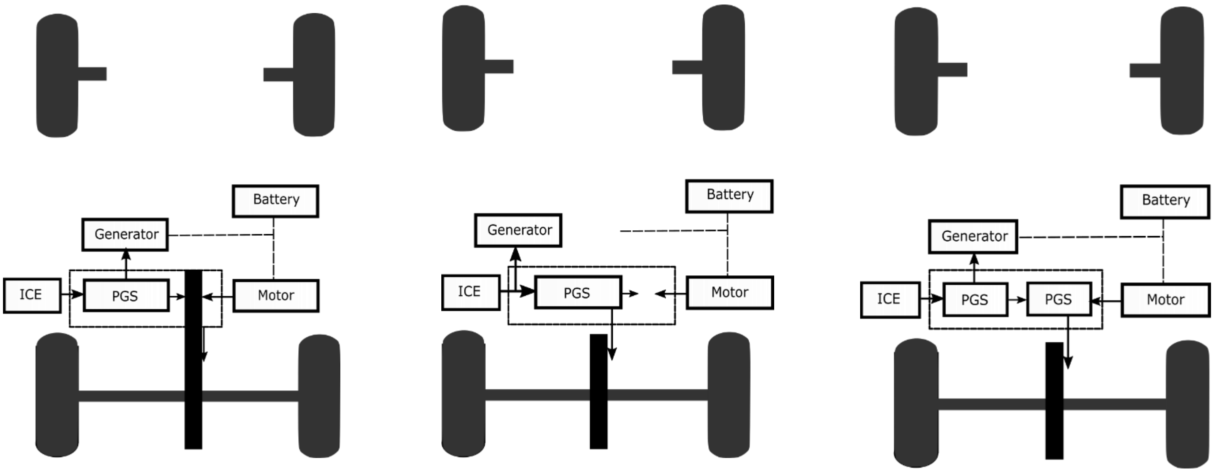
Table 2.3: Possible applications of each type of parallel hybrid powertrain architecture

2.2.4 Power-split hybrid architectures

Previously, this dissertation described the series and the parallel hybrid powertrain architectures. However, before moving on to the Battery Electric Vehicle (BEV) powertrain architectures, a third basic hybrid architecture archetype must be reviewed: power-split hybrid architectures. This category of architectures could be described as an intermediate solution between series and parallel hybrids and aims to overcome the disadvantages of each type.

The main components of a power-split (also called series-parallel) hybrid powertrain are the power-split device (PSD), the engine, two motors, energy storage system (ESS) and a vehicle central controller (VCC). This technological design allows the engine torque to be divided into two parts and then be delivered through an efficient mechanical path and a not so efficient electric one. To do so, a planetary gear set (PGS) is used (the concept of how it works is explained in section 2.3.2). Its main functions are to control that the ICE works only in its efficient zone and to deliver to the EMs the torque so that they have a big torque output level. Thanks to this configuration, power-split HEVs are very efficient when it comes to fuel consumption. However, everything comes at a cost. Although the engine works only on its peak-efficiency level, this does not apply when the vehicle is running at a very high speed. Moreover, considering everything above, Wu, G., Zhang, X., and Dong, Z. (2014) argue that due to the relatively rigid design architecture (both the ICE and the EMs must be connected with the PSD) there is not too much room for change. Furthermore, this design is most frequently more expensive than the typical parallel configuration and, on top of that, it limits the vehicle when it accelerates.

After considering all the possibilities of a power-split design, Wu, G., Zhang, X., and Dong, Z. (2014) propose three basic architectures: input-split, output-split, and compound-split. However, that being said, they suggest that there are many more configurations other than the three mentioned. Each of the types is depicted in Fig. 2.10. By looking at each of the three designs, one could observe that the input-split architecture requires both the engine and the motors to be connected to the PSD while one of the EMs is directly linked to the output shaft. On the other hand, output-split configuration requires the output shaft to be connected to the PSD together with the ICE and one motor while the second motor is linked to the engine. The third basic power-split architecture requires a PSD with two PGSs. This allows the PSD to have 4 ports instead of 3 because each PGS provides 2 ports while 1 is used to link the two PGSs. Of course, by changing the location of the ICE and the motors, different possibilities could be generated.



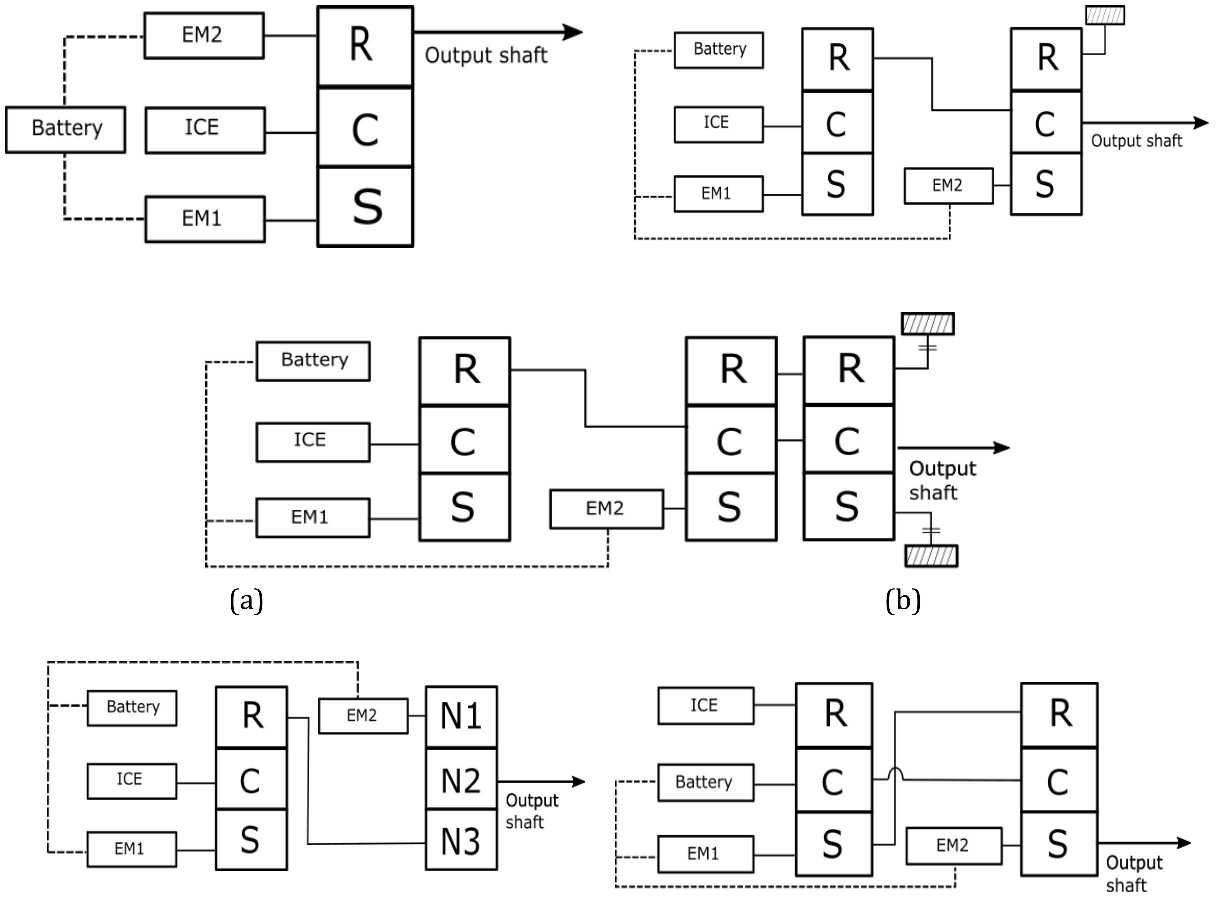
(a) (b) (c)

Fig. 2.10: Basic power-split hybrid architectures. (a) Input-split, (b) Output-split, (c) Compound-split

In their 2014 work, Wu, G., Zhang, X., and Dong, Z. contribute to the scientific literature by stating that the most popular basic power-split architecture is the first one, input-output. This design is “the only one suitable for full-range single-mode hybrid system” (Wu, G., Zhang, X., and Dong, Z. 2014, p. 440). Examples of input-split configurations can be found in Fig. 2.11.

Moving next to output-split hybrid architectures, it is quite important to mention that they are comparable to a 2 EMs electric vehicle. At low speed, the efficiency level is quite low. However, as the speed increases, the efficiency increases due to the fact that the power starts to be transmitted through a mechanical path rather than electric. As a counterpart to the input-split architectures represented by Toyota Prius and Ford Escape Hybrid, the output-split architecture is represented by GM Chevrolet Volt.

Compound-split architecture is also a very efficient design. It can be fit on both input- and output-split architectures. In addition to the flexibility, it requires less torque power from the motors. Its main limitations are the complicated structure and efficiency loss when the vehicle is not driving a high-range speed. Fig. 2.12 and 2.13 show examples of output- and compound-split architecture respectively.



(a)

(b)

(c)

(d)

(e)

Fig. 2.11: Input-split architectures

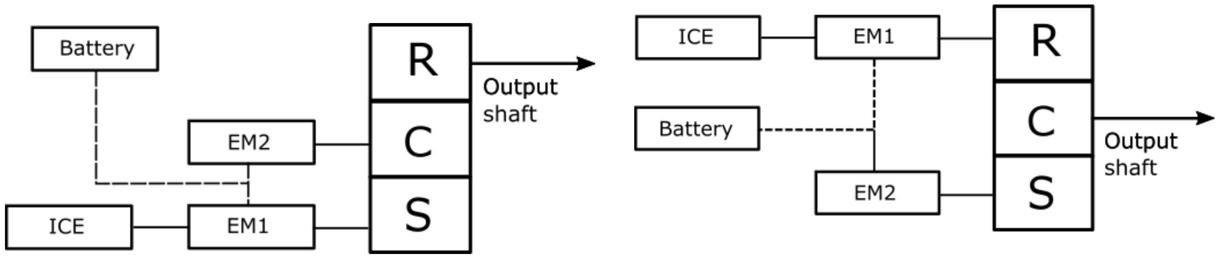


Fig. 2.12: Output-split architectures

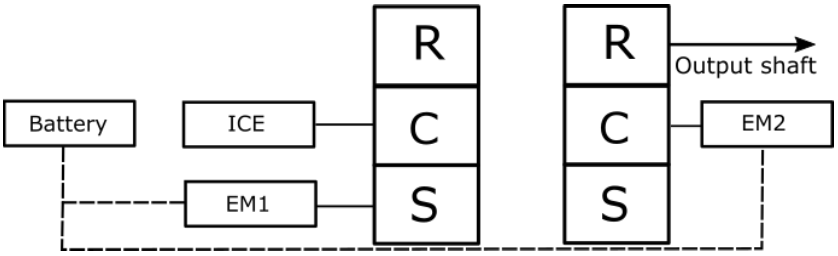


Fig. 2.13: Compound-split architecture

2.2.5 Compound hybrid powertrain architectures

An additional archetype of hybrid powertrain architecture has to be mentioned and described beyond the 3 basic architectures (i.e. series, parallel, power-split). There are multiple ways to organize a compound hybrid powertrain, however, only some of them are economically and technologically feasible for further applications: series-parallel, series-power-split, parallel-parallel, and power-split-power-split.

The series-parallel (SP) hybrids mainly have the structure of a series architecture with two motors. However, above the mentioned elements, a coupling device is added and a transmission in order to be able to send engine torque to the wheel-drive mechanically.

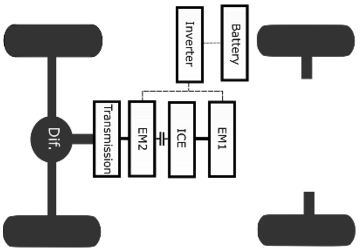
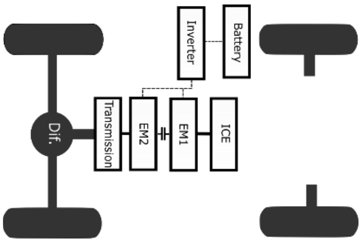
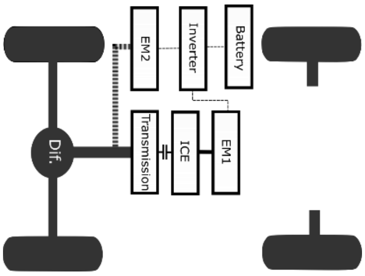
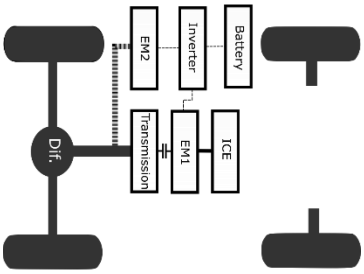
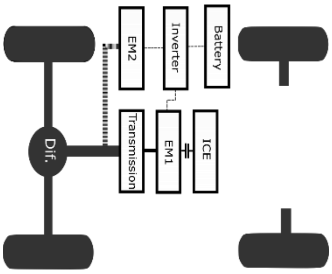
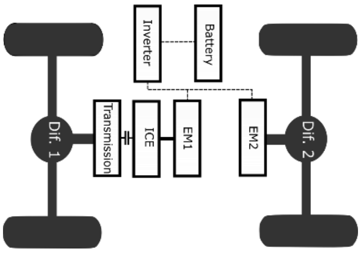
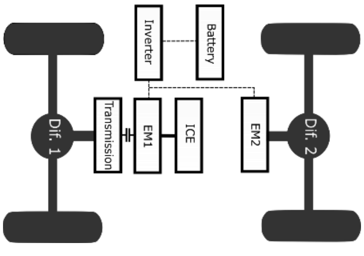
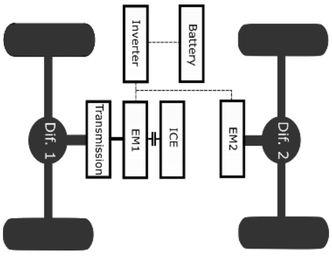
EM1/ EM2	1	2	3
3			Not possible
4			
5			

Table 2.4: Series-Parallel architectures

The work of Wu, G., Zhang, X., and Dong, Z. (2014) states that SP HEVs are able to operate in series mode, parallel mode, and a mix of two depending on the driving environment. Considering that this architecture is, although complex, superior to both series and parallel architectures, it is also better at distributing the power and the layout is somehow simpler than power-split hybrids. To have a better comprehension of what are the possible alternatives of having a SP HEV powertrain architecture, consult Table 2.4. The configurations shown in Table 2.4 are the result of a matrix modelling. By moving horizontally from left to right through the table, the generator (EM1) is changing its position. It starts by being post-ICE positioned, then it moves in between the clutch and the engine and lastly it is placed between the transmission and the coupling device. On the other hand, by moving vertically from up to down, the electric motor changes its location. In the upper row of the table, EM2 is placed as in a series hybrid vehicle. Next, it moves to a parallel layout but to the same wheel drive. In the last case it moves to the other wheel drive allowing the vehicle to operate not only FWD and RWD, but also AWD. Among the 8 configurations, the same general principle is shared. For instance, looking closer at the 6th layout, the vehicle can drive in full electric mode when the engine is off, and the clutch is not closed. Another mode is when the engine works but the clutch is still open. Under this mode, the ICE-generator produces energy and sends it to the battery (i.e. series mode). The moment when the clutch closes, the vehicle starts operating in the parallel mode. A fourth possibility is to engage only the engine. Each of the modes has its advantages and limits. Fig. 2.14 illustrates all of the 4 operating modes.

