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# 1. Introduction

The analysis submitted in the present thesis work has been performed during the traineeship carried out in FCA Italy S.p.A., more specifically in the Advanced Network Engineering unit. Its fundamental goals include the assessment of the economic impact related to the introduction of possible logistic scenarios (inbound or outbound costs and outbound investments) and focusing on the cost targets of the logistic services, in compliance with the quality constraints and the on-time deliveries. The other two principal objectives are the update of the transport network, by providing innovative solutions (when volumes or other network parameters vary) through software simulation and the costs/performance optimization of the inbound flows for all the EMEA plants (Europe, Middle East and Africa).

The main subject of the work analyses the FCA plant of Melfi and in particular the introduction of electric innovation within its distribution network. As a matter of fact, the introduction of electric vehicles in the current organization of the network requires dedicated equipment that must be integrated to a specific selected part of the first intermediate and final distribution nodes.

Therefore, the topic fits inside a contemporary crucial issue: the sustainable transport and carmakers' reaction with electric innovation. The need for an improvement in green emissions is leading automotive brands to an increasingly development of low impact vehicles, in particular electric and hybrid ones.
Electrification in FCA begins in 2020 with the production of Fiat 500 BEV (Battery Electric Vehicle) in Mirafiori and Jeep Compass PHEV (Plug-in Hybrid Electric Vehicle) and Jeep Renegade PHEV in Melfi. In particular, this latter plant has been selected in order to analyze how these two new hybrid models will influence the current distribution network, formed only by internal combustion engine cars.

Firstly, it is outlined how the distribution of the vehicles produced in Melfi is carried out. This initial argument is approached with an important assumption: hybrid vehicles are supplied with the same procedures used for traditional vehicles; in this way, it is so presented the unconstrained network. Next, the electric innovation of Melfi distribution network is added: the tools, devices and physical structures necessary to monitor the conditions of hybrid vehicles are introduced in Melfi Plant compound and in the analyzed intermediate/final nodes.
Once the value of the equipment is obtained, it can be summed to the unconstrained network, and the final constrained network is discovered.

These three just listed high-level objectives could be developed using four different databases: the most important one have the distribution plan of FCA for 2020, while the other ones used are the transport fees database, the transit time database and the average stock time database.
By considering all the routes, their unitary fee, and the period required to supply a specific market, the related costs are consequently calculated. In particular, the data analyzed are not all, but only a specific group obtained by filtering the general databases.
A first filter is applied to identify only the Melfi volumes among the total distribution, while the second limitation used in the work reduces the geographical area analyzed (Northern Italy and the most supplied European countries).

Before the central case study chapter, the work initially explains the current state of art of electric innovation in automotive and its consequences in the traditional automotive supply chain and distribution network, with a special focus to the environmental and customer point of view.
A chapter including a deeper analysis of the distribution of electric vehicles follows the literature review. Here are detailed the requirements, the constraints, the processes used in EVs transportation and the main differences with the traditional distribution.
Once the current landscape is presented with these two chapters, the case study is designed in the immediately following one.

At the end of it, it is shown the final cost of the distribution constrained network and its comparison with the unconstrained one (where hybrid vehicles are treated like traditional diesel/petrol ones). The difference between them is the value of the costs incurring in 2020 for the implementation of Melfi electric network.
Considering the current importance of sustainability in carmakers' outbound operations, another comparison is carried out: the total amount of $CO_2$ produced in the constrained network is compared to the emissions resulting from an optimized scenario where intermediate points are minimized.

# 2. Literature review

## 2.1. Introduction

The first electric vehicle was built by Frenchman Gustave Trouvé in 1881. It was a tricycle powered by a 0.1-hp direct current (DC) motor fed by lead-acid batteries (Ehsani et al., 2018).

Near the dawn of the automobile era, electric vehicles commanded roughly 30% of the nascent market, preferred over chemically-fueled vehicles for their dependability, silence, simplicity of operation and ease of 'refueling' (Tamor et al., 2013). In the year 1900, 1575 electric automobiles were produced versus only 936 gasoline cars. But the advantages of the internal combustion engine soon overshadowed these minor benefits. By 1905, gasoline automobiles had taken the lead in numbers and popularity. The 70-mile range of the typical gasoline car was more than double the 30-mile range of the electric in 1900. Also, electrics required a significantly greater initial investment and up to three times as much money to run as their gasoline counterparts (D'Agostino, 1993).

However, from the 80's, the impending environmental issues and growing concerns for global energy crises are driving the need for new opportunities and technologies that can meet significantly higher demand for cleaner and sustainable energy systems (Habib et al., 2018).

One of the main driving forces for these developments, in addition to the volatility of oil prices, is the increasing concern regarding climate change and $CO_2$ emissions (Steinweg, 2011).

By using electricity rather than petroleum, EVs and plug-in hybrid electric vehicles (PHEVs) reduce our petroleum use. Overall, from well to wheels, GEVs (grid electric vehicles) reduce the energy consumption and emissions in the transportation sector: PHEVs reduce GHG (greenhouse gases) emissions by 32% compared to conventional vehicles (Boulanger et al., 2011).

Electric vehicles significantly reduce production of vehicles emission and noise (Mažgút et al.,2015), while from a technical point of view BEV (battery electric vehicle) and FCV (fuel cell vehicle) are currently clearly preferable to conventional ICE (internal combustion engine) vehicle for their better energetic conversion efficiency (Ajanovic and Haas, 2013); the acceleration performance of these vehicles would be comparable or better than conventional ICE vehicles (Burke, 2007).

For these reasons, vehicle electrification is now seen as the main decarbonization pathway for nearly all road-based transportation (Cano et al., 2018). If a new energy economy is to emerge, it must be based on a cheap and sustainable energy supply (Armand and Tarascon, 2008).

Four general types of electric vehicles can be distinguished:

1) MHEV: the mild hybrid is a regular car that includes a small electric motor that is used for start-stop systems; this motor is only used to assist the car's regular propulsion system when accelerating

or braking (Steinweg, 2011). Simulation results indicate fuel economy improvements of 40%– 50% in city driving using (Burke, 2007).

2) HEV: hybrid electric vehicles; these types of cars feature a larger electric motor as well as a large electric battery which is put to use when starting the engine, accelerating and driving at low speeds (Steinweg, 2011). The batteries of these EVs could achieve fuel economy improvements of 50% and greater (Burke, 2007).

3) PHEV: the plug-in hybrid is an upgrade of the hybrid car, whose battery can be charged through the electricity grid (Steinweg, 2011).

Plug-in hybrids can be designed with effective all-electric ranges of 30–60 km using lithium–ion batteries that are relatively small. The effective fuel economy of the PHEVs can be very high (greater than 100 mpg based on gasoline use only) for long daily driving ranges (80–150 km) resulting in a large fraction (greater than 75%) of the energy to power the vehicle being grid electricity (Burke, 2007).

4) BEV: the end-point of the evolution of the electric car is the full electric vehicle. This model uses only electricity to drive the car, and the electricity from the grid is stored in a large battery, usually a Li-ion battery (Steinweg, 2011).

Extensive research has been done to study the impacts of EVs in three major areas:

- Economic impact assessment of EVs.
- Environmental impact assessment of EVs.
- Power grid impact assessment of EVs (Habib et al., 2018).

The environmental and economic impact of electric vehicles will depend on the fraction of users that can accept an EV of a given capability (Tamor et al., 2013).

The high growth rate of EVs is projected to have huge penetration in distribution networks in the coming future. The current power networks may suffer from additional loads due to extensive charging consumption of EVs, which are adversely affecting the existing conventional distribution grids (Habib et al., 2018).

In spite of the benefits of EVs, several obstacles need to be overcome before EVs will be widely adopted (Egbue and Long, 2012): incremental costs, life cycle of batteries, deficiency in the infrastructure of charging the EVs and issues regarding battery chargers (Habib et al., 2018). For example, battery powered vehicles (EVs) using lithium–ion batteries can be designed with ranges up to 240 km with reasonable size battery packs (Burke, 2007).

In the following paragraphs is reported the literature review about the EVs supply chain and how it influences the traditional automotive industry, the future trends and the environmental aspect. Then it focuses on EVs distribution, the development of the necessary charging infrastructure and finally is treated the market and customer vision about electric vehicles and their diffusion.

## 2.2. Supply chain for electric vehicles

### 2.2.1. Structure of the supply chain

A generic supply chain (SC) can be assumed like an organization of relatively enduring inter-firm, cooperative and collaborative entities, using resources from participants with consistent interests (Lee, 2004). Under such a paradigm the members of a SC share equitable risks, expenses and benefits to accomplish shared information and strategic quality systems whose goals are independent for each one of them (Ketchen and Giunipero, 2004).

Complexity of supply chains depends on the scope of the production that needs to be distributed, features of geographic distribution, and elements of logistics infrastructure, such as numbers of different types of transport, terminals and ports (Vilkelis and Jakovlev, 2014).

In the automobile industry and corresponding SCM there are significant frameworks of strategic operations in several areas like procurement, management of materials, production, factoring, general distribution and final transportation to markets (Dias et al., 2010).

It is and will be important for automobile manufacturers and suppliers to select the right partners (Couzin et al., 2001).

The electric car is powered by an electric motor and its power source would usually be represented by a battery that needs to be charged before travel (Marcincin et al., 2017).

Battery-powered EVs are becoming an important component of automotive manufacturers' strategies. The first generation of mass-produced EVs has just entered the Market (Hawkins et al., 2013). They lessen fuel usage because they employ the electric motor frequently, especially in slow traffic (Denholm and Short, 2006), and because they recapture otherwise discarded kinetic energy during braking (Romm and Frank, 2006).

Although range anxiety is often portrayed as the primary reason electric vehicle adoption is not growing more rapidly by the general population, the cost of vehicles is actually the larger issue (Radomski et al., 2013).

The electric car battery is manufactured using a number of raw materials that need to be mined or sourced otherwise. Next, these raw materials are used to manufacture battery cells, which in turn form the building blocks of the electric car battery. This battery is then assembled into the electric vehicle. After the production phase, the car is purchased by the end consumer, whose demand is a large determinant for the rest of the supply chain (Steinweg, 2011).

So, the actors involved in the EVs supply chain are:

- Tier 1, tier 2 and tier 3 for battery manufacturing (tier 3 extracts minerals, tier 2 produces battery cells, tier 1 assembles cells into final battery packs used by carmakers)
- Tier 1 and tier 2 for electric powertrain manufacturing (tier 2 for components production, tier 1 semi-assembles them for carmakers)
- Tiers for mechanical parts (used also in traditional ICEs supply chain)
- Automotive original equipment manufacturers (OEMs)
- Local dealers
- Final customers
- Recycling, remanufacturing and reuse firms for batteries (Radomski et al., 2013).

Note: the inbound side of any supply chain (sometimes until the second tiers network suppliers), corresponds to raw materials transportation usually made by heavy transportation modes (Dias et al., 2010).

Using different components if compared to traditional vehicles, e-car production has an effect not only on the flow of materials from the suppliers to the vehicle plant and the finished car distribution to the markets, but also inhouse material flows have to be taken into account (Klug, 2013). Moreover, in the environmental point of view the supply chains involved in the production of electric powertrains and traction batteries add significantly to the environmental impacts of vehicle production. The EV production phase is more environmentally intensive than that of ICEVs for all impact categories (Hawkins et al., 2013).

Another main difference, talking about EVs supply chain, has to be taken into account: due to the dangers linked to Li-ion batteries (listed in the next paragraph), safe storage, packaging and labelling practices as well as communication among parties involved are essential to ensure safety across the whole lifecycle of primary lithium and lithium-ion batteries. Consequently, transportation costs for suppliers and OEMs grows significantly (Lisbona and Snee, 2011).

For OEMs, the full integration of e-cars at a single assembly line leads to an increase in the different part numbers required and thus has an impact on the inventory policies and the general need to maintain supply flexibility to remain competitive (Berry and Cooper, 1999). So, a focus on temporal and spatial proximity between supplier and vehicle manufacturer becomes of strategic importance (Bennett and Klug, 2012).

Proximity enables low inventory, late configuration and also last-minute revisions in the sequencing to cope with planning failures (Sako, 2006). Where short order cycle time is only a matter of hours, the supplier must be located in close proximity to provide the correct modules within tight time constraints (Fredriksson, 2006). Moreover, the new spectrum of parts, which comes along with e-cars, will change the after sales logistics significantly. Car manufacturers will face radical changes in

sales and distribution so that dealer and service networks must be made ready for the broader product portfolio (Valentine-Urbschat and Bernhart, 2009).
The local car distributors play a key role in the distribution process, in particular when orders must be placed: because since car shortages do occur, they sometimes create safety inventories (reporting less supply and larger demand of cars) in order to ensure meeting the future expected demand of their customers. The safety inventories can result in incomplete or inaccurate data for the OEMs central distribution planning (Holmberg et al., 1998).

Among different battery technologies, lithium ion batteries (LiBs) are the most desirable ones for the automotive applications because of high power, energy capacity and long lifetime (Omrani and Jannesari, 2019).
The lithium-ion battery owes its name to the exchange of the Li+ ion between the graphite anode and a layered-oxide cathode, thanks to a transition metal (usually cobalt) (Armand and Tarascon, 2008).
At present, the battery pack is the highest cost component driving the price of EVs (Radomski et al., 2013): the price of new LiB packs is US$ 227/kWh for Toyota and Kia models, while US$ 216/kWh and US$ 190/kWh, for Nissan and Tesla, respectively (Lee and Clark, 2018).
The battery cell materials supply chain, including cell assembly, is currently dominated by Asian suppliers (Radomski et al., 2013). China plays a big role in the geopolitics of rare earth supply: it now controls 93% of worldwide production; given that the easily-exploitable reserves of lithium and rare earths are finite, they have strategic value and thus may become resources to control in the geopolitical sphere, potentially causing shortages in the future (Boulanger et al., 2011).
The raw materials are used to produce Li-ion battery cells; these cells define the quality of the battery itself, including its safety, performance, lifespan and other qualities. (Steinweg, 2011).
The cells are then joined to produce battery packs: if there are roughly 19 components that need to be assembled to make a cell, as compared to 200+ components in pack assembly (Radomski et al., 2013).
The labour costs for the production of the battery pack are low, as the process is not very labour intensive. Therefore, there will not be a strong urge to locate production facilities in low wage countries, as the cost benefit of doing so will only be marginal (Steinweg, 2011).

The progressive electrification of the worldwide vehicle fleet is leading to an increasing importance of electric motors in the automotive industry. Driving cycles of vehicles characterized by pronounced dynamics require a robust and high-quality powertrain. This results in an increase in the complexity of the production of the electric motor and thus, adequate quality assurance and testing processes are required in order to be able to manufacture and assemble it (Kampker et al., 2018).
The electric engine consists of five main components: the housing, the stack of electric sheets, the rotor, the stator and the shaft. Each element has specific production steps with alternative processes,

depending on the requirements. In the final assembly the components are joined together, as it is possible to see in Figure 2.1.

<table>
<tr><th colspan="2">Components</th><th colspan="4">Technologies</th></tr>
<tr><td rowspan="2">Laminated stack</td><td>Electrical sheet</td><td>Stamping</td><td>Rotational Cutting</td><td>Laser Cutting</td><td rowspan="2">Progressive stacking</td></tr>
<tr><td>Connection (PSM)</td><td>Adhesive bonding</td><td colspan="2">Laser welding</td></tr>
<tr><td rowspan="4">Stator</td><td>Slot insulation</td><td colspan="2">Foil insulation / Slot liner</td><td colspan="2">Thin-walled injection molding</td></tr>
<tr><td>Impregnation</td><td colspan="2">Trickle impregnation</td><td colspan="2">Impregnation and induction heating</td></tr>
<tr><td rowspan="2">Winding technology</td><td>Linear winding</td><td>Needle winding</td><td>Flyer winding</td><td>Hairpin bending</td></tr>
<tr><td colspan="4">Shaping of coil ends</td></tr>
<tr><td rowspan="4">Rotor</td><td>ASM cage</td><td colspan="2">Continuous casting</td><td colspan="2">Die casting</td></tr>
<tr><td rowspan="2">PSM</td><td colspan="4">Magnetization</td></tr>
<tr><td colspan="2">Robotic handling of magnets</td><td colspan="2">Adhesive bonding</td></tr>
<tr><td>Balancing</td><td colspan="4">Balancing by machining</td></tr>
<tr><td rowspan="2">Shaft</td><td>Shaping</td><td colspan="2">Continuous casting</td><td colspan="2">Machining</td></tr>
<tr><td>Hardening</td><td colspan="4">Hardening</td></tr>
<tr><td>Housing</td><td>Shaping</td><td colspan="2">Die casting</td><td colspan="2">Continuous casting</td></tr>
<tr><td rowspan="3">Final asembly</td><td>Joining of components</td><td>Heat shrinking</td><td>Press-fitting</td><td>Adhesive bonding</td><td>Screwing</td></tr>
<tr><td rowspan="2">Contacting</td><td>Soldering</td><td colspan="2">Ultrasonic welding</td><td>Arc welding</td></tr>
<tr><td>Laser welding</td><td colspan="2">Crimping</td><td>Plug connection</td></tr>
</table>

Figure 2.1. Technologies used in the production of electric motors

At first, the housing is shrunk on the stator by an induction system. Following, a custom designed robot system interposes the rotor in the stator as a small air gap hampers manual assembling. After mounting the end shields, which protect the interior of the motor, the finished engine is checked in an end-of-line test. The used equipment compromises an induction heating system for the housing, a robot system for assembling the rotor and a tester (Kampker et al., 2012).
Electric engines for vehicle traction are responsible for 5% to 20% of the costs of the electrical power train (including battery) and 5% of the costs for the complete car (Kampker et al., 2013).
By structuring the electric engine in a modular product architecture and subsequently analyzing the dependencies between function level and component level, manufacturers can adapt their production system to development processes economically in earlier stages (Kampker et al., 2015).

Growing numbers of electric vehicles present a serious waste-management challenge for recyclers at end-of-life. Nevertheless, spent batteries may also present an opportunity as manufacturers require access to strategic elements and critical materials for key components in electric-vehicle manufacture:

recycled lithium-ion batteries from electric vehicles could provide a valuable secondary source of materials (Harper et al., 2019).

Repair, remanufacturing, and recycling of large format lithium ion batteries is an area of growth, presenting both challenges and opportunities. When a battery is either defective, does not operate effectively for its intended primary use, or has reached the end of its life cycle of between five to ten years, it may be repurposed or may need to be recycled (Radomski et al., 2013).

If LiBs' primary capacity downgrades to 70–80%, they will not be able to provide the required power in EVs (Assunção et al., 2016). However, the power density is not important in ESSs, consequently batteries could be secondarily used (Martinez-Laserna et al., 2018): the total lifetime of EV LiB packs is 20 years for combination of primary and secondary utilization (Omrani and Jannesari, 2019).

Given that the environmental footprint of manufacturing electric vehicles is heavily affected by the extraction of raw materials and production of lithium ion batteries, the resulting waste streams will inevitably place different demands on end-of-life dismantling and recycling systems. In the waste management hierarchy, re-use is considered preferable to recycling, in order to extract maximum economic value and minimize environmental impacts (as represented in Figure 2.2).

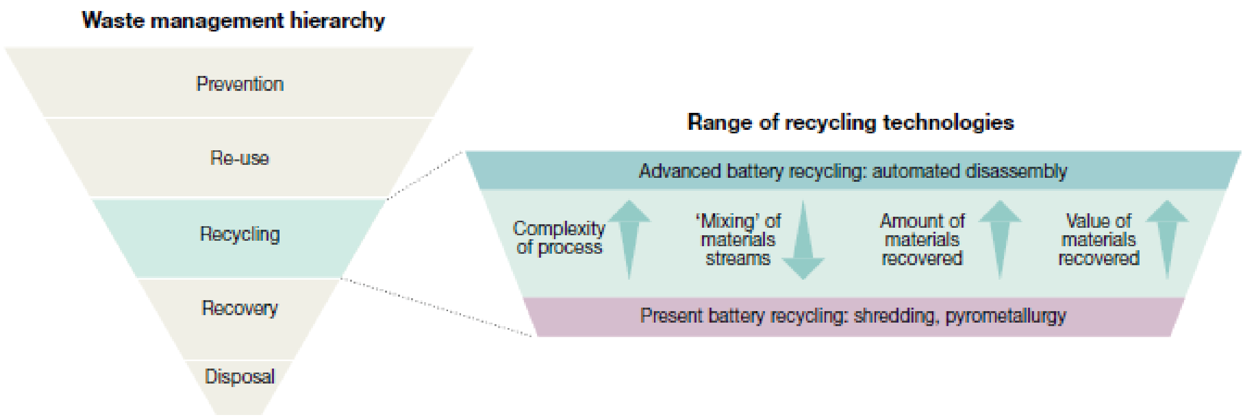



Figure 2.2. The current lithium-ion batteries waste management hierarchy

Many companies in various parts of the world are already piloting the second use of electric-vehicle LIBs for a range of energy storage applications. Advanced sensors and improved methods of monitoring batteries in the field and end-of-life testing would enable the characteristics of individual end-of-life batteries to be better matched to proposed second-use applications, with concomitant advantages in lifetime, safety and market value (Harper et al., 2019).

As final consideration, it is possible to affirm that since the electric car market is still very much under development, the supply chain still needs to mature. This implies that current players might be outcompeted in the future, while new actors will appear. It also means that it is currently too early to draw solid conclusions on the nature of the electric car supply chain and its eventual formation (Steinweg, 2011).

### 2.2.2. Differences with the traditional automotive supply chain

Automakers have recognized that electric drive vehicles are critical to the future of the industry (Boulanger et al., 2011).
All major automakers have R&D (research and development) programs for electric vehicles (EVs) and have indicated their intentions to begin mass production within the next few years (Hidrue et al., 2011).
The future shift in the automotive value chain of e-cars, especially the question of battery, electric motor and transmission production, will transform the nature and level of logistics coordination across dispersed plants (Klug, 2013). Supply chains must be highly dynamic to be able to rapidly respond and adapt to the existing changes in the market (Vilkelis and Jakovlev, 2014).

Why, then, did the automobile companies resist EVs? The reason may stem from the differences between electric vehicles and conventional vehicles. The heart of an electric vehicle is electronic, rather than mechanical. Electric vehicles do away with gasoline engines, with their thousands of precisely engineered and moving parts operating at high temperatures, and replace them with motors having one major moving part and a controller with no moving parts. Electric vehicles thus require an entirely new set of suppliers, assembly processes, and technicians for EVs service (US DOT, 2007).
The alteration of manufacturing processes and creation of new production lines would, therefore, require considerable intellectual and human capital along with huge financial expenditures in hundreds of billions of dollars (Sovacool and Hirsh, 2009); car industry has to rethink existing inbound, inhouse and outbound operations (Klug, 2013). For example, electrification means that components such as air-conditioning units, water pumps, brakes and steering systems have to be adapted (Valentine-Urbschat and Bernhart, 2009).
Moreover, a transition to EVs would likely induce a significant loss of business for repair and maintenance companies. The cost of EV maintenance should be minimal, since the vehicles have fewer moving parts and need no lubricating oils, filters, coolants, clutches, spark plugs, wires, oxygen sensors, timing belts, fan belts, water pumps, catalytic converters, or mufflers (Fontaine, 2008).

For this considerable change of know- how, companies need to build up new competencies to be able to develop and produce competitive electric vehicles (Kampker et al., 2012).
The major uncertainty regarding EVs is how fast will be the technological development about the battery (Ajanovic and Haas, 2013), so one crucial determinant of future inbound logistics processes from a car manufacturer perspective is the make-or-buy decision of major modules like batteries (the

same is for electric motors or power transmissions) (Klug, 2013). Figure 2.3 shows the current choices for batteries made by some EVs carmakers.

| Electric car model | Battery producer |
|---|---|
| Nissan Leaf | Automotive Energy Supply (Nissan NEC JV) |
| Chevrolet Volt | Compact Power (subsidiary of LG Chem) |
| BMW Megacity | SB LiMotive (Bosch Samsung JV)[20] |
| BYD E6 | BYD |
| Coda | Tianjin Lishen[21] |
| Ford Focus EV | Compact Power (subsidiary of LG Chem)[22] |
| Ford Transit Connect Electric | Johnson Controls-Saft[23] |
| Mini E | E-One Moli[24] |
| Mitsubishi iMiEV | Lithium Energy Japan (Mitsubishi GS Yuasa JV)[25] |
| Renault Fluence | Automotive Energy Supply (Nissan NEC JV)[26] |
| Smart ED | Tesla[27] |
| Toyota FT-EV | Panasonic EV Energy (Panasonic Toyota JV)[28] |
| Tesla Model S | Panasonic Energy[29] |

Figure 2.3. Current lithium ion batteries make or buy decisions made for some EVs production

There are different scenarios, which will play a major role for future logistics implications of e-car manufacturing. Likely scenarios are:

- The vertical integration of a battery producer and an automobile manufacturer in a single company
- The acquisition of a battery producer by a car manufacturer
- The expansion of a battery producer into car production
- Cooperation of e-car manufacturers with local and foreign battery suppliers
  (Wang and Kimble, 2011).

Tier-one suppliers like battery makers will try to secure the value implicit in owning core skills, including innovation in batteries and in the new features they could make possible. Competence will migrate from the cell-level chemistry to the level of battery pack systems, including power and thermal management software, and to the electronics optimising a battery's performance in a specific vehicle (Hensley et al., 2009). This gives battery manufacturer a dominant power in the future value split of e-car manufacturing. China will, together with Japan and Korea, play a major role in battery production (Wang and Kimble, 2011).

Automotive manufacturers and suppliers, which have traditional core competencies in engines, clutches and gearboxes have to realign their strategy and identify new business opportunities (Dombrowski et al., 2011).

Production workers that should benefit from this new development are assemblers, fabricators, metal and plastic workers, as well as electrical, chemical, and mechanical engineers.
Some factors are related not only to the actual sales of EVs, but also to breakthroughs that would allow for much cheaper materials and components to be manufactured on a mass scale. Roughly, 60% of the battery cell cost is attributed to the raw materials used to produce the electrodes, electrolyte, separator, and housing. Growth beyond laboratory scale would translate to a significant price decrease in an EV battery pack. The ETA has allocated funding to provide free training to employees in southeast Michigan who need to upgrade their skills in the area of advanced energy storage. Macomb Community College and Wayne State University are the training partners in this grant and have designed a number of courses to upgrade current employee's skills as well as to train dislocated workers to enter the field of advanced energy storage (Radomski et al., 2013).

The use of scalable production machines, small automation systems and virtual factory planning support a quick ramp-up from small scale to large-scale production of electric engines. Combined with product and process construction kits for electric engines, scalable production systems could enable manufactures to enter the market for electro mobility (Kampker et al., 2013).
Necessary process technologies for the electric motor production are gradually replacing well-known process technologies in the automotive production (Kampker et al., 2017).
At the same time, dynamic driving cycles and a generally high quality requirement profile in the automotive industry pose new challenges for electric motor manufacturers with regard to testing processes (especially in the area of end-of-line testing) (Kampker et al., 2018).
The evaluation of process technologies of the production of electric motors shows that there are several needs for action. It is outlined that standardization, cycle times and measurement of critical process parameters must be considered in future research. Additionally, rejects need to be detected at an early stage in the production line, which requires further development of monitoring and evaluation methods. Finally, efficient methods of rework for faulty process outputs be investigated (Kampker et al., 2017): successful companies have to follow a dual strategy by leading in cost as well as quality (Kampker et al., 2012).
The BCG (Boston Consulting Group) calculated that producing the battery in the United States would only be 6% more expensive than doing so in South Korea, which in turn is only 8% more expensive than China. One of the factors that explains this, is that car batteries are heavy and difficult, and therefore expensive, to transport (Steinweg, 2011).
Development of green energy technology have promoted the lithium-ion batteries into an extensive applying in the field of electric vehicles (EV) (Wen et al., 2012). Unfortunately, as will be explained more precisely later, primary lithium batteries contain hazardous materials such as lithium metal and

flammable solvents which can lead to exothermic activity and runaway reactions above a defined temperature. Lithium-ion batteries operating outside the safe envelope can also lead to formation of lithium metal and thermal runaway (Lisbona and Snee, 2011).

The safety issues of the lithium-ion batteries are mainly caused by the failure of individual components (cathode, anode, electrolytes or current collector) and the whole system of battery in some abuse conditions, including overcharge, thermal runaway, dendritic lithium growth, current-collector dissolution, gas evolution and so on (Wen et al., 2012). These hazards have materialised not only during use at the intended application, but also during transport and storage of new and used battery packs: transport and warehousing operations must be provided with structural protection as well as a thermal management system (e.g. adequate ventilation) to prevent overheating due to operation or heat input from the surroundings. Battery packs and modules are frequently thermally managed using air-cooling systems (Lisbona and Snee, 2011).
The effects of the safety concerns on the future of electric cars are as much a matter of real safety concerns as it is of image: 'One bad incident can spoil the public's opinion' (Steinweg, 2011).

