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Analysis of the corporate Italian ecosystem and macro-economic factors influencing plug-in electrical vehicle diffusion

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SUMMARY

1. Introduction

In order for the world to respect the Paris agreement (United Nation, COP21 (2015)) and its second article – stating to remain below a 2°C temperature increase of the pre-industrial phase world – the transport sector needs to evolve and decarbonize.

Greenhouse Gasses (GHG) are responsible for the world temperature increase, with CO2 being one of the main components. After three years of flat CO2 emissions, in 2017 they rose again by 1,6% (World Energy Outlook, IEA (2018)). In addition to this, since 2014 GHG emissions from the European transport sector have increased by almost 3% yearly. This sector contributes to 27% of the GHG emissions in the EU-28, of which 44% come from passenger cars (Greenhouse gas emission from transport, EEA (2018)). On the other side, macroeconomic factors should disincentivize the use of traditional internal combustion engine (ICE) vehicles. Oils prices have continued to rise, reaching 80$/barrel in 2018 for the first time since 2014. Furthermore, there are risks related to the oil supply due to the persisting crisis in Venezuela and the cost of wind and photovoltaic plants continue to decrease.

In this scenario, electric vehicles (EV) may seem the natural response as they help reduce GHG emissions at a global scale if energy is produced through renewable sources. Nonetheless, until now they have failed to reach a widespread diffusion, with EV accounting for 1-2% of the new registered cars in almost all European countries (European Alternative Fuel Observatory). The purpose of this thesis is to assess how Italy is performing with respect to Plug-in Electrical Vehicles (PEV) diffusion. In particular, the aim is to understand whether Italian companies are moving in a way that supports the diffusion of PEV as well as providing recommendation to the Italian government to further sustain this phenomenon.

To do so, this research paper will be divided into two major parts. To set the actual context, an overview at of the diffusion of PEV at the world level and then at the European one will be provided. In particular, the Italian performance will be compared with the one of the principal EU28+EFTA[1] countries such as: France, Germany, Netherland, Sweden, Norway and United Kingdom. This will allow us to have an idea of where Italy stands in the European landscape.

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[1] EFTA: European Free Trade Area composed of four countries: Switzerland, Iceland, Liechtenstein and Norway

After this initial picture of the current situation, the paper will proceed by analysing more in detail the Italian market of electrical vehicles. This chapter will focus on understanding how the Italian value chain of EV is structured, its main players, their roles, as well as the evolution of the recharging infrastructure and the business model they have adopted. This part will allow to respond to the following research question: “Are companies in Italy ready to support the diffusion of PEV?”. The importance of this chapters is stressed by several factors. On one side, when studying a diffusion phenomenon that is so young and, because of a lack of historical data, the best way to understand if this technology will succeed is by directly observing how players are moving in the industry and positioning themselves. Furthermore, at the basis of the diffusion of a new technology, there is not just the performance of this one in comparison to older technologies but a whole technological paradigm (Dosi (1982)) must be in place. This technological paradigm is made of both supply-side and demand-side elements that will give birth to a new technological trajectory only if their blending is suitable for companies and interesting for the customers. Therefore, it is of paramount importance to study the “readiness” of Italian companies in promoting such a new technology. On the other side, EV generate a two-sided market, with positive cross-sided network externalities. This implies that the higher is the number of recharging stations the greater will be the number of PEV and the other way around (Chun and Hahn (2008)). For this reason, it will be initially modelled how the Italian EV ecosystem is structured, its challenges, how companies are positioned, which actors will be able to capture most of the value created, where the new entrants are specializing as well as what this the evolution of the recharging infrastructure in Italy and the associated business models. In this way it will be possible to assess whether the ecosystem of companies involved in the PEV business are ready to support its large-scale diffusion in the Italian market.

In the second part of the paper, a cross-country multiple regression analysis is run. This statistical tool will allow to answer to the following research questions: i. “What are the macro-economic factors that are driving the Plug-In Electrical Vehicles diffusion at an international level?”; ii. “Are there significant differences between the variables having a positive impact on BEV demand and those on PHEV?”; iii. “What policy measures can the Italian government put in place in order to foster the PEV diffusion?”. This chapter plays an important role in this research paper for several reasons. After having analysed the Italian value chain of electrical vehicles and understood the readiness of its companies in supporting and enabling the diffusion of PEV, it is important to give an international perspective to this paper. Indeed, the companies’ readiness and strategies with regard to a new technology are not the only divers influencing its diffusion in a country. For this reason, in order to assess which macro-economic factors will have a positive impact on the Electrical Vehicles diffusion as well as which type of policies can governments put in place in order to foster their diffusion, a cross-country multiple linear regression has been run.