Regarding the power-split compound architectures, such designs can be obtained by adding some elements (such as additional clutches and brakes) to the basic power-split hybrids. In their work, entitled "Powertrain architectures of electrified vehicles: Review, classification and comparison", Wu, G., Zhang, X., and Dong, Z. (2014) affirm that since power-split hybrids have 2 powerful motors, it is reasonable to have series and power-split modes on a compound architecture. An example of such design being applied in a real scenario is Chevrolet Volt. Moreover, they assert that compound-split PSD could be used in input- and output-split hybrids and that a compound hybrid with multiple power-split modes can be developed. The 2-mode hybrid system (input- and compound-split) developed by GM could be referred as to an example of the compound power-split hybrid system. Furthermore, power-split together with parallel architectures could also be combined.

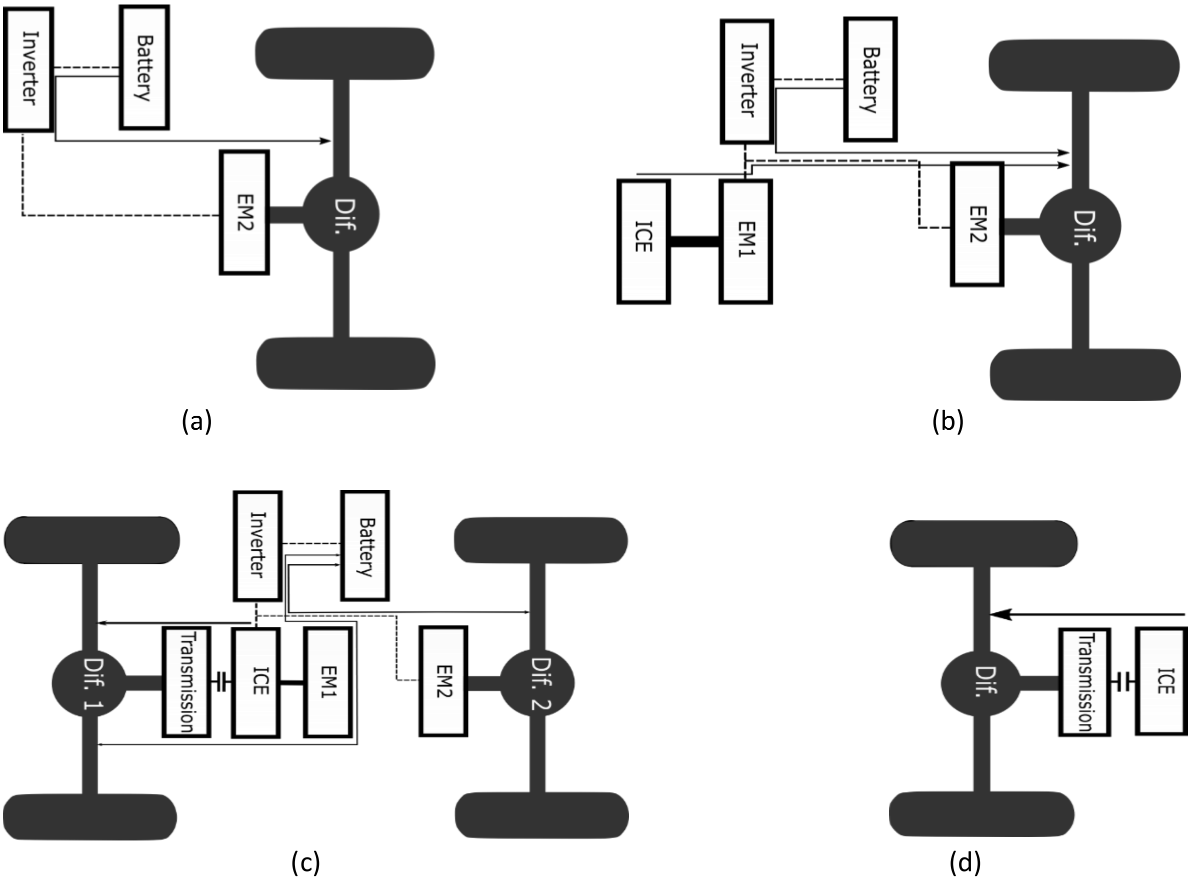


Fig. 2.14: 4 operation modes of the 6th Series-Parallel hybrid architecture. (a) BEV, (b) Series, (c) Parallel, (d) ICE

2.3 Battery Electric Vehicle (BEV) powertrain architectures

There are multiple BEV powertrain architectures depending on factors such as the transmission system, the number of EMs that are being used and their positioning. To have a better understanding of the concept, below there is a detailed description of the main archetypes, starting with the no transmission and one EM type, going next to the multiple-speed gearbox and one EM type, and finishing with the powertrain architecture that includes more than one EM.

2.3.1 BEV with no transmission and one EM

According to Wu, G., Zhang, X., and Dong, Z. (2014, p.429), “This is the simplest layout and widely employed by almost all PEVs on market”. Comparing it to the conventional ICEV powertrain architecture is rather an easy task due to the fact that it is very similar in how it is arranged while the only difference being the lack of the transmission and the clutch (Larminie, J., and Lowry, J. 2003). To have a better image of the layout, Fig. 2.15 is a representation of such a powertrain. This layout uses a differential in order to drive a couple of wheels. There are certainly other options that could substitute the differential, but as stated by Larminie, J., and Lowry, J. (2003), the differential being included in the powertrain architecture offers many advantages, such as reliability due to the fact that it is a commonly used and produced component and has been tested throughout the past century. Nevertheless, according to the same authors, its main disadvantages are the driveline power loss, the weight, and the inefficient space utilization. A typical example of a vehicle having this type of layout is the 2012 Tesla Model S (Tesla, 2012) and Nissan Leaf (Nissan, 2018).

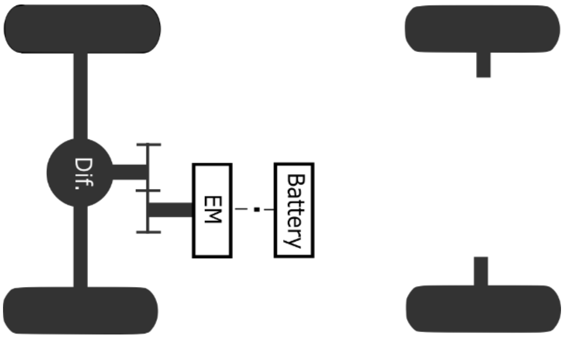


Fig. 2.15: Basic BEV powertrain architecture

As many of the technologies, it has its advantages but also disadvantages comparing to the ICEV, HEV, or even other EV powertrain architectures. Wu, G., Zhang, X., and Dong, Z. (2014) state that due to its simplicity, this architecture saves a lot of weight but also reduces the installation space. Moreover, it is much more cost convenient both for the producer and for the consumer. Additional to that, there is less drivetrain loss and the driving experience becomes much more comfortable for the consumer. Nevertheless, due to the fact that the vehicle loses efficiency when the EM is working at either low or high speed and that the EM at low speed can operate only at a portion of its potential, it makes this architecture not as flawless as one might believe.

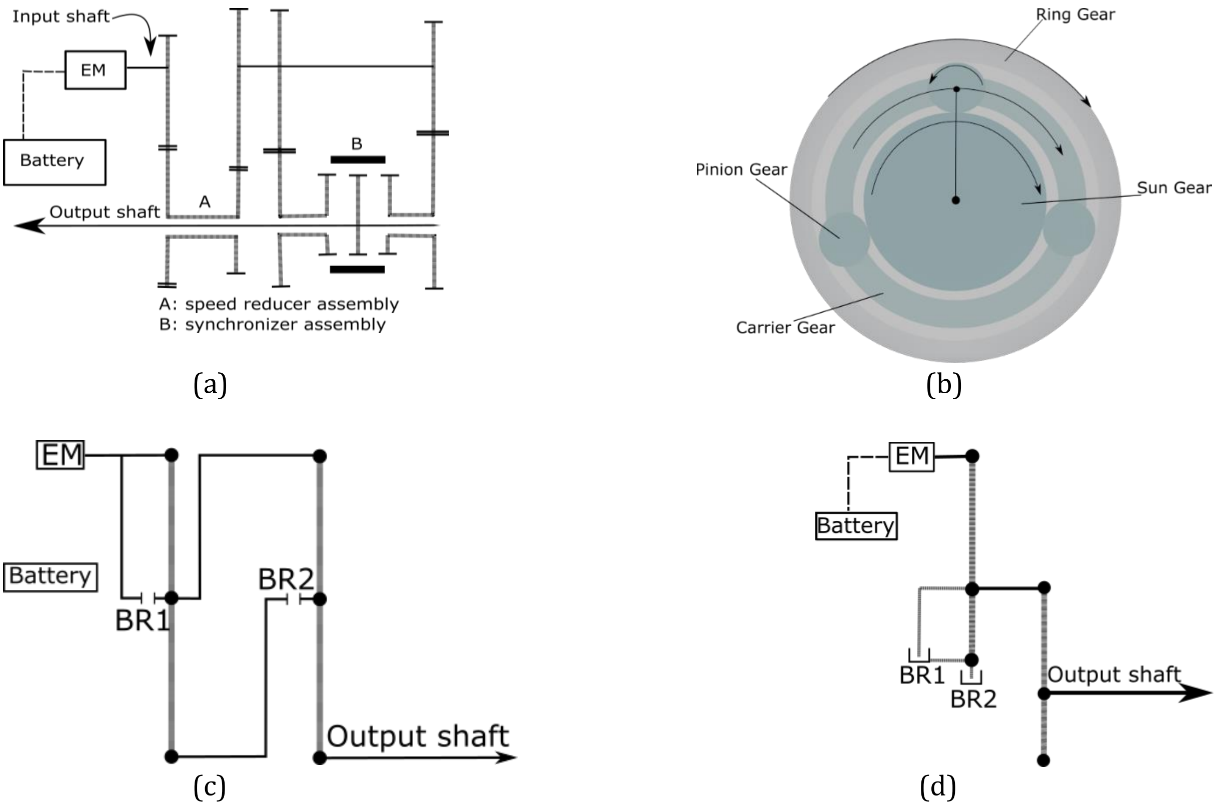
2.3.2 BEV with multiple-speed gearbox and one EM

As compared to the BEV without the transmission, this powertrain architecture is different by having a gearbox. From this perspective, it is very similar to the conventional car with the exception of not having a coupling device. The presence of the gearbox allows this architecture to overcome the disadvantages that the BEV with no transmission has and also can increase the fuel efficiency by as much as 2-5%.

As to what the architecture of the gearbox could be, there are several options. Wu, G., Zhang, X., and Dong, Z. in their 2014 paper explore the possible forms of the BEV architecture with a multiple-speed gearbox. They suggest that the form of the gearbox in a BEV powertrain can be quite similar to the manual one in the ICEV powertrain. In addition to the conventional system, it has a speed reducer assembly in order to increase the torque when needed and the synchronizer assembly in order to switch to high or low gears. For a better comfort, however, it is suggested to use another form of the gearbox - the automatic transmission, despite the higher price and lower efficiency. The automatic transmission gearbox has a planetary shape due to its internal structure which consists of planetary gear sets such as the sun gear, pinion gears, carrier gear and ring gear. Fig. 2.16 shows the structure of such a gearbox. So as an alternative to the parallel-shaft gearbox, two alternative planetary gearboxes are available. Both can be depicted in Fig. 2.16 (c) and Fig. 2.16 (d) respectively. The additional planetary gear sets have the role of a reduction gear, whereas states of brake 1 and 2 determine the engaged gear.

2.3.3 BEV powertrain architecture with multiple EMs

There are several different layouts of BEV powertrain with 2 or more EMs. Most of these configurations are not using a differential due to the fact that during the driving process the EMs can independently adjust the rotation speed of the wheel while the the vehicle is performing a curve. However, according to Wu, G., Zhang, X., and Dong, Z. (2014), there is the possibility of two configurations involving a differential. The first one is very flexible as it involves 2 EMs located both in front and in the back of the car allowing it to run in front-wheel-drive (FWD) and rear-wheel-drive (RWD). Moreover, as stated by



(a) (b)

(c) (d)

Fig. 2.16: BEV architectures with a two-speed gearbox. (a) parallel-shaft gearbox, (b) PGS, (c) Planetary gearbox 1, and (d) Planetary gearbox 2.

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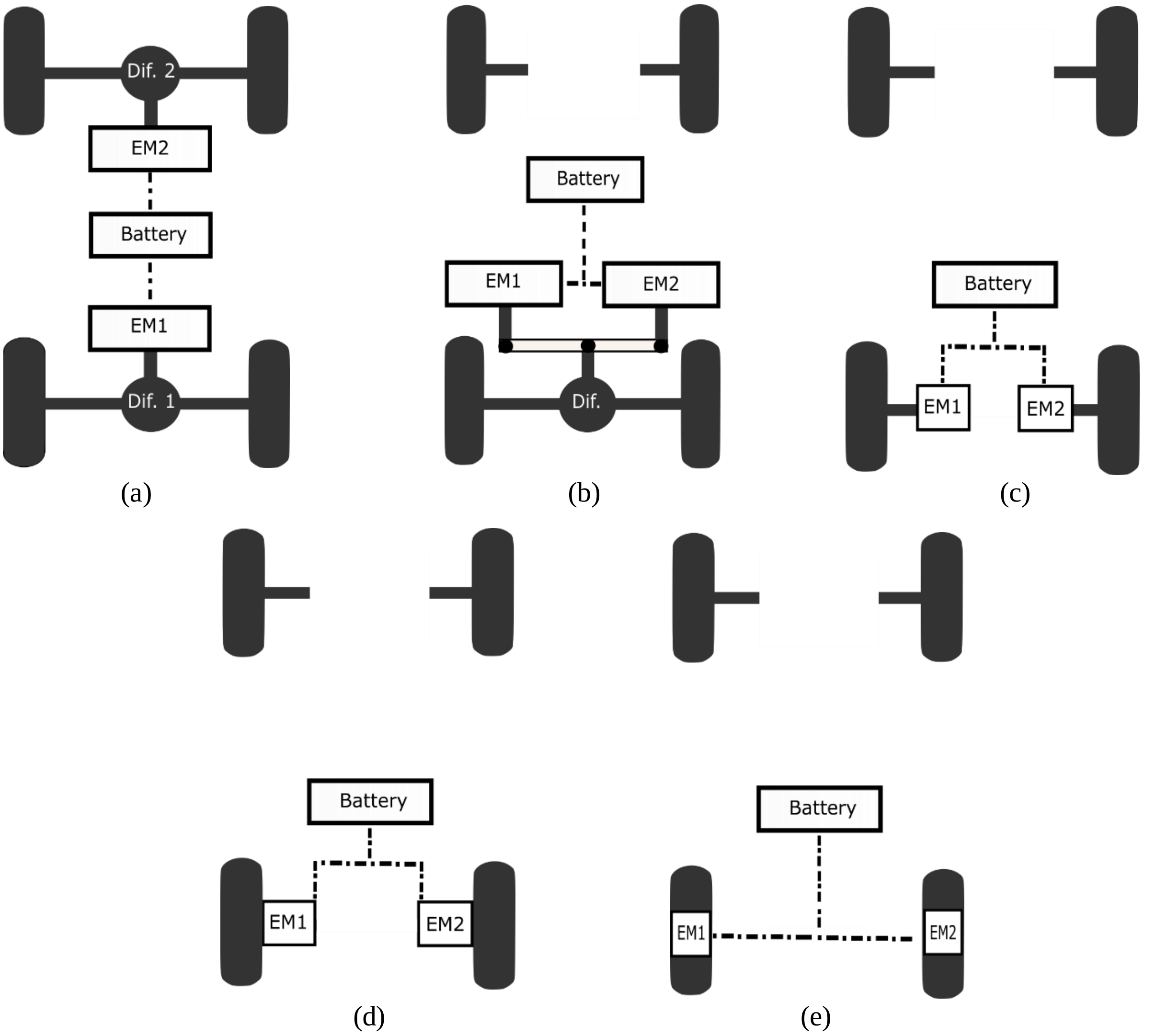
the same authors, RWD and FWD can be controlled depending on the speed of the vehicle making it a 2-speed transmission system. In certain situations when more torque is needed, all-wheel-drive (AWD) can be used. Fig. 2.17 (a) is the representation of such layout. A second configuration with a differential is depicted in Fig. 2.17 (b). Under this layout, the two EMs are connected to only one wheel-drive. Regarding this configuration, however, ”No PEV with this architecture has been found by authors”. (Wu, G., Zhang, X., and Dong, Z. 2014, p. 433). Regarding the conventional multi-EM configurations, the first option is described earlier in this section. The basic concept is having no differential by substituting it with 2 EMs. Each of them is placed next to a wheel and operates at a certain speed depending on the shape of the driving path. The transmission system is represented by fixed gearing. A further simplification of the drivetrain is represented in Fig. 2.17 (c). This configuration is different from the previous one by the fact that the EMs are located inside the wheel. In order to diminish the speed while increasing the torque, a planetary gear set could be used. Moreover, “The thin planetary gear set offers the advantage of a high-speed reduction ratio as well as an inline arrangement of the input and output shaft”

(Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005, p.101-102). The third configuration which, again, represents a further simplified version of the previous one, entirely lacks any mechanical gearing between the EM and the wheel. In this way, the speed of the EM represents the speed of the wheel, meaning the speed of the vehicle. Due to this, such powertrain requires a low-speed EM. However, as stated by (Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. 2005, p.102), this configuration needs the EM to have a higher torque “to start and accelerate the vehicle”.