The main differences related to the paragraph are briefly summarized in Table 2.1.

| | **ICEs supply chain** | **EVs supply chain** |
|---|---|---|
| **Innovations** | Few (static structure) | Continuous |
| **Basic know-how** | Mechanical | Electronic |
| **Logistic operations** | Stationary | In evolution |
| **After-sale services required** | High | Low |
| **Supply chain main actor** | Carmaker | Battery manufacturer |

Table 2.1. Main differences between the traditional automotive supply chain and the SC for EVs

### 2.2.3. Future challenges

Due to the extensive conversion of vehicle fleets in private transport to electrified drive trains, the industry as well as research institutions and politics face major challenges (Kampker et al., 2015).

The fundamental technological constraint to the commercialization of EVs is energy storage (Anderman, 2007). Battery technology is limited by tradeoff between five major attributes including power, energy, longevity, cost and safety (Axsen et al., 2010).

The electric car is still very much in development, and large scale production has started only recently and for just a few brands. This means that the supply chain is still very much in development, and might grow in unexpected ways (Steinweg, 2011).

To enable an efficient production within broad quantity ranges at constantly low costs, scalable production systems are required. Scalability indicates the ability to adapt to variable quantities and to be capable of enlargement, leading to significantly lower costs. Consequently, the sales price of electric vehicle decreases, whereas the attraction for customers increases (Bondi, 2000).

Wiendahl describes the scalability as the technical, spatial, organizational and personal ability (expandability and reducibility) of plant modules and plant elements (Wiendahl et al., 2005), while according to Schuh and Gottschalk, scalability is the characteristic of a production line or production system to adapt to variable requirements of production with highly limited resources and time (Schuh and Gottschalk, 2004).

Cost innovations in the production process and lower R&D costs will play a crucial role for the future growth and competiveness of electric cars due to costs being one of the major barriers for successful economic producible electric mobility so far (Kampker et al., 2015).

The main driving force would be a drop in their retail price, thanks to declining battery pack costs. Such a scenario is not unlikely, given the current pace of technological improvements and the growing economies of scale in battery production (Danielis et al., 2018).

Due to increase in electric vehicle sales in recent years, LiB pack price has fallen from US$ 1000/kWh in 2010 to US$ 273/kWh in 2016, which represents 73% drop. Also, it is expected to reach US$ 75/kWh by 2030 (Omrani and Jannesari, 2019).

The development and production of electric traction engines has become a main subject for nearly all car manufacturers (Kampker et al., 2015).

A ramp-up of production with finally capable processes and predictable process outputs is therefore complex, time-consuming and cost-intensive (Kampker et al., 2017).

Currently the optimal target cost, quality and scalability requirements have not been met, but can be addressed by purpose design, integrated product and process development, modularization of machinery and intense process know-how along with a continuous consideration of alternative production processes.

Some current and future challenges are illustrated by the production of the stator. In addition, the potential of scalability can be exemplified by the winding process. The winding of the rotor with needle winding can be scaled by integrating additional needles when exceeding a specific quantity.

To ensure a competitive sales price of 18,000 Euro for an electric vehicle in the market segment of short range city cars (~120 km range), the target costs for an electric engine must not exceed 570 Euro (Schuh et al., 2013). The current production costs for a comparable electric engine are still about 200% above the target costs, but simulations show that a virtual electric engine production site with an output of 100.000 electric engines per year is capable to beat the target cost (Kampker et al., 2012).

Another factor that will determine the future shape of the electric car industry is the development of technological capabilities. There is increasing interest and activity, in exploring new electrochemical mechanisms that might boost the specific energy and performance of future batteries. These developments might have an effect on the entire supply chain, as they might require other raw materials or different production processes and might have an effect on consumer demand (Steinweg, 2011).

For example, the components of today's lithium-ion batteries, such as $LiCoO_2$ and $LiMn_2O_4$, are not produced from renewable energy resources but from ores, and extracting the raw materials and manufacturing the electrodes will require increasing amounts of energy as they become scarcer, as analyzed in Table 2.2. Will the lithium-ion battery, which is so energetically expensive to fabricate, remain attractive and viable in the long term? (Armand and Tarascon, 2008).

| Country | 2005 Production (tonnes) | Reserves (tonnes) | Reserve Base (tonnes) |
|---|---|---|---|
| United States | 1,700 (MIR) | 38,000 | 410,000 |
| Argentina | 2,000 | 1,000,000 (MIR) | 2,000,000 (MIR) |
| Australia | 2,240 (MIR) | 160,000 | 260,000 |
| Bolivia | - | 2,700,000 (MIR) | 5,400,000 |
| Brazil | 240 | 190,000 | 910,000 |
| Canada | 700 | 180,000 | 360,000 |
| Chile | 8,000 | 1,500,000 (MIR) | 3,000,000 |
| China | 2,700 | 1,100,000 (MIR) | 2,700,000 (MIR) |
| Portugal | 320 | NA | NA |
| Russia | 2,200 | NA | NA |
| Zimbabwe | 240 | 23,000 | 27,000 |
| TOTAL | 20,340 | 6.8M | 15.0M |

Table 2.2. World lithium production and reserves (2005)

Current technological developments are mostly focused on improving the performance of Li-ion batteries on a number of different dimensions: life, performance, specific energy, specific power, safety and costs (Steinweg, 2011).
Lithium–sulfur batteries have received increased attention owing to the 4.5 times higher theoretical lithium capacity and much lower cost of sulfur cathodes relative to typical Li-ion insertion cathodes. Zinc–air batteries, despite having a lower specific energy than Li–air batteries, seem more likely to be used in future EVs because of their more advanced technology status and higher practically achievable energy density (Cano et al., 2018).
Moreover, much is expected of the lithium–air system, which offers a great improvement in energy density, and lithium- based systems that use electroactive organic molecules, which could be obtained from biomass using green chemistry.
Most attempts to improve the design of lithium ion batteries have tackled the problem at the macroscopic scale, but work is now focusing on the nanoscale. The arrival of nanomaterials gave lithium-ion batteries a new lease of life and provided benefits in terms of capacity, power, cost and materials sustainability that are still far from being fully exploited (Armand and Tarascon, 2008).
Batteries with improved specific energy, energy density, cost, safety and grid compatibility are necessary to electrify the long-range, low-cost and high-utilization transportation sectors.

Inadequate driving range, or 'range anxiety', is frequently reported as a key technological barrier preventing consumers from purchasing EVs (Cano et al., 2018).
The range issue has the greatest impact on BEVs, which do not have the flexibility of fuel source like HEVs and PHEVs and therefore may require charging en route during long trips that exceed the range of the batteries. Consequently, there is also a need for EV charging infrastructure to charge EVs during trips (Egbue and Long, 2012).
Developing the charging infrastructure, a good addition could be equipping charging stations with the vehicle to grid system: an automobile capable of ''vehicle-to-grid'' (V2G) interaction mates an automobile with the existing electric utility system (Williams and Kurani, 2007). Vehicles must possess three elements to operate in V2G configuration: a power connection to the electricity grid, a control and/or communication device that allows the grid operators access to the battery, and precision metering on board the vehicle to track energy flows (Tomić and Kempton, 2007). This intelligent, two-way communication (shown in Figure 2.4) between the electricity grid and the vehicle enables utilities to manage electricity resources better, and it empowers vehicle owners to earn money by selling power back to the grid. EVs and V2G systems are thus intimately interconnected (Sovacool and Hirsh, 2009).

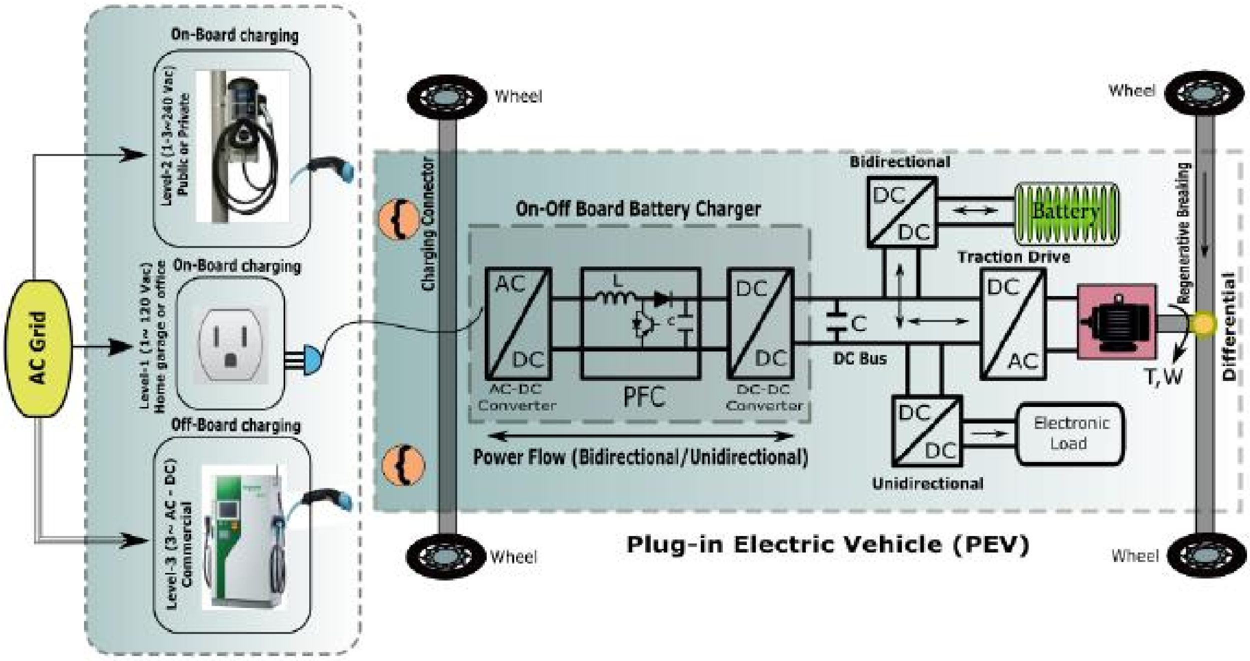



Figure 2.4. How bidirectional flows performance happens on a PEV (V2G)

The ability to use EVs as a resource depends on appropriate support infrastructure, as well as the existence of aggregators, and customers who are willing to provide the service. The initial use of vehicles for grid services will occur in areas that require the lowest infrastructure investment (Boulanger et al., 2011).

The substantial benefits provided by bidirectional V2G technology are: support to active power and reactive power, sustenance for power factor regulation and help to improve the integration of variable renewable energy resources (Habib et al., 2018). Moreover, it provides additional economic benefits to EV owners (provides car owners a monthly revenue and makes the electricity grid more efficient and cleaner), improves grid efficiency, and may help integrate renewable energy (Noel et al., 2019).

The current charging technology of EVs has certain restrictions in relation to V2G technology. The battery chargers are not fully matured for V2G deployment in smart grid environment. In the present situation, unidirectional chargers are mostly adopted in the market.

However, advance bidirectional chargers are needed for standardized V2G implementation. Therefore, additional focus is required for advance research techniques in planning and development of bidirectional chargers (Habib et al., 2018).

The fastest method to extend the travel range of electric vehicles currently available is the replacement of flat battery with a new one at an exchange station (SDEM in Slovak Republic, 2015).

Studies showed that the battery swapping technology is more favorable choice than quick charging for long distance travel (Habib et al., 2018). It is demonstrated the capability of switching an automotive battery in less than three minutes, the amount of time it takes to fill up a gas tank (Boulanger et al., 2011).

The question of battery recharge versus exchange strategy will have a tremendous influence on the logistic structures. Exchanging heavy and expensive batteries at special service points involves high handling, transport and storage costs (Klug, 2013).

The industry has proposed a novel solution centered around the use of “swapping stations,” at which depleted batteries can be exchanged for recharged ones in the middle of long trips. The possible success of this solution hinges on the ability of the charging service provider to deploy a cost-effective infrastructure network; because batteries can be swapped, they are not owned by the EV users themselves but rather leased to them based on some service contracts. Users will be charged based on usage (i.e., miles driven) (Mak et al., 2013).

This in turn would require some level of standardization of batteries, so that charging stations would only have to deal with a manageable inventory of different battery types (Boulanger et al., 2011).

### 2.2.4. The environmental aspect

The transportation sector is responsible for approximately 14% of global greenhouse gas emissions and this is projected to increase to 50% by 2030 (IEA, 2007). This projection implies that the current transportation system is unsustainable (Egbue and Long, 2012).
$CO_2$ emissions and consumptions of fossil fuel will drastically reduce with large-scale deployment of EVs (Habib et al., 2018). This transformation of transportation sector provides a friendly environment, which is based on reduced levels of $CO_2$ emissions (Shaukat et al., 2018). The $CO_2$ emissions will be reduced up to 1-6% until 2025 and 3-28% till the end of 2030 (Karsten et al., 2012).

EVs offer advantages in terms of powertrain efficiency, maintenance requirements, and zero tailpipe emissions, the last of which contributes to reducing urban air pollution relative to conventional internal combustion engine vehicles (ICEVs) (Wang and Santini 1992). This has led to a general perception of EVs as an environmentally benign technology. The reality is more complex, requiring a more complete account of impacts throughout the vehicle's life cycle. Consistent comparisons between emerging technologies such as EVs and their conventional counterparts are necessary to support policy development, sound research, and investment decisions (Hawkins et al., 2013).
There is international consensus that the improvement of the sustainability of electric vehicles can only be analysed on the basis of life cycle assessment (LCA) (Jungmeier et al., 2013).
LCA involves compiling an inventory of the environmentally relevant flows associated with all processes involved in the production, use, and end of life of a product and translating this inventory into impacts of interest (Curran 1996).
The contribution electric cars may make to sustainability can only truly be assessed when the full impact throughout the supply chain is considered (Steinweg, 2011).
The vehicle cycle includes the production, use and end of life of the vehicle including its battery. It is generally recognised that the production of electric vehicles has higher environmental impacts compared to conventional vehicles mainly due to the necessary production of the battery (Jungmeier, 2012).

The main influences of the environmental effects of vehicles with an electric drivetrain in the life cycle are:

- Production and life time of the battery
- Electricity consumption of the vehicle in the operation phase incl. energy demand for heating and cooling

- Production and source of the electricity, where only additional generated renewable electricity might maximise the environmental benefits
- End of life treatment of the vehicle and its battery (discussed in paragraph 2.2.1) (Jungmeier et al., 2013).

While the benefits of reduced $CO_2$ emissions through increasing the use of electric cars are well documented, such discussions do not take into account the potential social and environmental costs throughout the supply chain. Not much is said about the conditions under which minerals such as lithium, cobalt, phosphate or rare earth metals are extracted, nor are the working conditions at production facilities included in the equation (Steinweg, 2011).

Billions of lithium-ion cells are produced for portable electronics, but this is not sustainable as cobalt must be obtained from natural resources (it makes up 20 parts per million of Earth's crust) (Armand and Tarascon, 2008).

If we consider the two main modes of primary production, it takes 250 tons of the mineral ore spodumene when mined, or 750 tons of mineral-rich brine to produce one ton of lithium. The processing of large amounts of raw materials can result in considerable environmental impacts. Production from brine, for example, entails drilling a hole in the salt flat, and pumping of the mineral-rich solution to the surface (Harper et al., 2019).

Replacing each of the world's 800 million cars and lorries with electric vehicles or plugin hybrids powered by 15-kWh lithium-ion batteries would use up to 30% of the world's known reserves of lithium. All these problems must be overcome if lithium batteries are to take their place as the batteries of the future (Armand and Tarascon, 2008).

The mining and production of lithium itself can also create great environmental problems, as listed in Figure 2.5.

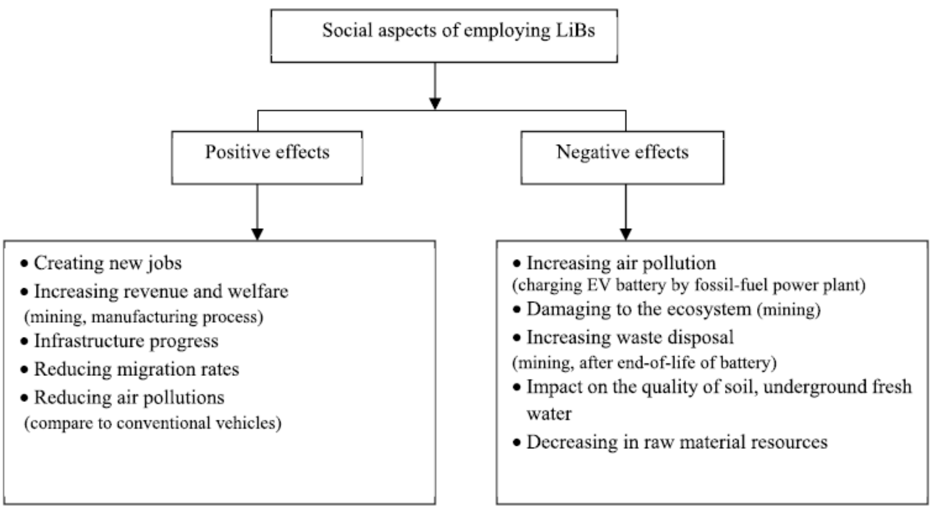



Figure 2.5. Social pros and cons in the production of lithium ion batteries

The Democracy Center has written a paper in which it describes the possible effects of large scale lithium production on groundwater, flora and fauna and soil and air pollution due to the large quantities of chemicals needed in the industrial process of lithium production.
Another social problem linked to lithium ion batteries production are the bad working conditions in production facilities in China or cobalt mines in the Democratic Republic of Congo (DRC). All these issues need to be taken into account to be able to have a fruitful discussion about the costs and benefits of electric cars.

It is clear, however, that the sustainability of the electric car goes beyond the environmental benefits during the use of the car (Steinweg, 2011).
The use phase is responsible for the majority of the GWP impact, either directly through fuel combustion or indirectly during electricity production.
EVs powered by the present European electricity mix offer a 10% to 24% decrease in global warming potential (GWP) relative to conventional diesel or gasoline vehicles assuming lifetimes of 150,000 km. Because production impacts are more significant for EVs than conventional vehicles, assuming a vehicle lifetime of 200,000 km exaggerates the GWP benefits of EVs to 27% to 29% relative to gasoline vehicles or 17% to 20% relative to diesel. An assumption of 100,000 km decreases the benefit of EVs to 9% to 14% with respect to gasoline vehicles and results in impacts indistinguishable from those of a diesel vehicle (Hawkins et al., 2013).
Considering the total emissions in the entire electricity supply chain, because of the usage of cleaner and more efficient power generators, especially in more developed countries, the total emissions by EVs are still significantly lower than by ICE vehicles (MIT Electric Vehicle Team 2008).

Negative environmental impacts of EVs will be observed when charging is completely reliant on fossil fuel-based power units (Habib et al., 2018).
Electricity can be produced in many different ways, and depending on the production method, different amounts of energy is used and emissions generated (Edwards et al., 2014). The primary energy sources including coal, nuclear, natural gas, etc. have an important impact on the total energy consumption and $CO_2$ (carbon dioxide) emissions of the electricity generation (Lajunen and Tammi, 2016). There is different availability of primary energy sources depending on the geographical location. Therefore, it is important to take into account the local electricity generation when analyzing the energy consumption and $CO_2$ emissions of BEVs (Lajunen, 2018).
According to the research studies, electricity produced from fossil energy sources has $CO_2$ emissions between 150–300 g/MJ. $CO_2$ emissions from renewable energy sources are minimal, and could be even negative e.g. when biogas is used for generating electricity (Edwards et al., 2014). For these

results, the assessment of $CO_2$ emissions of EVs can be challenging due to the varying energy sources of the electricity generation and charging strategies (Jochem et al., 2015).

The V2G technology plays a vital role in clean energy environment (Habib et al., 2018).

The V2G concept excites advocates because it offers mutual benefits to the transportation and the electric power systems. It could assist the former by reducing petroleum use, strengthening the economy, enhancing national security, reducing strain on petroleum infrastructure, and improving the natural environment. It could help the latter by providing a new demand for electricity, ideally during the parts of the day when demand remains low. Moreover, it could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants (Sovacool and Hirsh, 2009).

That is the reason why V2G technology is a captivating research outlook: it could bring numerous potential economic and environmental benefits and provide various services to power network (Habib et al., 2018).

The economy of utility grid and profit for EVs owners based on electrification of transportation system will greatly enhance by realizing the V2G technology (Habib et al., 2015).

## 2.3. Distribution of electric vehicles

### 2.3.1. Distribution system and methods

Recent technological and automotive advances are rapidly changing the way supply chains are managed and goods are transported. Nowadays logistics, and the broader concept of supply chain management, is mainly intended as a business function that has the scope to make goods available where and when needed and in the needed quantities. Transportation management can be seen as part of logistics, when referred to the business processes (Speranza, 2018). Consequently, whether the goods are carried by road, air or sea, one should always consider which transportation mode should be supported, with a view towards optimizing time and associated costs and depending on various constraints (Couzin et al., 2001): proper coordination of the manufacturer's inbound and outbound logistics that covers optimization of the supply chain is a crucial factor in reducing the amount of stock and ensuring faster response to client orders.
Constantly growing fuel prices, rising taxes for road infrastructure and pollution are the macro measures that constantly boost transport costs, at the same time encouraging industries and logistics operators to pay more attention to optimization of transport processes and reduction of resources used (Vilkelis and Jakovlev, 2014). This has led automakers to attempt to institute a 'build-to-order' approach to fulfilment, in which consumers are able to define the characteristics of the vehicles before they are produced. The time from order to delivery takes on an average of 40 days, of which only 60 hours are used for production (Sturgeon et al. 2009).
Nowadays different transportation means are available with different levels of cost (Speranza, 2018). Rail, road or container vessel carriers are used (Johnson et al., 1998) often using multimodal or special intermodal services. The inter-modality is a very important operation in transport management, especially in most cases of automotive SCM (Torbianelli, 2000).
The Association of European Vehicle Logistics (ECG) has initiated the creation of uniform rules for automobile transportation, fastening and warehousing for road, railway and sea transport.

Automobile roads currently account for haulage of 44% of all EU cargo, as compared to 39% of cargo transported in short sea shipping and 10% by rail. The demand for road transport is highly affected by traffic congestions, partial loading, driving restrictions and relatively low demand for railway transport, as represented in Figure 2.6.

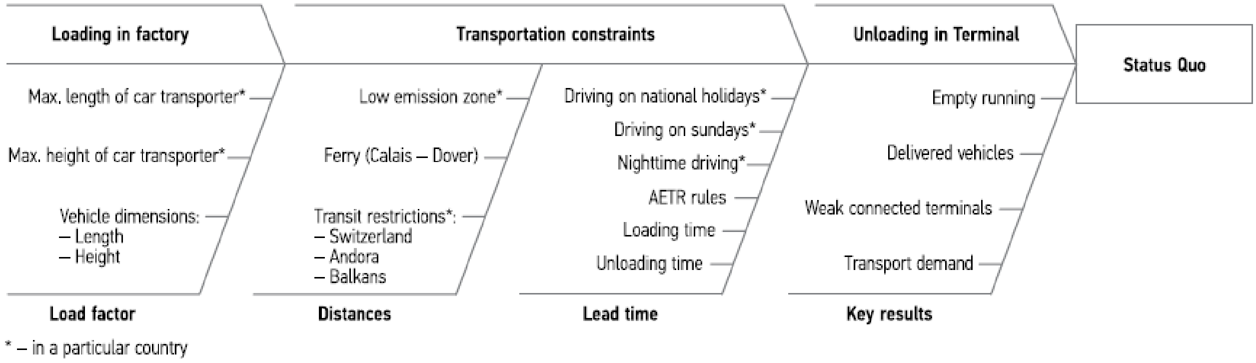



Figure 2.6. All the possible problems occurring in road transport

Considering for example traffic restrictions, there are many situations currently present in Europe; one of the most representative is the road transport from Northern Italy to Germany and back bypassing Switzerland: companies must follow the severe environmental requirements applied for cargo trucks crossing the Alps.

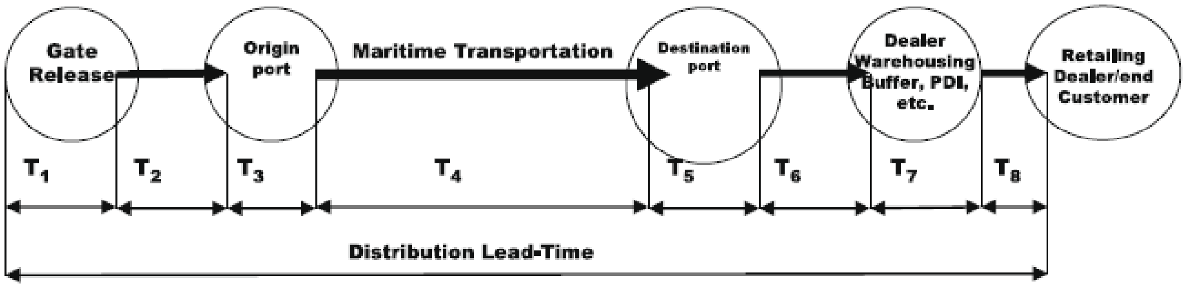
Due to restrictions of work and rest time for drivers (AETR rules), a car transporter can cover 500 km a workday, while an expert survey revealed that a car transporter is fully loaded within an average of 2 hours and unloaded within 1 hour.

Sea and railway transport, which has a characteristic high loading factor and a better price ratio, may be a superb alternative for serve the badly-connected transport regions in large distances. These types of transport should get as much attention as possible in order to diminish the negative factors of the logistics system (Vilkelis and Jakovlev, 2014).

Train transportation capacities are managed by a booking system, and the available capacity for empty coaches in each train is therefore known by the planner.

There are two major problems related to the current rail distribution process. First, car shortages occur at the terminals, which lead to unsatisfied customer demand, a potential loss of customers and a loss of goodwill. Second, the size of the car fleet becomes unnecessarily large, resulting in high capital costs for cars. In order to prevent these problems, all trains are scheduled long in advance and the departure and arrival times are specified in detail according to a given timetable. The timetable is constructed in such a way that the yards can handle and classify arriving cars and build departing trains in due time. The capacities of the trains are determined in connection with the construction of time tables. An additional improvement will be achieved by increasing the quality of the data acquisition, in addition to a more efficient usage of the data by the optimization model (Holmberg et al., 1998).

By taking into account sea transport, inter-modality is evident in port movements of new cars (Evangelista and Morvillo, 2000), where vehicles are driven on or off special vessels called car carriers (Mendonça and Dias, 2007), using ramps to do it (Johnson et al., 1998). Car carriers consist of four, five, six or more parking grounds with capacity up to eight thousand cars or more. Ships have an important advantage: flexibility; however, they need a demanding stevedoring operation to hold cars on or off the decks (Stopford, 1997). Also the long lead times necessary for sea transport, listed in chronological order in Table 2.3, represent a problem that must be optimized.




| | |
|---|---|
| $T_1$ | hold-up time until gate release in the automotive plant assembly plus the time for the handling operations necessary for land transportation (rail or road) |
| $T_2$ | transit time between the gate release and the port terminal including the time for handling operations in the port terminal |
| $T_3$ | hold-up time in the terminal of origin plus the time to board cars on plus hold-up time for the vessel to exit from port |
| $T_4$ | maritime transit time between origin and destination ports including the time for the cars to board off in the destination port terminal |
| $T_5$ | hold-up time in the destination terminal plus handling operations to land transportation |
| $T_6$ | transit time to distribution centre and handling operations time |
| $T_7$ | hold-up time in the warehousing centre that includes transit time and PDI (Pre-Delivery Inspection) operations time, postponement time, etc. |
| $T_8$ | the transit time to dealer and delivery time to end customer |

Table 2.3. Sea transport lead times

A port terminal (to import) should be located as near as possible to market dealers and, simultaneously as near as possible to car production assembly factories (to export) allowing car import and export using the same vessel (car carrier) (Dias et al., 2010). It also provides an important conjunction in outbound car distribution: scope and scale economies (Evangelista and Morvillo, 2000); moreover, the use of port terminals can provide economies of scope if they can allow buffering, warehousing with pre-delivery inspections (PDI) and postponement customization (Mendonça and Dias, 2007).

New highest performance ports are lean and agile ports. In these conditions the port terminal should not be classified as nodes, because they are not neutral points, but instead they should be classified as special attractive points adding value to the new cars and also meeting points between push and pull value chains (Marlow and Casaca, 2003).

Fundamental in car distribution is the involvement of intermediate points: when the capacity limits get tighter for a given monetary value of the lead-time, the number of VDCs (Vehicle Distribution Centers) opened increases. However, the other performance measures (i.e., the percentage of the direct shipment volume, the average lead-time, and the average transportation cost) do not change significantly because of that the new VDCs are opened at the neighborhood of already open VDCs. Thus, the values of the performance measures are not affected much with tighter capacity limits. Hence, if a larger capacity at a VDC does not cause any inefficiency or congestion in the system, having a larger VDC might be more desirable instead of having multiple VDCs in close proximity. (Eskigun et al., 2005).

The optimal number and location of intermediate points is one of the multiple problem studied by the operational research, subject that has given fundamental contributions for the optimization of many supply chain management and transportation problems (Speranza, 2018).

Moreover, as already cited in the previous paragraphs, the batteries present unique challenges in the way of safety, storage, shipping and handling (Radomski et al., 2013).

Overcharge is one of the most common and dangerous problems associated with commercial lithium-ion batteries now (Wen et al., 2012); if the safety mechanisms in the battery fail, fire and explosion events could occur (Lisbona and Snee, 2011).