(a) (b) (c)

(d) (e)

Fig. 2.17: Powertrain architectures with multiple motors. (a) 2 EMs each connected to a wheel drive, (b) 2 EMs both connected to the front drive, (c) 2 EMs each connected to a front wheel, no differential, (d) 2 EMs each connected to a front wheel, no differential, no mechanical link between the EM and the wheel, and (f) 2 EMs located inside the front wheels.

BEVs have become quite popular in the past years. Thanks to the European Union’s promotion of environmentally friendly behavior, more consumers are considering acquiring an electric vehicle. For instance, as stated by Eurostat, leading European countries such as Germany and France have already stepped up as early adopters of this technology. The number of BEVs registered in the former country hugely increased from 7 thousand in 2012 to 34 in 2016. France has gone even further: from 18 thousand in 2013 to 64 thousand in 2016. Nevertheless, Norway has almost 55% more electric vehicles than France, with a record-breaking number of 97.532 BEVs in 2016. It seems that with the advantages offered by many European governments such as tax exemption, no charges on highways, import tax exemption on car distributors, free parking and other benefits, BEVs are becoming increasingly popular. Moreover, countries such as Germany and France have already declared that in the near future, fossil-fueled cars will not be distributed anymore.

2.4 Fuel Cell Electric Vehicles (FCEVs), Flexible Fuel Vehicles (FFVs) and other powertrain architectures

The last alternatives to the conventional internal combustion engine vehicles to be described in this chapter are fuel cell, flexible-fuel, and other fuel type vehicles such as natural gas or LPG. Although the latter type is mainly a variation of the internal ICEVs, it promises lots of potential for fuel saving for the next years. In fact, the Eurostat reports that there are slightly more than 77 thousand vehicles running on natural gas in 2016. However, Italy is the absolute leader with 911.246 vehicles registered in the same year. Other European countries do not find this fuel as useful and reliable. Regarding liquefied petroleum gas (LPG), Italy has a total of 2.211.368 passenger cars registered in 2016, surpassed by Turkey and Poland with over 4.4 and 3 million respectively. On the other hand, the first of the three alternatives is highly related to BEVs with the noticeable difference being the different fuel type (i.e. hydrogen). It is not very popular though on the European territory. Denmark registered 69 such vehicles in 2016, followed up by Poland with 53 and Norway with 41. Flexible-fuel vehicles (FFVs) also have the potential to overcome the issues of ICEVs. Among the European countries, France has the most registered FFVs with a total of 29 thousand. A special case concerning FFVs are the bi-fuel vehicles. They are quite popular in France, Croatia, Hungary, and the UK. More details regarding FFVs are given in the next sections. Fig. 2.18 shortly presents the already described vehicle possibilities with some additional information regarding the classification and the fuel/energy source whereas Table 2.4 presents examples of vehicles with alternative fuel type. This information is provided by the Alternative Fuels Data Center (2018, a) - a division of the U.S. Department of Energy.

Fuel type	**Vehicle name**	**Vehicle type**	**Engine size**
B20 (biodiesel)	Ford Transit T150 Wagon	Van	3.2L
B20 (biodiesel)	Land Rover Range Rover Velar	SUV	2.0L
B20 (biodiesel)	Jaguar XE AWD	Sedan	2.0L
B20 (biodiesel)	GMC Canyon 2WD	Pickup	2.8L
CNG	Ford Transit Connect	Van	3.7L
CNG	GMC Sierra 2500 HD	Pickup	6.0L
Propane	Ford F-150	Pickup	5.0L
Propane	Chevrolet Express 2500	Van	6.0L
FFV	Chevrolet Impala	Sedan	3.6L
FFV	Dodge Grand Caravan	Van	3.6L
FFV	Ford F150	Pickup	3.3L
FFV	Ford Escape	SUV	2.5L

Table 2.4: Examples of vehicles with alternative fuel

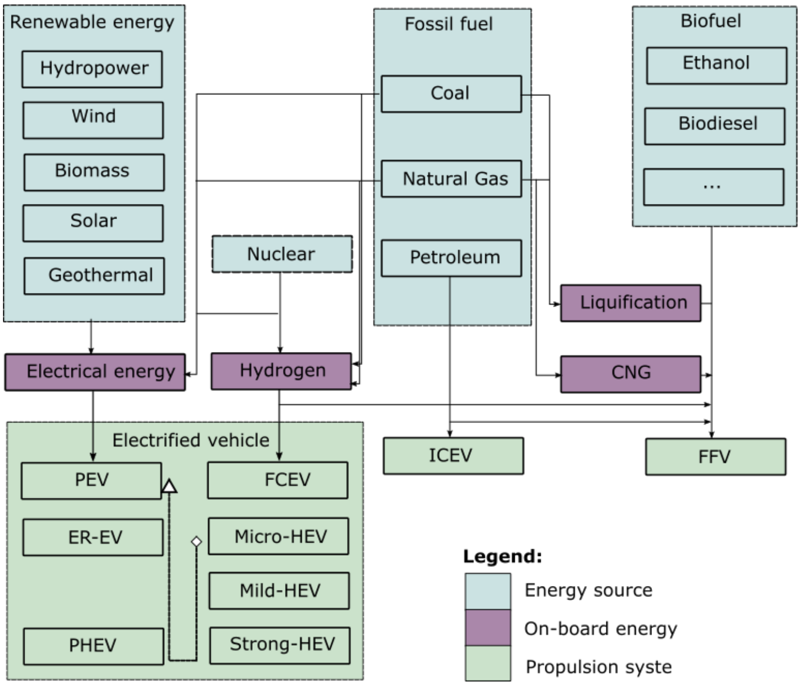


Fig. 2.18: Powertrain alternatives classified

2.4.1 Fuel Cell Electric Vehicles (FCEVs) powertrain architecture

As mentioned earlier, FCEVs represent a variation of electric vehicles. The main difference between a BEV and an FCEV is the energy source and the onboard energy type. As opposed to the former, the latter does not use energy from the battery but rather continuously transforms hydrogen into electricity. In simple words, a "fuel cell is a galvanic cell in which the chemical energy of a fuel is converted directly into electrical energy by means of electrochemical processes" (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. 2005, p. 348). It does that by continuously adding fuel and oxygen, hydrogen peroxide or a halogen to the 2 electrodes located inside the cell. In their 2005 work entitled *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles,* Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. explain how a fuel cell is operating. As stated by them, an electrolyte is needed in order to move positive particles released by the fuel from the positive electrode to the negative electrode where, in reaction with the oxidizing agent, energy is released. At a first glance, its biggest advantage over BEV technology is extended driving range and fast refueling as compared to the time the batteries need to be charged. On the other hand, by comparing FCEVs to ICEVs, they have the advantage of being eco-friendly by having very low emission-level. This is possible as a result of converting hydrogen into energy rather than fossil fuel and also more efficiently managing the torque-speed ratio (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. 2005). The basic chemical reaction happening in a fuel cell is the following: $2H_2 + O_2 \rightarrow 2H_2O$. As stated by Larminie, J., and Lowry, J. (2003), since fuel cells are operating at a quite low temperature (approximately 85°C), neither the hydrogen nor the oxygen interacts with the nitrogen in the atmosphere, thus it does not produce any nitrous oxide, and, as a result, FCEVs could be considered emission-free vehicles. Generally speaking, fuel cell technologies allows the vehicle to be zero-emission and also maximally silent while keeping the same advantages he ICEVs have, namely the driving range and the performance.

However, despite all the advantages it has both over ICEVs and BEVs, FCEVs are not being as popular as they should. This is true due to several crucial factors. In the first place, the cost has to be mentioned. The technology requires quite expensive materials for a better functionality. Secondly, fuel cells are in theory emission-free but in reality, they produce a small amount of nitrous oxide which, according to Stolarski, R.S., Douglass, A.R., Oman, L.D, and Waugh, D.W. (2015), is one of leading factors that contribute to the formation of ozone holes. Thirdly, water management is, although at a first glance an issue to be neglected, a complex problem that needs to be taken care. Due to the properties the hydrogen has, under certain circumstances dehydration could create big problems. This will not be further explained as this topic is beyond this study. A fourth disadvantage is the cooling. Considering that fuel cells are very different from internal combustion engines. In the case of ICE, the heat leaves the engine with the exhaust gas, whereas in the case of fuel cells this does not happen as much as it is required. The last but not the least issue is the difficulty in supplying, storing, and transporting hydrogen. Although there are producers of hydrogen fuel on a big scale, nothing is developed for small-scale mobility (Larminie, J., and Lowry, J. 2003). Regarding the storage and transportation of hydrogen on-board, there are 3 alternatives presented by Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. (2005): (1) compressed hydrogen is difficult to store, requires additional energy to be stored under high pressure and could potentially leak through cracks or even worse - cause an explosion; (2) cryogenic liquid hydrogen is hardly achievable because technologically it is a difficult task to have a storage system able to maintain the temperature at -259.2°C; (3) metal hybrids can be used to stabilize the hydrogen but have a very reactive nature.

According to what has been said earlier, the electrolyte is a key component of the fuel cell. There are mainly different types of fuel cells considering the possibilities of electrolytes that can be used: proton exchange membrane (PEM) uses an electrolyte made of solid polymer membranes, alkaline fuel cells (AFCs) use a potassium hydroxide as electrolyte, phosphoric acid fuel cells (PAFCs) use phosphoric acid to conduct the positive ions from the anode to the cathode, molten carbonate fuel cells (MCFCs) operate at a very high temperature in order to melt the carbonate salt which is the electrolyte, solid oxide fuel cells (SOFCs) conduct ions through a ceramic membrane at high temperature levels, and the last type is direct methanol fuel cells (DMFCs) which uses methanol instead of hydrogen as fuel (Ehsani, M., Gao, Y., Gay, S.E., Emadi, A. 2005).

As regarding the powertrain design specific to the fuel cell electric vehicles, Ehsani, M., Gao, Y., Gay, S.E., and Emadi, A. (2005) argue that the most important elements of the drivetrain are the fuel cell system which represents the energy converter mechanism, an EM, a peaking power source (PPS), a vehicle controller, and an interface connecting the fuel cell with the PPS. A graphical representation of such powertrain architecture is illustrated in Fig. 2.19.

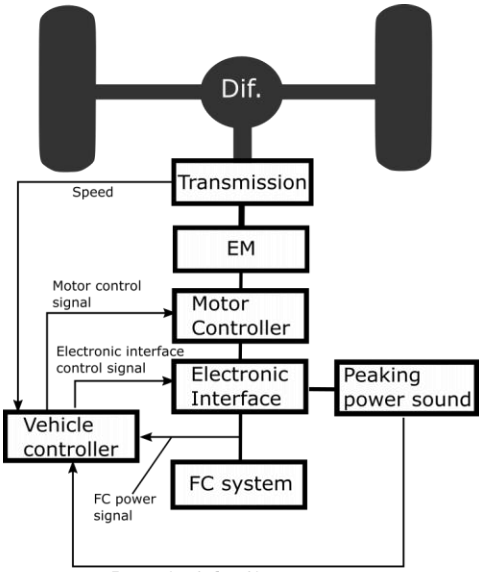


Fig. 2.19: FCEV powertrain architecture

2.4.2 Flexible Fuel Vehicles (FFVs) powertrain architecture

A flexible fuel vehicle (FFV) is a variation of a vehicle using an internal combustion engine as its energy converter mechanism. However, as opposed to the conventional

ICEVs, FFVs are able to operate not only with a single fuel type (be it diesel or gasoline) but on multiple fuel alternatives such as ethanol or methanol. As presented in Fig. 2.18, several types of fuel are used by FFVs: as a baseline are the biofuels which are then combined with gasoline and natural gas sometimes. The most popular FFVs are running on a mix of ethanol and gasoline or another hydrocarbon fuel. Usually, the E85 mix is used which is composed of 85% of ethanol and the 15% of gasoline. Other combinations are also possible. For instance, Kar, Y. and Deveci, H. (2007) suggest that P-series fuels could also be a good alternative. They are obtained by having a mix of 45-50% ethanol, up to 20% methyl tetrahydrofuran, and about 30-35% natural gas liquids such as pentane. They also suggest that during cold weather additional butane can be included to have a better engine start. This said other alternative fuels are getting popular as well.

Alternative Fuels Data Center's official website provides some information regarding the structure of an FFV. It suggests that FFVs, similarly to ICEVs have one fueling system and most components are identical to the ones used in a conventional vehicle. However, in order to be able to run on ethanol, the vehicle requires some components to be changed. Such components are the fuel pump and the injection system which need to be changed in order to function as good with the new fuel type. In addition to that, the engine control module (ECM) properties are changed so that it lets more oxygen together with the ethanol during the combustion. As with the ICEVs, other components needed are: (1)the battery which is needed for the engine start and as a power source for the electronics, (2) the ECM which is used to manage the mixture of fuel and oxygen, engine processes, emissions, etc., (3) the exhaust system which is used to get rid of the gases from the engine, (4) the fuel injection system used to inject fuel into the engine, (5) the ICE used for converting chemical products into energy and (6) the transmission used for transmitting power from the engine to the wheels. What is interesting about FFVs, as stated by the same observatory (AFDC), there are more than 20 million flex-fuel vehicles in the United States, however, a big portion of the drivers are unaware that the vehicle is able to run on other fuel mixtures. For an illustration of the FFV powertrain architecture, refer to Fig. 2.1.

In their 2012 study, Thomas, J.F., Huff, S.P., and West, B.H. have studied the impact of converting an ICEV into an FFV. The vehicle observed during this research is a 2006 Dodge Charger. After calibrating the powertrain system in order to be able to run on multiple fuel mixtures, the authors noticed that the overall fuel efficiency dropped proportionally to the increase of ethanol percentage in the mix. This was not a surprise since the ethanol is of a lower density than the typical gasoline and more fuel is needed under such scenario. On the other hand, carbon emissions have remained constant even after the conversion and the nitrogen oxide emissions decreased due to the lower combustion temperature that ethanol requires. Furthermore, it has been observed that the more the portion of the ethanol in the mixture, the better accelerating performance the FFV has.

2.4.3 Other powertrain architectures

So far, this chapter reviewed in detail conventional vehicles with an internal combustion engine, hybrid vehicles with an engine and an additional electric system, fully electric vehicles powered by a powerful battery, electric vehicles with fuel cells using hydrogen as fuel, and flexible-fuel vehicles using multiple fuel types. This section will provide information regarding the remaining possibilities such as ICEVs running on natural gas, liquefied petroleum gas (LPG), or biodiesel. Needless to mention, all of the possibilities mentioned are variations of vehicles with an internal combustion engine as the mechanism to convert fuel into energy. In addition to that, all three powertrain possibilities can be developed by the OEM or converted from a conventional ICEV after being purchased.

Starting with the first alternative, namely natural gas, according to the information provided by the U.S. Department of energy there are more than 150 thousand natural gas vehicles (NGVs) in the U.S. and approximately 15.2 million throughout the world. Natural gas is most frequently used in a compressed form which is quite popular due to an improvement in the last years of storage and transportation safety. However, compressed natural gas (CNG) is not the best choice for the vehicles supposed to travel very long distances. A better solution is the liquified natural gas (LNG). Compared to other vehicles running on alternative fuel, the advantage of NGVs is that natural gas availability is rather high due to its domestic use. Moreover, compared to conventional ICEVs, NGVs have a clear advantage when it comes to the quality of the emissions. AFDC (2018, c) confirms that the amount of greenhouse gas emissions is lower when compared to the quantity produced by ICEVs. In addition to what has been said, there are 3 typologies of NGVs: (1) dedicated NGVs run solely on natural gas, be it CNG or LPG, (2) bi-fuel NGVs are hybrid vehicles that are able to run either on natural gas or on gasoline, and (3) dual-fuel NGVs are able to operate using natural gas assisted by diesel for better performance and are usually applied on heavy-duty vehicles.

LPG, also called propane, is another alternative fuel that can be transformed into mechanical energy. It does not have color or smell, but an odorant is added in order to detect leakages. Onboard, it is stored under high pressure. The number of propane vehicles operating on the American roads is close to 200 thousand. On the other side of the Atlantic Ocean, the numbers are much higher. As mentioned at the beginning of Section 2.4, some countries have even reached the one million threshold. One of the main applications is heavy-duty vehicles such as school buses. Compared to NGVs, there are only 2 types of vehicles running on propane: dedicated and bi-fuel. The description is similar to the one provided for NGVs. AFDC suggests that the performance of the vehicle in terms of acceleration, power, and speed along with the driving range is rather similar to the conventional ICEVs. The reason why many drivers are preferring LPG vehicles over gasoline or diesel vehicles is that the maintenance costs are lower for the former type. Propane characteristics allow the engine to function better and have a longer life and to perfectly operate in cold weather. Furthermore, considering the issues regarding gas emissions, propane vehicles have the potential to be more efficient than typical ICEVs. The disadvantages related to this technology is that LPG has a lower density compared to gasoline or diesel making the vehicle less fuel efficient. However, if well designed, the engine could take advantage of the chemical properties propane has.

Biodiesel represents a variation of the commonly used diesel and is obtained from vegetable, animal, or recycled fats. It is used by the same diesel-engine vehicles in form of B20 or B5. These fuels are mixtures of biodiesel and petroleum diesel where the number in the name is essentially the percentage of biodiesel used in the mix. As a result, B5 diesel has 5% biodiesel and 95% petroleum diesel, whereas B20 has 6-20% biodiesel and 94-80% normal diesel. As suggested by AFDC (2018, c), each mixture has its own advantages, such as better performance in cold weather is achieved by blends with less biodiesel. Furthermore, by using biodiesel mixtures emissions are reduced in the long run considering the carbon dioxide produced while driving and carbon dioxide absorbed while growing soybeans or other plants with the purpose to transform them into biodiesel. In addition to the emissions benefit, many OEMs suggest that the biodiesel is able to improve engine performance because of its enhanced lubricity characteristics. Moreover, all carmakers approve the use of B5. Lastly, it is biodegradable and is less harmful to the environment if accidentally spilled.

Chapter 3: Global automotive industry overview

This chapter focuses on the global situation in the automotive industry. It aims to analyze the structure of the supply chain, identify the major players, and differentiate between “who creates value” and “who appropriates the value”. By doing so, this is an attempt to spot the “bottlenecks” and to determine how the value is distributed throughout the global automotive supply chain. The theoretical framework used in this chapter was developed by Jacobides, M.G., Knudsen, T., and Augier, M. in their 2006 research paper called “Benefiting from innovation: Value creation, value appropriation and the role of industry architecture”. Although this paper has not been developed exclusively for the auto industry, it is easily applicable to any sector. To support the points presented in the next sections, examples from several scientific papers will be cited together with some data provided by EU, ANFIA, and Automotive News.

3.1 Top 100 automotive industry suppliers globally

The range of products that the automotive industry offers is quite broad. According to the European Commission (REF), there are 4 categories of motor vehicles: (1) mopeds, motorbikes, quadricycles, and other small vehicles with 3-4 wheels, (2) motor vehicles used to carry passengers and which have not less than 4 seats, (3) motor vehicles used for commercial purposes (carry goods), and (4) trailers and semi-trailers. Moreover, other than these 4 categories of products, the automotive industry is involved also in the production of components for final consumers (B2C) or for other businesses (B2B). Besides having different companies working in a wide variety of production fields, the automotive industry has one important feature - it is organized into a tier-system. According to this organizational style, there is a hierarchy regarding who produces what. At the top of everything is the vehicle manufacturer. Going down the pyramid, the next players are the tier-1 suppliers. Usually, they are very big in terms of resources and productive capacity. A car manufacturer does not have too many tier-1 suppliers. Each such supplier has its own tier-2 suppliers and so on and so forth. An example of this organizational chart is illustrated in Fig. 3.1.

Before going to the main point of this section, it could be useful to mention, without putting too much emphasis, that the mapping of the automotive sector could be performed not only by looking at the individual firms such as the ones presented in the next paragraphs but also by looking at clusters. As stated by Porter, M.E. (1998), clusters are geographically close groups of companies that are somehow related in a specific field. There are several automotive clusters around the globe, each with its own characteristics and particularities. Renowned examples of such are the Piedmont Region in Italy, especially the metropolitan area of Turin, famous for its engine-building competencies and for one of the biggest car makers – Fiat (FCA starting 2014); Detroit – the Motor City – historically the center of the North-American automotive industry since its inception, the Bavarian region in the south of Germany known for its luxury brands such as BMW and Mercedes-Benz.

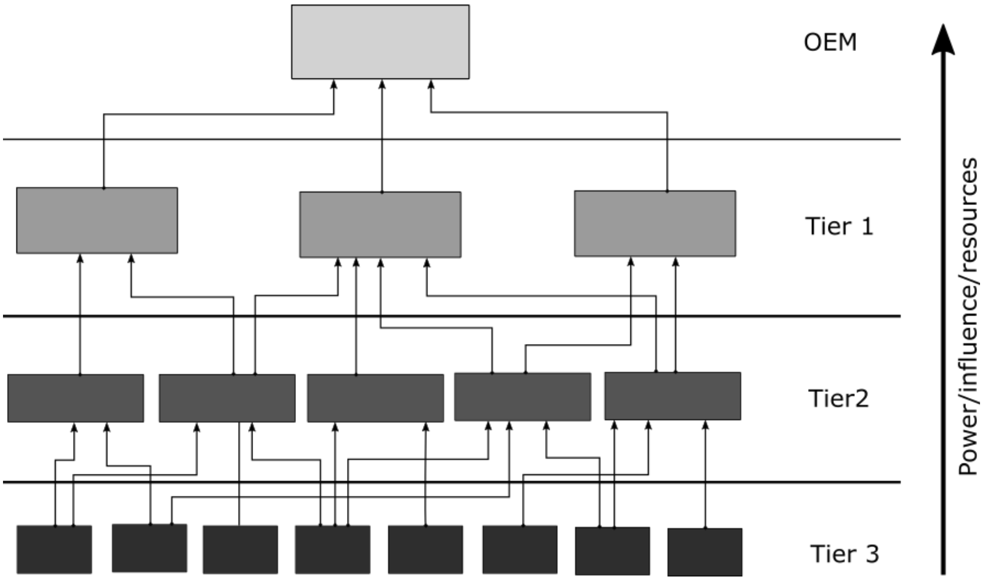


Fig. 3.1. The hierarchical structure of the automotive supply chain

Concerning industry-wide data, according to a study conducted by ANFIA – a renowned source of statistical data in Italy, the auto industry is still growing. In fact, 2016 recorded the highest revenues up to that date with over 94 million vehicles sold globally. As stated by ANFIA, the sales increased by 4,8% in 2016 as opposed to the 2015 levels. Among the top 100 suppliers 2016 list prepared by Automotive News, there are companies representing 20 countries in total. The absolute leadership is held by Japan - the country with the most companies in the one-hundred list. All of the 28 Japanese suppliers are quite uniformly distributed with an average of 3 companies per every 10 ranks. Most of them are working in the electronics and powertrain field, building essential components for the drivetrain and accessories. Denso, for instance, is specializing in manufacturing alternators, starters, spark plugs, ignition coils, engine management units but also air conditioning and several types of sensors for a better driving experience. Aisin, another Japanese tier-1 auto supplier, has extended competencies in building powertrain components such as transmission systems, brakes, engine and chassis components. Other Japanese manufacturers are confidently looking into the future by specializing in building components for the next generation of cars which are expected to be highly connected to the environment surrounding them, electrified and autonomous. Examples of such companies are Yazaki being a global leader at building wiring harness of the vehicle (i.e. the nervous system of a car), Hitachi's automotive division having huge competencies in the designing and manufacturing of components for electric powertrain and drive control systems, and Mitsubishi Electric with extended knowledge in the field of e-mobility, human interface devices and automatic driving.

Japan's follower is the United States. According to Automotive News (2017), there are 21 US automotive suppliers in the top 100. There are only 3 American companies in the upper 30% of the list as opposed to Japan who has 9. Regarding the distribution, there are 2 to 3 US auto suppliers per every 10 ranking positions starting with rank 31 and lower. Comparing, once more, to their Asian rivals, American companies operating in the automotive industry are specialized less on electronics and more on mechanic components. This does not mean, however, that all the US auto suppliers have not developed capabilities in the electronics field. Lear and Delphi, positioned on the 9th and 12th spots globally and 1st and 2nd place among the US automotive companies respectively, are an example of such exceptions. Their main business areas are connectivity systems, electric systems as part of the energy management, body electronics, wireless technology, and also lighting and audio components. In addition to these products, Delphi is investing lots of resources in autonomous driving technology. Citing Automotive News (2017, p. 3) "In 2015, Delphi Automotive […] bought Ottomatika Inc., a Pittsburgh-based supplier of automated-driving software". Moreover, it invested in building partnerships with several other companies that specialize in cloud connectivity. On the other hand, firms like Borg Warner, Federal-Mogul, Flex-N-Gate, Dana, American Axle, and some other tier-1 suppliers are specialized more on designing and manufacturing mechanical components such as engine parts, transmission systems, axles, differentials, drive shafts, etc. Many of them, understanding the upcoming trends in the automotive industry are investing a considerable amount of resources in developing competencies highly connected to e-mobility. For instance, Nexteer Automotive is already building knowledge on automated driving systems.

Not too far from the USA is placed Germany with 17 companies in the top 100 auto suppliers, 3 among which are dominating the first 10: Bosch, ZF Friedrichshafen, and Continental. The first one is the number 1 auto supplier in the world in 2016 and is specialized in a very wide variety of products manufacturing such as air management, temperature, and pressure sensors, alternators and starters, batteries and accessories for them, brakes, components for diesel ICEVs, engine parts, fuel injectors and pumps, ignition parts, lighting components, steering systems, throttle devices, spark plugs and wiper blades. According to Automotive News (2017), Bosch announced that it will invest $336 million in R&D over the next half of decade. Its interest mainly lays on artificial intelligence for the auto industry. Moreover, as stated by the same source, it has already established an alliance with another German auto giant – Daimler AG – to put in production self-driving taxis. To safely develop high-quality products without risking going alone into the future, Bosch formed partnerships with Nvidia and HERE to manufacture vehicle processors and roadmaps respectively. ZF Friedrichshafen and Continental, placed on the second and fifth places respectively, in addition to Bosch, are developing car software, chassis electronics, safety-related components such as airbags, driver assistance systems, and parts for electrified powertrains. The rest of the German auto suppliers in the top 100 list are highly involved the production of e-mobility components as part of the orientation towards the future, but also have vast knowledge in developing mechanical components for the conventional powertrain architectures. Examples of such companies are MAHLE – specialized in producing pistons, cylinders, valves, engine management system, ThyssenKrupp Automotive – specialized in building a wide variety of products including axles, shafts, drivetrain components, valves, bearings and batteries, Schaeffler – an expert in engine and transmission manufacturing, and others. Exceptions are Eberspacher and Webasto which are specialized in thermal management systems, and Basf – an expert in the production of plastic components.

Overall, there are 15 German companies on this list, 9 of which can be found in the top half of the ranking provided by Automotive News.

The fourth place from a nation-level perspective is South Korea with only 6 companies in the top 100. The highest ranked supplier among them is Hyundai Mobis (ranked 7th globally in 2016), a member of the Hyundai Chaebol. Its main business areas are interior components manufacturing such as the cockpit, chassis, and front & end modules; safety, braking, steering, air suspension, and lighting systems; electric components such as chargers, inverters and converters, traction motors, battery systems, and parts for fuel cell electric vehicles. Furthermore, Hyundai Mobis has invested a lot of resources in R&D fields such as autonomous driving, cruise control, drive motors, traffic sign recognition systems and blind spot detection components, and also parking assist. Other notable Korean names are Hyundai WIA Corp who has acquired capabilities useful in producing powertrain components both for ICEVs and xEVs, and Mando Corp – an important player producing integrated driver assistance systems, brakes, steering and suspension components. The other 3 Korean giants are Hyundai Powertech, Hanon Systems and Hyundai Dymos who develop automatic transmission systems, thermal management systems, and manual transmission systems respectively. Korean suppliers are mainly concentrated in the middle of the list.