As a result, improvements in monitoring and management are essential if lithium-ion batteries are to fulfil their potential in the automotive market (Armand and Tarascon, 2008).

Measurement of the battery performance is necessary to ensure safe operation. Examples of parameters that may be good indicators of cell performance are cell/pack voltage, temperature, current, state of charge, and their values may differ among cells in a pack or module (Lisbona and Snee, 2011).

In case of fire, the use of water to tackle primary lithium and lithium-ion battery is recommended (Farrington, 2001) when fires involve small inventories (Lisbona and Snee, 2011), while during transport automakers might limit the battery from being fully charged to 100% SOC in order to enhance the battery’s safety (Boulanger et al., 2011).

### 2.3.2. Electrification infrastructure

When estimating operating costs, powering a vehicle using electricity is significantly cheaper than powering it using fossil fuels (Boulanger et al., 2011).

It is surprising how little has been done on this front given the interest in the technology (Hidrue et al., 2011), considering that EVs are poised to link the personal transportation sector together with the electricity, the electronic, and the metal industry sectors in an unprecedented way (Hawkins et al., 2013).

Moreover, because of the limited capacity of batteries, typical EVs can only travel for about 100 miles on a single charge and require hours to be recharged (Mak et al., 2013).

So, in case of expansion of electric vehicles will also increase the demands on the construction of an adequate network of charging stations (Marcincin and Medvec, 2015). Vehicles owners must have at least one reliable place to charge their vehicle. In most cases this will be their home, but it could be a parking garage or some other location. The challenge is delivering the electricity to a wide variety of vehicles, in many possible locations, at the minimum system cost, and with an acceptable charging time. In order to achieve the goal, a few challenges must be addressed:

- Interoperability of chargers and vehicles (standardization of communications, plugs, interfaces, and power)
- Clear regulations and standards for the installation of chargers
- Reliable access to charging infrastructure
- Availability of widespread fast charging, to permit long trips

Greater access to charging infrastructure will also accelerate public adoption. Smart grid technology will optimize the vehicle integration with the grid, allowing intelligent and efficient use of energy (Boulanger et al., 2011).

Based on comprehensive investigation of several technical studies, the considerable issues associated with integration of EVs to power networks are: increase in load profile during peak hours, overloading of power system components, transmission losses, voltage deviations, phase unbalance, harmonics and system stability issues that reduce the power quality and the reliability of the power system (Habib et al., 2018).

Two types of charging points are considered: individual charging points, located in residential or parking areas designed for normal or slow charging rates and charging stations, which similarly to current gas stations, comprise several connection points for fast charging (Fernandez et al., 2010).

Charging could be carried out in different modes:

1) Slow charging (with the alternate current up to the output of 3.7 kW): expected at private charging stations, designed mainly for charging of a single electric vehicle overnight or even during working hours at company parking lots.
2) Accelerated charging (output from 3.7 kW to 22 kW): public charging stations using either the alternating or direct current. The charging power is limited by both the capacity of connection into the distribution grid and design specifications of the electric vehicle.
3) Fast charging (output exceeding 22 kW): may use direct or alternating current (SDEM in Slovak Republic, 2015). Drivers would be less prone to range anxiety. Unfortunately, virtually all lithium ion battery chemistries suffer from significantly lower life if they are subjected to fast charge (Boulanger et al., 2011).
4) Replacement of batteries: battery replacement represents a technologically proven method avoiding the need to wait for battery charging. The replacement process itself is currently many times shorter than the fastest charging method available (taking 1.5 to 7 minutes, compared to at least 20 minutes of fast charging) (SDEM in Slovak Republic, 2015).
Concerning the recharging strategies - the installation of a charging infrastructure for supplying the electric vehicles with power - and the metering infrastructure requires a high investment (Ernst et al., 2011). EV charging stations do not exist now in several major cities. Many parties are competing to develop and deploy charging infrastructure. Since automakers, charging infrastructure companies, governmental agencies and organizations all have an interest in developing the EV market, partnerships are being formed to deploy hardware.
Denmark is spending $100 million on EV infrastructure, including charging points and battery-swap stations and the goal is to run it with wind power. The French government has announced a ten-year, 2.5 billion euros program to jump-start vehicle electrification in the country. In Australia, Better Place, the electric vehicle (EV) infrastructure and services provider, will roll out electric vehicle infrastructure city-wide in Canberra (Boulanger et al., 2011).

The development of such a network is not only dependent on public financing for charging stations, and the necessary political will to do so, but is also dependent on additional power generating facilities to meet the additional demand for electricity (Steinweg, 2011).
The emissions of electricity is directly dependent on the original energy source in electricity generation. There are significant differences between European countries in electricity generation sources and $CO_2$ emissions (Lajunen, 2018): it is counterproductive to promote EVs in areas where electricity is primarily produced from lignite, coal, or even heavy oil combustion.
The combination of EVs with clean energy sources would potentially allow for drastic reductions of many transportation environmental impacts, especially in terms of climate change, air quality, and

preservation of fossil fuels (Hawkins et al., 2013). For these purposes seems to be very advantageous to combine the emerging system of infrastructure charging stations with renewable power sources, such as the energy produced by the sun with the possibilities of accumulation and its subsequent delivery to the uniform charging infrastructure (Chlebišová et al., 2010).

There are a number of considerations that should be worked through in relation to specific decisions regarding adoptions of vehicle technologies, such as the additional stress that a large fleet of EVs would place upon electricity production and distribution infrastructures (Lemoine et al. 2007).
More attention on EVs has been paid previously in the investigations on the economic and environmental influence (Williamson et al., 2007), whereas little analysis has been gained on the impact of EVs on the grid. As the penetration of EVs becomes higher and higher, the potential effect on the electrical distribution grid, will be constantly arising (Kalhammer et al., 1995).
Suppose the batteries of the vehicles would be charged at home, through plugging in to an outlet, winter represents the peak season for electrical consumption. The minimum demand occurs in the early morning because for convenience people are inclined to start charging immediately as soon as an electric outlet is available, for instance, the only time returning at home from work or during office hour. If a large number of EV charging occur during the same time, especially the time vehicle owners first returning home, then the peak may be beyond the limits of the grid: the uncoordinated charging would be disastrous to the grid, while coordinated charging can improve the load profile.
An analysis is performed for a power grid to demonstrate the impacts of coordination of charging; the best time from the grids view point would be at night during off-peak hours, as the off-peak charging would be more efficient in terms of grid stress and energy costs. This approach improves the load curve and has positive effects on the distribution grid (Jian et al., 2011).

As cited in paragraph 2.2.3, when EVs are connected to a power outlet they can serve in two modes: charging mode, which is called Grid-to-Vehicle (G2V) mode and discharging mode, which is called Vehicle-to-Grid (V2G) mode (Kempton and Tomić, 2005). V2G configuration could provide additional revenue to owners who wish to sell power back to the grid (Tomić and Kempton, 2007). In numbers, it has been estimated the value of those electric services at up to $12 billion per year, some of which would flow to V2G owners. Follow-up business studies have projected additional annual revenue for V2G ancillary services at between $3,777 and $4,000 per vehicle (Kempton, 2005).

### 2.3.3. The current market and future trends

The electric car is on the rise, and the fact that every large automotive company has developed, or is currently developing, electric models, is a sign that this trend is irreversible (Steinweg, 2011).
In urban areas of the world, the EVs are projected to increase substantially and will achieve larger acceptance in the transport market due to their higher efficiency. Numerous benefits achieved from EVs will undoubtedly get a considerable attention from utility operators and EVs owners in near future (Habib et al., 2018). In addition, V2G vehicles can reduce the lifetime cost of EVs, making them more attractive (Sovacool and Hirsh, 2009).

New models of EVs are available in the market every year (Lajunen, 2018): global leading car manufactures have already spent a large amount of time and energy in the development and industrialization of EVs. Some EVs already on the market are for example the General Motors Volt, Toyota Prius, Honda Insight, Tesla Roadster, Mitsubishi i-MiEV and others. In China, BYD, Chery, New-Ri and Wanxiang (Jian et al., 2011).
Toyota is the leader in EVs, while GM believes that range anxiety is a key challenge and it is focusing its researches on this problem; Nissan is using its vertical integration and is making a significant investment in EVs, in order to bring costs down faster than its competitors. BYD has less experience, but more to gain, and is pursuing EVs partly due to the simpler engineering; the Chinese battery manufacturer and automaker also is taking advantage of vertical integration and is not bound by legal enforcement and liability constraints that other manufacturers face. The lower requirements of the domestic Chinese market, with less danger in hurting their brand, allow BYD to be more aggressive than traditional automakers. Tesla is introducing high performance sports cars for the luxury performance market initially, with plans to pursue the broader, mainstream market in their next vehicles. Although these automakers have different strategies, all share a common perspective: electric drive vehicles are critical to the future of the auto industry (Boulanger et al., 2011).

But these efforts made by carmakers are not completely visible today: cumulative vehicle sales of about 2 million and a market share of 0.2% in 2016 demonstrates the extremely early stage of current global EV adoption and the large amount of future adoption that is needed (Cano et al., 2018).
In 2017, sales of electric vehicles exceeded one million cars per year worldwide for the first time (Harper et al., 2019).
In particular, Italy is one of the countries with the lowest uptake of electric cars (BEVs) in Europe, equal in 2017 to 0.01% of the total new car sales, while in neighboring countries, such as Austria, France, Switzerland or Germany, BEVs have a market share ranging from 1.5% to 3%, and growing (Danielis et al., 2018).

This happens because, despite all the potential advantages, significant barriers remain to widespread adoption of EV technology (Kampker et al., 2017).

Research suggests that battery technology limitations and high battery cost are the major obstacles to widespread adoption of EVs (Axsen et al., 2010). The starting price of EVS is still much higher in comparison with conventional ICE vehicles due to higher cost of EV batteries (Habib et al., 2018), while the driving range of the modern electric vehicle is only modestly greater than that of its predecessor a century ago! (Tamor et al., 2013). Moreover, there are not just technological and engineering obstacles, but also cultural, social, political, and economic impediments (Sovacool and Hirsh, 2009). As a result, much research is aimed towards addressing the limitations placed on performance by the weight, bulk and storage capacity of batteries (Kampker et al., 2017), but the major driving force could be a drop in their retail price, thanks to declining battery pack costs, and a possible revision of the taxes on diesel (Danielis et al., 2018).

Therefore, certain measures need to be taken to increase the market share of EVs: they include education, increased EVs infrastructure, battery swap programs, strong warranties on the EV batteries and perhaps increased tax credits to subsidize the cost of EVs (Egbue and Long, 2012).

In this regard, different public policies have been implemented to support electrification in the transportation sector (Habib et al., 2018).

Governments around the world are using rebates to reduce the initial cost of EVs to encourage their adoption. The current federal rebate for EVs in the U.S. ranges from $2500 to $7500, depending on the size of the battery, while in China has a pilot subsidy program reduces the cost of EVs by 60000 RMB (US$8800) (Boulanger et al., 2011).

With better vehicle performances and more incentives given by governments, forecasts are optimistic: according to a study commissioned by the World Business Council for Sustainable Development (2004), light-duty vehicle ownership could increase from roughly 700 million to 2 billion over the period 2000–2050. In fact, experts forecast up to 40 million vehicles using an electric drive and traction motor by 2030 (CAM, 2016), while the global EV sales will be over 100 million by 2050 (Omrani and Jannesari, 2019), reaching a peak of 1.8 billion and an EV market share of 86% in 2060 (Cano et al., 2018).

#### 2.3.4. The customer's point of view

Product quality and after-sale are two key determinants factors of consumers' purchase intentions (Taylor and Baker 1994). One set of literature has found that service quality and customer satisfaction play a key role in formulating the purchase intention among consumers (Bitner 1990). While another set of literature indicates that product quality and price are important determinants of shopping behavior and of product choice (Zeithaml 1988).

In the automotive industry, customer loyalty is affected not only by the image of the brand, but also by the quality of service received at the dealership that sells the brand. This implies that the overall image of the product extends beyond the quality of the manufacturing operations to include the quality of service received after purchase (Devaraj et al., 2001).

The relationship between the purchase intention and customer satisfaction has been widely investigated (Bearden and Teel 1983). The evidence suggests that there is a strong positive relationship between the two. Several of these studies indicate that higher levels of satisfaction lead to greater customer loyalty (Anderson and Sullivan 1993).

Impact of quality suggests that providing superior quality results in better financial performance (Aaker and Jacobson 1994). Consumers who pay a premium price for their cars are those who take special care in the service and maintenance of their cars to preserve their investment. Superior service-related experiences thus may lead to higher satisfaction among the consumers, which in turn might not only translate in increased customer loyalty, but also the willingness of these customers to pay more for higher quality products.

This explains the quality assurance programs many Japanese manufacturers deploy at dealerships including the use of information systems to gather quality data for use in product redesign (Devaraj et al., 2001).

Customer value management aims at meeting customer requirements while keeping the incurred costs as low as possible (Hein, 2011). This is necessary to permit a dual strategy, which combines differentiation and cost leadership (Jenner, 2000).

Product specifications that have a high impact on the production costs, but only insignificant improvement in customer valuation must be eliminated (Kampker et al., 2012); in the present fast moving environment, a company's preferred strategy for delivering its products might be the crucial one, given the consequences of delays on costs and the potential knock-on effect for the final customer. For instance, optimal routing or delivery frequency are essential pieces of information for manufacturers' involved in scheduling organisation, as they make it possible to confirm the accuracy of the production planning forecast (Couzin et al., 2001).

It is clear that a large amount of attention has been directed at electric cars in the media, by politicians and consumers. In response, nearly all carmakers are currently developing or producing electric models to tap into this new market (Steinweg, 2011).

Many factors play a role in the consumers' car purchase decision; they are both monetary (e.g., purchase price, excise taxes, operational costs, parking fees) and non-monetary (e.g., driving range, car size and segment, brand, attitudes, charging time and charging infrastructure) (Danielis et al., 2018).

Consumers are especially cautious about how they spend their money, and consumers are also weary of EVs that may cause them to experience range anxiety. The industry is still in its embryonic stage despite the vast amount of funding and resources invested and the vast progress made in the last five years. There is still a long way to go to achieve a mature market (Radomski et al., 2013).

A major barrier is that consumers tend to resist new technologies that are considered alien or unproved the ''social'' barriers may pose as much of a problem as the ''technical'' in the development of EVs for the mainstream consumer market (Egbue and Long, 2012).

Research shows that some common barriers to the adoption of any new technology include lack of knowledge by potential adopters, high initial costs and low risk tolerance (Diamond, 2009). Consumer acceptance of EVs is limited partly due to perceived risks with new products and tradeoffs between vehicle fuel efficiency, size and price. So, the most tough technical barrier for EVs adoption are: the high initial cost, the low battery range, the limited access to charging and the precarious safety of lithium ion batteries (Boulanger et al., 2011).

The expected decrease in battery production costs will obviously also have a downward effect on the price that consumers pay for their vehicle (Steinweg, 2011).

The charging infrastructure in residential and commercial areas should be user-friendly for wider acceptance, especially in domestic areas because charging could take place at night in the owner's garage (Habib et al., 2018). Adding V2G capability may be a cost-effective means to increase EV adoption: it could improve renewable grid integration and overall grid efficiency (Noel et al., 2019).

For safety problems, in the event of multiple failures in the battery's systems, battery packs are still designed to be safe: during catastrophic circumstances, such as a car accident, most battery packs have sensors which will trigger a signal to open switches or contactors to immediately disconnect or de-energize the pack (Boulanger et al., 2011).

Since public opinion can be influenced through media and social networks, policy makers can use this medium to influence the public appreciation for non-financial benefits of adopting EVs such as energy security and reduction of ecological footprint (Egbue and Long, 2012).

The willingness-to-pay (WTP) for electric vehicles has been of keen interest: assessing the WTP for EVs is essential to better understand the consumer dynamics of a more sustainable transition from internal combustion engine vehicles (ICEVs) to EVs (Noel et al., 2019).

Results show that attitudes, knowledge and perceptions related to EVs differ across gender, age, and education groups (Egbue and Long, 2012). A person's propensity to buy an electric vehicle increases with youth, education, green life style, believing gas prices will rise significantly in the future, and living in a place where a plug is easily accessible at home. It also increases if a person has a tendency to buy a small or medium sized vehicle and/or is likely to be in the market for a hybrid vehicle for their next car purchase (Hidrue et al., 2011). Moreover, young individuals (under 30 years) and households with children have a positive effect for the EV choices (Noel et al., 2019).

Comparing consumer preferences in the US and China, significant differences in WTP between the countries are found: the average US consumer has a WTP of $10,000–$20,000 less than a conventional vehicle, whereas China the WTP was comparable to a conventional vehicle (Helveston et al., 2015).

In few words there is overall a tendency towards choosing EV alternatives (the average split for EV and petrol vehicle is 61–39), there are noticeable differences in the overall EV tendency between the countries and, as expected, consumers prefer EVs with higher range, clean electricity sources and V2G capability (Noel et al., 2019).

# 3. Analysis of requirements, constraints, characteristics and changes in the transportation of electric vehicles

## 3.1. Requirements for electric vehicles transportation

### 3.1.1. Production requirements (finished Electric Vehicle - EV)

The first basilar transport requirement is the existence of finished and perfectly functioning electric vehicles. In order to achieve this objective, there are two main inspections carried out to check efficient a finished EV, starting from this point its introduction in the distribution network. The first one is conducted at the end of the production line by the carmaker's workers and is exactly equal to what occurs for a traditional internal combustion engine vehicle. In particular, all the components and tools are analyzed to proof they have no problem: lights are turned on and off, so as for turn signals, air conditioning and so on to complete the inspection. After the vehicle is declared good, it is stored in a temporary little yard near the production line. When it is required for the market, it is moved to the so called "pick area", located just before the main plant compound, where occurs the second inspection, this time made by the compound manager's workers. In fact, external logistic companies or carriers who stores and distributes vehicles (for example Bertani and Altmann), manage FCA plant compounds. The "pick area", in a few words, represents a transfer of responsibility from the carmaker to compound managers: the former delivers the vehicle, while the latter verifies it is ready for distribution and take the responsibility for any damage occurring to the vehicle in the plant compound. Once these two steps are completed, vehicle transport could begin.

### 3.1.2. Requirements for transport companies' drivers

Fundamental requirements involve transport companies' drivers, whose work consists in moving vehicles by road in the terms and conditions agreed between the carmaker and the transport company, avoiding every possibility of damage for the vehicles in loading, transport and unloading phases. Important quality standards are also defined in the clothing and the behaviour that each operator must follow.

About the right clothing, it is required: clean working clothes, without any type of stain, the use of long sleeves and long trousers; safety shoes always worn, safety gloves only during loading operations. Moreover, high visibility elements on the jacket and trousers are necessary, buttons and belts are forbidden, rings or other jewels are not allowed, unless they are covered, and the use of a safety helmet during loading and unloading operations is obligatory. These rules are useful to achieve two of the main goals of transportation: the driver's safety and the prevention of damages for the vehicle.

Each carrier must have a valid driving license and has to receive a training for an impeccable transportation, from the transport to the behavioural point of view. In order to obtain this target, the driver has to drive at moderate speed, respecting all the speed limits, without inappropriate actions like overtaking, driving with flat tires or open doors. Driving in total safety, the risk of damage is minimized.

Other forbidden behaviours are rather linked to maintain intact the good reputation of the transportation company and especially the manufacturer's one. In particular, is strictly forbidden to lean, stand or sit on the vehicles, to eat, drink or smoke in the vehicles and near them, to wear headphones or listen to music or radio.

The last carrier's transportation requirements are normally agreed between the two parts in order to eliminate the risk of damages or to keep the vehicles as clean as at the end of the line production. Carriers can't move the electric mirrors manually, get in or get out of the vehicle by other doors than the driver's one and remove protection materials from it, for example seat protections. During breaks, or in every situation the vehicle is left, doors, windows and the roof must be closed. All vehicles loaded with manual transmission are engaged in 1st gear and have the hand brake applied (for storage, hand brake must be released if possible), while for vehicles with automatic transmission the driver puts the transmission selector lever in "P" position and applies the hand brake (for storage, handbrake must be released).

The car transporter could not be parked on inflammable materials, such as dry grass or leaves.

### 3.1.3. Requirements for plant compounds and transit points

By definition, plant compounds are storage yards containing the sum of vehicles produced on site plus those ones coming from the other distribution points or plants, while vehicle transit points are areas with only intermediate distribution storage yards. It is important to divide them into well-separated areas for the car storage, the loading and unloading on trucks and in case of long period parked car transporters, a dedicated parking. Each of these three areas must be asphalted or paved, they have to be free from objects or debris from the ground (maybe through a regular and efficient cleaning schedule), sufficiently lit with lighting posts cushioned around their lower parts for damage prevention. They must be free from any type of vegetation and is not allowed to park any vehicle under trees, in order to preserve the paint from resin and leaves.

Moreover, car parking storage bays must be clearly painted on the ground and each parking bay must be identifiable by an alphanumeric classification of bays. Where possible, it is a good thing to cover all vehicles against natural sources of damage, using sheds or covers. In any case, compound operators should have action plans for all adverse weather events.

Vehicles should be left in park mode. Always ensure this mode is enabled, considering that even a soft press on the accelerator pedal can cause the vehicle to move quickly. Particular attention is required to operators while moving in storage yards: electric vehicles are silent, so there is no engine sound to indicate that an EV is coming.

Every yard must be equipped with a sufficient number of hydrants and fire extinguishers according to the fire protection regulations of each country. There must be a sufficient number of sets of jumpstarting equipment and portable tyre pressure checking equipment available on site. Moreover, plant compounds and transit points must have vehicle identification systems, to ensure a fluid stock management or to report eventual problems occurring to vehicles. The manufacturer may require other equipment elements (battery testing equipment, compressors, car wash).

Yard lighting is another important factor; every car storage point should follow the requirements included in the regulation for outdoor working places in Europe (EN 12464-2:2007). Otherwise, the compound illumination follows the requirements imposed by the manufacturer. Spill light on adjacent areas and, in particular, residential buildings has to be avoided in order to minimize the environmental impact of yard operations. Spill light is wasted light and thus wasted energy: this represent an unnecessary cost for the manufacturer.

Finally, in order to obtain a safe plant compound/transit point, a fence of at least 2 meters in height must surround it. Natural or artificial obstacles should complement the fence in anti-theft protection.

The entrance must be equipped with a gate barrier and guarded with constant surveillance. The whole compound area must be under constant camera supervision or a similarly effective surveillance system. Moreover, security personnel has to patrol it and access yards must be restricted to the personnel, subjecting visitors to individual authorization.

### 3.1.4. Requirements for road transport

The road transport is carried out only with car transporters, according to the European quality standards; they must be in good condition, painted and rust-free. Hydraulic systems must function properly and they should be equipped with stone guards above the wheels.

The most important parts of a car transporter are decks and ramps; their surface must offer good grip without sharp edges, while loading ramps must be placed at a low angle (maximum 8 degrees) to enable easy access and prevent damage to the underbody of the transported vehicles.

The upper deck has to be equipped with safety ropes in conformity with the local legal requirements. Moreover, the loading deck pillars, the ropes and the supports of the safety ropes should be cushioned to secure damage free opening of the vehicle doors. The manufacturer may require inspection of new car transporters or new car transporter types before approving them as suitable for the transport of their vehicles. The details of any other requirement must be clearly stated in the contractual agreement.

Finally and most importantly, the transporters must respect all other local health and safety requirements.

The equipment required for car transporters consists of two sets of ramps measuring approximately 50-100 centimeters, 3-4 chocks per and 1-2 lashing straps per transported vehicle. Lashing straps must be 2.2 meters long and stretch maximally by 4%.

Moreover, they must be equipped with movable strap control (meeting the norm EN 12195-2). The label on the lashing has to be always read: the norm must be clearly visible.

### 3.1.5. Requirements for rail transport

For rail transport, wagons should be in good condition, painted and rust-free. Moreover, they should be regularly cleaned, painted and repaired according to an established maintenance schedule. In addition, wagons involve decks and ramps like car transporters. Wagons must not have any structural damage, mechanical deck faults or obstacles on the decks that may complicate loading or unloading procedures and should have protective material applied to surfaces in order to avoid any contact with transported vehicles (particularly their doors and bodywork).

The profile of the deck must offer a good grip, but may not be sharp-edged.

Loading ramps, whether fixed or mobile, must be placed at a sufficiently low angle to enable easy access, also preventing any damage to the underbody of vehicles (recommended maximum ramp angle: 8 degrees, the same of road transport).

The customer has the right to inspect all the wagons put to his disposition and refuse those that do not meet the quality criteria.

The only equipment requirement suggests the sufficient number of wheel chocks for rail transport: as general rule, four wheel chocks per vehicle. However, on some routes and in some countries, vehicles can be fixed with two chocks on the same side of one wheel or a double chock, protecting the wheel from the front and from the back, on one wheel.

### 3.1.6. Requirements for sea transport

In sea transport, only car carrying-purpose ships can be used for transporting new vehicles. The safety and quality rules that follow are integrally applied on this kind of vessel. If the manufacturer agrees, cars can also be transported in containers. However, it has to be noted that cars transported in containers are exposed to a significantly higher damage risk. The quality and safety criteria are then subject only to the local minimum legal requirements and to the contractual agreement negotiated with the logistics services provider.

In general, ships used for transport of vehicles must be in good physical condition and must respond to internationally recognised quality standards. The manufacturer has the right to impose stricter conditions and refuse those ships that do not meet them.

The decks and ramps of the ships are constructed in such a way that there is sufficient distance between inner pillars for easy, damage free loading and unloading.

Any gaps in the decks or between ramps and decks, as well as any perpendicular differences in height must be reduced to a minimum to preclude damage to tyres. All elements on and off the decks should be rust free. In no case rusted elements can enter into contact with the transported cars. Vehicles are stored in clean holds, odour free and adequately ventilated. All traces of chemical or greasy substances must be removed, while decks and ramps must be well lit.

Moreover, all obstacles have to be painted or marked in safety colours. The construction elements with the highest probability to accidentally crash into cars are padded to minimize the probability of serious damage.

Internal and external connecting and access ramps must be set at a sufficiently low angle to enable easy access and prevent damages: the recommended maximum ramp angle is 8 degrees, the same of road and rail transport.

Additionally, it is recommended to apply antiskid tapes or antiskid painting to driveways in the turning points.

The ship must be equipped with the adequate stocks of jump leads, a 12V booster to enable non-starters to be loaded and unloaded without any problem (problem fully described further). It must be equipped with sufficient lashing points, while mobile chains must be properly taut, so that they do not become more tensioned and touch the underside of the vehicles. A sufficient number of car lashings in good technical condition is also needed; the lashings' resistance capacity must be adapted to the type of vehicle transported with a sufficient safety margin. Metal parts of the lashings should be protected to preclude damage.

### 3.1.7. Requirements for battery management

The first general rule states always to assume that a vehicle is powered, even if it is silent.

It is prohibited to touch, cut or open any high voltage cable (orange coloured cables) or high voltage component (cables marked with a high voltage sign). Basic but important advice: do not damage the battery pack, even if the propulsion system is deactivated.
In case of accident or fire, considering that a damaged high voltage battery can create rapid heating of the battery cells, if smoke coming from the battery is noticed, it is important to assume it is overheating and to take appropriate action.
A burning or overheated battery releases toxic vapors: everyone in proximity should protect himself with full personal protective equipment and personnel must act appropriately to protect people downwind from the incident.
A Lithium-Ion battery has a behaviour that requires special firefighting tactics. Instead of stopping the thermal runaway by extinguishing the fire, focus should be on preventing the fire from spreading. This could be done for example by cooling the fire and the adjacent vehicles using water. If the high voltage battery becomes involved or it is suspected of overheating, use large amounts of water to cool the battery. Do not try to extinguish fire with a small amount of water. Always establish or request an additional water supply.

Charging the vehicles before delivery to dealers depends on individual manufacturer requirements; if the manufacturer allows for charging at the compound, it is recommended not to charge under extreme weather (snow for example) or extreme hot and cold conditions. It is also recommended to avoid parking the vehicle with near zero charge for more than 3 months or with a high charge for more than a month.

## 3.2. Constraints on electric vehicles transportation

There are few constraints to consider in the distribution of electric vehicles: substantially it is carried out like the traditional one for diesel and petrol models.

The main inspections are connected to the state of charge (SOC) of an electric vehicle staying in a plant compound or in a transit point.
Generically, electric vehicles are composed of three parts: electric components, a body and a battery. The first two ones are innocuous during the production, while the battery is considered innocuous while kept in stock, but in the finished product, considering the proximity of the electric components, the status changes to dangerous because the fire risk becomes concrete. For these reason the following procedures try to maintain a low risk and a low battery discharge for the vehicles produced.

During its stay in the yard, the battery loses about 1.5-2% of the charge in a month; for this reason, every 30 days, the battery charge is controlled and recharged. This operation, in FCA yards, is outsourced and so carried out by third party professionals (belonging to specialized logistic service companies). The operator inserts a diagnostic key in the electrical outlet of the vehicle and verify the percentage of charge. After that, if necessary, he recharges it. The connection with the outbound software, allows a better performance of this procedure: the central software, by knowing the real time charge status of all the vehicles in the yard, alerts the operator with a message on his personal hand-held with the specified vehicles to check, in order to prevent any unnecessary charge verification. If a vehicle to transport stays less than a month in the yard or it has not been a month since the last control, the battery percentage of charge is not analyzed. On the contrary, if vehicles could stay more than a month in the yard, it has to be set up with all the equipment necessary for the management of electric vehicles (charging stations, etc.). This is the first main constraint.

The second one is related to the target battery percentage of charge value during the transportation: it must be equal to 30-40%; this percentage lowers the fire risk and it is useful to prevent the battery overheating, so the cells do not stress. This constraint is the same in all transportation modes: by road, by rail or by sea, the battery must stay in this desired range.
The other main constraint for electric vehicles is the Logistic Mode: it is a software management, activated by the manufacturer and deactivated by the dealer, that disables during the yard period and the transportation the main services that could cause the battery discharge (ceiling light power, headlights, air conditioning, etc.).

Further SOC constraint: if the charge decreases of a 6% value during the yard maintenance, there is a serious problem on the vehicle and it can’t be transported. The vehicle must be checked and repaired before living the plant compound or the intermediate transit point.

Currently there is not a precise and detailed legislation about the constraints to meet in the transportation of electric vehicles; for this reason, every company has today its own policy about it. This situation will last until there will not be provided an official document with international standards to respect. Many organs and manufacturers are working to make it happen.

Otherwise, all the main constraints in transportation of EVs are the same of traditional ones, as described in the following paragraph.

## 3.3. Vehicles transportation processes

### 3.3.1. Rules to follow in plant compounds and transit points

Before the loading phase on car transporters, rail wagons or sea ships, the first important aspect to analyze for finished electric vehicles is their management in the main car storage park of a distribution network: a plant compound or a transit point. Every movement in these areas must be planned and executed accurately by trained personnel, who knows how to handle vehicles in complete safety, following rules that try to set a zero damage management.

After every movement, made with low speed, the operator remove the key from the ignition and put it where the manufacturer has decided, so that to facilitate the next operator who has to start the car to find it easily. Before leaving the vehicle, if there is a manual transmission it must be secured by engaging first gear, while in case of automatic transmission the selector lever must be in "P" position.

Also for parking there are a series of rules to follow by car storage operators; vehicles are parked .in the plant compound or in the transit point according to the pattern decided by the manufacturer. The two most used patterns are the herringbone and the bumper to bumper. For a safe and clever parking, quality criteria for the design of the storage area require the following minimum measures among parked vehicles: between two cars, bumper to bumper 20 cm, while 30 cm side to side. These measures help the parking activities without any damage, especially in driver's door opening. In the pre-loading area, where vehicles are going to be inspected, the side separation must be a minimum of 60 cm, so inspectors can easily pass between vehicles and see medium distance visible damages too.

### 3.3.2. Road transport

Road transport is one of the three main transportation modes used by a vehicle manufacturer, with rail and sea transport. For the following explanation, all the vehicle handling (in particular loading and unloading), must be done by a trained personnel, following European quality standards. The only exception occurs in loading: in this phase the loaded weight, height and length could be adapted to the national requirements and to the chosen distribution routes.
The driver should always be able to ask for assistance and obtain it during operations.

Before loading or unloading, the operator parks the car transporter on a level and firm ground, so to avoid a difficult and dangerous loading phase. Moreover, the loading decks are clear of all lashings, chocks, tools or other objects; the operator shall ensure that decks are fixed in a suitable position for loading vehicles without causing damage to their underbody: once this is done, the loading can start.

During loading (and in unloading) the operator drives vehicles at walking speed to reduce the probability of causing damage; in particular, speed is highly reduced before driving onto or off the ramps. Each vehicle is loaded or unloaded only if turned on, since it is strictly forbidden to push the vehicles off the transporter, or to brake with the hand brake.

Important is the checking of the standardized measures to keep among the vehicles on the car transporter. For road transport, between the cars the distance from bumper to bumper is 10 cm, the same for a car's roof and the upper deck and between overlapping vehicles, while the distance doubles between a car on the truck and another on the trailer (bumper to bumper). The distance required between the car's underbody and the deck is at least 5 centimeters. After the loading of a vehicle is complete, the driver leaves the first gear and the handbrake applied, in case of manual transmission, or the lever in "P" position and the handbrake for automatic transmission. Headlights are switched off immediately after loading/unloading, the vehicle is locked, key is secured and could be finally lashed for transport.

Lashing is done with the use of straps and chocks: the normal procedure includes three point-lashing straps with a strap sleeve in combination with wheel chocks. The use of wheel chocks is not necessary if wheels are secured in troughs or chamfers that are openings in the ramps/decks, which serve for fixing the wheels. The first hook is anchored to the transporter deck in such a way that the strap runs as vertically as possible. Then the strap is tied round the wheel and the operator makes sure that the strap sleeve is positioned correctly. Subsequently, the second hook is anchored to the transporter deck and the third hook is anchored at the anchor point lying laterally away from the wheel, tightening the strap using the ratchet.

A vehicle could be loaded in the direction or in the opposite direction of the traffic. In the former case, the operator places one wheel chock in front and one behind either rear wheel then secures them with three-point lashing; diagonally from this wheel place one chock in front of the respective front wheel (if wheel chocks cannot be used for technical reasons, an additional wheel must be secured with a lashing strap). In the latter case, the first two points are the same but in addition, both front wheels are secured with one three-point lashing each. Finally, there is a more specific securing procedure for vehicles loaded rearmost in an angled position: they shall be further secured at the wheels of the rearmost axle with two chocks and a lashing strap each.

### 3.3.3. Rail transport

Rail transport could be carried out with the use of:

- Open wagons (L class wagons in UIC classification)
- Closed wagons (H class wagons in UIC classification)

Also for rail transport, the loading and unloading processes require a trained and qualified personnel for vehicle handling. Before starting to load, wagons should be at the loading platforms in the right direction: standard rules avoid reversing vehicles onto the wagons. To facilitate the unloading process in case of enclosed wagons, a chalk or a sticker arrow indicating the direction of vehicles can be applied on the wagon. Moreover, the operator moves the upper deck in loading position and secures it; then he checks if the loading width of the wagon is sufficient for the track of the vehicles being loaded and that vehicles' height is minor than the wagon's one. For those transported on the top deck, he checks the total height (top deck + vehicle) to prevent any danger of touching the electric lines. Before loading/unloading, the deck must be free of any materials that might cause damage to the vehicles.

A loading plan should be drafted before the loading procedure begins and it has to be followed throughout the process.

During loading and unloading operations, vehicles are driven at walking speed, both on the ramps and on the train, to reduce the probability of damage, slowing down in particular before driving onto or off the ramps. The operator loads each vehicle only by driving forwards, to avoid every risk of damage. The upper deck is loaded before the lower one and unloaded after it. In loading, it is important to separate vehicles with these distances between the cars: bumper to bumper, or bumper to fixed wagon structure not less than 15 cm in single wagons or group wagons, minimum 10 cm in full block trains. Bumper to bumper, in the area where the axle is not chocked, the suggested rule considers not less than 26 cm over or next to a short coupling and not less than 40 cm over or next to a permanent coupling. Clearance between the vehicle's roof and the upper platform: 8 cm. A minimum clearance is kept above the roof of the upper deck vehicles to avoid damage from bridges, tunnels and electric lines. Once a vehicle is loaded, the operator applies the handbrake and puts the first gear or the selector lever in "P" position; for vehicles loaded over joining parts of the train, only the gear or the handbrake is used, allowing freedom of moving for train components during the transport. Keys are removed from vehicles and stored in the door pocket of the driver's side. Vehicles are now ready for lashing procedures.

Wheels are secured with chocks; for two wheels on the same axle, two chocks are placed both behind and in front of a wheel. The axle secured by wheel chocks is the one on which the handbrake and/or gear is applied.

The wheel chocks are placed and removed carefully in order not to damage the tyre and they do not have to touch any part of the vehicle other than tyres; if a lever is used to remove the chock, it must be properly protected to prevent damage to the vehicles.

### 3.3.4. Sea transport

Sea transport is carried out by trained personnel, following European quality standards in all processes of loading, transport and unloading. There are two main modes of vehicle sea transport:

- Roll on / Roll off (Ro-Ro) ship for wheeled cargo: loading and unloading with a ramp
- Lift on / Lift off (Lo-Lo) ship for container cargo: loading and unloading with a cradle

The following description represents how a Ro-Ro ship is loaded.
First, it is important to organise a meeting involving the Captain, the Chief Officer of the ship and the Port Captain to draft a loading/stowage plan. This plan has to be followed throughout the loading process, while enough driveways and walkways are designated and marked, according to the ship's safety requirements. Then, operators set the ramps and deck in the correct position and open internal doors.
During loading or unloading, an experienced supervisor coordinates all operations: vehicles, with headlights on, are loaded in groups of similar dimensions to facilitate their positioning on the loading deck, keeping a safety distance between vehicles ahead and behind when driving on the ramps and decks. Once inside the ship, speed must be limited to preclude damage. Parked each vehicle in the below deck, the operator turns off the headlights, applies the first gear or "P" position (for automatic transmission), then he puts the key in the door pocket of driver's side, leaving the vehicle unlocked. If possible, cars should be stowed longitudinally: this way, the risk of displacing during lateral movements of the ship is minimized. During loading, care must be taken to cars situated in the left external positions, near ship structure: they have to be easily accessible from the driver's side, so enough space should be left for the driver's door to be opened without damage. Loading order is strictly linked to unloading: the last car to be loaded is the first to be unloaded.
On board, keep the following distances among vehicles: bumper to bumper and from bumper to ship's superstructure a minimum of 30 cm, while this clearance is doubled considering the driver's side and halved from passenger's one. Between two cars, mirror to mirror and between the vehicle's roof and the upper deck the recommended distance is at least 10 cm.

After loading, vehicles are lashed according to the procedures defined in the following section. Lashings is inspected and re-tensioned in case of necessity at least every day during the first three days and then every third day. In case of bad sea conditions, check become daily.
Each vehicle is secured using two lashings at each end. These lashings are applied to the vehicle's points specifically designed for the purpose and recommended by the manufacturers. Vehicles stowed transversely or on ramps are lashed with a minimum of three lashings at each end and additionally secured with wheel chocks.

The two main methods used are wheel rim lashing and towing eye lashing. In wheel rim lashing, vehicles are lashed on aluminium and steel rims. In the case of steel rims, the plastic wheel protectors is removed from the wheel before lashing, to prevent damage to them. For alloy/aluminium rims, fit the loose nylon loop around a wheel spoke and insert the hook into the loop with the hook opening facing downwards, while for steel rims, attach the plastic protected hook directly to the rim, with the hook opening facing downwards. An important aspect is that lashing must be attached to the lower part of the wheel, and it must be aligned with the centre of the wheel, avoiding the wheel to turn during transport and loose the lashing. In towing eye lashing, the shorter end of the vehicle lashing is hooked in the towing eye of the car, than the other end of the lashing is to be anchored to the deck and the lashing is to be locked by pulling at an angle. At least two lashings must be attached to each of the towing eyes.
It is not recommended to mix the two methods on an individual vehicle.

On Lo-Lo and Ro-Lo (an hybrid sea transport mode between Ro-Ro and Lo-Lo) ships, in order to limit damage probability, additional procedures are applied for loading. It is carried out not with a standard crane but with a special designed cradle used for lifting vehicles; if it is designed for lifting two cars at a time, cars must be loaded by two, never alone. When lifted, vehicles are turned on with the handbrake applied and the neutral gear engaged. At the end of the lifting procedure, vehicles are handled according with the same rules applied on Ro-Ro ships.

There are also special provisions if the ship transport is carried out with containers: containers used for car transport must meet the relevant ISO standards. There are three solution for container vehicles transport: flat (1 or 2 vehicles), on a palette adapted to vehicle transport (1 or 2 palettes tied to the ground and to one another), or using a mechanical system (from 3 vehicles).

Standard containers are compact, without holes and tightly closed to keep saltwater away from the transported cars; a special protection is fixed between the container wall and the driver's door to prevent any damage. Vehicles are lashed with four lashings by rim or towing eye lashing and additionally secured with wheel chocks to avoid movements. If cars are stacked inside the container, the maximum angle recommended is 25 degrees. Moreover, clearance between a vehicle and the container wall should be 10 cm, the same between the vehicle's highest point and the roof and the triple between the front and back of vehicles.

A quality control before loading and just after unloading is performed to define the transfer of responsibility. In case of damages found, a record has to be established.

### 3.3.5. Inspections and damages reporting

An inspection of each vehicle transported must be done in every intermediate distribution point and in the final destination, or in each possession change. The procedures described in this paragraph follows the standards defined in the last version of “AIAG-ECG Finished Vehicle Transportation Damage Standards and Guidelines” manual, where is explained a correct way of inspecting, recording, and transmitting vehicle damages seen during inspections. The documents involved in this procedure are:

- AIAG-ECG Global Damage Code, Grid Location Matrix, and Vehicle “Splat” Chart.

These three different elements are useful to define a standard form of reporting damages. The Global Damage Code is a five digit code where the first two digits identify the damage area code (example: 78 = right front tyre), the third and fourth digits the damage type code (example: 03 = cut) and the fifth one is the damage severity code (scale of 1 to 6). The Grid Location Matrix improves the reporting accuracy dividing into nine sections the major parts of a vehicle, like a door or a wheel. Instead, the Vehicle “Splat” Chart is a one-dimensional picture of a car with the indicating all damage area codes.

- Similarity Matrix.

This matrix identifies damage areas, damage types, and severities of damage that can be interchanged with other codes in the same category, improving the standardization of filing and adjudicating claims processes. It adds objectivity to the inspecting process.

- AIAG-ECG Non-Transportation Damage Standard.

The third part of the regulation lists all the possible encountered problems that could not be considered transportation damages. These problems are still reported, but is well underlined that the carrier is not accountable for the problem. Moreover, an auxiliary “Photo Sheet” provides a visual representation of these conditions not considered transportation damage, standardizing the analysis.

- Inspection and Verification Guideline.

In this list are provided the basic instructions for a correct and impartial transportation inspection. The proposed guideline advises a circular check, starting from the right side of the vehicle and then analyzing the rear, the left side and finally the front. In the manual, are also described the specific procedures for rail inspection, final delivery inspection and sea transport one.

- Key Placement Guideline.

This guideline develops a common procedure among all the carmakers to help reducing the risk of key thefts. Each manufacturer decides where to place the key of each model, in order to shift the responsibility of a missing key to the carrier. In order of priority, these are the three suggested places: cup holder, center console and glove box.

- AIAG-ECG Inspection Type Location Codes.

It is a schedule of codes referring to the type and location of the inspection. This is useful for a more complete report and to localize the precise vehicle distribution path (joining all the inspection reports for the same car).

- Photo standard for damaged finished vehicle.

With an inspection report where is described a damage found, there must be a photograph in annex to provide support. It has to include the date and time the photo was taken and then needs to be converted to a PDF format before sending the electronic report to the carmaker.

## 3.4. Key aspects of electric vehicles transportation

### 3.4.1. Rules on non-starting up vehicles

The main difference between the traditional transportation and electric vehicles one is the regulation about non-starting up vehicles, those one who do not start when they are loaded or unloaded on car transporters, rail wagons or sea ships.

About diesel and petrol vehicles, the procedure followed is organized into three steps: first, the driver controls the battery; if the engine does not start up because the battery is flat, it must be jump-started using an auxiliary battery, connecting the positive (+) pole first then the negative (-) or earth pole. After jump-starting, he disconnects the cables in reverse order. Push starting and tow starting are strictly forbidden. Obviously, to complete the process in complete safety, jump-starting cables must be handled with caution to prevent damage to the vehicle.
However, for an optimal service it is recommended to replace the flat battery by a new one before loading the vehicle onto every mean of transport; this rule must be clearly stated and agreed by the parties with a written contract. Second step: if the problem does not concern the vehicle battery, but it is found non-starting cause is the empty tank, in this case the vehicle needs refueling. The driver adds a sufficient amount of the correct fuel type using a plastic or protected funnels and fuel can nozzles in order to minimize the risk of both static flash ignition and damage. Third step: if the two previous methods fail, contact the manufacturer of the car.
Another important consideration about a non-starting fuel vehicle is that it must never be jumpstarted / refuelled by anybody who has not received a relevant training. Whenever possible, non-starters should be handled by specialized personnel and not drivers.

Obviously, for electric vehicles, the battery/fuel method could not be applied; for these alternative vehicles, the driver connects the car with a 12V booster. This will allow in many cases engaging in "tow" mode. It is not possible to tow some models that have a key card because the wheels are blocked: these models have to be boosted and transported to the closest workshop to change the 12V battery. If any such "immobilization" occurs, the vehicle cannot be towed. In this case, a towing bar must be used: it needs to be attached to the towing eye or to the lower suspension arms of the vehicle. If these methods fail, contact the manufacturer for alternative instructions.

### 3.4.2. Noise in vehicle storage yards

After the end of production, when an electric vehicle is stored in the plant compound (waiting to be loaded and transported), or in transit point, where vehicles are constantly relocated or loaded/unloaded on car transporters or rail wagons, there is a significant difference if compared with a traditional one: the electric vehicle emits no noise.

In the last years, the development of artificial noise systems has been the path travelled; in particular, there is European legislation that requires the mandatory use of "Acoustic Vehicle Alerting Systems" (AVAS) for all new electric and hybrid electric vehicles. Manufacturers shall install AVAS in all new hybrid electric and pure electric vehicles by July 2021.

This system will help not only transportation management in plant compounds and transit points, but more important in common situations, for example in citizen ZTL areas: electric vehicles can still today get into these areas, but these ones are also the most crowded due to the fact that they often correspond to city center areas. The AVAS is so useful for public safety, avoiding every type of accident linked to silent vehicles.

### 3.4.3. Investments in electric equipment for the network

Electric vehicles need a series of defined equipment in order to keep under control the units produced and transported all over the compounds. Therefore, plant compounds and selected transit points must be equipped with specific tools, devices and areas for EV maintenance or simple procedures like battery charging. In the specific, the key elements necessary to set up an electric-friendly plant compound/transit point are:

- Electric panel
- Cable channels
- Charging stations (22kW of power)
- Protecting sun roofs
- Quarantine area (for vehicles with battery flammable exhalations or other dangers)
- Excavations and workforce cost
- Permits and authorizations

Set up this innovation is not free; for a manufacturer with high volumes and an extremely ramified distribution network, it becomes complex to understand in which intermediate points or final destinations introduce such an expensive equipment.

This become a fundamental challenge for carmakers: to place electric equipment in the right points of the current network, in order to minimize the cost sustained for the innovation, analyzing different scenarios of compounds innovated looking at the sum of investments plus the transport cost to keep the EVs to those specialized centers. The scenario with the best result suggests to the manufacturer which distribution compounds set up with electric modifications.

### 3.4.4. New agreements for SOC control

As reported in the paragraph about the constraints for the distribution of electric vehicles, the monthly charging procedure of yard-stored vehicles could be outsourced to specialized firms that carry out this service in the manufacturer areas. In order to figure out the terms and conditions of performance, an agreement between the two parties is necessary. This could be realized with the stipulation of a contract approved and signed by the manufacturer and the logistic service company. It represents a cost for the carmaker, but in a decision between in house service or outsourcing, the second one has been the final decision due to cost saving tested in a make or buy decision and specialization of external companies' operators.

# 4. Case study: Melfi Assembly Plant

## 4.1. Melfi Plant data analysis

### 4.1.1. Melfi Assembly Plant

The FCA plant of Melfi, a town located in the province of Potenza (Basilicata, Italy), is also known with the acronym SATA (Società Automobilistica Tecnologie Avanzate).

Built between the 1991 and 1993, it has started its operations in 1994. After a variety of models assembled in it, belonging to Fiat and Lancia brands, from 2014 (thanks to the Fiat acquisition of all Chrysler shares) the two models of cars produced in this plant are Fiat 500X and Jeep Renegade. However, the number of vehicle types produced will increase this year with the start of the production of three other cars: Jeep Compass (Melfi Plant is going to absorb part of the total production) and the new plug-in hybrid Jeep Renegade PHEV and Jeep Compass PHEV. Thus, with the 500 BEV produced in Mirafiori, Melfi has been selected as one of the two plants where FCA intends to begin its electric innovation. The distribution of the finished vehicles assembled in Melfi will so include electric vehicles that need particular conditions and above all a set of new equipment to introduce firstly in Melfi but also in the selected intermediate compounds and final destination points, where the cars must be supplied in order to meet the forecasted demand for 2020.

For these reasons, the following case study focuses at the beginning on the analysis of the network in an unconstrained view, considering the PHEV vehicles as traditional ICE ones.

Then, with the calculation of the required electric investments, the division between ICEs and PHEVs will be taken into account, creating a constrained network with increased distribution costs (if compared to the unconstrained one). Moreover, due to the current relevance of sustainability in carmakers' vehicles transport, also the emissions of the distribution network has been calculated. This value is nowadays a fundamental KPI: the achievement of a low $CO_2$ distribution provides a competitive advantage for a carmaker, starting for example from an increased reputation of the brand from customers.

Finally, the case study ends with the comparison of the costs between the constrained and the unconstrained network (cost comparison) and the $CO_2$ emitted in the constrained network compared to an optimized scenario where intermediate distribution points are minimized ($CO_2$ comparison).

### 4.1.2. Initial data

The database used in the case study is the forecasted distribution plan for 2020 of all the FCA plants. The fields of the database useful for the case study, reported in each row (a single route), are:

- The vehicle model: in total 68 models (Fiat Ducato, Jeep Renegade, Alfa Romeo Stelvio, etc.)
- The macro-market (Apac, Emea, Latam or Nafta)
- The final country to supply: in total 152 countries (Germany, South Africa, USA, etc.)
- The final zone to supply: in total 192 zones
- The delivery source: in total 180 sources
- The delivery destination: in total 355 destinations
- The transport mode chosen (by road, by rail or by sea)
- The distribution channel of the final client: in total 10 channels (dealers, fleets, etc.)
- The quantity of vehicles transported

In addition, there are other fields, such as the logistic service provider in charge of transporting cars from Mellfi plant to the point of sale that are considered in the initial file but not included in the analysis, since these variables do not affect the outcome of the analysis.

From the general distribution plan, filtering the data with the selection of "Melfi" from the production plant field, a specific distribution database with SATA routes is obtained. This limited database involves 62 final countries among the 152 of the total distribution, in particular 29 European markets (including Italy) and 33 extra-European ones. The next step, in order to extrapolate the volumes of the five different vehicles forecasted in the DP, is to apply the filter on the model field in the specific Melfi DP database; the results are the following:

- Fiat 500X: 78.000 units
- Jeep Compass: 31.000 units
- Jeep Compass PHEV: 18.000 units
- Jeep Renegade: 154.000 units
- Jeep Renegade PHEV: 19.000 units
- Total Melfi distribution volumes: 300.000 units

With the normalization of this data is possible to understand the weight of each model on the distribution plan of Melfi; the formula used is:

$$Model\ (i)\ \%\ weight = \frac{Model\ (i)\ units}{Total\ Melfi\ units}$$

Applying it on the five models data, it turns out that the distribution of  Fiat 500X accounts for the 26,00 % of the total, the 10,33 % for the Jeep Compass, the 6,00 % for Jeep Compass PHEV, while the 51,33 % is covered by Jeep Renegade and the 6,34 % by its PHEV version (Figure 4.1).

By aggregating the values concerning the plug-in hybrid models, the sum equals to 37.000 PHEVs delivered, a total 12,33 % of Melfi distribution: in few words, during 2020, if 100 vehicles are distributed from SATA, 13 will be PHEVs while 87 will be ICEs.

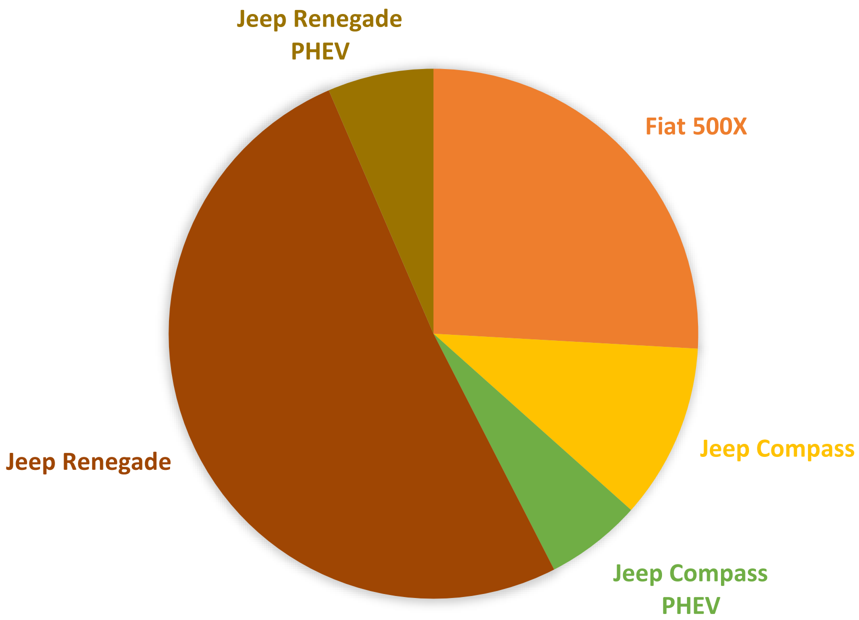



Figure 4.1. Normalized volumes of Melfi 2020 DP

Note that the use of the normalization, in this case as in all the other ones it is used over the case study, is useful because if the volume of a single model varies in an updated distribution plan version (forecasted distribution quantities could be updated during the months) the percentages permit to preserve the validity of the argument, bringing it beyond the simple numeric change.

### 4.1.3. Classification of Melfi Plant volumes

Given the quantities of vehicles delivered in each country or Italian province, the following step is the division of the total distribution in three different sections:

- Italian volumes
- European volumes
- Extra European volumes

The Italian distribution includes all the provinces where a vehicle produced in Melfi could be delivered; there are 30 possible destinations, from Northern to Southern Italy: Ancona, Bari, Bologna, Bolzano, Brescia, Cagliari, Catania, Cosenza, Florence, Genoa, Livorno, Mantua, Milan, Malpensa, Monfalcone, Naples, Novara, Padua, Palermo, Parma, Perugia, Pescara, Potenza, Ravenna, Reggio Calabria, Rome, Turin, Trieste, Varese, Venice.

The European DP includes 28 different markets: Albania, Austria, Belgium, Bulgaria, Cyprus, Croatia, Denmark, Finland, France, Germany, Greece, UK, Ireland, Lithuania, Macedonia, Malta, Norway, Netherlands, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Sweden, Switzerland, Ukraine, Hungary.

Melfi Plant 2020 distribution plan reaches 33 international countries: Angola, Saudi Arabia, Bahrain, Canada, Russia, South Korea, Egypt, Gabon, Guadeloupe, French Guiana, Hong Kong, Reunion, Israel, Japan, Ivory Coast, Kuwait, Lebanon, Madagascar, Morocco, Martinique, New Caledonia, Oman, Puerto Rico, Qatar, Dominican Republic, Singapore, South Africa, Tahiti, Tunisia, Turkey, Dubai, Abu Dhabi, Usa.

The following maps are useful to visualize the just listed global Melfi destinations.


Figure 4.2. Circle map of 2020 Melfi DP: the size of dots is proportional to the demand

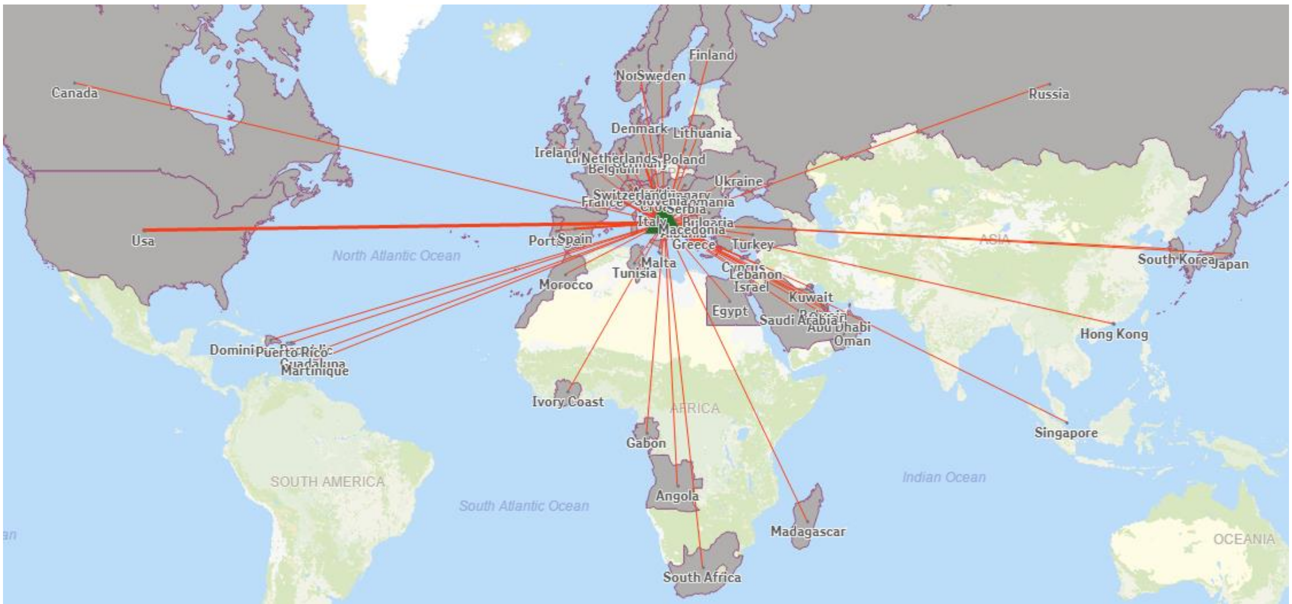



Figure 4.3. Flow map of 2020 Melfi DP. Grey areas show the countries supplied

Through the filter on the field “Zone”, by adding up the quantities is possible to know how much vehicles must be delivered in 2020 to every market segment; the results are the following:

- Italian market: 100.000 units
- European market: 105.000 units
- Extra-European market: 95.000 units

Similarly to the previous paragraph, it is possible to normalize these data in order to understand the weight of one of the three macro-markets in the distribution from SATA and if there are some big differences among them; the percentage of volumes involved in each area are shown in Figure 4.4.