Right next to South Korea, another Asian country has added positions in the automotive industry. Considering that China is not historically known for a highly developed national automotive industry, it has gained massive success in the latest years. According to Automotive News, 5 companies among the top 100 were Chinese in 2016. The first on the list is Yanfeng Automotive Interiors who was ranked 15th. Its main business areas are interiors, exteriors, electronics, seating, and safety. Beijing Hainachuan Automotive Parts (BHAP), Citic Dicastal, Johnson Electric, and Minth are the other 4 Chinese automotive giants who produce body components, aluminum parts, electric powertrain components and interior and exterior decorative parts respectively. Although Yanfeng Automotive Interiors is placed in the high-end of the ranking, the others managed to reach only the 68th, 73rd, 83rd, and 95th spots respectively.

The 6th rank among the countries with the most suppliers in the top 100 global list is shared by Canada and France with 4 companies overall. The North American state is represented by Magna, Linamar, Martinrea International Inc. and ABC. The first among them is ranked 3rd worldwide and not quite specialized in one single field since it has competencies in a wide range of areas: body and chassis systems, seats, and exterior components; driveline systems; fluid pressure and control mechanisms; powertrain components including transmission and fuel systems; advanced future-oriented technologies such as intelligent driving and driver assistance systems; and electronic components. In addition to all the above-listed products, Magna is also able to fully design a vehicle. Carmakers could require this service for specific models. Linamar and Martinrea International Inc, on the other hand, are more specialized. Both have great skills in developing powertrain components including driveline, transmission, and engine. The latter, in addition, produces also suspension modules, fuel and brake lines, filters, and doors. ABC's main competencies and knowledge include the design and production of heating, ventilation, and air conditioning (HVAC) systems. Their French rivals, on the other hand, are ranked higher in terms of sales revenues for the 2016 financial year. Faurencia, Valeo, and Plastic Omnium are all ranked within the first 30 spots while Michelin – the well-known tire manufacturer was ranked 90th. As a general observation, French suppliers specialize in interior and exterior components without going too much into detail with powertrain components. The only one among the 4 mentioned companies to be involved with electronics, sensors, security systems, transmission systems and xEV technology is Valeo. Furthermore, it is highly competent in the area of interface systems between the driver, the car, and the environment and powertrain components such as the engine and the transmission.

Moving to the Spanish manufacturers – Gestamp, Grupo Antolin, and CIE Automotive - all three companies are positioned somewhat in the middle of the ranking. The business area of the Gestamp and Grupo Antolin is the manufacturing of interior, exterior and body related components, whereas CIE Automotive builds engine and powertrain components, chassis and steering components, and, above everything, roof system components.

The Iberian state is followed by other 2 European countries, one situated on the Scandinavian Peninsula and the other one on the British Island. Sweden – the home of the famous brand Volvo – is globally represented by 2 firms: Autoliv and AB SKF. The former is a producer of airbags, seat belts, safety electronics and steering wheels. Its active safety electronics division has reached a $740 million sales level in 2016. Similarly to Bosch, Autoliv is already preparing for the future automotive industry by building partnerships and creating joint ventures. For instance, it came to an agreement with Volvo Car Corp. and created Zenuity – a company specializing in the development of software responsible for decision-making regarding the course the car should take (Automotive News, 2017). The latter, on the other hand, manufactures bearings, seals, and molded rubber products. These companies are ranked 23rd and 86th respectively by Automotive news in its 2017 report. GKN and TI Automotive – two British companies were ranked 37th and 64th respectively. The first one is a producer of driveshafts, AWD components, powder metal engine and transmission components, automotive structures, and chassis systems. The other one is specialized in producing automotive fluid systems.

Lastly, Austria, Switzerland, India, Ireland, Italy, Luxembourg, Mexico, Netherlands, Norway and Singapore are represented globally only by one automotive company among the 100 biggest. Benteler, a Salzburg headquartered auto supplier, is a very important manufacturer of steel products. It is one of the global leaders in the steel/tube industry, but it also produces chassis and modules structures. Furthermore, it is engaged in the development of electro-mobility engines and exhaust systems for the same vehicles. In 2016 it was ranked number 39 in the top 100 list. Autoneum, on the other hand, is specialized in the production of engine components, carpets, shields, and acoustic parts. The Swiss-based company is 43 ranks lower than its Austrian rival. Samvardhana Motherson is the only Indian company in this list. It is specialized in the production of modules and systems, wiring harness, metal parts, mirrors, and air-related components such as AC. Ireland is represented by Adient – a global leader in seats manufacturing. It was ranked 11th globally and managed to overrun most of the companies mentioned earlier. The Apennine Peninsula, although historically one of the global auto centers is rather underrepresented among the biggest automotive suppliers. Only 1 company managed to compete for global leadership: Magneti Marelli. Its main products are highly representative of what the whole Italian automotive industry has been good at always: mechanics. What Magneti Marelli is best at is the designing and manufacturing of powertrain components including transmission, engine, and power management units. With the latest trends, it went further to producing similar components for electrified powertrain architectures. Although in previous years Magneti Marelli was not alone in the top 100 list, Pirelli has not managed to be profitable enough in 2016. This could be explained by looking at the competition in the tier market and noticing that many Chinese and Korean rivals are able to offer product at lower prices.

The remaining European companies based in Luxembourg, Netherlands, and Norway are IAC - a supplier of door and overhead systems, instrument panels and consoles, Sensata Technologies - a supplier of pressure, temperature, speed and position sensors, motor protectors and switches, and Kongsberg Automotive ASA - a Norwegian producer of electronic control units, seat ventilation and heating solutions, interior parts and window regulators. Lastly but not the least, 2 companies from different parts of the world should be mentioned. Flex is a Singaporean auto supplier of entertainment components for the car, batteries, wired harness, electrics and electronics, modules and telematics devices. Nemak, on the contrary, is a Mexican producer of cylinder heads, engine blocks, transmissions, and structural components.

After identifying what are the countries with the most top-tier auto suppliers and what are those companies doing, it is essential to look at the whole picture. Information about each enterprise's business areas has been collected from the public domain, namely corporate websites. As a consequence, there is no evidence of all the projects that the companies are working on. But concluding from the available information, several observations could be made. Firstly, more than half of the companies in the top 100 ranking are involved in the production and sometimes the design of chassis, body, interior and exterior components. This includes all types of accessories such as mirrors and cockpits, body parts such as doors and roofs, structural form of the car, bumpers, and others. This, however, should not be taken as if these companies are involved only in the production of such components. In fact, such companies as Bosch are highly diversified and also produce electronics; lighting; engine; steering, suspension, and braking; e-mobility; and energy and exhaust components. The next business areas in which companies are involved is the development of electrics and electronics powertrain components such as engine and transmission parts, energy storage and distribution, exhaust system, and steering, suspension and braking systems. The second observation is related to electric mobility. About 23 of the discussed companies are involved in the production of components directly or indirectly related to electric powertrains, including hybrid vehicles, electric vehicles, and fuel cell vehicles. Following this observation, one could conclude that although the e-mobility phenomenon is still at the early stage, it has already reshaped the auto industry in such a way that a big share of the tier-1 auto suppliers feels the need to adapt to the upcoming changes. Moreover, many other manufacturers might have the abilities needed to be part of the new supply chain but have not embraced the new trend yet or are simply not reporting on their websites about their investment projects. The third finding is the confirmation of another direction in which the automotive industry is moving – the self-driving car. By reviewing the data available in the public domain, 14 companies among the 100 have been identified as producers of components directly or indirectly related to autonomous driving. For instance, Tokai Rika, a Japanese multinational, designs and produces safety and intelligence components such as sensors, speakers, navigators, cameras, but also smart mobility components including automatic driving system and human interface devices.

3.2 Who drives the innovation?

In the previous section, the first out of the several questions of this chapter has been addressed, namely "Who does what?". Mapping the whole industry is rather a difficult task and, moreover, the purpose of this dissertation is to hypothesize on the future of the Italian auto industry and not the global one. As a result, only the biggest and most influential auto suppliers have been analyzed and described as to what their contribution to the automotive industry is. Moving to the next step, this section tries to analyze who are the players that create value, who appropriate it and as a result who are the industry bottlenecks.

As mentioned in the first chapter, e-mobility is an effort that aims to entirely or partially solve some issues regarding carbon and nitrogen emissions. Although it is considered to be a disruptive technology, underneath it clearly depends on the perspective one considers. Electric mobility, indeed, disrupts the conventional powertrain architecture by entirely making some components such as the internal combustion engine and gasoline fuel tank obsolete and by introducing new ones such as the electric motor and energy storage systems including batteries with large capacity. This is a hard hit not only for the OEMs and OESs but also for the aftermarket parts sales. On the other hand, it is a rather big opportunity for new entrants and for the established firms who have the required skills to take the lead into the new business areas such as the development of inverter/converter modules, high-voltage chargers, high-capacity batteries, AC-DC or DC-DC converters. According to Roscoe, S., Cousins, P.D., and

Lamming, R.C (2016), the main drivers of innovation are the new players that enter the industry from outside. However, many other components that are not powertrain-related remain untouched. For example, the chassis, the body parts, interior, accessories and other components remain useful both for the ICEVs and xEVs with slight modifications in some instances.

Several studies have been performed aiming to identify how innovative is the automotive industry and who are the innovators. Stolz, L., and Berking, J. (2012) state that auto suppliers are crucial to the automotive industry as they possess unique capabilities and contribute as much as 65% to the total value of the car and 32% of the research and development. Other authors also support this view, including Hannigan, T.J., Cono-Kollmann, M., and Autenrieb, N. (2015) according to whom it is the suppliers who contribute the most by producing the vast majority of the components, and Schulze, A., MacDuffie, J.P., and Taube, F.A. (2015) who believe that as a result to the requirements that OEMs have, huge suppliers emerge. Among the pieces of research conducted in the last years, one comes up quite unique. In their 2017 paper, Borgstedt, P., Neyer, B., and Schewe, G. have used a different approach in trying to describe how innovative the automotive industry is. As opposed to other works, they analyzed both the incumbent suppliers and the new entrants and went further by answering the question: “How is the automotive supply chain industry affected by the technological change towards alternative powertrain systems?” (Borgstedt, P., Neyer, B., and Schewe, G., 2017, p. 76). What is interesting about the analysis they performed is that they used several categories of players (i.e. car manufacturers, top 100 suppliers discussed in the previous section, and other patent holders which are represented by new entrants) to compare to each other for each of the powertrain technologies available on the market, namely ICEVs, HEVs, BEVs, and FCEVs. Three indicators have been used to make an objective comparison: PS, RTA, and h-index. The former is the ratio between the number of patents of a group for a specific technology at a given time and the total number of patents for the same technology at the same given time. The higher the ratio, the more patents a group has. The second one is the ratio between the former and the combined share in all the technical categories. For obvious reasons, a high RTA means a focus on a respective technology and vice versa. The latter shows the quality of the patent portfolio a firm has. The higher the h-index, the better.

Overall findings show that during the 1990-2013 period, the majority of the patents issued are still ICEV-related. The peak number for such patents has been reached in 2008 with over 4000 units. On the other hand, although from 1998 to 2006 the number of FCEV-patents has considerably grown after it reached almost 2000 units, it dropped to less than 1000 in 2013. It seems that the interest for this technology has rather diminished in the last years. Both BEV- and HEV-related patents have grown in quantity starting the 1990s reaching a maximum in 2011 of over 2200 and 1500 respectively.

Moving to each technology separately, the results of the analysis show that the biggest automotive suppliers, although having a low PS ratio (23-35%), are quite specialized in the development of ICEV technology (i.e. high RTA). As a conclusion to this statement, the top 100 suppliers have core competencies in designing and producing components specific to the internal combustion engine vehicle powertrain. For instance, Bosch - the biggest auto supplier, has nearly 3000 ICEV-related patents, while Denso almost 3100. H-indices for Bosch and Denso are 35 and 30 respectively, which means that their skills in building components or parts for the ICEV powertrain are undoubtedly very advanced. On the other side of the spectrum, the other patent holders have a very low share of ICEV-related patents. Moreover, this group is generally speaking not overinvesting in ICEV powertrain. Lastly, as one would expect, automakers have a very high PS ratio, meaning that comparing to the other 2 groups, they have more patents related to the combustion engine powertrain. This, however, does not mean by any chance that car manufacturers are not investing in alternative technologies. In fact, according to Borgstedt, P., Neyer, B., and Schewe, G. (2017), this group has proven to be quite involved in the R&D of alternative powertrain solutions, thus showing a moderate rather than a high RTA ratio as one would expect.

Regarding the next step in the evolution of the automotive powertrain - the hybrid electric vehicle - as stated earlier, HEV technology was not so popular in the first half of the 1990s. What Borgstedt, P., Neyer, B., and Schewe, G. have discovered is that starting from the second half of the 1990s significant resources have been invested to study this technology. As suggested by them, the biggest suppliers on a group level do not show any specific interest in this technology resulting in having a very low PS ratio and a lower than one RTA ratio. Nevertheless, by looking closer at the firm level, some companies prove to be very involved in this technological field, mainly the Japanese ones. Aisin Seiki, for example, has 953 high-quality HEV patents, whereas Denso and Hitachi have 430 and 213 respectively. Similarly to the top suppliers, the new entrants and/or niche producers had little interest in the HEV technology and so little investments have been made in this direction. On the contrary to the big 100 and other patent holders, car manufacturers have shown much attention to the HEV technology. Not only this group has a high RTA ratio suggesting that they are quite specialized in this field but also an incredibly elevated PS ratio reaching sometimes as much as 83%. Among all the automakers, it seems that Asian firms show a stronger interest than other carmakers.

Battery electric vehicles (BEVs), although not new to the automotive industry, became popular in the 21st century, more specifically from 2006 onwards. Remarkably, a surprising finding made by Borgstedt, P., Neyer, B., and Schewe, G. (2017) is that among all the automotive industry players, the biggest suppliers have been the most passive in patenting new BEV-related technologies. Only in 2000, it reached a sufficient level to overcome the level of the other patent holders. Moreover, the RTA ratio is also quite low for this group, taking us to the conclusion that the top 100 suppliers are not quite specialized in the field of full electric mobility. This being said does not mean that there are no high-rank suppliers that are interested in this technology. Japanese manufacturers such as Panasonic, Hitachi, Denso, and Yazaki are clearly an exception to the results presented above. As opposed to the big 100 suppliers, other patent holders are a much more interested and specialized in the field of e-mobility. After 2010, the PS ratio reached as much as 41 % and the RTA ratio way above the average. This shows the tendency of the small, medium and niche manufacturers and new entrants to do more research in the technologies of the future. The most prominent representatives of this group of suppliers are Toyota Industries Corporation, LG Group, Samsung, Toshiba, and Fuji Electric. In 2013, their cumulative number of BEV patents is just above 820. Car manufacturers, from this perspective, are quite innovative in the pre-financial crisis years. In 2008, this category reached a 62% PS ratio. The reason why this ratio is so big is that because of the size and resources, car manufacturers clearly outperform the other patent holders. However, as regarding the specialization, the specialization as a whole is very low, reaching even lower levels after 2008.