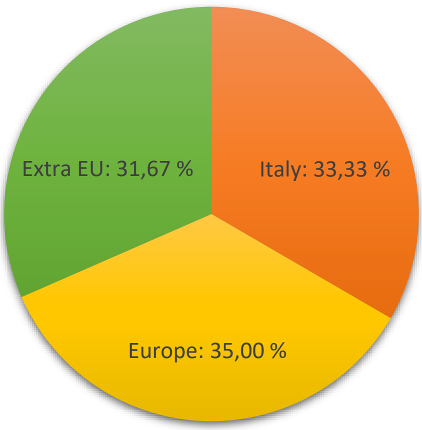



Figure 4.4. Normalization of the quantities delivered in the market segments

Figure 4.4 shows that the volumes are quite equally distributed among the three sections: the percentages are very similar. Therefore, it is possible to state that the distribution for these general segments is pretty balanced. These percentages also suggest that a third of the volumes will be delivered to the brand home country (to Italy).

#### 4.1.4. ABC analysis for Italian volumes

The Pareto analysis, also known as ABC, is a technique that could help to identify the importance of a model or a country in Melfi distribution. Issues such as which models are going to be distributed in major quantities or the main distribution countries, the most distributed model and other possible focus could be investigated using this statistical tool. From the results obtained, it is possible to claim if a country or a model is part of the category "A", containing the most influential elements, which approximatively covers the 75% of the cumulative data, part of category "B", including the next 20% of the cumulative curve, while the final 5% is allocated to category "C".

For the Italian demand, it possible to carry out five different Pareto analysis, increasingly specific:

- Northern, Central and Southern Italy volumes division
- Quantities destined to each province
- Models distributed (product market share)
- Division among North, Centre and South of each model
- Volumes of each model among all Italian delivery points

The first one requires assigning initially the attribute North, Centre or South to all the provinces listed in the Italian market (examples: Turin = North, Florence = Centre, Palermo = South); once made this for each city, volumes are aggregated. Results are the following (Figure 4.5):

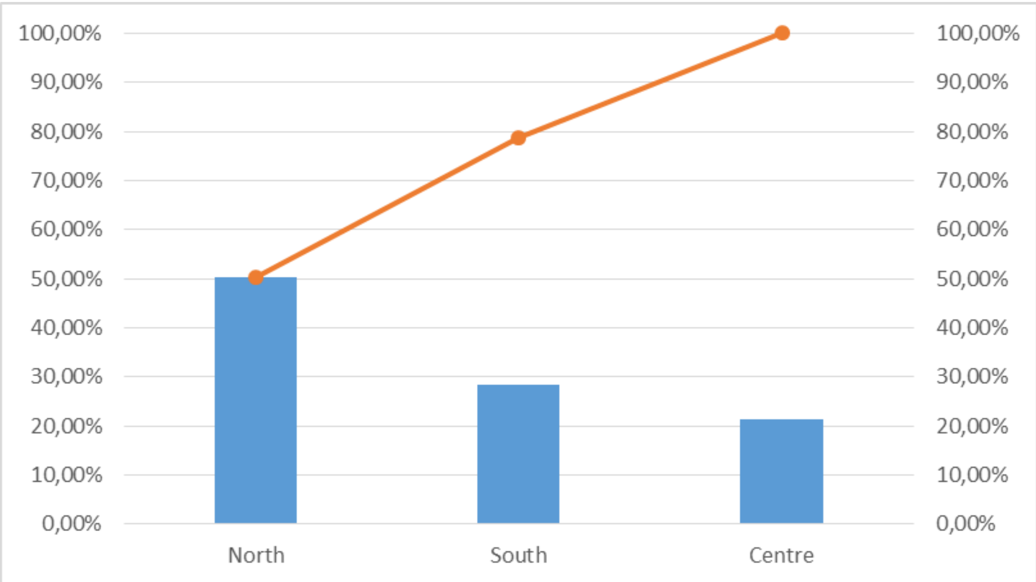



Figure 4.5. Volumes distributed in the three Italian geographical areas

The analysis regarding the volumes delivered to each province is important to understand the cities where efforts are necessary to carry out an optimal transport in order to supply successfully the majority of customers. The ABC curve is shown in Figure 4.6.

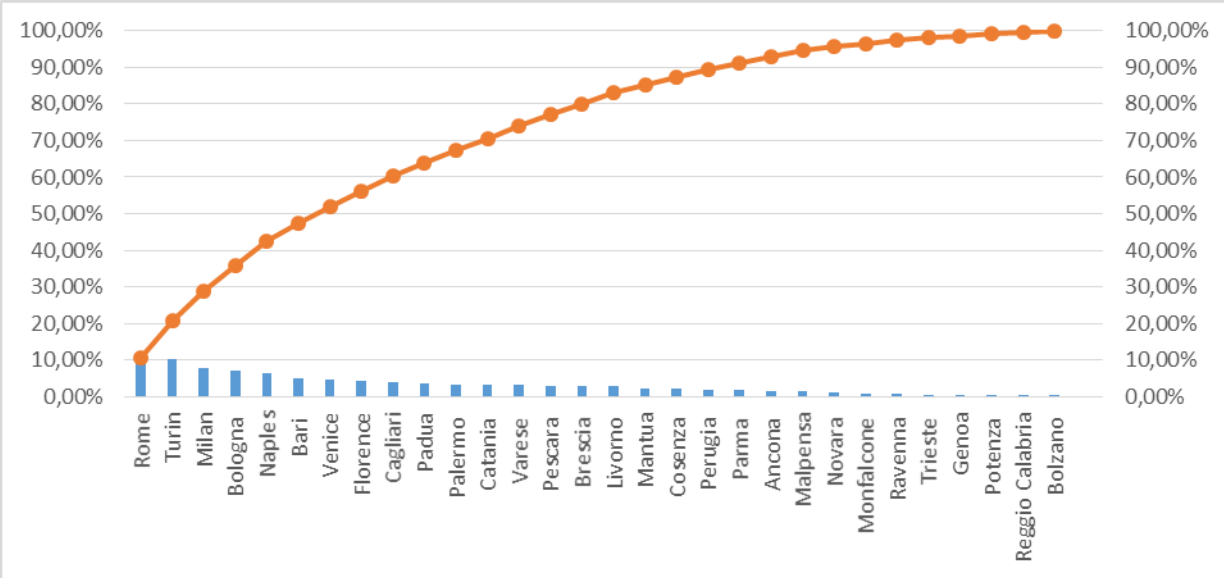



Figure 4.6. The most important Italian province in Melfi distribution

The category "A" is composed by the first 13 cities listed in the graph (from Rome to Varese), category "B" starts from Pescara and ends with Ravenna volumes (12 provinces) and category "C" counts the remaining 5 Italian markets.

The other fundamental analysis is the third one, associated with the quantities delivered for each model, in order to suggest an Italian market share of Melfi Plant (more basically, which models are preferred by Italian people). The results, using the Pareto curve, reveal as most appreciated models in Italy Jeep Renegade (37,62%) and Fiat 500X (35,53%), leaving a small percentage for each of the other three types produced in SATA (see Figure 4.7).

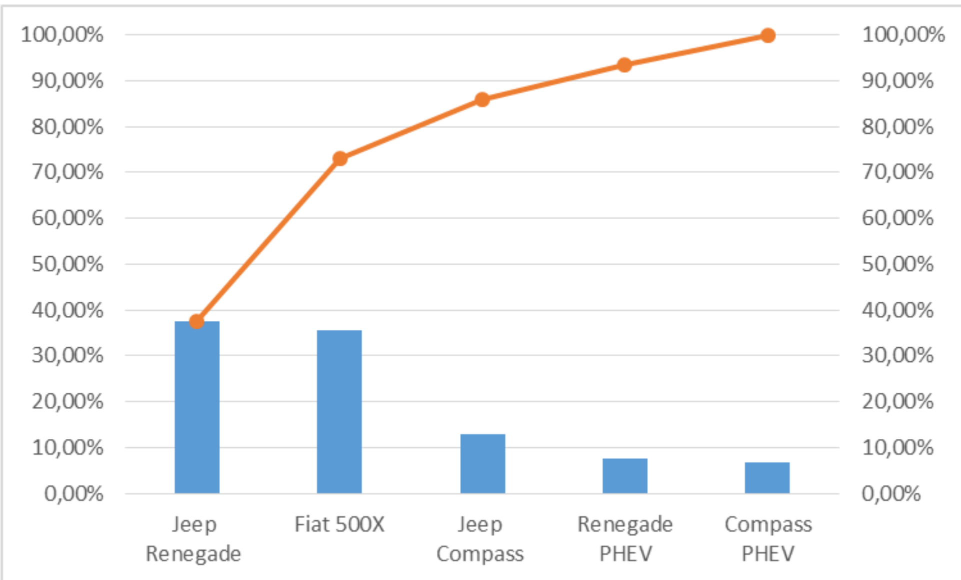



Figure 4.7. Distributive market share for 2020 of the five models assembled in Italy

#### 4.1.5. ABC analysis for European volumes

The same ABC techniques could be applied to the European volumes. In particular, without a geographical area division (applied only for Italy), three analysis may be performed:

- Vehicles delivered in each country
- Five models market share
- Single model-country relation (the market share for each of the five vehicle types)

To discover the most supplied European countries, the procedure is the same used for Italian provinces. Thus, is possible to understand not only the countries that brings to Melfi the demand that supports the production, but also which are the nations to focus about for an optimal distribution to maintain an higher customer satisfaction level. This rank of importance is represented in Figure 4.8.

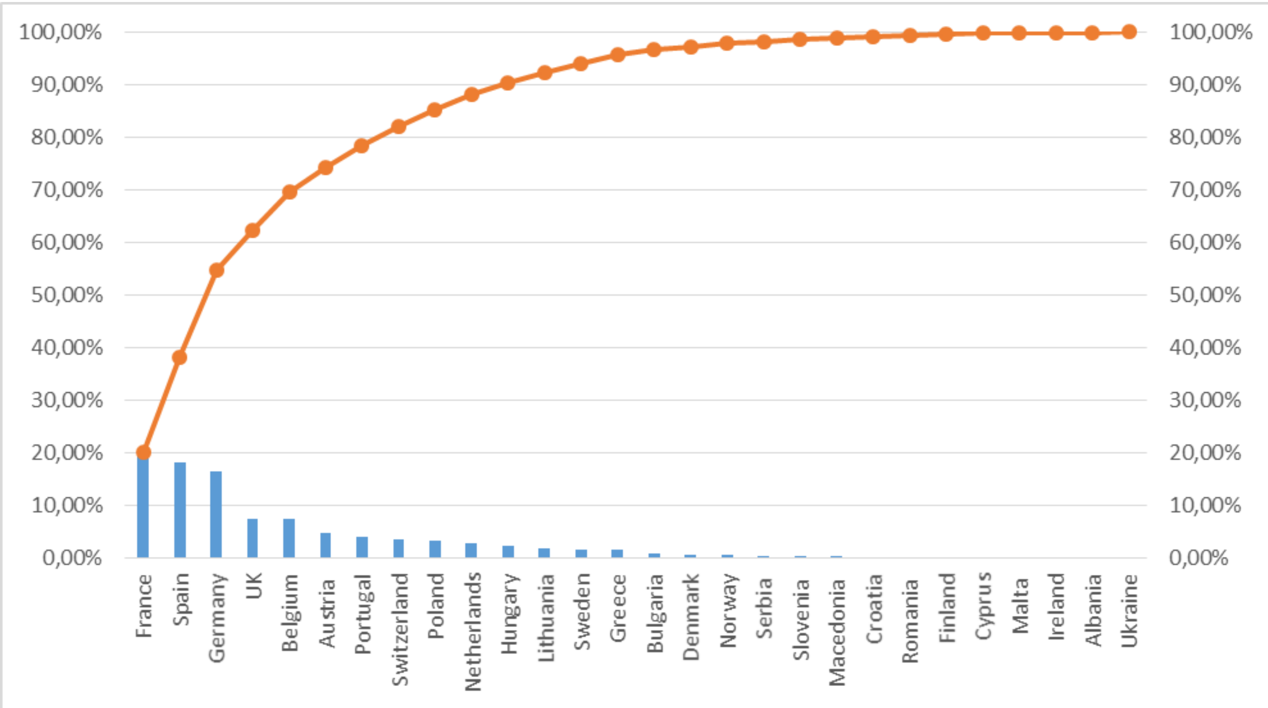



Figure 4.8. The impact of European countries on Melfi distribution plan

As it is possible to see, France, Spain, Germany, UK, Belgium and Austria form category "A", while the following six nations could be included in category "B" (Portugal, Switzerland, Poland, Netherlands, Hungary and Lithuania). Practically, 9 out of 10 vehicles delivered from Melfi to the foreign European market, is destined to one of these 12 countries. The other 16 nations, demanding low volumes, are all together members of the category "C".

The second survey to be conducted is also this one the same to what has be done for Italian volumes. By aggregating all the units of a single model distributed in Europe during 2020, it is found the preference of Europeans for which regards the models of vehicles produced in Melfi Plant. Figure 4.9 reports the results.

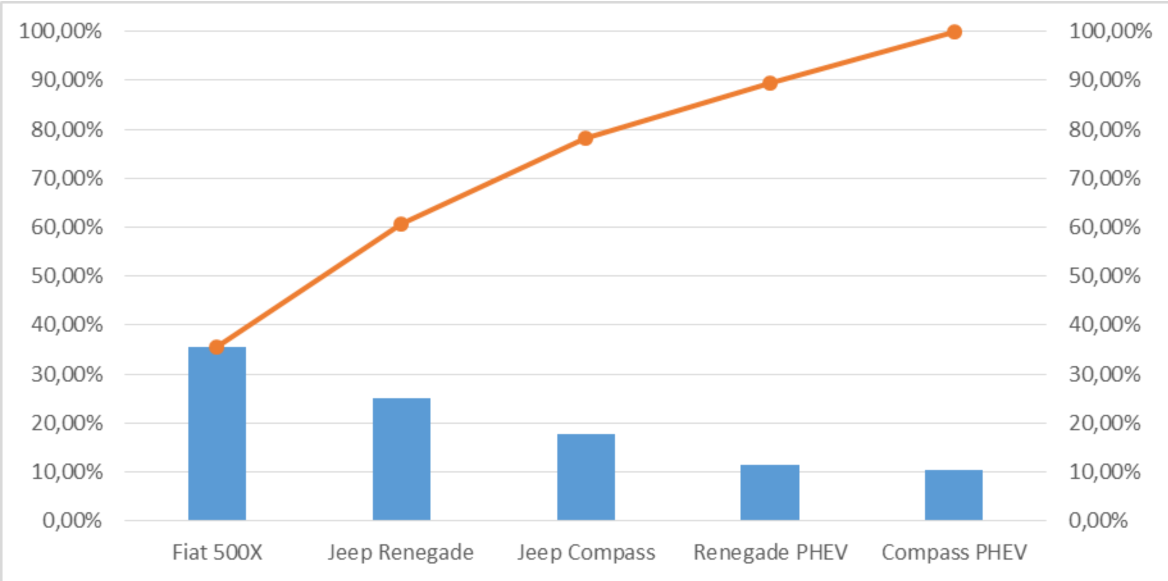



Figure 4.9. Percentage volumes of each model delivered in European countries for 2020

Differently from Italy, in the Europe the most delivered type is the Fiat 500X (35,49%), followed by Jeep Renegade (25,10%), Jeep Compass (17,64%) and the PHEVs (11,31% for Renegade PHEV, 10,46% for Compass PHEV).

From this last Pareto analysis, since both 500X and Renegade are reversed in the two segments surveyed, it is reasonable to sum the volumes of Italian and European final nodes to point out the total distributive market share in the aggregated European distribution (Italy + European countries) and the weight of Italian volumes compared to European countries' ones.

As expected, also considering for example Figure 4.4, Italy is the dominant country with the 48,77% of volumes, while the second place is taken up by France with a 10,34% weight and the third by Spain (9,29%). Moreover, the most delivered model in Italy + Europe aggregated volumes is Fiat 500X (35,51%), preceding Jeep Renegade (31,21%), Jeep Compass (15,26%), Jeep Renegade PHEV (9,45%) and Jeep Compass PHEV (8,57%). Comparing these new weights with the European ones (without Italy; see Figure 4.9), two considerations could be done:

- Fiat 500X results first because volumes are similar with Jeep Renegade ones for Italy, while in the other European nations Jeep Renegade is less demanded.
- PHEVs percentages decrease in the aggregated Italy-Europe analysis: PHEVs are mainly required in foreign countries (indication of a low spread of EVs in Italy).

### 4.1.6. Data limitation

For the next paragraphs, starting for example from the baseline scenario analysis, the volumes considered are not the total one, but a geographical limitation is introduced.

First of all, extra-European vehicles are not considered.

Secondly, in the European segment, only the nations belonging to categories "A" and "B" of the country Pareto analysis (Figure 4.8) are taken into account. Germany (category "A") and Switzerland (category "B") are considered negligible for another reason: the distribution for these countries involves three nodes, Kippenheim for Germany and Carimate and Altishofen for Switzerland market, that are used exclusively for these nations. So, it is unnecessary to consider them in an extended network consideration, because the distribution in these two nations does not affect the other countries considered in the network design. For these reasons, in the baseline scenario cost calculation, only 10 European countries are considered.

Moreover, as regards Italy, all the provinces of Central and Southern Italy are not involved in the case study calculations because they are all supplied with direct routes, with the exception of Catania, whose volumes pass through the port of Salerno, used for European distribution. Therefore, the remaining data to be used in the following steps of the case study are:

- Northern Italy (Turin, Milan, Bologna, Venice, Padua, Varese, Brescia, Mantua, Parma, Malpensa, Novara, Monfalcone, Ravenna, Trieste, Genoa, Bolzano)
- Catania
- European countries of "A" category (France, Spain, UK, Belgium and Austria)
- European countries of "B" category (Portugal, Poland, Netherlands, Hungary and Lithuania)

The updated volumes considered, compared to the input total Melfi volumes, are shown in Table 4.1. Note that in the limited volumes analyzed from here, the 16,92 % are PHEVs (= 22.000/130.000).

| | **Total DP** | **Limited DP** | **% of the total** |
|---|---|---|---|
| **Vehicles** | 300.000 units | 130.000 units | 43,33 % |
| **ICEs** | 263.000 units | 108.000 units | 41,06 % |
| **PHEVs** | 37.000 units | 22.000 units | 59,46 % |

Table 4.1. Limitation of the volumes used for the next analysis

In order to better visualize this reduced area and its involved volumes, the following heat map (Figure 4.10) and proportional circle map (Figure 4.11) represent the quantities demanded by final nodes.

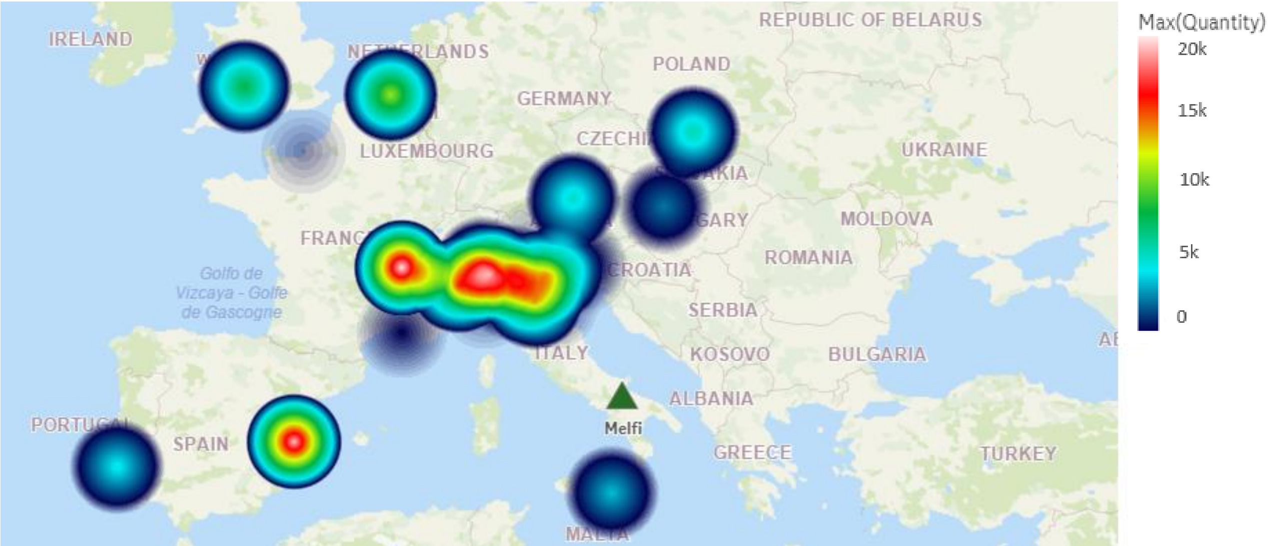



Figure 4.10. Heat map of the European limited volumes analyzed in the case study

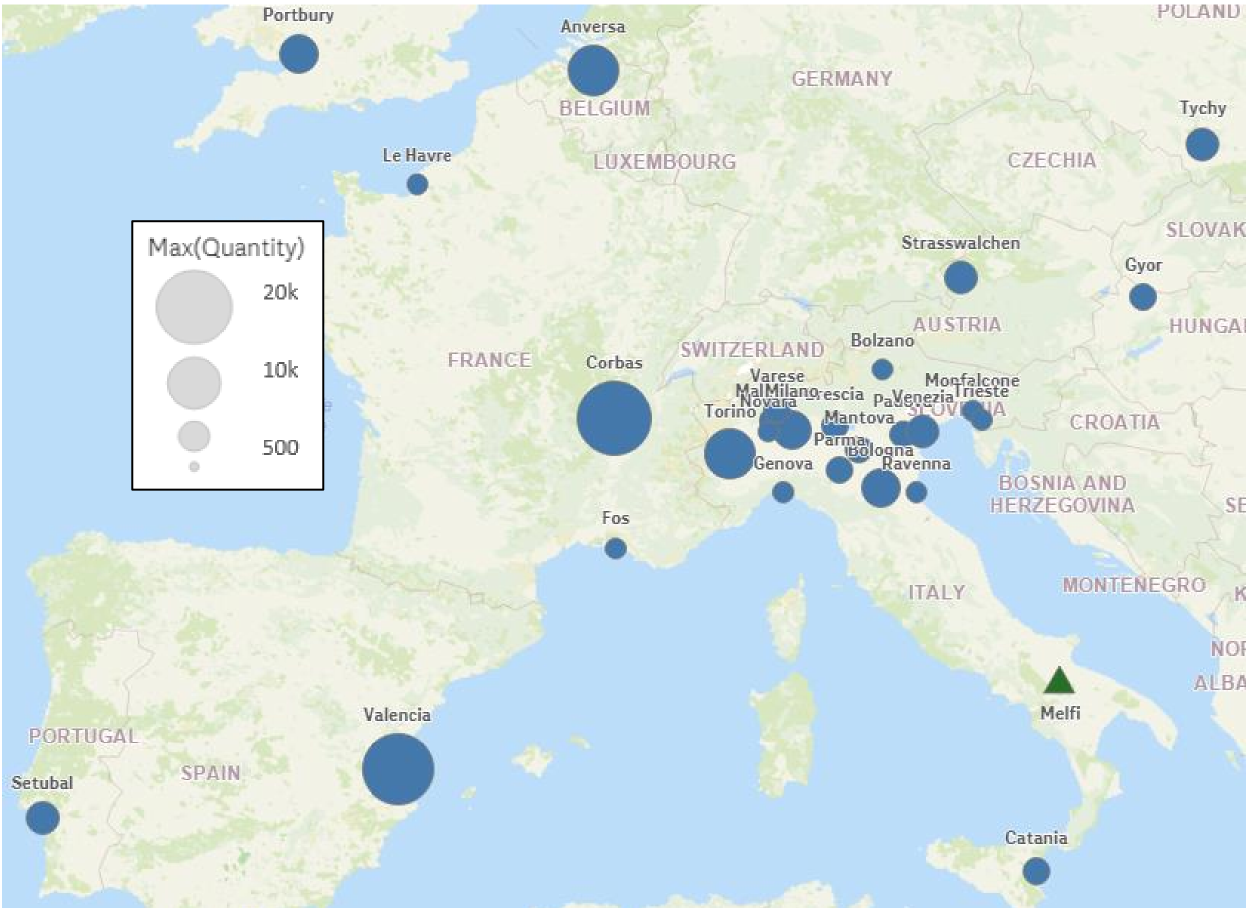



Figure 4.11. Proportional circle map: the bigger the dot, the higher the demand of a final node

## 4.2. Current network

### 4.2.1. Baseline analysis (Scenario 0)

The baseline analysis is the starting point of the distribution cost analysis. Taken the transport routes of the limited research field described in the previous paragraph (filtered from Melfi 2020 DP), it is possible to calculate the transport cost of the Scenario 0 ("As is" scenario). From this one, a couple of alternative scenarios (Scenario 1 and Scenario 2) are successively investigated to understand the differences with the baseline and to choose the best option for the SATA deliveries involving the geographic stratification created for the case study.

A fundamental assumption is considered in the second and third case study chapters: PHEV vehicles transport is carried out in the same way of ICEs. Since electrification is not processed until chapter 4, for the baseline analysis and the next alternative scenarios is represented an unconstrained network.

The routes considered for the baseline cost calculation are the colored ones of Figure 4.12.

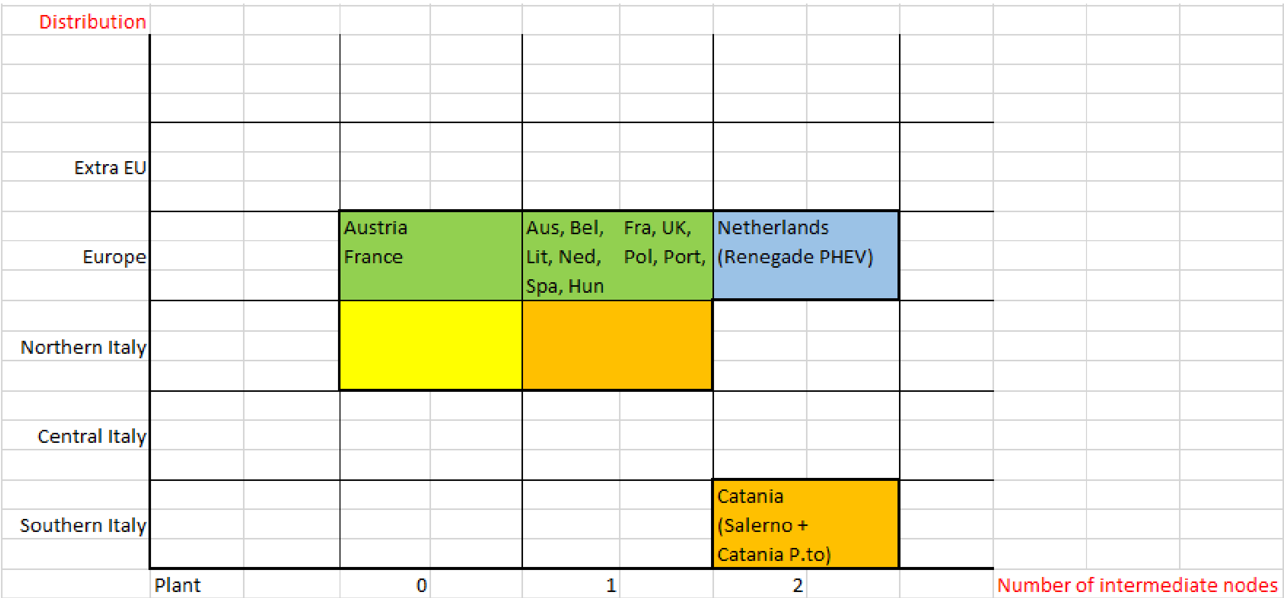



Figure 4.12. Limited survey grid of Melfi 2020 for baseline cost calculation

The yellow area represents the direct transport from Melfi to Northern Italy (16 provincial markets supplied without intermediate points), in total 21.000 units (3.000 PHEVs, the 14,29%) of the 130.000 analyzed.

The Italian distribution through a single intermediate point is represented with the orange color. It concerns 12 provinces for a total of 33.000 vehicles transported, 4.000 of which are plug-in hybrid cars. The exception of Catania is included in this data set, with its 3.500 units carried out.