The last technology analyzed by Borgstedt, P., Neyer, B., and Schewe, G. in their 2017 paper called "Paving the road to electric vehicles - A patent analysis of the automotive supply industry" is the fuel cell vehicle powertrain. Overall, the quantity of patents related to this technological field has risen from 1998 until 2006. The top 100 suppliers have not contributed considerably during this years. Their PS ratio remained lower than 30%. It is interesting that among the whole group, only some companies have FCEV patents. , including Panasonic, Denso, and Aisin Seiki. Most of the big suppliers are not even involved in FCEV R&D. The group of the smaller patent holders, once more, has shown interest in patenting FCEV inventions. During the analyzed years, this class of suppliers (similarly to the BEV technology, most of the other patent holders in this field are from Asia) has invested in the development of new FCEV components. Although having lower PS ratios than those of car manufacturers since early 2000s, the other patent holders group has maintained their leadership in terms of specialization until 2011. Some companies, furthermore, are fully specialized or have fully specialized divisions in the field of FCEVs but are having a tough time lately. Examples of such are UTC Power who was purchased by Doosan Group in 2014 and Ballard Power Systems who was acquired by Daimler AG and Ford in 2007. Among the three observation groups, car manufacturers have been the most productive in terms of quantity of FCEV patents issued. However, considering the skills and specialization, due to an even higher specialization in ICEV and HEV technologies, this class of players is little oriented in producing mass-marketed fuel cell electric vehicles.

As a conclusion to this section, some final remarks need to be pointed out. Firstly, the automotive industry as a whole is undoubtedly changing towards alternative technologies. Whether it will be xEVs or FCEVs it is unclear as the industry is entering a new cycle at its early stages. Bakker, S., Maat, K., and van Wee, B. (2014) argue that it is not an easy task to understand when the technological shift will end and which of the alternative designs will become the new dominant design, as ICEV has been for almost a century. Borgstedt, P., Neyer, B., and Schewe, G. (2017) state that the main driver of change and innovation is the other patent holders group. New entrants such as Samsung and LG Group have found their way into the automotive industry by re-deploying their already developed competencies in the area of battery manufacturing throughout the years. Although this study promotes the idea that the top 100 suppliers are not investing enough in alternative powertrains, it definitely cannot be called flawless as the data used is not up-to-date. It should also be considered the fact that most of the big suppliers are operating in business areas that are neutral as to what is the dominant powertrain. Many of the suppliers in the top 100 list manufacture components for the body, chassis, lighting systems, suspension and braking systems, etc. Considering these two objections, it would be unwise thinking that tier-1 suppliers are not innovative enough with respect to the new technologies. And, in fact, the authors of the paper suggest that some incumbent suppliers are very competent in xEV technology but at the group level this is rather hard to observe. Following the same line of reasoning, the second remark of this whole study is that incumbent players will most likely suffer from the shift to alternative powertrain architectures. This will result as a consequence to over-committing to ICEV technology and being too dependent on it. As described earlier, top 100 auto suppliers failed to adapt to the changing industry by deciding not to invest enough in e-mobility. This, however, should not be criticized too much as the chosen path is simply auto-defensive. By changing to the alternative powertrains, suppliers would cannibalize over their competences because e-mobility technology is disruptive and is promoting competence-destroying technologies rather than competence-enhancing. As a result, these firms that do not wish to embrace the next step in the evolution of the automotive industry risk to be replaced by new entrants as their products and competencies will eventually become obsolete. On the other hand, many of the incumbents, although not investing now in future technologies, might be able to adapt quite easily because of transferable competencies or because of nearly unlimited resources. Lastly, the final remark involves the new entrants. According to Borgstedt, P., Neyer, B., and Schewe, G. (2017), the new players are mainly operating in the areas of BEV and FCEV. Many electronics manufacturers who have not been linked to the automotive industry in the past are entering it by offering their services and competencies to car manufacturers.

3.3 The “bottlenecks” of the automotive industry

Depending on the perspective, time, country, and several other factors, the opinion on the existence and purpose of firms is variable. Some consider that companies have the goal and the duty to serve the society by creating jobs and behaving socially responsible. Other assert that firms are nothing more than an instrument helping the investors to maximize the profits. Either way, no matter how noble the cause, any profit organization aims making money and surviving in the long term. That being said, it is only reasonable to assume that most firms (with the exception of non-profit organizations) focus on being profitable, overcoming the competition and getting on the top of the hierarchy. In order to achieve that, one should be able to maximize the captured value of an innovation. In the context of this dissertation, considering the slow but steady shift to e-mobility, the best way to reach maximum profitability is by being the best at appropriating the value created from innovating the car. Before going into detail, it is important to differentiate between two types of players that, in certain situations might be represented by the same company or not. The first category has at its core members that create value, those that truly innovate. The second class is represented by those who are able to appropriate the value created by the first category, also called "bottlenecks". Ideally, it should be the same company that both innovates and receives proportional benefits. However, the reality dictates other rules and the value sometimes is appropriated by followers or even players from other industries. An example of such is given in the 2006 paper written by Jacobides, M.G., Knudsen, T., and Augier, M. named "Benefiting from innovation: Value Creation, value appropriation and the role of industry architectures". According to the authors, the wine industry in the 18th to 20th centuries is a good case study as it reveals that in certain areas it was the distributor who was receiving the most out of the sales due to its high credibility among the consumers, whereas in other regions it was the wine producer whose name was a sign of quality. This instance shows clearly how there are two alternatives: one in which the producer is not able to appropriate the value that is created and, as a result loses money to the distributor, and the other one resulting both in value creation and appropriation. In addition to the above mentioned categories, Jacobides, M.G., Knudsen, T., and Augier, M. (2006) argue that the industry architecture has two templates, each having its own rules: the first one defines how value is created and how the work is divided among the members of the industry (i.e. value creation), and the second one is related to how the surplus is divided (i.e. value appropriation). Furthermore, Santos, F.M., and Eisenhardt, K.M. (2006) state that any member of the industry could potentially find a comfortable position in such a way to influence the structure of the sector in which they act. As a consequence to these findings, one could conclude that even small firms with the right capabilities and resources could influence the industry in such a way in order to maximize the benefits created by an innovation. Section 3.2 successfully identified the companies and groups that are the most responsible for innovativeness, consequently - the value creators. This section aims identifying the possible value appropriators and hypothesize on the future of the global automotive industry architecture.

As to what concerns the industry of interest, there are several alternatives that should be considered in order to make a conclusion about the possible winners. It is important to remind that, although electric mobility is not a long-distant future anymore, the automotive industry is only at the beginning of a new cycle when things are constantly changing and no dominant design has been selected, thus, any of the presented ideas in the next few paragraphs are hypothetical but backed down by real-time observations, studies, news, and other trustworthy sources.

First of the possible automotive industry architectures involves the most straightforward approach: the situation does not change essentially, keeping the OEMs in charge for the production of several important powertrain, body and chassis components, and, additionally, managing all the assembly and work distribution operations. Suppliers continue to be coordinated by the car-makers without being involved too much in the design of the vehicle. Although there are suppliers with enough resources to switch the power balance in the agreement between them and the OEMs, they do not possess enough capabilities required to manage all the labor division in the automotive supply chain. Automakers, although not being as competent in certain fields as suppliers are, have grown immense managerial competencies over the course of more than a century of industry history. Toyota's success is not simply luck, it is a system developed through time. Although it outsources the production of more than 50% of the car value, it manages to stay globally on top and, moreover, to be highly profitable. A second point to be made in favor of carmakers is that although the comments in section 3.2 of this dissertation imply that they are not innovative enough in the field of alternative technologies, considering the amount of resources they have and the number of patents at their disposal, OEMs have the potential to be time resilient and highly adaptive. Several well-known brands have already begun to pursue a green-oriented strategy and introduced one or several models or electric cars. Volkswagen has already introduced the electric version of the popular hatchback model Golf, Nissan has been quite famous for a while due to its Leaf brand, BMW and Mercedes-Benz entered the electric world with their i-series and EQ model respectively. These are only some examples of the progress that automakers are making towards keeping their dominance over the automotive world.

The second possible alternative is the one in which suppliers of important components are able to appropriate more efficiently the created value as compared to the automakers. Although it seems rather hard to expect such a turnover, some suppliers are a force to be recognized. A recent paper written by Schulze, A., MacDuffie, J.P., and Taube, F.A. (2015) argues that there have been some changes in the automotive industry lately. This regards the emergence of mega-suppliers, often called Tier 0.5. Companies such as Bosch and Continental have surely gone beyond their hierarchical level due to their massive resources and size. Thanks to such a distribution of power, these mega-suppliers are able to influence the OEMs and participate in more integrated activities than simply transaction-based manufacturing. That being said, such suppliers have already shown interest in technologies such as batteries and electric motors. On the other side of the equation, most of the original equipment manufacturers have shown little interest in electric mobility, thus, they do not have the right competencies to compete under such conditions. Even with the help of a push towards the alternative technologies, building new competencies is not an easy task. It requires massive investments and much time. For decades, OEMs have specialized in designing and manufacturing engines, transmissions, and other valuable powertrain components. This results in a very possible inertia which will not allow any of the carmakers to be saved from their competence trap easily. Their knowledge and skills in the electric and electronics field is rather limited as in most of the situations, an intervention from a specialized supplier is required to whom the production is outsourced. A recent example highly related to this point is BYD Co Ltd. This Chinese company has been established in 1995 and its core business was batteries manufacturing. After intensively developing its skills and competencies, in 2003 it entered the automobile industry becoming a promising electric vehicle manufacturer, competing with other OEMs. Although only a supplier at the beginning, BYD was able to reach new highs and maximize the value appropriation. Moreover, as stated by the company's website, BYD is able to compete on three fronts: IT services for the automotive industry, electric vehicles, and energy storage systems. Following the reasoning behind this point, the same conclusion could be drawn for other important powertrain components other than batteries. Suppliers of electric motors, inverter and converter modules could also take the lead and overshadow the current automakers.

The third possibility could involve neither the OEMs nor the OESs. In a future where the vehicle will become simply a mobility instrument and not a symbol of one's status as it is mainly regarded now, both automakers and their suppliers risk losing a lot of value to the distributors. As shown in the example of the wine industry several centuries ago, due to a massive reputation, companies responsible for the distribution could become the dominant players. According to many studies conducted by several consulting agencies, one of which is Goldman Sachs, among the several trends in the auto industry that have been noticed in the last decade, shared mobility is believed to be a very promising one. Nielsen, a global company operating in the field of information and its analysis which provides market research for other firms, has established that the willingness to share a car is actually quite popular. According to Goldman Sachs citing data provided by Nielsen, Millennials are very open to car sharing. In fact, every third Millennial would not mind sharing a vehicle. This group is followed by Generation X and Z. The numbers, but not the conclusions, change quite a bit by looking at each region. Just under 50% percent of the Asian-Pacific and Middle-East-African Millennials support car sharing whereas the same age generation in Europe and North-America are less willing to do that, dropping the percentage to 17 and 18% respectively. So, what this information actually tells is that there might be a possibility for a future where vehicles are not bought by individuals but rather by other companies offering car-sharing services. The distributors of such services could potentially become the most important entity representing mobility, rather than individual car brands. Moreover, referring to what Goldman Sachs reports, this shift could be benefiting one side (mobility service provider) at the expense of the other (carmakers and suppliers). Car sales could drop significantly if consumers change their lifestyle by empowering this trend. In order to anticipate such a future, some OEMs have already entered the market for shared mobility. One prominent example of such is Daimler AG with its Car2go service. According to the information posted on the official Daimler website, this service is very easy to use and to set up. In fact, a certain number of vehicles are placed all around the cities in which the service is available and only with several touches on the smartphone, one is able to get the car, drive wherever needed and park it in any place. Car2go improves the urban mobility and saves a lot of money to the people using vehicles on an irregular base. At the moment, this service is available in 26 cities around the globe including Berlin, Vienna, and Washington, D.C. Daimler uses 14 thousand vehicles to implement its service efficiently and plans to expand as the number of customers will increase. As a result of this move, Daimler AG is successfully anticipating major changes in the automotive industry and secures its position by maximizing the value appropriation.

A final possible outcome in the value appropriation race is the emergence of new market entrants that will partially or entirely put the actual automakers in the shadow. For obvious reasons, there is rather little probability of such an outcome. Nevertheless, as to what this dissertation is concerned, all the possibilities are being considered. The setting point of this alternative has been Google's announcement of its electric vehicle. Although it is hard to believe that a company from the tech rather than the auto industry would make it through, despite all this, Google launched its autonomous electric car in 2016 under the brand name Waymo. Moreover, even though it is not confirmed, other tech companies, including Apple, are working on their own electric car projects. If Google will prove to be successful, it could most certainly drag more companies alike in the automotive industry, becoming a threat for the incumbent OEMs.

Chapter 4: The Italian automotive supply chain

The remaining topic and, by definition, the nucleus of this dissertation is the analysis of the automotive supply chain in Italy and the impact the shift to the new dominant design will have on the local suppliers. In order to successfully answer the questions that this dissertation aims to address, several steps had to be followed. The first one was the setting of the basic model to be used as a reference upon which data will be analyzed. The second and the third steps required to investigate in detail the available data and draw conclusions/hypothetical assumptions on the future of the Italian auto supply chain.

4.1 The model

The first step taken towards setting up the model of analysis was the identification of the different product archetypes congruent with the topic of electric mobility which would be used to define the scenarios. Considering what has been discussed in the Chapter 2, five archetypes have been selected to represent the different evolutive stages of the auto: internal combustion engine vehicles (ICEVs), traditional hybrid electric vehicles including micro, mild, and full hybrids (HEVs), plug-in hybrids – an intermediary stage between full HEVs and electric vehicles (PHEVs), battery electric vehicles (BEVs) and EVs running on hydrogen – fuel cell electric vehicles (FCEVs). These five classes have been consequently grouped into three scenarios. The first one, namely T_0, represents the current situation. By looking at the data provided by any source of official statistical information such as Eurostat or A.N.F.I.A, one could easily notice that the existing automotive industry is characterized by the dominance of two vehicle categories: ICEVs (including diesel and gasoline types) and HEVs. In order to reach the final scenario, the transition will have to be a bit softer than one would expect. As a result, an intermediate step has been defined ($T_{0,5}$) – the near future – characterized by an increase in both the production and sales of PHEVs. Lastly, T_1 – medium to long-term future – represents the final point of this transition. T_1 is characterized by the full market dominance of BEVs. On the other hand, FCEVs will probably see an increase in the total number of sales but never reach the popularity of BEVs. However, in order to have a full understanding of the Italian automotive supply chain, all the possibilities have been selected.

The second step essential to the development of the data model was the identification of all the powertrain components specific to the selected archetypes.