The green areas are both referred to the distribution in the European countries. The left-sided one represents the cars transported from Melfi to the final destinations in Europe: this occurs only for Austrian and French market. However, almost the entire European distribution is carried out passing through one intermediate point, as possible to see in the second green field. The units here counted are 75.000, including 14.000 of the 22.000 PHEVs analyzed.

The blue area, as for Catania province, represents an exception; the distribution of the Renegade PHEV to Netherlands (750 units) is in fact performed by the use of two intermediate compounds.

The specific compounds involved in the baseline analysis are listed in Figure 4.13.

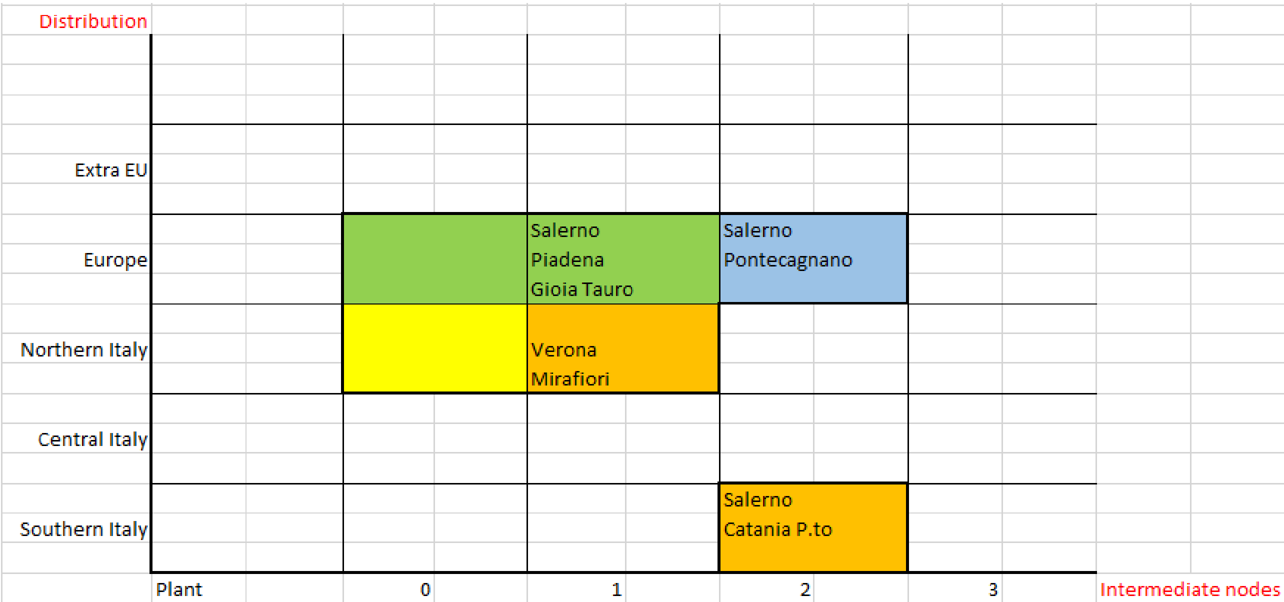



Figure 4.13. The specific intermediate points of the baseline analysis

With the help of this figure, it is immediately understood which intermediate and final points are used in the baseline scenario. The complete country routes are itemized below (the last column of a market DP represents the final destination of FCA competence) and shown in a flow map (Figure 4.14):

| | | |
|---|---|---|
| | Melfi | Bologna, Bolzano, Brescia, Genoa, Mantua, Milan, Malpensa, Monfalcone, Padua, Parma, Ravenna, Turin, Trieste, Varese, Venice |

| | | | |
|---|---|---|---|
| | Melfi | Verona | Bolzano, Brescia, Mantua, Milan, Malpensa, Monfalcone, Padua, Trieste, Varese, Venice |
| | | Mirafiori | Novara, Turin |

| | | | |
|---|---|---|---|
| Direct | Austria | Melfi | Strasswalchen |
| | France | | Corbas |

| | | | | |
|---|---|---|---|---|
| Not direct | Austria | Melfi | Piadena | Strasswalchen |
| | Belgium | Melfi | Salerno | Antwerp |
| | France | Melfi | Salerno | Le Havre |
| | | | | Fos |
| | | | Gioia Tauro | Le Havre |
| | UK | Melfi | Salerno | Portbury |
| | Lithuania | Melfi | Piadena | Tychy |
| | Netherlands | Melfi | Salerno | Antwerp |
| | Poland | Melfi | Piadena | Tychy |
| | Portugal | Melfi | Salerno | Setubal |
| | Spain | Melfi | Salerno | Valencia |
| | Hungary | Melfi | Piadena | Gyor |

| | | | | | |
|---|---|---|---|---|---|
| | Netherlands | Melfi | Pontecagnano | Salerno | Antwerp |

From the routes, it is evident that some points are used in common for different European markets:

- Salerno is an intermediate compound for Belgium, France, UK, Netherlands, Portugal, Spain
- Piadena is an intermediate compound for Austria, Lithuania, Poland and Hungary
- Antwerp is the final node for Belgium and Netherlands
- Tychy is the final node for Lithuania and Poland

Given the routes, if it is assigned a cost to each transport, by multiplying this value for the units delivered in each route in 2020 (model by model), it is found out the total transport costs for the baseline scenario. This process is better detailed in the following paragraph (4.2.2).

Figure 4.14 represents the flows involved in the baseline network; all the flows are weighted proportionally to the route with the biggest volume supplied (Melfi – Salerno).
In particular, the purple flows link Melfi Plant with the intermediate or final nodes directly supplied by SATA (primary transportation), while the red flows show the secondary transportation (the deliveries from an intermediate distribution point to another intermediate one or to a final node). Similarly, the orange dots of the map indicate the primary transportation nodes, while blue dots identify the secondary transportation ones.

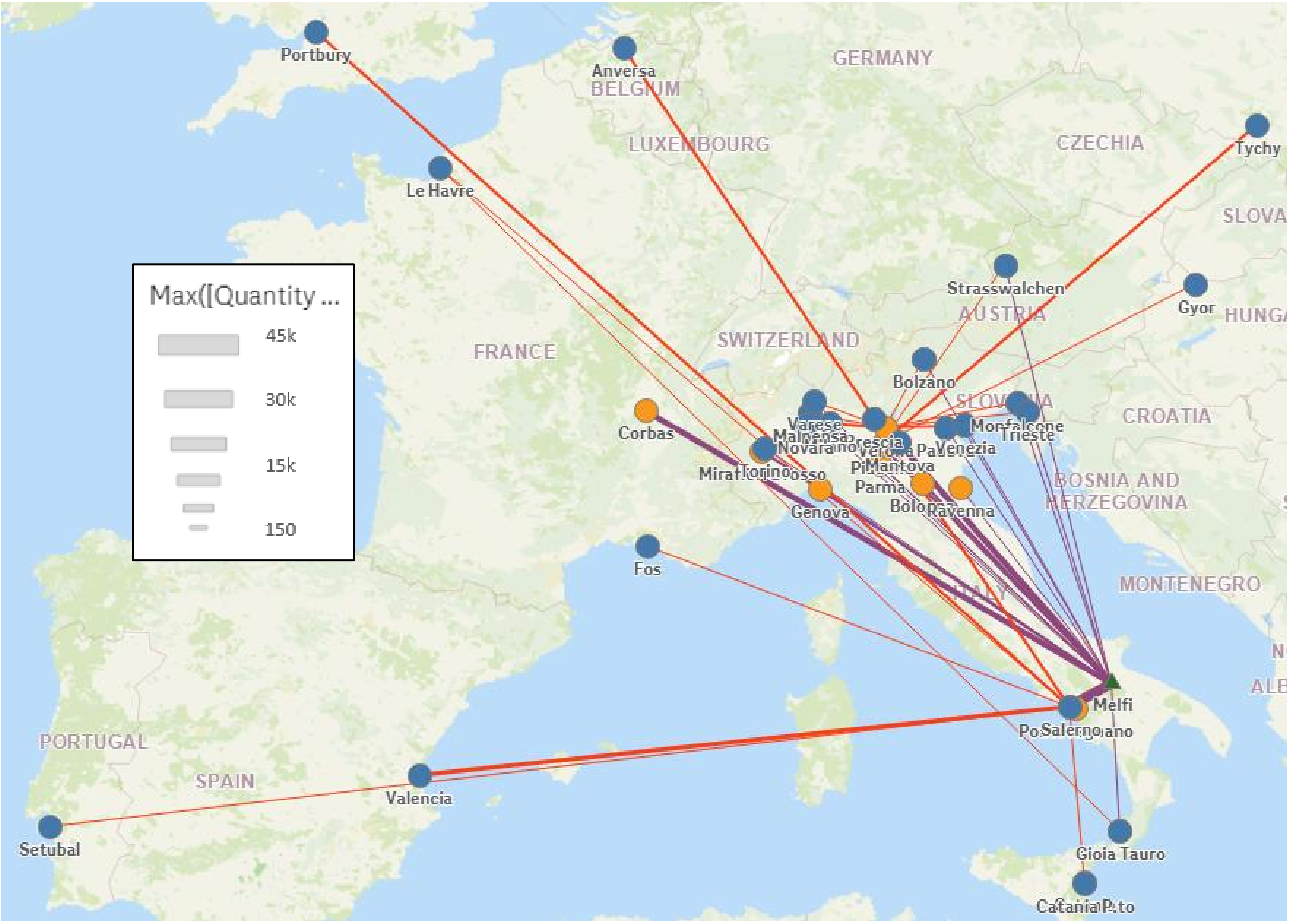



Figure 4.14. Weighted flow map of the baseline network

### 4.2.2. Baseline distribution costs

The calculation of the total cost for the unconstrained baseline network begins with the introduction of a new database: the route fees database for the transport of a single vehicle. The cost incurred in the transport of a car from Melfi to Italian and European markets varies due to the distance travelled, the model delivered and above all the transport mode used. In the case study, three different transport modes are considered: road transport, rail transport or sea transport; the same delivery has a different cost if it is carried out by rail or road. Considering for example the Poland and the Hungarian market, Table 4.2 shows how these three parameters (distance, mode, and model) influence the fee of a route. Data refer to the current year 2020.

| Market | Model | Source | Destination | Mode | Quantity | Fee €/vehicle |
|---|---|---|---|---|---|---|
| Poland | Fiat 500X | Melfi | Piadena | Rail | 100 | 90,00 |
| | | Melfi | Piadena | Road | 300 | 110,00 |
| | | Piadena | Tychy | Road | 400 | 200,00 |
| | Jeep Renegade | Melfi | Piadena | Rail | 400 | 90,00 |
| | | Melfi | Piadena | Road | 1200 | 110,00 |
| | | Piadena | Tychy | Road | 1600 | 200,00 |
| Hungary | Fiat 500X | Melfi | Piadena | Rail | 700 | 70,00 |
| | | Piadena | Gyor | Road | 700 | 360,00 |
| | Jeep Renegade | Melfi | Piadena | Rail | 400 | 90,00 |
| | | Piadena | Gyor | Road | 400 | 380,00 |

Table 4.2. Examples of fees for a single vehicle in Melfi distribution

Having available all the fees of each route for all the routes of the baseline scenario, by multiplying the cost per vehicle and the quantities delivered in a route, it is possible to calculate firstly the cost of the distribution for a single model market adding the routes involved in the specific country. Then, the sum of the costs per model reveals the value of a model distribution. Finally, the union of the five model costs obtained represents the distribution cost for the unconstrained baseline network. The results obtained in the second and third steps are reported in Table 4.3.

| Model | Distribution costs (€) | % of the total |
|---|---|---|
| Fiat 500X | 9 M | 34,62 % |
| Jeep Compass | 4 M | 15,38 % |
| Jeep Compass PHEV | 2 M | 7,69 % |
| Jeep Renegade | 8 M | 30,77 % |
| Jeep Renegade PHEV | 3 M | 11,54 % |
| **Total** | **26 M** | |

Table 4.3. Total distribution costs per model and total cost for the unconstrained network

It is also important to see how costs are divided among the countries supplied and the transport modes used, in order to understand the nations to which transport is more expensive and maybe change the transport mode or to allocate more quantities on the cheapest solution. Table 4.4 analyses the split of costs among countries, Table 4.5 among the transport modes, in the unconstrained "as is" scenario.

| Country | Distribution costs (€) | % of the total |
|---|---|---|
| Austria | 1 M | 3,85 % |
| Belgium | 2 M | 7,69 % |
| France | 5 M | 19,23 % |
| UK | 2 M | 7,69 % |
| Italy (North + Catania) | 8 M | 30,75 % |
| Lithuania | 1 M | 3,85 % |
| Netherlands | 1 M | 3,85 % |
| Poland | 1 M | 3,85 % |
| Portugal | 1 M | 3,85 % |
| Spain | 3 M | 11,54 % |
| Hungary | 1 M | 3,85 % |

Table 4.4. Unconstrained network cost split by country

| Transport mode | Distribution costs (€) | % of the total |
|---|---|---|
| Road | 11 M | 42,31 % |
| Rail | 9 M | 34,62 % |
| Sea | 6 M | 23,07 % |

Table 4.5. Unconstrained network cost divided by transport modes

Also important is the calculation of the cost for a vehicle delivered and, considering that the major part of the volumes pass through an intermediate points, the cost for a movement. The starting data to find these value are: 130.000 vehicles delivered in Italy and Europe limited area, a total of 220.000 movements carried out and as found before, an overall cost of € 26 M.
With three ratios, these fundamental results are found:

- Baseline €/movement = € 26 M / 220.000 movements = 118,00 €/movement
- Baseline €/vehicle = € 26 M / 130.000 vehicles = 200,00 €/vehicle
- Movements per vehicle = 220.000 movements / 130.000 vehicles = 1,7 movements/vehicle

These three values will be compared with the results obtained in the next two scenarios with the same calculations in order to understand how things change in particular conditions.

## 4.3. Alternative scenarios

### 4.3.1. Total direct distribution costs (Scenario 1)

The first investigated alternative scenario could be seen as the optimal one; in scenario 1, all the vehicles belonging to the limited geographic stratification are delivered without the use of intermediate points. For this reason, in comparison to scenario 0, the markets, the final nodes, the demand of each market and the route fees involved remain the same, while intermediate compounds are now inexistent and transport is performed only by road and rail (no sea transport). So, the routes used and the associated demands for each market are:

- Austria: Melfi – Strasswalchen (5k units)
- Belgium: Melfi – Antwerp (8k units)
- France: Melfi – Corbas (20k units); Melfi – Fos (1k units); Melfi – Le Havre (1k units)
- UK: Melfi – Portbury (8k units)
- Italy (North + Catania): Melfi – Italian provinces (54k units)
- Lithuania: Melfi – Tychy (2k units)
- Netherlands: Melfi – Antwerp (3k units)
- Poland: Melfi – Tychy (3k units)
- Portugal: Melfi – Setubal (4k units)
- Spain: Melfi – Valencia (19k units)
- Hungary: Melfi – Gyor (2k units)

Knowing the fees from the dedicated database, by multiplying these values with each demand required by a market and successively aggregating the market costs, it is turned out the total direct distribution cost (scenario 1 total cost).

There is still an open issue: except for five countries (Austria, Italy, Lithuania, Poland and Hungary), the fee database does not report the direct transport fee, so basically the fees for the remaining six European countries are made by adding the fees of the separated routes; therefore, the total costs for these markets are equal to scenario 0 ones. For example, Melfi – Valencia direct road fee does not exist, so direct transport fee to Spanish market is equal to Melfi – Salerno fee plus the Salerno – Valencia fee.

The resultant saving introduced with direct transport by these five countries is shown in Table 4.6.

| Model | Distribution costs (€) | % of the total |
|---|---|---|
| Fiat 500X | 8 M | 33,33 % |
| Jeep Compass | 4 M | 16,67 % |
| Jeep Compass PHEV | 2 M | 8,33 % |
| Jeep Renegade | 7 M | 29,17 % |
| Jeep Renegade PHEV | 3 M | 12,50 % |
| **Total** | **24 M** | |

Table 4.6. Total distribution cost of scenario 1

With the total direct distribution, the weighted costs for Fiat 500X and Jeep Renegade decrease, while for the other three models they are higher than in baseline scenario.
As previously affirmed, not all countries have direct fees available in the fee database, so the cost comparison in the countries and transport modes between the two scenarios is possible in half. Anyway, the costs found and, most important, the cost saving brought by a direct road-rail delivery, are summarized in the three following tables (Table 4.7, 4.8 and 4.9).

| Country | Distribution costs (€) | % of the total |
|---|---|---|
| Austria | 1,5 M | 6,25 % |
| Belgium | 2 M | 8,33 % |
| France | 5 M | 20,83 % |
| UK | 2 M | 8,33 % |
| Italy (North + Catania) | 6,5 M | 27,09 % |
| Lithuania | 500 k | 2,08 % |
| Netherlands | 1 M | 4,17 % |
| Poland | 1 M | 4,17 % |
| Portugal | 1 M | 4,17 % |
| Spain | 3 M | 12,50 % |
| Hungary | 500 k | 2,08 % |

Table 4.7. Country distribution costs using direct transport

| Transport mode | Distribution costs (€) | % of the total |
|---|---|---|
| Road | 18 M | 75,00 % |
| Rail | 6 M | 25,00 % |
| Sea | - | - |

Table 4.8. Cost split for scenario 1 transport modes (sea transport is not used)

| Country | Scenario 1 €/vehicle | Scenario 0 €/vehicle | Quantity | Total saving (€) |
|---|---|---|---|---|
| Austria | 300,00 | 200,00 | 5 k | + 500 k |
| Italy | 122,00 | 150,00 | 54 k | - 1,5 M |
| Lithuania + Poland | 200,00 | 300,00 | 5 k | - 500 k |
| Hungary | 200,00 | 450,00 | 2 k | - 500 k |
| **Total** | **-** | **-** | **66 k** | **- 2 M** |

Table 4.9. Cost savings for the countries where direct transport fees are given

The results of Table 4.9 are very interesting because they suggest that not always direct transport is the cheapest solution; in the case of Austria, for example, the cost increases because in scenario 0 part of the demanded vehicles are transported in the intermediate route Melfi – Piadena by rail, which has a low fee. By adding this fee to the Piadena – Strasswalchen one, the result is lower than the direct road transport Melfi – Strasswalchen one.

Lastly, it is not difficult to realize that scenario 1 €/vehicle cost is equal to the €/movement one; in fact, by eliminating intermediate routes, the transport of a vehicle to its final destination consists of a single movement:

- Scenario 1 €/movement = € 24 M / 130.000 movements = 185,00 €/movement
- Scenario 1 €/vehicle = € 24 M / 130.000 vehicles = 185,00 €/vehicle
- Movements per vehicle = 130.000 movements / 130.000 vehicles = 1 movement/vehicle

In comparison to the "as is" scenario, direct transport leads to a saving of € 15 per vehicle delivered.

### 4.3.2. Intermediate volumes minimization costs (Scenario 2)

The second alternative scenario focuses on another type of improvement for the baseline unconstrained network; it tries to reduce the intermediate movements with two possibilities:
(1) If a market is supplied using two alternative intermediate points, all the volumes involved must be assigned to the most convenient one, while the other intermediate compound is removed for that market.
(2) If the distribution to a market in scenario 0 passes through two or more intermediate nodes, the new distribution, used in scenario 2 database, includes only one of the intermediate compounds previously included.
With the introduction of these two changes to the baseline unconstrained network, only two routes are involved:

- Fiat 500X for French market: with the change (1) of the two possible scenario 2 changes, due to the simultaneous use of the ports of Salerno and Gioia Tauro, this second one is eliminated, because of economy of scale. In fact, this is the only movement involving Gioia Tauro, while Salerno receives the volumes destined also to Catania, Belgium, UK, Netherlands, Portugal and Spain. The Fiat 500X delivered in scenario 0 from Melfi to Gioia Tauro are now inserted in the Melfi – Salerno route and in the same way to Salerno – Le Havre route.
- Jeep Renegade PHEV for Dutch market: this is the only market that involves two intermediate compounds, therefore the only one where to apply change (2). In scenario 2, the compound of Pontecagnano disappears from Dutch distribution, so the 750 units reaches Netherlands passing only through the port of Salerno (Melfi – Salerno + Salerno – Antwerp).

Only these two model markets varies in scenario 2, compared to the baseline; this means that the starting "as is" scenario, for what concerns the management of the volumes to intermediate compounds, is still well designed.
Moreover, considering that Gioia Tauro and Pontecagnano are only used in these two model distribution markets, from the parametrical point of view, the only change from scenario 0 regards the intermediate points considered: they are now two less. Models, final nodes, quantities, transport modes and fees are equal to the baseline.
In order to analyze the modifications in the distribution costs, the same tables created for the previous scenarios are made for to the intermediate volumes minimization case. Split by model, country and transport mode, the following three tables report the result of scenario 2 distribution costs; the differences with scenario 0 are represented by the underlined values.

| **Model** | **Distribution costs (€)** | **% of the total** |
|---|---|---|
| Fiat 500X | 8,5 M | 33,33 % |
| Jeep Compass | 4 M | 15,68 % |
| Jeep Compass PHEV | 2 M | 7,84 % |
| Jeep Renegade | 8 M | 31,39 % |
| Jeep Renegade PHEV | 3 M | 11,76 % |
| **Total** | **25,5 M** | |

Table 4.10. Scenario 2 model distribution costs

| **Country** | **Distribution costs (€)** | **% of the total** |
|---|---|---|
| Austria | 1 M | 3,92 % |
| Belgium | 2 M | 7,84 % |
| France | 4,5 M | 17,65 % |
| UK | 2 M | 7,84 % |
| Italy (North + Catania) | 8 M | 31,39 % |
| Lithuania | 1 M | 3,92 % |
| Netherlands | 1 M | 3,92 % |
| Poland | 1 M | 3,92 % |
| Portugal | 1 M | 3,92 % |
| Spain | 3 M | 11,76 % |
| Hungary | 1 M | 3,92 % |

Table 4.11. Distribution costs for each market

| **Transport mode** | **Distribution costs (€)** | **% of the total** |
|---|---|---|
| Road | 11,5 M | 45,10 % |
| Rail | 8,5 M | 33,33 % |
| Sea | 5,5 M | 21,57 % |

Table 4.12. Transport mode costs in intermediate volumes minimization

A couple of comments are necessary: first, the Jeep Renegade PHEV and distribution costs for Netherlands values do not change, even if theoretically they should, for the same problem found for scenario 2. Since the fees for Melfi – Pontecagnano and Pontecagnano – Salerno routes do not exist in the fee database of the case study, in the baseline distribution these two fees have been calculated by splitting in half the available Melfi – Salerno fee. For this reason, the elimination of Pontecagnano do not brings a cost saving, so the distribution costs for Jeep Renegade PHEV and Netherlands remain the same. Anyway they are underlined because with the introduction of the fees for the two routes involving Pontecagnano, their sum will be certainly higher than the Melfi – Salerno one, bringing the expected saving.
Secondly, as introduced before, also the distribution costs evidences a strong similarity between this optimal scenario and the starting baseline, in confirmation of the good design of scenario 0.

Also for scenario 2 could be performed the calculation of:

- Scenario 2 €/movement = € 25,5 M / 219.250 movements = 116,00 €/movement
- Scenario 2 €/vehicle = € 25,5 M / 130.000 vehicles = 196,00 €/vehicle
- Movements per vehicle = 219.250 movements / 130.000 vehicles = 1,69 movements/vehicle

In comparison to scenario 0, the €/movement decreases because of the 750 movements eliminated in scenario 2 from Jeep Renegade PHEV Dutch market; also the €/vehicle value as expected decreases, even if only of € 4. The missing fees for Melfi – Pontecagnano and Pontecagnano – Salerno routes cause the restricted delta; having them available, the delta would be higher.

## 4.4. Electrification

### 4.4.1. Infrastructural investments (fixed costs)

This section shows the introduction of the electric innovation for Melfi distribution plan.

The first task to perform is the creation of the PHEVs database; this requires the following operation: filtering the two hybrid models from the initial Melfi 2020 DP, used for the unconstrained network, the wanted database is created. The elimination of ICE vehicles leads to the loss of some routes and in particular to a whole market, the Lithuanian one (it demands only ICEs).

In particular, the countries and volumes involved in SATA 2020 PHEVs database are:

| Country | Volume | % of the total | Model | Units |
|---|---|---|---|---|
| Austria | 2 k | 9,09 % | Compass PHEV | 500 |
| | | | Renegade PHEV | 1.500 |
| Belgium | 1,5 k | 6,82 % | Compass PHEV | 500 |
| | | | Renegade PHEV | 1.000 |
| France | 3 k | 13,64 % | Compass PHEV | 1.000 |
| | | | Renegade PHEV | 2.000 |
| UK | 2 k | 9,09 % | Compass PHEV | - |
| | | | Renegade PHEV | 2.000 |
| Italy | 7 k | 31,82 % | Compass PHEV | 3.000 |
| | | | Renegade PHEV | 4.000 |
| Netherlands | 2 k | 9,09 % | Compass PHEV | 1.000 |
| | | | Renegade PHEV | 1.000 |
| Poland | 0,5 k | 2,27 % | Compass PHEV | 250 |
| | | | Renegade PHEV | 250 |
| Portugal | 1,5 k | 6,82 % | Compass PHEV | 500 |
| | | | Renegade PHEV | 1.000 |
| Spain | 2 k | 9,09 % | Compass PHEV | 1.000 |
| | | | Renegade PHEV | 1.000 |
| Hungary | 0,5 k | 2,27 % | Compass PHEV | 250 |
| | | | Renegade PHEV | 250 |
| **Total** | **22 k** | | **Compass PHEV** | **8.000** |
| | | | **Renegade PHEV** | **14.000** |

By taking up Figure 4.11 and 4.14, also for PHEV volumes the same maps could be introduced.

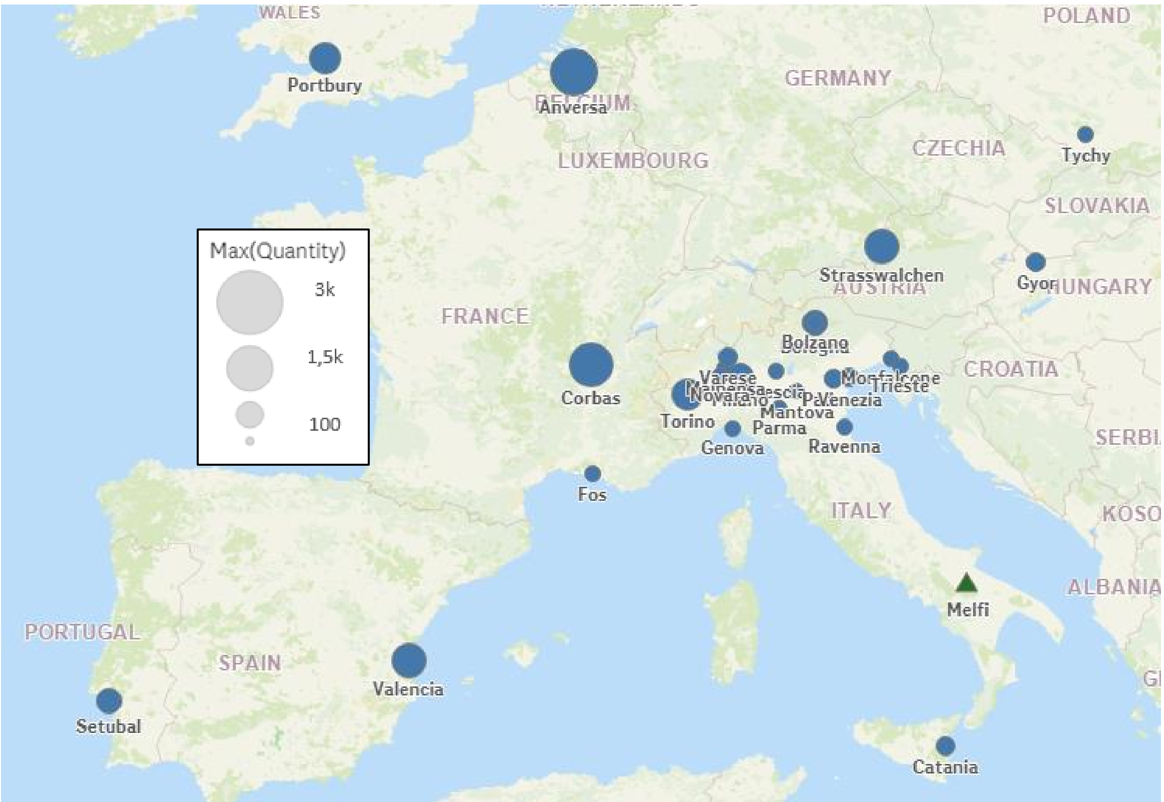



Figure 4.15. Proportional circle map of Italian and European PHEV volumes

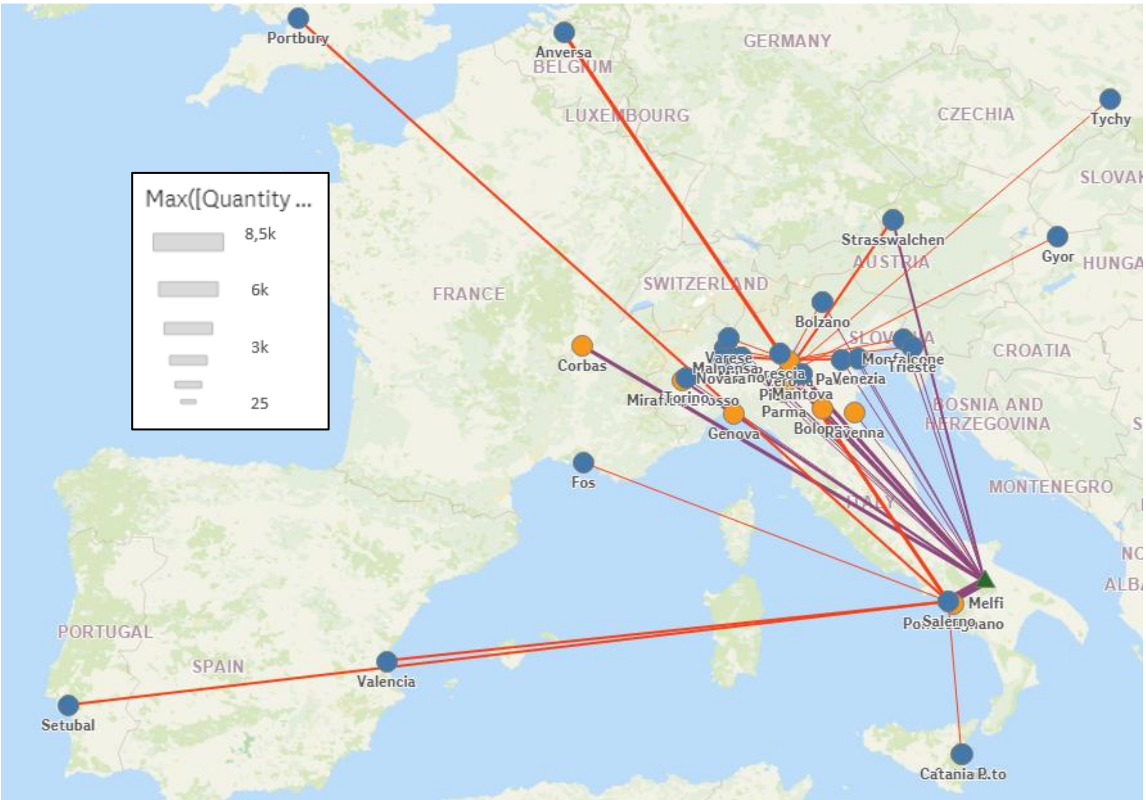



Figure 4.16. Weighted flow map of 2020 Melfi PHEV distribution

In addition, market channels have been taken into account, in order to see how the distribution is split and the differences among the channel deliveries, in terms of quantities and time. The 22.000 total PHEVs delivered in 2020 are so divided into the three channels involved in Melfi DP:

- Dealers: 20.000 units
- Fleets: 1.000 units
- Rent: 1.000 units

Found the starting database, the very next fundamental element to be considered is the introduction of a detailed equipment in the compounds to innovate the current unconstrained network. This specific list of tools, devices and physical structures allows a regular inspection and battery charge (when needed) for those hybrid vehicles stored in Melfi Plant compound or in one of the intermediate/final compound yards. This necessary equipment to set up in the selected nodes, so as to manage also PHEVs, is composed of:

- Charging stations
- Diagnostic keys (DSA WDI)
- DSA WDI devices (for charging and updating)
- Handhelds
- Software
- Services
- Constructions
- Electrical enclosures

The inspection and charge procedure is performed as follows: a software communicates with the handheld of the operator suggesting that the charge level of a precise PHEV in the compound must be controlled. By inserting the DSA WDI key into an outlet present inside the vehicle, used for diagnostic procedures, the operator checks that effectively the level of charge is the same the software has provided. If the charge level is so lower than a specified threshold that each carmaker establishes, the car must be driven next to the charging station, in order to restore the correct charge level. The other fixed costs are related to the implementation of the electric equipment: diagnostic keys need to be charged and updated by the use of a specific charger, while constructions are necessary to set up charging stations, so excavation costs are directly linked with the number of stations to be realized in the compound. Meanwhile, an electrical enclosure is required only if more than 4 charging stations are going to be built in a yard, because more than 150 kW are needed to power such an amount of stations. Otherwise, with 4 or less stations, it is required a cheaper investment useful to link the charging stations to the already present electrical system (used in the compound).

Finally, the item "services" includes all the other costs to set up the electric equipment all over the network considered (project management, documentation, etc.).

The intermediate and final nodes involved and the corresponding volumes are shown in Figure 4.17 (final nodes are highlighted in bold):

| Compound | PHEV volumes |
|---|---|
| Melfi | 22.000 |
| Salerno | 9.000 |
| Verona | 3.000 |
| Piadena | 2.000 |
| Mirafiori | 1.500 |
| Pontecagnano | 750 |
| Catania P.to | 450 |
| **Strasswalchen (Austria)** | 2.000 |
| **Antwerp (Belgium, Netherlands)** | 3.500 |
| **Corbas (France)** | 2.500 |
| **Fos (France)** | 500 |
| **Portbury (UK)** | 2.000 |
| **Tychy (Poland)** | 500 |
| **Setubal (Portugal)** | 1.500 |
| **Valencia (Spain)** | 2.000 |
| **Gyor (Hungary)** | 500 |

Figure 4.17. Compounds involved in fixed costs calculation

Note: the Italian final nodes are not taken into account because the delivered vehicles are no more considered of competence FCA once they are arrived there, while inspections and charging must be cured also in the final points in European distribution.

During this introductive paragraph it is not clear what compounds must be innovated and which are the specific total fixed costs. This occurs because the number of charging stations to introduce in the network and in which yard is a problem that depends on the quantities involved in the distribution of the hybrid vehicles produced in SATA, but mainly by the delivery times required for the distribution in a specific country, for a specific channel. With the following analysis, it will pointed out the charges necessary in every node for 2020 and by estimating the capacity of a single charging station, it will be defined the number of stations to introduce in each compound. Given the number of charging stations, an appropriate number of tools and devices (keys, handhelds, etc.) will be assigned to each node. By multiplying these numbers for the unitary costs and by adding the total results, the final result represents the fixed cost of Melfi electric innovation.

### 4.4.2. Variable costs

The variable costs of Melfi electric network include the costs of all the recharges necessary during the inspections made in Melfi Plant compound and in the other distribution points' yards as well as the labour costs associated to all the inspections carried out. The first variable cost comes out by multiplying two values:

- Single charge cost (€) = electric power (kW) * power cost (€/kWh) * hours of charge (h)
- PHEVs charged in all the compounds during 2020

In the same way, the associated labour costs are found by multiplying:

- Single charge labour cost (€) = hourly labour cost (€/h) * charge handling time (h) * vehicles rechargeable in 1 hour
- PHEVs charged in all the compounds during 2020

The single charge cost and the associated labour cost are two constants easy to be found out:

- Single charge cost = 22 kW * 0,05118 €/kWh * 0,5 h = € 0,56
- Single charge labour cost = 10,00 €/h * 0,5 h * 2 (vehicles rechargeable in 1 hour) = € 5,00

The major problem is to find out the number of charges necessary; with this value it would be easy to trace not only these variable costs but also the number of charging stations for each compound, fundamental data to calculate the infrastructural investments described in the previous paragraph.
In order to discover this value, not only the quantities demanded for each country-channel market are involved, but above all the target lead times and the average stock time values are necessary.
They are provided by introducing two different new databases:

- the lead time database reports the required days to transport a vehicle from a node to another one
- the average stock times database lists how many days a single vehicle stays, on average, in a precise compound.

Therefore, by aggregating the values in the two databases (divided also by channel), the sum shows the average time necessary to deliver a vehicle from Melfi compound to the final node of each market, for a selected channel.

The following example reports how has been calculated the average market time necessary to supply the British market with the Jeep Renegade PHEVs demanded:

Step 1) Database value for transit times and average stock times used to deliver the vehicles:

| Market | Source | Destination | Transit time (days) |
|---|---|---|---|
| UK | Melfi | Salerno | 5 |
| | Salerno | Portbury | 15 |

| Market | Compound | Channel | Avg stock time (days) |
|---|---|---|---|
| UK | Melfi | Dealers | 5 |
| | | Fleets | 10 |
| | Salerno | Dealers | 45 |
| | | Fleets | 50 |
| | Portbury | Dealers | 10 |
| | | Fleets | 10 |

Step 2) Aggregation of transit times and average stock days for both country-market combination:

| Market | Channel | Avg market time (days) |
|---|---|---|
| UK | Dealers | 80 |
| | Fleets | 90 |

Step 3) Introduction of the market time standard deviation: the delivery is carried out in a range time of (average market time - market time standard deviation ; average market time + market time standard deviation)

| Market | Channel | Avg market time (days) | Market time st. dev. (days) |
|---|---|---|---|
| UK | Dealers | 80 | 3,16 |
| | Fleets | 90 | 3,16 |

Note that in the first step is shown another important advantage that the presence of channels brings to the procedure: the average stock time could vary from a channel to another one. So, introducing this parameter, it is permitted to evaluate all the final customers and the times necessary to satisfy the different demands. Moreover, the gap in the average stock time causes the introduction of a certain amount of charges: considering only the “Dealers” channel in the third step only two charges are obtained, but only with the introduction of the “Fleets” channel it is introduced a third control (90 days) for a part of vehicles distributed to UK.

Applying this procedure for all the country-market combinations of the Melfi PHEVs database, the result is the complete table reporting the times required to deliver each hybrid vehicle produced in SATA plant to all the final customers in Italy and Europe.
In the next paragraph, these results are used for the statistical approach applied to calculate the total charges planned for 2020, useful to find out the fixed and variable costs of Melfi electric network.

#### 4.4.3. Inspection/charging probability

The statistical method applied to the complete average market time database (obtained in the previous paragraph) involves the normal distribution. The Gaussian curve parameters, the mean and the standard deviation, are represented in the case study by the average market time and market time standard deviation values.

Assumed a 30 days range of inspection (this means an inspection for each vehicle every 30 days, or earlier in case the 30 days would arrive during a transport), with the use of the cumulate curve of the normal distribution, it is identified the amount of charges necessary during a market delivery and the compound where those inspections and charges must take place.

The following example helps to better understand this calculation. Taking the Austrian distribution of PHEVs destined to Dealers and directly delivered from Melfi (750 units), it is known that the average market time is 31 days. It means that the vehicle under study requires 31 days to reach an Austrian point of sale once it leaves the Melfi production line. In particular, this time is obtained as the sum of the time spent in the Melfi compound, the time required to arrive in Strasswalchen and the time spent in Strasswalchen compound, with a 3,16 days standard deviation. Therefore, the delivery range fluctuates from 27,84 to 34,16 days. Figure 4.18 suggests the following step.

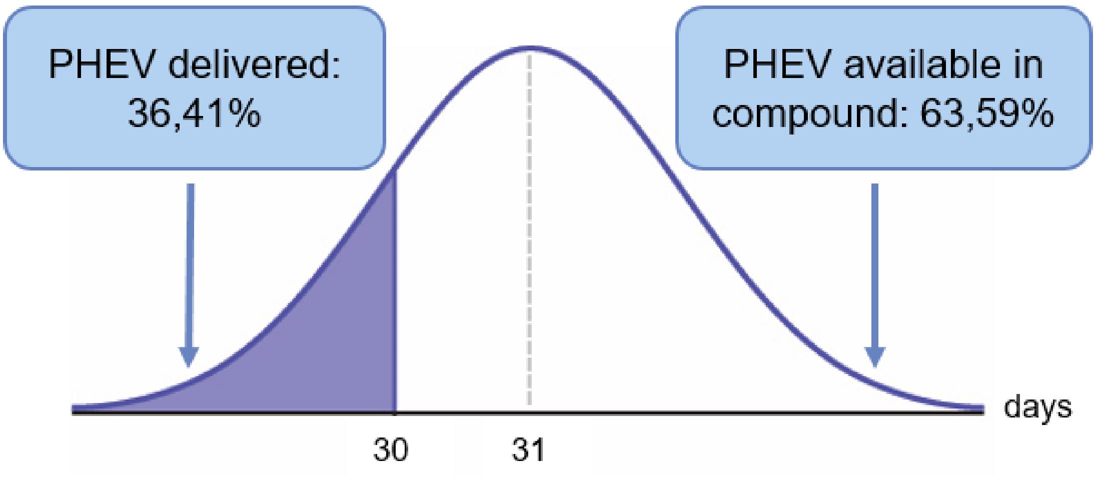



Figure 4.18. Normal distribution for Austrian PHEVs distribution (destined to Dealers)

Added the analyzed parameters to the normal distribution curve, it is important to focus on what happens at the end of the 30$^{th}$ day of delivery. Using the cumulated value, it turns out a statistical percentage of 36,41 %, considering the purple area. In a practical view, if the delivery involves 100 PHEVs, after 30 days, deadline for the first distribution inspection and charge, 36 vehicles have been already delivered and do not need any control. On the contrary, the white complementary area

represents the 64 vehicles that need to be charged. Since the vehicles delivered to this specific market are not 100 units but 750, by multiplying this volume for the 36,41 % probability, it is obtained the number of charges necessary in this distribution segment (equal to 477).
The last element to discover is where these 477 charges take place. The solution used consists in tracing the delivery path and figure out where a vehicle is located at the end of the first 30 days since the distribution start. It is clear that, in the example considered, after 30 days all the vehicles are stored in the Strasswalchen compound, so the charges must take place there.
Iterating this procedure to all the country-market distribution, the last columns of the average market time database reports the charges needed after 30, 60 and 90 days and the specific location.

Taking back to the British distribution, with a longer average market time, also a second and a third control are expected:

| **Market** | **Channel** | **Avg MT** | **MT st. dev** | **30 days** | **60 days** | **90 days** |
|---|---|---|---|---|---|---|
| UK | Dealers | 80 | 3,16 | 1.500 char. | 1.500 char. | - |
| (1.500 Jeep Renegade PHEVs) | | | | in Salerno | in Salerno | |
| UK | Fleets | 90 | 3,16 | 500 char. | 500 char. | 250 char. |
| (500 Jeep Renegade PHEVs) | | | | in Salerno | in Salerno | in Portbury |

In UK distribution, differently from the Austrian one, more than one control is required for both channels, because the sum of transit times and average stock times of the compounds involved (Melfi, Salerno, Portbury) is major than 60 days for Dealers and Fleets. For Dealers channel all the PHEVs considered, after 30 or 60 days, are still in the distribution process, so all of them must be inspected twice in the compound they are in the $30^{th}$ and $60^{th}$ day (Salerno in both cases). Fleets channel is instead supplied with 10 more days, so at the 90 days control a part of vehicles results delivered (a probability of 50%), therefore the remaining 250 PHEVs (the remaining 50% still available in Portbury compound) must be inspected for the third time.

### 4.4.4. Number of charges

By summing up the charges corresponding to each intermediate or final node for the first, second and third controls (30, 60 and 90 days), the final result is a table reporting the total charges that must be carried out in all the compounds of the PHEVs distribution network (Table 4.13; final nodes are underlined).

| Compound | Markets supplied | 2020 PHEVs | 2020 total charges |
|---|---|---|---|
| Melfi | all | 22.000 | 8.200 |
| Salerno | Bel, Fra, UK, Ita, Ned, Por, Spa | 9.000 | 3.896 |
| Piadena | Austria, Poland, Hungary | 2.000 | 1.930 |
| Mirafiori | Italy | 1.500 | 1.246 |
| Catania P.to | Italy | 450 | 3 |
| <u>Strasswalchen</u> | Austria | 2.000 | 480 |
| <u>Antwerp</u> | Belgium, Netherlands | 3.500 | 2.509 |
| <u>Corbas</u> | France | 2.500 | 400 |
| <u>Fos</u> | France | 500 | 69 |
| <u>Portbury</u> | UK | 2.000 | 250 |
| <u>Setubal</u> | Portugal | 1.500 | 790 |
| <u>Valencia</u> | Spain | 2.000 | 358 |
| **Total** | | **48.950** | **20.131** |

Table 4.13. Inspections and charges performed in Melfi PHEVs distribution compounds

In the previous table are listed only those compounds (and their total distribution volumes) where inspection and charges to plug-in hybrid vehicles must be performed. By comparing it with the list of intermediate and final nodes of the baseline unconstrained scenario, it results two missing intermediate points and two missing final nodes. In particular, they are:

- Verona
- Pontecagnano
- Tychy
- Gyor

This occurs because in Verona all the PHEVs vehicles involved are charged once (Dealers channel) or twice (Rent channel) in Melfi, then delivered to the intermediate point of Verona, compound that

supplies the final Italian provinces before the arrival of the next control to be carried out. For Pontecagnano the argument is the same: all the Jeep Compass PHEV and Jeep Renegade PHEV destined to Netherlands require, depending on the channel considered, a single inspection in Salerno or Antwerp.
Also for the other two final nodes, Tychy (Polish PHEVs market) and Gyor (Hungarian PHEVs market), the vehicles involved are not inspected in the final nodes because the 30 days control take place in Piadena and once they arrive in Poland and Hungary are all sold before the second inspection must be carried out.

Moreover, the total result obtained at the end of Table 4.13, a total of 20.131 charges for Melfi electric network in 2020, is just the number necessary to be multiplied with the single charge cost and the single charge labour cost, found in paragraph 4.4.2, in order to obtain the variable costs expected for 2020 PHEV distribution. This is completely explained in paragraph 4.4.6.
Similarly for fixed costs, the following two paragraphs focus on the single values of Table 4.13; obtained a certain value representing the capacity of a charging station, it is known the number of charging stations for each compound. By summing this values, it could be calculated the total amount of fixed investments for Melfi electric network (in particular the part of the investment related to 2020).

### 4.4.5. Constrained nodes and charging stations

As mentioned at the end of the previous paragraph, in order to discover the exactly number of charging stations to introduce in the compounds listed in Table 4.13 (where inspections and charges are necessary), the initial value to find out is the capacity of a single charging stations.

The input data used for this calculation are the following ones:

- Charging time: 0,5 hour
- Handling charge time (before and after the charge): 0,5 hour
- Assumption: due to idle times, breaks and other works to do for ICE vehicles, it is assumed an additional hour to each charge in order to spread these times among the daily operations
- Connectors per charging station: 2 (possibility to charge two vehicles simultaneously)
- Compound working hours in 1 day: 12
- Compound working days in 1 year: 300

With this initial data, it is immediate to calculate the daily and annual capacity of a single charging station operating in a compound:

- Daily capacity: [12 hours / (0,5+0,5+1) hours] * 2 connectors = 12 vehicles charged
- Annual capacity: 12 vehicles charged a day * 300 days = 3.600 vehicles charged

The annual capacity result is fundamental to understand the number of charging stations required; the calculation is immediate:

$$Compound\ charging\ stations = \frac{2020\ compound\ total\ charges}{3.600\ vehicles\ charged\ yearly}$$

By implementing this formula to all the single rows of the last column of Table 4.13, the results listed in Table 4.14 are easily obtained.

Among all the ratios calculated, except for Melfi and Salerno (the only two compounds where big volumes of PHEVs are stocked in 2020), each intermediate or final node is expected to have only a charging station. Since charging stations are basically operative machines, also for them there is the possibility of failures. In these cases, when a charging station is being repaired, but charges must be performed, an additional charging station is introduced for these compounds, adding in this way 10 more stations to the initial 15, getting a final value of 25 charging stations for the whole network.

This resulting delta is visible from the last two columns of Table 4.14.

| **Compound** | **2020 total charges** | **Charging stations** | **Charging stations + backup** |
|---|---|---|---|
| Melfi | 8.200 | 3 | 3 |
| Salerno | 3.896 | 2 | 2 |
| Piadena | 1.930 | 1 | 2 |
| Mirafiori | 1.246 | 1 | 2 |
| Catania P.to | 3 | 1 | 2 |
| Strasswalchen | 480 | 1 | 2 |
| Antwerp | 2.509 | 1 | 2 |
| Corbas | 400 | 1 | 2 |
| Fos | 69 | 1 | 2 |
| Portbury | 250 | 1 | 2 |
| Setubal | 790 | 1 | 2 |
| Valencia | 358 | 1 | 2 |
| **Total** | **20.131** | **15** | **25** |

Table 4.14. Charging stations to introduce in the network for PHEVs management

### 4.4.6. Fixed-variable costs calculation

Coming back to the list of items necessary for a compound to manage PHEV vehicles, described in paragraph 4.4.1, from the number of charging stations it is obtained the proportional amount of tools and devices used in each intermediate or final node. By introducing the unitary cost of each item, mentioned before the final table with the calculations, it is finally obtained the total investment (fixed costs) needed to equip the compounds involved in Jeep Compass PHEV and Jeep Renegade PHEV distribution.

Unitary costs (source: company's budget estimates for the initiative):

- Charging station: € 3.500,00
- Diagnostic key (DSA WDI): € 1.600,00 (note: number of keys must be equal to handhelds)
- DSA WDI devices (for charging and updating): € 2.300,00
  (note: a charger is enough for 3 diagnostic keys)
- Handheld: monthly rent = € 50 → annual rent = € 600
  (note: minimum 2 handhelds for each compound in order to have a backup handheld)
- Software: € 700.000,00
- Services: € 130.000,00
- Constructions: € 25.000,00 per charging station
- Electrical enclosure: € 15.000 if the charging stations required for a compound are 4 or less, € 270.000,00 if charging stations needed are 5 or more (electrical enclosure must be built).

The final matrix, with compounds on the rows and items on the columns, allows to calculate the amount of the infrastructural investment for Melfi electric innovation. It is represented in Table 4.15.

| Compound | Charging stations | DSA WDIs | DSA WDI devices | Handhelds | Electrical enclosure |
|---|---|---|---|---|---|
| Melfi | 3 | 2 | 1 | 2 | € 15.000,00 |
| Salerno | 2 | 2 | 1 | 2 | € 15.000,00 |
| Piadena | 2 | 2 | 1 | 2 | € 15.000,00 |
| Mirafiori | 2 | 2 | 1 | 2 | € 15.000,00 |
| Catania P.to | 2 | 2 | 1 | 2 | € 15.000,00 |
| Strasswalchen | 2 | 2 | 1 | 2 | € 15.000,00 |
| Antwerp | 2 | 2 | 1 | 2 | € 15.000,00 |
| Corbas | 2 | 2 | 1 | 2 | € 15.000,00 |
| Fos | 2 | 2 | 1 | 2 | € 15.000,00 |

| | | | | | |
|---|---|---|---|---|---|
| Portbury | 2 | 2 | 1 | 2 | € 15.000,00 |
| Setubal | 2 | 2 | 1 | 2 | € 15.000,00 |
| Valencia | 2 | 2 | 1 | 2 | € 15.000,00 |
| **Total** | **25** | **24** | **12** | **24** | **€ 180.000,00** |

| **Item** | **Unitary cost** | **Quantity** | **Total item cost** |
|---|---|---|---|
| Charging stations | € 3.500,00 | 25 | € 87.500,00 |
| DSA WDIs | € 1.600,00 | 24 | € 38.400,00 |
| DSA WDI devices | € 2.300,00 | 12 | € 27.600,00 |
| Handhelds | € 600 | 24 | € 14.400,00 |
| Electrical enclosures | € 15.000,00 | 12 | € 180.000,00 |
| Constructions | € 25.000,00 | 25 | € 625.000,00 |
| Software | € 700.000.00 | | € 700.000.00 |
| Services | € 130.000,00 | | € 130.000,00 |
| **Total** | | | **€ 1,8 M** |

Table 4.15. Total fixed costs (total investment) for Melfi electric innovation

The total value found at the end of Table 4.15 is the total investment for Melfi electric network. As an investment, it is subject to depreciation. Assumed a period in years in which this amount is spread (with a particular interest rate), it is pointed out the depreciation and interest amount for 2020. In particular, as shown in Figure 4.19, with the applied financial method, the constant instalment is divided in the chosen 3 years period of depreciation for the investment with an increasing depreciation and a decreasing interest.

| 2020 investment depreciation | |
|---|---|
| Total investment | € 1,8 M |
| Period (years) | 3 |
| Interest rate | 4,5% |

| Year | Residual value | Instalment | Interest | Depreciation |
|---|---|---|---|---|
| 2020 | € 1,8 M | € 650 k | € 80 k | € 570 k |
| 2021 | € 1,23 M | € 650 k | € 50 k | € 600 k |
| 2022 | € 630 k | € 650 k | € 20 k | € 630 k |
| 2023 | € 0 | | | |

Figure 4.19. Division of the investment depreciation among the assumed 3 years period

It is important to underline that the sum of the instalments is not equal to the investment amount, by following the principle of the present value of an investment. The formula used to evaluate the sum of the three instalments is:

$$Investment = \left( \frac{1 - (1 + Interest\ rate)^{-Period}}{Interest\ rate} \right) * Instalment$$

$$€\ 1.8\ M = \left( \frac{1 - (1 + 4{,}5\%)^{-3}}{4{,}5\%} \right) * Instalment$$

$$Instalment = €\ 650\ k$$

The difference between the sum of the three instalments and the initial investment value (equal to € 150 k) is nothing but the sum of the interests cumulated during the 3 years considered.

The other costs involved in Melfi electric network are those introduced in paragraph 4.4.2. Found the value of the total charges performed during 2020 in Melfi distribution compounds, the two different variable costs are easily calculated, as represented in Figure 4.20.

| Data | Value |
|---|---|
| Electric power (kW) | 22 |
| Power cost (€/kWh) | 0,05118 |
| Hours of charge per vehicle (h) | 0,5 |
| Unit cost of charge (€) | 0,56 |
| Total charges (2020) | 20131 |
| Total charging cost (€) | 11.273,36 |

| Data | Value |
|---|---|
| Labour hour cost | 10 |
| Charge handling time | 0,5 |
| Vehicle rechargeable in 1 hour | 2 |
| Unit labour cost per charge | 5,00 |
| Total charges (2020) | 20131 |
| Total labour cost (€) | 100.655,00 |

Figure 4.20. Variable costs for Melfi electric network in 2020

The sum of these costs is the total variable cost of 2020 PHEV network: € 11 k + € 101 k ~ € 112 k

### 4.4.7. Innovated compounds

In this paragraph are summarized all the results obtained in the previous ones, in order to point out the future modifications applied to the network distribution of SATA plant (in Italy and in the European countries considered).

Firstly, Figure 4.21 evidences in a more practical visual point of view, all the compounds involved in Melfi distribution and in particular the 12 ones that are subject to electric innovation (blue dots) with a total of 25 charging stations, while orange dots identify the compounds not equipped with electric tools, devices and physical structures (charging stations, diagnostic keys, etc.).

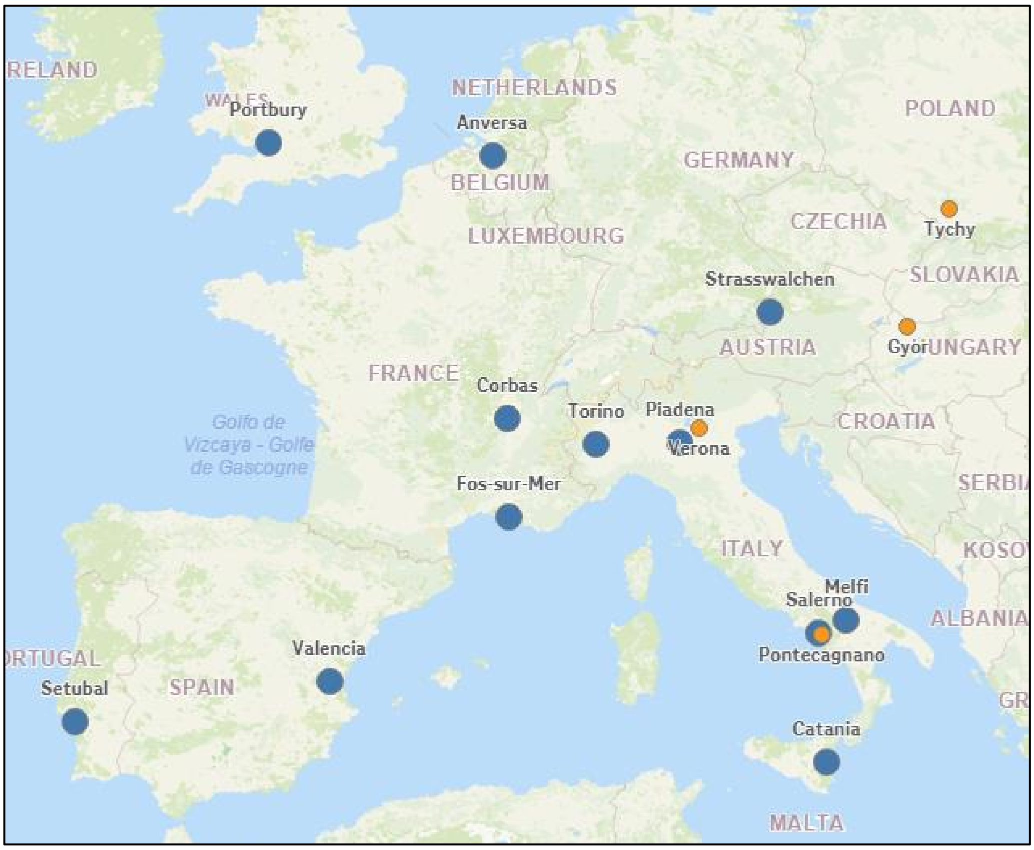



Figure 4.21. European map with the distinction of equipped and not equipped nodes

The costs incurred for realizing the electric network in order to introduce the PHEV distribution together with the traditional ICE models are listed below (found in paragraph 4.4.6):

- Total charges for 2020: 20.131 charges
- Total fixed costs (investment): € 1,8 M
- 2020 investment instalment: € 650 k
- 2020 investment depreciation: € 570 k
- 2020 investment interests: € 80 k
- 2020 variable costs: € 112 k

#### 4.4.8. Melfi 2021 DP: delta investments

It is important to analyze how results could change if it is considered an alternative long-term vision. The question this paragraph is drown around is: "What happens to the electric network and its relative costs if it is built using 2021 Melfi PHEV DP volumes?"