Choosing only the components specific to each powertrain architecture is rather self-explanatory when the topic of the dissertation is considered. Many components such as the chassis, exterior and interior parts, accessories, doors and roof (and many others) will remain equally important, independently if the vehicle is electrified or runs on fossil fuel. For this reason, only 11 components divided into 42 subcomponents have been selected for the list. The engine is the first among other 10 elements chosen for this analysis. It includes 6 subcomponents and systems: (1) mechanic components including engine blocks, cylinders, pistons, flywheels, valves, crankshafts and camshafts; (2) LPG/CNG powertrain elements; (3) air and liquid filters; (4) ignition system including spark plugs, coils, and distributors; (5) starting system; and (6) injection system. Transmission follows up the engine-related components. Although many American sources use the term "transmission" to identify the mechanism used to shift the gears (gearbox), this dissertation treats this term as the whole system that transmits power from the engine to the wheels. As a consequence, the transmission-related subcomponents are (7) the gearbox, (8) the clutch for manual transmission and the torque converter for automatic transmission, (9) differentials, (10) axles, and (11) the driveshaft. Next up on the list is the electric motor. It includes elements such as (12) rotor, (13) bearings, (14) stator, and (15) commutator. The fourth category includes only one element – (16) the electric generator/ alternator. According to AFDC (2018, b), the new generation of vehicles, compared to several decades ago, are quite sophisticated in terms of energy management. This is the result of implementing energy management systems (EMS) helping to improve efficiency. BEVs, for instance, have a power electronics controller (17) – an electronic device that controls the flow of energy circulating from the motor to the wheels. On the other hand, ICEVs have an engine control module (18) which is responsible for several functions such as the on-time delivery of the fuel to the engine and, moreover, the perfect quantity. The last models of vehicles could even have a software-based high level supervisory control (HLSC)(19). The 20th subcomponent identified is only related to the fuel cell vehicles – the fuel cell stack. This component is responsible for transforming hydrogen into emission-free energy. The next group of parts and components concerns inverters and converters. Since there are 2 types of current, depending on the motor and on the source of energy, converters (DC-DC, AC-AC) or inverters (DC-AC, AC-DC) are needed. These components are placed 21st to 24th on the list. The 8th group of components included in the list is the one concerning energy and fuel storage and delivery system. The battery (25) typically found in most of the vehicles was the first to be mentioned. Do not get it confused with the traction battery pack (26) which is a much bigger battery used by electric vehicles to power the electric motor, as opposed to the first one which is used to power accessories and, in many cases, to deliver power to the starter. Next on the list in this group are the ultracapacitor (27), high-voltage battery charger (28), hydrogen tank (29), gas/diesel tank (30), fuel pump and line (31 and 32 respectively). One element which became very important to the modern vehicle is the wiring harness (i.e. the set of cables representing the “nervous system” of the car). Among different types, 3 subcomponents have been identified: engine compartment harness (33), vehicle’s cable infrastructure (34) and miscellaneous cables (35). The suspension, steering and braking systems (SSBSs) (36) have been categorized as one single element as they are part of the drivetrain but are specific to all the vehicles and so, no distinction has been made. Lastly, some auxiliary systems and components have been selected. Although it might not come as a straightforward decision, choosing not to consider these elements would make the model, and, therefore, the analysis incomplete. Among the auxiliary systems and components, thermal management system (managing some important functions such as the engine cooling) has been identified as 37th, whereas oil level/pressure sensors, fuel level sensors, temperature sensors, lubrification system and exhaust system have been positioned from 38th to 42nd respectively. After having identified the 42 powertrain components, the next thing that had to be done is assigning an evaluation to each of the components. Two different perspectives have been followed, each presented in sections 4.1.1 and 4.1.2. A synthesis of the described list can be found in Table 4.1.

4.1.1 Component-powertrain relevance model

The first of the alternatives concerned the components themselves and their relevance to the specific powertrain. By relevance, it is meant if the selected component is used as part of the corresponding powertrain. Three values have been assigned to each component in the cases of each powertrain: irrelevant, relevant under specific conditions, and very relevant. The first grade is given to the corresponding couple component-powertrain only in the situation when the component is incompatible with the matching powertrain architecture. A simple example represents the traction battery pack for a conventional vehicle. Component-powertrain matches that were assigned the “relevant under specific conditions” grade are those which are qualified as relevant only if certain conditions are met (for example, electric vehicles, usually, have a fixed gear-speed ratio meaning the gearbox as a component is rather irrelevant but certain BEV carmakers still use two- or three-speed gearboxes). Lastly, the “very relevant” mark is given only to the component-powertrain couples that are compatible under any circumstances. For instance, the gearbox represents a crucial component of the ICEV powertrain. As explained in Chapter 2, internal combustion engines are not able to generate enough torque at low RPM, therefore, they need gearboxes to adapt the rotations to the standstill wheels. BEVs, on the other hand, do not have this issue. A summary of all the results is presented in Table 4.2.

No.	Components	Subcomponents	No.	Components	Subcomponents
1	Engine	Mechanical components	**22**	Inverter - Converter	DC-AC inverter
2		Filters	**23**		AC-AC converter
3		LPG/CNG components	**24**		AC-DC inverter
4		Ignition system	**25**	Energy storage and delivery system	Battery
5		Starting system	**26**		Traction battery pack
6		Fuel injection system	**27**		Ultracapacitors
7	Transmission	Gearbox	**28**		High-voltage battery charger
8		Clutch/Torque converter	**29**		Hydrogen tank
9		Differential	**30**		Gas/Diesel tank
10		Axle	**31**		Fuel pump
11		Driveshaft	**32**		Fuel line
12	Electric traction motor	Rotor	**33**	Wiring harness	Engine compartment harness
13		Bearings	**34**		Vehicle's cable infrastructure
14		Stator	**35**		Miscellaneous cables
15		Commutator	**36**	SSBSs	Suspension, steering and braking systems
16	Electric generator	Generator/Alternator	**37**	Auxiliary systems and components	Thermal management system
17	EMS	Power electronics controller	**38**		Oil level/pressure sensors
18		Engine control module	**39**		Fuel Level sensors
19		HLSC	**40**		Temperature sensors
20	Fuel cell	Fuel cell stack	**41**		Lubrication system
21	Inverter -	DC-DC converter	**42**		Exhaust system

Table 4.1. Powertrain components and subcomponents list

Component	Subcomponent	ICEV	HEV	PHEV	BEV	FCEV
Engine	Mechanical components	●	●	●	○	○
	Filters	●	○	○	○	○
	LPG/CNG components	●	●	●	○	○
	Ignition system	●	●	●	○	○
	Starting system	●	●	●	○	○
	Fuel injection system	●	●	●	○	○
Transmission	Gearbox	●	●	●	⊙	⊙
	Clutch/Torque converter	●	●	●	⊙	⊙
	Differential	●	●	●	⊙	⊙
	Axle	●	●	●	●	●
	Driveshaft	●	●	●	⊙	⊙
Electric Traction Motor	Rotor	○	⊙	●	●	●
	Bearings	●	●	●	●	●
	Stator	○	⊙	●	●	●
	Commutator	○	⊙	●	●	●
Electric	Generator/Alternator	●	●	●	●	●
EMS	Power electronics controller	○	●	●	●	●
	Engine control module	●	●	●	○	○
	HLSC	⊙	⊙	●	●	●
Fuel Cell	Fuel cell stack	○	○	○	○	●
Inverter-converter	DC-DC converter	○	⊙	●	●	●
	DC-AC inverter	○	⊙	●	●	●
	AC-AC converter	○	⊙	●	●	●
	AC-DC inverter	○	⊙	●	●	●
Energy storage and delivery system	Battery	●	●	●	⊙	⊙
	Traction battery pack	○	⊙	●	●	⊙
	Ultracapacitors	○	⊙	●	●	⊙
	High-voltage battery charger	○	○	●	●	○
	Hydrogen tank	○	○	○	○	●
	Gas/Diesel tank	●	●	●	○	○
	Fuel pump	●	●	●	○	●
	Fuel line	●	●	●	○	●
Wiring harness	Engine compartment harness	●	●	●	○	○
	Vehicle's cable infrastructure	⊙	●	●	●	●
	Miscellaneous cables	●	●	●	●	●
SSB	Suspension, steering and braking systems	●	●	●	●	●
Auxiliary systems	Thermal management system	●	●	●	●	●
	Oil level/pressure sensors	●	●	●	○	○
	Fuel Level sensors	●	●	●	○	●
	Temperature sensors	●	●	●	●	●
	Lubrication system	●	●	●	⊙	⊙
	Exhaust system	●	●	●	○	⊙

Legend: ○ - irrelevant; ⊙ - relevant under specific conditions; ● - very relevant.

Table 4.2. Component-Powertrain relevance matrix

4.1.2 Competence – powertrain model

The second perspective from which the data has been analyzed considers the competencies rather than the components. The distinction, although might seem not fully clear at the first sight, is quite simple. Some of the components listed in Table 4.are quite similar by their nature. However, some correspond so certain powertrains, whereas others do not. In this case, the manufacturer of one of the components potentially has the competencies to produce the other component if the demand for the current products falls. An excellent example of such scenario is the battery (25) and the traction battery pack (26). Although the two components serve different purposes, most likely, the producer of auxiliary batteries will be able to expand the product range to big batteries used by BEVs. It is not to be said, however, that all the manufacturers having adaptable competencies will do so. It is beyond the scope of this dissertation to determine whether the suppliers with adaptable competencies will have enough resources to change.

This being said, similarly to the previous model, 3 evaluation grades have been given to each component-powertrain matching: Yes (Y), Maybe (M) and No (N). The first of them is assigned exclusively to the perfect matches (for instance, the competence in building mechanical components for ICEV powertrain). The "M" evaluation is given to the competencies which, as explained in the previous paragraph, have the potential to be transferable to other products for the selected powertrain. Finally, the negative evaluation (N) is given only to those competencies which cannot be transferred to other products for the selected powertrain (e.g. fuel tanks for BEV powertrain).

A final word regarding the two models concerns their relative importance for the conducted research. It should be highlighted that both models have their advantages and their limits. The first one, although it is very specific and cuts many companies which would be included in the second model, gives a better understanding of what product categories will be the most impacted. On the other hand, the second model considers the competencies and gives results based on them but does not take into account that some firms are producing multiple products that are not powertrain-related and will probably survive the change to electric mobility. Both approaches have been used to build a better understanding both from the perspective of the products (components) and of the companies (competencies). A synthesis of this matrix is presented in Table 4.3.

Component	Subcomponent	ICEV	HEV	PHEV	BEV	FCEV
Engine	Mechanical components	Y	Y	Y	N	M
	Filters	Y	N	N	N	N
	LPG/CNG components	Y	Y	Y	N	M
	Ignition system	Y	Y	Y	N	N
	Starting system	Y	Y	Y	M	M
	Fuel injection system	Y	Y	Y	N	N
Transmission	Gearbox	Y	Y	Y	M	M
	Clutch/Torque converter	Y	Y	Y	N	N
	Differential	Y	Y	Y	Y	Y
	Axle	Y	Y	Y	Y	Y
	Driveshaft	Y	Y	Y	Y	Y
Electric Traction Motor	Rotor	N	Y	Y	Y	Y
	Bearings	Y	Y	Y	Y	Y
	Stator	N	Y	Y	Y	Y
	Commutator	N	Y	Y	Y	Y
Electric	Generator/Alternator	Y	Y	Y	Y	Y
EMS	Power electronics controller	M	Y	Y	Y	Y
	Engine control module	Y	Y	Y	M	M
	HLSC	M	M	Y	Y	Y
Fuel Cell	Fuel cell stack	N	N	N	N	Y
Inverter-converter	DC-DC converter	N	Y	Y	Y	Y
	DC-AC inverter	N	Y	Y	Y	Y
	AC-AC converter	N	Y	Y	Y	Y
	AC-DC inverter	N	Y	Y	Y	Y
Energy storage and delivery system	Battery	Y	Y	Y	M	M
	Traction battery pack	M	M	Y	Y	Y
	Ultracapacitors	N	M	Y	M	M
	High-voltage battery charger	N	N	Y	Y	N
	Hydrogen tank	M	M	M	N	Y
	Gas/Diesel tank	Y	Y	Y	N	M
	Fuel pump	Y	Y	Y	N	M
	Fuel line	Y	Y	Y	N	M
Wiring harness	Engine compartment harness	Y	Y	Y	M	M
	Vehicle's cable infrastructure	M	Y	Y	Y	Y
	Miscellaneous cables	Y	Y	Y	Y	Y
SSB	Suspension, steering and braking systems	Y	Y	Y	Y	Y
Auxiliary systems	Thermal management system	Y	Y	Y	Y	Y
	Oil level/pressure sensors	Y	Y	Y	M	M
	Fuel Level sensors	Y	Y	Y	M	Y
	Temperature sensors	Y	Y	Y	Y	Y
	Lubrication system	Y	Y	Y	M	M
	Exhaust system	Y	Y	Y	N	M
Legend: Y – yes, M – maybe, N – no.						

Table 4.3. Competence-Powertrain matrix

4.2 The data

The data used in the process of mapping the Italian supply chain was provided by the Center for Automotive & Mobility Innovation (CAMI) – a research network of professors and specialists whose expertise in the automotive and sustainable mobility field has developed throughout years of experience. The supplied dataset contains updated to 2016 information regarding the whole Italian automotive supply chain with more than 2 thousand companies, including the manufacturers of exterior and interior parts, chassis, accessories, etc. As said at the beginning of this chapter, this dissertation is concerned only with the suppliers of powertrain components as they are the ones who are directly influenced by the new trend in the automotive industry. In order to differentiate between the suppliers of interest and those who are producing not powertrain-related components, a series of filters has been applied using keywords. Due to the fact that the dataset is written in Italian, the keywords used were in Italian as well.

Before going into detail with the results of the analysis, it would be appropriate to give some comments on the filters used. Firstly, some components required several keywords for a better accuracy. For instance, the exhaust system includes several components (such as the tailpipe, silencer, exhaust manifold). For that reason, several filters have been applied in order to be more precise. Secondly, the selected companies have been included only after an analysis of their product range. The information was double-checked by comparing it to available public data (i.e. company websites) and to the description provided by the CAMI dataset. As a consequence, some companies manufacturing, for instance, cables, have not been considered as they were not producing powertrain-related components (e.g. accessories cables/wires). Lastly, some components required the same keywords due to their similarity. For example, both the gas/diesel and hydrogen tanks have been identified by using the keyword "serbatoi". Since these two components serve the same function and using a combination of two words was inaccurate, the decision to use the proper category of products was made on the spot.

The complete list of the components and the keywords that were used to identify them can be found in Table 4.4.

Component(s)	Keyword(s)	Component(s)	Keyword(s)
Mechanic components: engine block, cylinder, piston, flywheel, valve, crankshaft, camshaft	Piston, cilindr, alber, fonder, cam, motor	DC-AC inverter	DC, AC
LPG/CNG	GPL, metano	AC-AC converter	AC
Air/Liquid filters	filtr	AC-DC inverter	DC, AC
Ignition system: spark plugs, coils, distributor	Candel, bobin	Battery	Batteri
Starting system: starter	Starter, avvia	Traction battery pack	Batteri
Fuel injection system: injector	Iniettor, iniez	Ultracapacitor	condensator
Gearbox	Cambio, trasmission	High-voltage battery charger	Batteri, ricarica
Clutch/Torque converter	Frizion, transmission	Hydrogen tank	Serbatoi
Differential	differenzial	Gas/Diesel tank	Serbatoi
Axle	Ass, assal	Fuel pump	Pomp, carburant
Driveshaft	Alber, trasmission	Fuel line	Carburant
Rotor	Rotor, motor	Engine compartment harness	Cablaggi
Bearings	Cuscinett	Vehicle's cable infrastructure	Cablaggi
Stator	Stator, motor	Miscellaneous cables	Cabblagi, cav
Commutator	Commutator, motor	Suspension, steering, and braking systems	Sterz, suspension, fren
Generator/Alternator	Generator, alternator	Thermal management system	Raffredda, temp
Power electronics controller	controll	Oil level/pressure sensors	sensor
Engine control module	controll	Fuel Level sensors	sensor
Software-based high level supervisory control (HLSC)	controll	Coolant temperature sensors	sensor
Fuel cell stack	cell	Lubrication system	Lubrifica
DC-DC converter	DC	Exhaust system	Scaric, marmit

Table 4.4. Components and keywords

4.3 The results

After having applied the necessary filters, 438 suppliers have been identified as manufacturers of powertrain-related components among the 2000+ companies in the dataset. Considering what has been told in the introductory part of this chapter, two scenarios have been identified: T_0 and T_1. Given the approach and the questions this thesis is trying to address, the results presented in this section concern only T_1 and consider neither the intermediary alternatives (i.e. PHEVs) nor the other possible dominant designs architecture (FCEVs).