From the distribution plan forecasted for 2021, the total volumes of Jeep Renegade PHEV and Jeep Compass PHEV consist of 75.000 units. Using a proportion, it is originated the relative part considered in the limitation area applied for the case study and Melfi 2020 PHEV volumes:

*22.000 limited units : 37.000 total units = X limited units : 75.000 total units* → X = 45.000 units (increase of 49 % between 2020 and 2021).

Also proportionally, the charges obtained (2021 total charges) for this amount of PHEVs are 40.672, value found by applying the same statistical method described in paragraph 4.4.3.
At this point, it is possible to evidence the differences, in terms of charging stations and investment (fixed costs), if it must be decided during 2020 the implementation of a short-term plan (using 2020 DP volumes) or a long-term plan. These resulting deltas are represented in Table 4.16.

<table>
<tr><th></th><th>with 2020 DP</th><th colspan="2">with 2021 DP</th><th>Delta</th></tr>
<tr><td rowspan="2">Charging stations</td><td rowspan="2">25</td><td rowspan="2">28</td><td>+2 Melfi</td><td rowspan="2">3</td></tr>
<tr><td>+1 Salerno</td></tr>
<tr><td>Constructions</td><td>25 * € 25 k</td><td colspan="2">28 * € 25 k</td><td>€ 75 k</td></tr>
<tr><td>DSA WDIs</td><td>24</td><td>25</td><td>+1 Melfi</td><td>1</td></tr>
<tr><td>Handhelds</td><td>24</td><td>25</td><td>+1 Melfi</td><td>1</td></tr>
<tr><td>Total investment</td><td>€ 1.800.000</td><td colspan="2">€ 1.900.000</td><td>€ 100.000</td></tr>
<tr><td>2020 instalment</td><td>€ 650.000</td><td colspan="2">€ 690.000</td><td>€ 40.000</td></tr>
<tr><td>2020 depreciation</td><td>€ 570.000</td><td colspan="2">€ 605.000</td><td>€ 35.000</td></tr>
<tr><td>2020 interests</td><td>€ 80.000</td><td colspan="2">€ 85.000</td><td>€ 5.000</td></tr>
</table>

Table 4.16. Delta in the initial investment for Melfi electric network considering the 2021 DP

With the values introduced in this paragraph, also the forecasted costs for 2021 are found:

- 2021 fixed costs: € 690 k
- 2021 variable costs: € 226 k
- 2021 total costs: € 916 k

An important comparison could be considered in order to test the validity of using a long-term plan and to evidence how close are the results obtained with the reality.
Currently, with the development of PHEV models in Melfi, also the production of the Fiat 500 BEV is planned to begin in 2020. This model is produced in Mirafiori, so the plant compound needs a specific number of charging stations to manage all the stocked 500 BEV (just come out from the production line). Engineers, by analyzing the volumes forecasted for the next years (not only 2020), have decided to install 6 charging stations in Mirafiori compound. Therefore, the comparison between the electric vehicles assembled in the two plants suggests confirms that the final result of 5 charging stations found for Melfi compound is a very realistic hypothesis, being near to the decisions taken by experts in real life. In fact, in terms of volumes and charging stations:

- Mirafiori Plant: 22.000 total Fiat 500 BEV distributed in 2020 → 6 charging stations installed
- Melfi Plant: 22.000 analyzed PHEVs distributed in 2020 → 5 stations to be installed

The delta of one charging station could be explained as follows. From the proportional value of 5 stations obtained in the case study, necessary to manage 22.000 EVs, by adding the charging station forecasted for Mirafiori compound in Melfi analysis, it is so practically explained the result of 6 (and not 5) stations installed in Mirafiori compound.

## 4.5. Final constrained network

### 4.5.1. Melfi 2020 final constrained network (Scenario 3)

Found all the results of the electric innovation introduced in Melfi distribution network, the next step is to incorporate them into the unconstrained network (scenario 0) in order to design the final constrained network (scenario 3) and calculate its costs. The fundamental difference between the two scenarios is that now PHEV vehicles are treated differently from the unconstrained network, so in this final scenario ICE models and PHEV ones are not the same thing (as assumed instead in the baseline unconstrained scenario 0).

In a practical view, the distinction among the models turns out in the fees. On the basis of the unconstrained network, now for Jeep Compass PHEV and Jeep Renegade PHEV the distribution fee is equal to the previous one plus an incremental value found spreading the total costs obtained to introduce the electric innovation in Melfi network. An example of these adjustments for hybrid vehicles is the following (Jeep Compass delivery to Belgian market):

Step 1) Input data = unconstrained network distribution fees:

| Model | Market | Source | Destination | Fee |
|---|---|---|---|---|
| Jeep Compass PHEV | Belgium | Melfi | Salerno | € 80,00 |
| | Belgium | Salerno | Antwerp | € 170,00 |

Step 2) Calculation of the incremental cost for PHEVs distribution:

$$Incremental\ cost = \frac{2020\ electric\ network\ fixed\ costs + 2020\ electric\ network\ variable\ costs}{2020\ PHEV\ movements}$$

$$Incremental\ cost = \frac{€\ 650.000 + €\ 112.000}{39.000\ PHEV\ movements} = 20\ €/PHEV\ movement$$

Step 3) Addition of incremental cost to PHEVs unconstrained fees = PHEVs constrained fees:

| Model | Market | Source | Destination | Fee |
|---|---|---|---|---|
| Jeep Compass PHEV | Belgium | Melfi | Salerno | € 100,00 |
| | Belgium | Salerno | Antwerp | € 190,00 |

Step 4) Calculation, with the market volumes, of the constrained PHEV distribution:

| Model | Market | Source | Destination | Quantity | Fee | Total cost |
|---|---|---|---|---|---|---|
| Jeep Compass PHEV | Belgium | Melfi | Salerno | 500 | € 100,00 | € 50.000,00 |
| | Belgium | Salerno | Antwerp | 500 | € 190,00 | € 95.000,00 |

By performing these calculations to all the PHEVs markets, the sum of the aggregated new PHEVs distribution costs with the unaffected ICE ones reports the total cost for the final Melfi 2020 constrained network. In particular, Table 4.17 lists the country distribution costs and the total cost.

| Country | Distribution costs (€) | % of the total |
|---|---|---|
| Austria | 1,5 M | 5,56 % |
| Belgium | 2 M | 7,41 % |
| France | 5 M | 18,52 % |
| UK | 2 M | 7,41 % |
| Italy (North + ICT) | 8 M | 29,64 % |
| Lithuania | 1 M | 3,70 % |
| Netherlands | 1 M | 3,70 % |
| Poland | 1 M | 3,70 % |
| Portugal | 1 M | 3,70 % |
| Spain | 3,5 M | 12,96 % |
| Hungary | 1 M | 3,70 % |
| **Total** | **27 M** | |

Table 4.17. Country distribution costs in the constrained network

Moreover, two other aspects to be analyzed are how the electric innovation costs are split between the two PHEV models (analyzing the division of the total cost for the constrained network among the five models) and how this new value is divided among the three transport modes used in the case study. The results are highlighted in Table 4.18 and in Table 4.19.

| Model | Distribution costs (€) | % of the total |
|---|---|---|
| Fiat 500X | 9 M | 33,33 % |
| Jeep Compass | 4 M | 14,80 % |
| Jeep Compass PHEV | 2,5 M | 9,27 % |
| Jeep Renegade | 8 M | 29,64 % |
| Jeep Renegade PHEV | 3,5 M | 12,96 % |

Table 4.18. Scenario 3 model distribution costs

| Transport mode | Distribution costs (€) | % of the total |
|---|---|---|
| Road | 11 M | 40,74 % |
| Rail | 9,5 M | 35,19 % |
| Sea | 6,5 M | 24,07 % |

Table 4.19. Transport modes distribution costs in Melfi constrained network scenario

Other three fundamental values for the constrained network analysis (the same found in scenario 0) are the €/movement fee, the €/vehicle one and the movements per vehicle. While the last one is expected to be equal (quantities are unchanged from the unconstrained scenario to the constrained one), the first two key performance indicators are subjected to small but important changes:

- Constrained €/movement = € 27 M / 220.000 movements = 123,00 €/movement
- Constrained €/vehicle = € 27 M / 130.000 vehicles = 208,00 €/vehicle
- Movements per vehicle = 220.000 movements / 130.000 vehicles = 1,7 movements/vehicle

The differences in terms of costs and indicators are explained in detail in paragraph 4.6.1.

### 4.5.2. Final constrained network $CO_2$ calculation

Another important aspect to be taken into account while analyzing the final constrained network is the total amount of carbon dioxide produced in the transport of all the 130.000 vehicles analyzed. Nowadays, the impact of the inbound and outbound logistics of a company is an important KPI that could bring to carmakers competitive advantage. So, the sustainability of the final network found for Melfi distribution of 2020 is an important aspect to calculate in order to understand above all if the value found is consistent with the 2019 one, maintaining in this way a constant balanced emissions indicator.

The input data used for $CO_2$ calculation are:

- FCA emission factors for the three transport modes used (road, rail and sea; see Figure 4.22)
- Length in kilometers of each distribution route contained in the network
- Tonnes transported in each distribution route = model weight * delivered quantity

$0{,}10\ \frac{\text{kg } CO_2}{\text{km} * \text{t}}$ $0{,}03\ \frac{\text{kg } CO_2}{\text{km} * \text{t}}$ $0{,}02\ \frac{\text{kg } CO_2}{\text{km} * \text{t}}$

Figure 4.22. Emission factors used in the analysis

The next step of this analysis is the calculation of the total kilograms of carbon dioxide emitted in a single route:

$$\textit{Single route kgs of } CO_2 = \textit{Route kms} * \textit{Tonnes transported} * \textit{Mode emission factor}$$

By aggregating the kilograms emitted in the routes used to supply a single country, it is obtained the total weight of $CO_2$ produced for each market, as reported in Table 4.20. The last row of the central column shows the final value, the total carbon dioxide produced in Melfi distribution network, achieved by summing the kilograms of $CO_2$ produced in each country distribution.

This final value is then split in the model and transport modes distribution in order to discover which are the more and less sustainable model deliveries (Table 4.21) and the weight of transport modes in the global emission value resulting from Table 4.20 (Table 4.22).

| Country | $CO_2$ emitted (tonnes) | % of the total |
|---|---|---|
| Austria | 450 | 6,43 % |
| Belgium | 600 | 8,57 % |
| France | 750 | 10,71 % |
| UK | 500 | 7,14 % |
| Italy (North + ICT) | 2.500 | 35,71 % |
| Lithuania | 300 | 4,29 % |
| Netherlands | 200 | 2,86 % |
| Poland | 600 | 8,57 % |
| Portugal | 200 | 2,86 % |
| Spain | 650 | 9,29 % |
| Hungary | 250 | 3,60 % |
| **Total** | **7.000** | |

Table 4.20. Total emissions for Melfi constrained network

| Model | $CO_2$ emitted (tonnes) | % of the total |
|---|---|---|
| Fiat 500X | 2.500 | 35,71 % |
| Jeep Compass | 1.250 | 17,86 % |
| Jeep Compass PHEV | 500 | 7,14 % |
| Jeep Renegade | 2.000 | 28,57 % |
| Jeep Renegade PHEV | 750 | 10,72 % |

Table 4.21. Production of carbon dioxide in the distribution of Melfi models

| Transport mode | $CO_2$ emitted (tonnes) | % of the total |
|---|---|---|
| Road | 4.000 | 57,14 % |
| Rail | 1.250 | 17,86 % |
| Sea | 1.750 | 25,00 % |

Table 4.22. Division of $CO_2$ emissions among the transport modes used

Also for emissions calculation it is found a certain average value showing how much kilograms of carbon dioxide are produced in a single distribution movement and another average amount reporting the kilograms of $CO_2$ emitted in the delivery of a single vehicle from Melfi to the final nodes:

- Constrained network kgs of $CO_2$ /movement = 7.000 tonnes of $CO_2$ / 220.000 movements = 32 kgs of $CO_2$ / movement
- Constrained network kgs of $CO_2$ /vehicle = 7.000 tonnes of $CO_2$ / 130.000 vehicles = 54 kgs of $CO_2$ / vehicle

As affirmed at the beginning of this paragraph, it is also useful to introduce the values obtained in 2019 in order to compare them with the final result shown in Table 4.20. This comparison permits to discover firstly if the 2020 result is a realistic amount and secondly (if the total emissions of 2019 and 2020 are similar) to affirm that for the upcoming year the forecasted emissions are in line with the previous year.

The tonnes of carbon dioxide produced during 2019 in Melfi network distribution amount to 17.000, resulting from a total distribution of 250.000 vehicles. These two results are then aligned to the data limitation used in the case study for 2020 (130.000 vehicles analyzed out of a total distribution of 300.000 units) with the following proportions:

- 2019 limited volumes → 130.000 : 300.000 = X : 250.000 → X = 109.000 vehicles
- 2019 limited emissions → 17.000 : 250.000 = Y : 109.000 → Y = 7.400 tonnes of $CO_2$

This final value, if compared to the obtained 7.000 tonnes of $CO_2$ forecasted for 2020 limited Melfi distribution, validates the constrained network emissions as a realistic amount and also suggests an improvement in the transport sustainability for the limited number of vehicles analyzed: distributed units increase (130.000 > 109.000), while total emissions decrease (7.000 < 7.400).

### 4.5.3. Intermediate nodes minimization $CO_2$

The emissions produced with the constrained network could be compared only with the second alternative scenario analyzed in paragraph 4.3.2. The implementation of electric innovation does not longer allow the possibility of considering a direct transport scenario (scenario 1), so the comparison with scenario 3 emissions is performed only with scenario 2, where intermediate nodes are minimized. Differently from the constrained network transports to Pontecagnano and Gioia Tauro disappear, while the associated volumes of these routes are entirely aggregated to Salerno volumes. So the only differences in markets emissions could be seen in France (for Gioia Tauro node elimination) and Netherlands (Pontecagnano elimination).

The result coming out from the analysis is remarkable but justifiable. In fact, it is obtained, by adding the country emissions, a value higher than the one found for scenario 3. This occurs because the deleted nodes are supplied completely (Gioia Tauro) or in major part (Pontecagnano) by rail. Since this transport mode is more sustainable than road transport, it is right that the final result obtained for the intermediate nodes minimization network is bigger. The results are listed in Table 4.23.

| **Country** | **$CO_2$ emitted (tonnes)** | **% of the total** |
|---|---|---|
| Austria | 450 | 6,38 % |
| Belgium | 600 | 8,51 % |
| France | 755 | 10,71 % |
| UK | 500 | 7,09 % |
| Italy (North + ICT) | 2.500 | 35,46 % |
| Lithuania | 300 | 4,26 % |
| Netherlands | 245 | 3,48 % |
| Poland | 600 | 8,51 % |
| Portugal | 200 | 2,84 % |
| Spain | 650 | 9,22 % |
| Hungary | 250 | 3,54 % |
| **Total** | **7.050** | |

Table 4.23. Scenario 2 total emissions

Considering models, as expected, the increasing emissions are imputable to Fiat 500X distribution, where Gioia Tauro node is involved in French distribution and to Jeep Renegade PHEV because Pontecagnano intermediate point is used in Dutch distribution (as shown in Table 4.24).
Emissions division among the transport modes are instead changed because of the reduction in rail utilization, while for sea transport the delta is attributable to the minor length of the shipping route Salerno – Le Havre in comparison with Gioia Tauro – Le Havre route (less kilometers, less kilograms of $CO_2$ produced). Road transport emissions increase due to the increased volumes involved in Melfi – Salerno route.

| **Model** | **$CO_2$ emitted (tonnes)** | **% of the total** |
|---|---|---|
| Fiat 500X | 2.505 | 35,53 % |
| Jeep Compass | 1.250 | 17,73 % |
| Jeep Compass PHEV | 500 | 7,09 % |
| Jeep Renegade | 2.000 | 28,37 % |
| Jeep Renegade PHEV | 795 | 11,28 % |

Table 4.24. Intermediates nodes minimization network models emissions

| **Transport mode** | **$CO_2$ emitted (tonnes)** | **% of the total** |
|---|---|---|
| Road | 4.105 | 58,23 % |
| Rail | 1.200 | 17,02 % |
| Sea | 1.745 | 24,75 % |

Table 4.25. Transport modes emissions in scenario 2

Finally, it is performed the calculation of the two indicators for movements and vehicles of intermediate nodes minimization scenario:

- Scenario 2 kgs of $CO_2$ /movement = 7.050 tonnes of $CO_2$ / 220.000 movements
  = 32,05 kgs of $CO_2$ / movement
- Scenario 2 kgs of $CO_2$ /vehicle = 7.050 tonnes of $CO_2$ / 130.000 vehicles
  = 54,25 kgs of $CO_2$ / vehicle

## 4.6. Final comparisons

### 4.6.1. Cost comparison

The final cost comparison for the case study could begin analyzing the differences among the four main scenarios discussed in the survey. Using a performance dashboard method, the three most important indicators to consider, in terms of costs, are:

- Scenario total cost
- Scenario €/movement cost
- Scenario €/vehicle cost

Through these fundamental values, some basic conclusions could result from the comparison of the unconstrained baseline network with the three-associated network coming out from the different assumptions added to scenario 0. In particular, it could be submitted that direct transport (scenario 1) provides a cost saving, result also observed with the minimization of intermediate nodes (scenario 2). For this second case, observing the limited delta in the total costs of scenario 0 and scenario 2, the limited difference shows how the planned use of intermediate points for scenario 0 is relatively close to the optimal structure. But the most important cost comparison is undoubtedly the one between the unconstrained and constrained network (scenario 0 with scenario 3). Because the introduction of electric innovation, the delta total cost is equal to the amount of the depreciation, the interests and the variable costs, incurring with the implementation of the Melfi electric network, expected for 2020. All the selected KPIs deltas and the consequent delta percentage share are reported in Table 4.26.

| | | | | Delta | Delta % |
|---|---|---|---|---|---|
| **Scenario 0** | € 26 M | **Scenario 1** | € 24 M | - € 2 M | - 7,69 % |
| | 118,00 €/mov | | 185,00 €/mov | + 67,00 €/mov | + 56,78 % |
| | 200,00 €/vehicle | | 185,00 €/vehicle | - 15,00 €/vehicle | - 7,69 % |
| | € 26 M | **Scenario 2** | € 25,5 M | - € 0,5 M | - 1,92 % |
| | 118,00 €/mov | | 116,00 €/mov | - 2,00 €/mov | - 1,69 % |
| | 200,00 €/vehicle | | 196,00 €/vehicle | - 4,00 €/vehicle | - 1,92 % |
| | € 26 M | **Scenario 3** | € 27 M | + € 1 M | + 4,00 % |
| | 118,00 €/mov | | 123,00 €/mov | + 5,00 €/mov | |
| | 200,00 €/vehicle | | 208,00 €/vehicle | + 8,00 €/vehicle | |

Table 4.26. Cost comparison of the initial unconstrained network with the other derived scenarios

As introduced before, the most important cost comparison to be examined in depth is the third one. From this single analysis it comes out the impact of the production of two hybrid models on the Melfi distribution network. How the delta total cost is spread among models, national markets and transport modes indicates the effect of the implementation of the SATA electric network on the traditional distribution network (for ICEs). The results are listed in Table 4.27.

| | **Unconstrained network** | **Constrained network** | **Delta** | **Delta %** |
|---|---|---|---|---|
| **Total cost** | **€ 26 M** | **€ 27 M** | **€ 1 M** | **4,00 %** |
| **ICEs** | € 21 M | € 21 M | - | - |
| **PHEVs** | € 5 M | € 6M | € 1 M | 20,00 % |
| **500X** | € 9 M | € 9 M | - | - |
| **Compass** | € 4 M | € 4 M | - | - |
| **Compass PHEV** | € 2 M | € 2,5 M | € 0,5 M | 25,00 % |
| **Renegade** | € 8 M | € 8 M | - | - |
| **Renegade PHEV** | € 3 M | € 3, 5 M | € 0,5 M | 16,67 % |
| **Austria** | € 1 M | € 1,5 M | € 0,5 M | 4,70 % |
| **Belgium** | € 2 M | ~ € 2 M | - | 4,41 % |
| **France** | € 5 M | ~ € 5 M | - | 1,34 % |
| **UK** | € 2 M | ~ € 2 M | - | 3,81 % |
| **Italy** | € 8 M | ~ € 8 M | - | 3,05 % |
| **Lithuania** | € 1 M | € 1 M | - | - |
| **Netherlands** | € 1 M | ~ € 1 M | - | 11,78 % |
| **Poland** | € 1 M | ~ € 1 M | - | 0,97 % |
| **Portugal** | € 1 M | ~ € 1 M | - | 4,63 % |
| **Spain** | € 3 M | € 3, 5 M | € 0,5 M | 2,55 % |
| **Hungary** | € 1 M | ~ € 1 M | - | 2,79 % |
| **Road** | € 11 M | ~ € 11 M | - | 3,82 % |
| **Rail** | € 9 M | € 9,5 M | € 0,5 M | 5,55 % |
| **Sea** | € 6 M | € 6,5 M | € 0,5 M | 8,33 % |

Table 4.27. Division of the electric innovation cost among the different distribution parameters

### 4.6.2. $CO_2$ comparison

Another comparison among scenarios it is conducted by taking into account the emissions of carbon dioxide produced. Similarly to the previous paragraph, the carbon dioxide emitted with all the transportation involved in the different scenarios could be compared. But in this case, since considering the environmental point of view route fees are unused in the calculation, unconstrained and constrained Melfi networks (scenario 0 and scenario 3) coincide. Moreover, if it is assumed a constrained network $CO_2$ calculation, it is no more useful to consider a total direct scenario, because the constrained network includes also PHEV vehicles that need inspection and charges during their distribution, so intermediate nodes are essential requirements that must be considered. For these reasons the only $CO_2$ comparison analyzed is between scenario 3 and scenario 2 (Melfi network with intermediate points minimized).

As evidenced in paragraph 4.5.3 the differences obtained are very close, as suggested also examining the fundamental indicators of this sustainability analysis (parallel to cost analysis KPIs):

- Scenario total $CO_2$ emissions
- Scenario kgs of $CO_2$ / movement
- Scenario kgs of $CO_2$ / vehicle

The overall results obtained for scenario 3 and scenario 2, with consequent deltas, are shown in Table 4.28. It is instantaneous to note the increase in the intermediate minimization scenario, reflecting the fact that scenario 3 is ideal from an environmental point of view due to the major utilization of rail and sea modes, the most ecofriendly ones (as suggested by the emission factors introduced in paragraph 4.5.2).

In Table 4.29 it is found out where this gap between the two scenarios is split among the distribution parameters (models delivered, countries supplied and transport modes used).

| | **Scenario 3** | **Scenario 2** | **Delta** | **Delta %** |
|---|---|---|---|---|
| **Total $CO_2$** | 7.000 t | 7.050 t | 50 t | + 0,71 % |
| **$CO_2$ / movement** | 32 kg | 32,05 kg | 0,05 kg | + 0,15 % |
| **$CO_2$ / vehicle** | 54 kg | 54,25 kg | 0,25 kg | + 0,46 % |

Table 4.28. Performance dashboard of the environmental impact for scenario 3 and scenario 2

| | Constrained network | Intermediate min. network | Delta | Delta % |
|---|---|---|---|---|
| **Total $CO_2$** | **7.000 t** | **7.050 t** | **50 t** | **0,71 %** |
| **ICEs** | 5.750 t | 5.755 t | 5 t | 0,09 % |
| **PHEVs** | 1.250 t | 1.295 t | 45 t | 0,39 % |
| **500X** | 2.500 t | 2.505 | 5 t | 0,20 % |
| **Compass** | 1.250 t | 1.250 t | - | - |
| **Compass PHEV** | 500 t | 500 t | - | - |
| **Renegade** | 2.000 t | 2.000 t | - | - |
| **Renegade PHEV** | 750 t | 795 t | 45 t | 6,00 % |
| **Austria** | 450 t | 450 t | - | - |
| **Belgium** | 600 t | 600 t | - | - |
| **France** | 750 t | 755 t | 5 t | 0,67 % |
| **UK** | 500 t | 500 t | - | - |
| **Italy** | 2.500 t | 2.500 t | - | - |
| **Lithuania** | 300 t | 300 t | - | - |
| **Netherlands** | 200 t | 245 t | 45 t | 22,50 % |
| **Poland** | 600 t | 600 t | - | - |
| **Portugal** | 200 t | 200 t | - | - |
| **Spain** | 650 t | 650 t | - | - |
| **Hungary** | 250 t | 250 t | - | - |
| **Road** | 4.000 t | 4.105 t | 105 t | + 2,63 % |
| **Rail** | 1.250 t | 1.200 t | - 50 t | - 4,00 % |
| **Sea** | 1.750 t | 1.745 t | - 5 t | - 0,29 % |

Table 4.29. Division of the emissions increase among the different distribution parameters

# 5. Analysis of results

In the paragraphs related to the case study chapter it could be understood how distribution costs and emissions are divided among the most important parameters and indicators used.
By taking into account the limitation data used for the case study (Northern Italy, Catania and 10 European countries), the three high-level open issues of the work have been addressed. The unconstrained network (scenario 0) and its associated cost has been charged with the 2020 competence costs related to the electric network created for Melfi Plant, achieving the total cost of the constrained network (scenario 3).

The total investment required for Melfi electrification is clearly pointed out in the middle of the Melfi analysis and the comparison with the real world (for example considering the number of charging stations installed in Mirafiori compound), shows a very close resemblance with reality. This means that the statistical approach used to obtain the number of charging stations and the variable costs for PHEVs distribution is reliable and leads to reasonable results.

Analyzing the final scenario 3 it is figured out which countries have a major influence on Melfi distribution, the division of the volumes among the three main transport modes and the influence of each model on the 2020 distribution, computing also the volume percentages of the new hybrid models.

The final cost comparison is useful to understand which countries and modes are more involved with the introduction of the Compass PHEV and Renegade PHEV, dividing them from those markets that also in 2020 are still more loyal to diesel and petrol cars.

Moreover, the sustainability comparison suggests a well balanced baseline network design. The routes used for the unconstrained network design are very close to an optimized intermediate point minimization scenario (scenario 2) and consequently their emissions are very similar, by observing the last paragraph of the case study ($CO_2$ comparison). By considering the real value of carbon dioxide from 2019 Melfi distribution, the amounts resulting from calculations are comparable and indicates an improvement for the 2020 constrained network.

# 6. Takeaways and conclusion

The main takeaways deriving from the development of the present work are:

- The automotive supply chain structure for electric and hybrid vehicles and the comparison with the traditional supply chain of diesel and petrol cars
- The environmental impact and the customer point of view about automotive electrification
- The requirements, the constraints and the modes involved in the transportation of EVs and PHEVs and the most important changes from the traditional ICE distribution network
- The main parameters used to develop a carmaker's outbound distribution network
- The main tools, devices and physical structures needed to electrify a baseline network
- The implementation of a statistical approach in order to find out fundamental results for a distribution network (fixed and variable costs resulting from the calculation of the charges to be performed on PHEVs)
- The importance of a sustainable outbound transportation

However, an issue arises by considering the results coming from the case study.
The analyzed volumes belong to the electrification of a single plant, with two models involved. But when the innovation will reach its peak, taking into account hundreds of models produced by a lot of brands, will the situation still be sustainable? The production of millions of batteries and their disposal, the electricity required for thousands of vehicles at the same time are in general the current unknown sides of the upcoming global development of electric and hybrid vehicles.

Considering this important issue, the most immediate response is related to time constraints: the environmental crisis faced nowadays and the not optimistic future prospects suggest a required sudden change in the emissions of vehicles all around the world. Electric and hybrid vehicles are the best solution to start this green revolution, that in the future will maybe be carried forward by improved solutions in terms of energy and emissions.
That is the reason why innovative vehicles need to be produced by car brands and increasingly adopted by customers: because they represent a chance of improvement for carmakers, a fundamental change in people's thinking and attitude in favor of a collective improvement, a cooperative and concrete reaction to the pessimistic environmental forecasts.
As a matter of fact, one crucial aspect appears to be clear: even if it is not known if a solution is the best possible one for tomorrow, until it remains the best possible for today, it is the best possible.

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## 7.2. Analysis of requirements, constraints, characteristics and changes in the transportation of electric vehicles

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