4.3.1 Main areas of competencies

The conducted analysis has revealed some interesting data regarding the structure of the automotive supply chain in Italy. Among the 438 identified companies, 10 could not be assigned to any of the 42 products as they lack any public information such as websites. As a result, they were categorized as not determined (N.D.). An impressive share of the remaining 428 companies shows quite a big interest in the production of mechanical components, mainly engine-related ones such as pistons, camshafts, and cylinders. To be more precise, 132 of the 438 manufacturers of powertrain-related components are involved in producing mechanical components for engines, 53 of which do not supply any other components. If taken altogether the engine as a complex system of subcomponents, 22 companies are producing LPG and CNG systems, 21 are producing filters, 16 are involved with the manufacturing of ignition components, 10 with the starting system and 30 with fuel injecting system. However, these numbers do not reveal separate companies but rather the number of the companies having the competencies to build such components. To what concerns LPG/CNG subsystems, it was quite expected to have such a result due to the fact that Italy is the European leader in terms of LPG/CNG vehicles sold every year. This unusual detail is the result of the mass diffusion of such powertrain by Fiat – a major producer of LPG/CNG vehicles in Italy.

Transmission-related components are also one of the main areas of knowledge characteristic to the Italian auto industry. More than 50 companies (12,6% of the 438 identified suppliers) are producing gearboxes both for conventional vehicles and for sportscars. Around the same number (6%) are working on clutches, differentials, axles, and driveshafts. With regards to the electromagnetic field, 14 companies have the knowledge and skills to produce generators. These suppliers will probably be in a very good position once the electric mobility takes the market. On the other hand, the number of suppliers of components for electric motors is quite low. Only 9 companies are specialized in the production of rotors and stators, even less (7) in the production of commutators. An interesting observation is that there are almost no producers of power electronics controllers. Hopefully, the 7 suppliers of engine control modules will be able to adapt to the new market and invest their skills in the manufacturing of similar components for BEVs. The same could be told about the auxiliary battery producers. Although the usual car battery is quite important as it powers the accessories, the battery-building skills will be much more valuable if used to produce traction battery packs for electric vehicles. The main reason behind the superior price of BEVs over ICEVs is the cost of the battery, meaning that 7 Italian suppliers could potentially become the value appropriators in the e-mobility supply chain.

Although the numbers described up to this point are in the favor of the current industry architecture, there are a lot of companies who are specialized in the future-proof segments. By analyzing the 438 identified suppliers, as much as 27,6% of them are specialized in producing suspension, steering and braking systems or components related to them. Most of the 121 companies are producing components for at least 2 of the systems. Some of them are suppliers of luxury brands such as Ferrari and Maserati. Another strong point for a successful transition is a partial specialization in the wiring harness segment. As much as 9% of the total identified suppliers are working in the field of miscellaneous cables and vehicle's cable infrastructure. After having analyzed every company's website, I've come to the conclusion that most of the identified wire manufacturers have advanced products that could compete on an international level. Besides the 2 most popular segments, the third one involves the cooling system – an essential element of any powertrain that will ensure a safe driving experience both for the vehicle and for the person in front of the steering wheel. More than 20 suppliers are manufacturing components for the thermal management system.

The complete list of results is presented in Table 4.4. One final remark that I would like to add before switching to other results is that overall, although some of the Italian auto suppliers are in a bad position with respect to the hypothesized future, it is crucial to consider the fact that the distribution of functions in the industry is quite wide considering that there are companies manufacturing almost all of the 42 powertrain components identified. Surely, it is not the best result having them concentrated in building engine-related components but, on the other hand, there are a lot of firms who are the only ones or among the few who are specialized in manufacturing a certain product. This gives them an enormous opportunity to become among the first to enter the electric mobility market and take a big share in their respective segments.

Component(s)	Nr. suppliers	Component(s)	Nr. suppliers
Mechanic components: engine block, cylinder, piston, flywheel, valve, crankshaft, camshaft	132	**DC-AC inverter**	1
LPG/CNG	22	**AC-AC converter**	1
Air/Liquid filters	21	**AC-DC inverter**	3
Ignition system: spark plugs, coils, distributor	16	**Battery**	15
Starting system: starter	10	**Traction battery pack**	7
Fuel injection system: injector	30	**Ultracapacitor**	0
Gearbox	55	**High-voltage battery charger**	3
Clutch/Torque converter	28	**Hydrogen tank**	0
Differential	25	**Gas/Diesel tank**	14
Axle	29	**Fuel pump**	21
Driveshaft	27	**Fuel line**	14
Rotor	9	**Engine compartment harness**	5
Bearings	19	**Vehicle's cable infrastructure**	32
Stator	9	**Miscellaneous cables**	40
Commutator	7	**Suspension, steering, and braking systems**	121
Generator/Alternator	14	**Thermal management system**	23
Power electronics controller	1	**Oil level/pressure sensors**	7
Engine control module	7	**Fuel Level sensors**	9
Software-based high-level supervisory control (HLSC)	1	**Coolant temperature sensors**	5
Fuel cell stack	3	**Lubrication system**	8
DC-DC converter	1	**Exhaust system**	33

Table 4.5 Number of suppliers for each component

4.3.2 Models-based results

By looking at a glance at the obtained results from the perspective of both the component-powertrain and competence-powertrain matrices, there are certain similarities when it comes to making a judgment on how electric mobility will impact the automotive supply chain in Italy. In order to not be repetitive, a comparison of the results with respect to the 2 models will be given.

The first group to start with is the one represented by companies who will most probably not face any huge problems related to the new product architecture. The component model identified 25 companies less than the competence one (223 vs. 248 respectively). This difference was expected due to the fact that competencies offer more flexibility when evaluating a supplier's future. Most of these suppliers (about 40% for the component model and 39% for the competence model) are concentrated in the Piedmont region, followed up by Lombardy with more than 50 suppliers and Emilia-Romagna (12% and 15% according to the component and competence models respectively). On the other hand, over140 suppliers have been identified as being at risk. The same pattern is followed in terms of regional distribution: Piedmont – around 50, Lombardy – 15 less, and Emilia-Romagna with Veneto – 19 in the case of component-powertrain model and 17 and 18 respectively, if analyzed from the perspective of competencies. Most probably, these companies will dismiss the production of their powertrain-related components as soon as the automobile architecture will be changed. The "maybe" group is mostly represented by companies from Piedmont, Lombardy, Emilia-Romagna, Campania, and Veneto regions. The difference between the two models, however, is almost 50% with 39 companies being identified by the competence model and 58 using the component approach. The not identified companies are mostly located in the Piedmont region.

From a macro-regional perspective, 86% of the 438 suppliers are located in the North (62% in the North-West and 24 in the North-East). The Center and the South plus the islands are represented only by 61 companies. More than 50% of the total companies manufacture relevant components or have important competencies for the BEV powertrain. The majority are concentrated in the North-West. The Center is underrepresented (only 7 companies produce relevant components and 8 have the competencies for BEVs, the same number corresponding to the irrelevant components and only 3 to stay in the middle). The biggest difference between the two models seems to root in how the components in the middle are evaluated. According to the second approach, fewer suppliers are in a position of uncertainty, all being transferred to the yes group. On the other hand, the first model is rather less flexible in this matter. A full summary of the results is presented in Table 4.6.

	Number of suppliers (2016)							
	Y		N		M		N.D.	TOTAL
	Component	Competence	Component	Competence	Component	Competence		
Abruzzo	8	8	4	4				**12**
Basilicata	3	3	2	2				**5**
Campania	10	12	4	4	4	2		**18**
Emilia-Romagna	27	36	19	17	12	5	2	**60**
Friuli Venezia Giulia	3	3	2	2				**5**
Lazio	1	1	1	1	1	1	1	**4**
Liguria	1	1	1	1				**2**
Lombardia	53	58	35	34	15	11	2	**105**
Marche	2	2	1	1				**3**
Piemonte	90	97	51	49	19	14	5	**165**
Puglia	4	4			1	1		**5**
Sardegna	1	1						**1**
Sicilia	1	1	1	1				**2**
Toscana	4	4	4	4	1	1		**9**
Trentino Alto Adige	3	4	2	2	1			**6**
Umbria		1	1	1	1			**2**
Veneto	12	12	19	18	3	4		**34**
Total	223	248	147	141	58	39	10	**438**

	Number of suppliers by macro-region (2016)							
	Y		N		M		N.D.	TOTAL
	Component	Competence	Component	Competence	Component	Competence		
North-West	144	156	87	84	34	25	7	**272**
Nord-East	45	55	42	39	16	9	2	**105**
Center	7	8	7	7	3	2	1	**18**
South/Islands	27	29	11	11	5	3	0	**43**
Total	223	248	147	141	58	39	10	**438**
%Cat	50,91%	56,62%	33,56%	32,19%	13,24%	8,90%	2,28%	100,00%

Table 4.6 Number of suppliers by regions, macro-regions and by evaluation model

Another data that the analysis revealed is the employment situation. More than 65 thousand employees are working in the powertrain segment in 2016. The data is quite similar for both models regarding the employment representing the companies that are in the riskiest position. Slightly below 15 thousand people risk losing their jobs if the companies with a “No” evaluation do not change the course of their business. Most of the identified employees of this group are located in the Piedmont, Lombardy, and Emilia-Romagna regions. The situation, however, changes as the “Yes” and “Maybe” groups are put under the observation. According to the component model, there are 40 thousand employees who are working in companies which produce relevant components for BEVs. On the other hand, the competence model states that there are 5 thousand more people who are in the same position. The same distribution pattern concerns all the groups: Piedmont is the leader while Lombardy follows up. The people who are employed by suppliers with an uncertain future are 9 and 4 thousand for component and competence models respectively. More than 700 employees could not be identified.

The Northern regions have the most employees in the powertrain sector, in particular, the North-West ones who represent 70% of the total employment. According to the first model, approximately 30 thousand employees (33 thousand for the second approach) who are working in a safe company are located in Piedmont and Lombardy only. Overall, the competence model is more optimistic with respect to the other one. A full summary concerning the employment numbers can be found in Table 4.7.

	Number of employees (2016)							
	Y		N		M		N.D.	TOTAL
	Component	Competence	Component	Competence	Component	Competence		
Abruzzo	1.595	1.595	889	889				**2.484**
Basilicata	88	88	116	116				**204**
Campania	256	300	37	37	174	130		**467**
Emilia-Romagna	1.981	2.339	2.106	2.060	543	231	29	**4.659**
Friuli Venezia Giulia	538	538	731	731				**1.269**
Lazio	32	32	1	1	3	3	0	**36**
Liguria	389	389	31	31				**420**
Lombardia	12.307	13.132	2.641	2.628	1.926	1.114	20	**16.894**
Marche	100	100	12	12				**112**
Piemonte	17.536	20.312	5.808	5.780	4.046	1.298	683	**28.073**
Puglia	1.997	1.997			800	800		**2.797**
Sardegna	9	9						**9**
Sicilia	9	9						**9**
Toscana	1.105	1.105	406	406	29	29		**1.540**
Trentino Alto Adige	1.474	2.252	1.026	1.026	778			**3.278**
Umbria		270	229	229	270			**499**
Veneto	812	812	872	868	622	626		**2.306**
Total	40.228	45.279	14.905	14.814	9.191	4.231	732	**65.056**

	Number of employees by macro-region (2016)							
	Y		N		M		N.D.	TOTAL
	Component	Competence	Component	Competence	Component	Competence		
North-West	30.232	33.833	8.480	8.439	5.972	2.412	703	**45.387**
Nord-East	4.805	5.941	4.735	4.685	1.943	857	29	**11.512**
Center	1.237	1.507	648	648	302	32	0	**2.187**
South/Islands	3.954	3.998	1.042	1.042	974	930	0	**5.970**
Total	40.228	45.279	14.905	14.814	9.191	4.231	732	**65.056**
%Cat	61,84%	69,60%	22,91%	22,77%	14,13%	6,50%	1,13%	100,00%

Table 4.7 Number of employees by regions, macro-regions and by model

Chapter 5: Conclusion

This dissertation, as planned from the very beginning, has discussed 3 topics: the structure of the products the automotive industry is offering, the structure of the industry itself on a global level, and, more important, the analysis of the automotive supply chain in Italy. Electric mobility is a rather destructive technology. Its adoption will transform quite a few components into obsolescence. The question this thesis tried to answer is "How will electric mobility impact the local auto suppliers in Italy?" and thanks to the data provided by CAMI, several conclusions could be made. The most important result to be pointed out is that, although there is a majority of companies working in the powertrain segment who have the right capabilities and knowledge to pass through the "e-mobility barrier", quite a high portion of the 438 identified companies will face big obstacles on their road to survival. No matter if the data is analyzed from the perspective of the components or competencies, the results are quite similar. About 32% or slightly above 140 of the identified companies risk losing a share of their product range with the emergence of the new dominant design. This result has been somehow intuitively expected due to the fact that, opposed to other macro-regions on the globe such as Japan, a lot of the Italian auto suppliers have developed skills and gained knowledge from a mechanical aspect point of view. Historically, Italy had more knowledge regarding engine and transmission manufacturing rather than electric and electronic components. The statistics regarding the number of companies producing components for the engine is as high as 132 and those producing gearboxes – 55. It is clear that the manufacturing of mechanical components is one of the dominant characteristics of the Italian automotive industry. Nevertheless, the data suggests that a very high number of companies is involved in producing components which are essential to the BEV powertrain. Although the distribution of the functions is divided between two segments (mechanical components for the engine and suspension, steering, and braking systems), one interesting pattern could be observed: the Italian supply chain manages to produce most of the 42 identified powertrain components. In some cases, there are only one or several producers for a single segment, making it an ideal opportunity for market growth with the upcoming changes.

The second observation that was made is that the average size of the Italian auto suppliers in terms of employees reaches 148 employees per company. However, this result is rather unreliable as there are 12 companies with over a thousand employees. The median, on the other hand, shows a more accurate image of the situation, and it is 36,5 employees per company. It is not, however, a surprise as small and medium businesses are typical for the Italian economy. But, as a consequence of the reduced size, most of the companies would incur the most damage due to their lack of substantial resources

Lastly, in terms of employment, hypothetically, almost up to 15 thousand people could risk ending up losing their jobs, most residing in the Northern regions. This is a tremendous damage both from an economic and social perspective. Thankfully, the transition to electric mobility will take a while as it requires heavy investments in the charging infrastructure, auto price drops and a collective approach on a global level regarding the regulations on emission-free vehicles.

Finally, I would like to finish with a closing remark concerning future pieces of research in a related to this topic field. The information gathered from the public sources could potentially be incomplete. Most companies have projects about which a certain level of privacy is kept. As a result, it could be possible that some of the companies who were classified as producing irrelevant components or who had not competences whatsoever related to the BEV powertrain are, in fact, investing in future-oriented technologies.

Acknowledgment

I would like to thank my supervisor - Professor Zirpoli, for being unbelievably supportive and helpful from the very beginning of this thesis. Most of the work done would not have possible without his pieces of advice.

I would like to thank also Professor Moretti and Pasquale Salvatore, Eng. Their guidelines and information have been essential to the writing of this thesis and to my graduation.

I am immensely grateful to the CAMI team who have provided valuable information core to the study pursued by this dissertation.

Lastly, but not the least, I would like to thank my family, friends, and my significant other who have been by my side in good and bad times.

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