Before starting, we ought to briefly introduce some concepts that will be extensively used in the following pages. With the term EV (electrical vehicles), we include any vehicles that is partly or fully equipped with electrical engine. In this category fall BEV (Battery Electric Vehicles: vehicles whose only source of power is electric), HEV (Hybrid Electric Vehicles: cars having both an electric and thermal engine, but whose batteries are solely recharged through regenerative breaking energy), PHEV (Plug-In Hybrid Electric Vehicles: vehicles having both types of engine but whose battery pack allows a significant range and can be recharged with specific plugs), EREV (Extended-range battery vehicles: it is a BEV that includes an external power unit called range extender). Finally, the term PEV – Plug-in Electric Vehicle – includes all types of electric vehicles whose battery can be recharged from external sources. The two biggest representatives of this category being BEV and PHEV. Therefore, in the rest of the paper the term PEV will be used to identify both battery and plug-in electric vehicles.

1.1. *Literature Review*

This section has been subdivided into the major topics that will be treated in the literature review.

Initially, the literature that covers the impact of fiscal incentives on the EV adoption will be presented. These papers cover several geographies – Europe, USA and Asia – as well as different time horizons. At the end of this first part, table 1.1 summarizes the papers analysed and presents the main calculation methods that have been used to compute the Total Cost of Ownership (TCO) of EV and ICE vehicles as well as the variables considered. After that, the literature covering cognitive factors and in particular the attitude of drivers toward radically innovative product such as EV, is presented. Finally, a review of the papers focusing on the impact of the recharging infrastructure on the EV adoption is made.

1.1.1. Fiscal incentives

In 2017, Lévay et al, conducted a study, based on real-life car prices to assess both the impact of fiscal incentives and the total cost of ownership (TCO) on the diffusion of electric vehicles. This study has been conducted by looking and the sales numbers of electrical vehicles in eight different European countries: Norway, Germany, France, Netherland, United Kingdom, Italy, Hungary and Poland, which covered 66% of 2014 EV sales in EU28 and EFTA countries. This study compares the TCO of EV with the one of ICE vehicles belonging to the same car segment. By computing the ratio between the TCO of small EV (segment A and B) and TCO of small ICE and comparing it with the ratio between TCO of big EV (segment D, S and J) and big ICE, this paper highlights the fact that small EV are relatively more expensive than big EV. Furthermore, in Norway, important incentives made EV cheaper in comparison ICE car belonging to the same segment while in the other countries it was not the case, therefore partially explaining the wider diffusion of EV in this country.

In their study, Mock and Yang (2014) try to understand the link between fiscal incentives and the diffusion of EV in several countries (Norway, Netherlands, United Stated of America, France, Japan, Sweden, Denmark, Austria, Germany, United Kingdom and China). Their study is based on the comparison of the TCO of one BEV (the Renault Zoe) with its non-EV counterparts (the Renault Clio) and of one PHEV (the Volvo V60 PHEV) against the same model in its diesel version. The major simplifications made in this study where to focus solely on nation-wide incentives – therefore neglecting the existence of regional and municipal incentives – as well as they supposed that the base selling price of each model was identical in all countries and took as reference the German price. Two major conclusions where drown out form this study. National fiscal policies are a powerful tool to reduce the TCO and therefore pushing the sales of EV. Indeed, some countries where proposing important fiscal incentives for BEV and resulted in important BEV market share and low PHEV one. The result was the opposite for countries proposing significant fiscal incentives for PHEV and smaller ones for BEV. The second observation was that considering solely governmental fiscal incentives is not enough to explain the difference in EV diffusion among countries.

Propfe et al. (2012) study is an interesting contribution to the TCO calculation for alternative fuel cars. This work focuses on the German market and analyses the different total cost of ownership for ICE, PHEV, hybrid electric vehicle (HEV), extended range electric vehicle (EREV), BEV and fuel cell electric vehicles (FCEV) according to two possible annual mileages. The values calculated are a TCO appraisal in 2020 supposing a 4-years holding period. The interesting aspect of this work is the estimation of maintenance and repair costs as well as the resale value for each of the beforementioned car categories. The main conclusion of this study is that in 2020 none of the alternative powertrains dominates in term of TCO. These figures depend on usage patterns, initial price and maintenance and repair costs, suggesting that automakers should develop a wide portfolio of offering to fit with the different customers' needs.

In their paper, Wu et al. 2015 evaluate the total cost of ownership per driven-kilometre of alternative powertrain vehicles (HEV, PHEV and BEV) with the TCO/km of ICE vehicles for the German market for the year 2014, 2020 and 2025. To do so, the comparison is performed considering also the vehicle class and use case. Three classes have been defined – A/B segment, C/D segment and J segment – and three uses cases – people travelling less than 50km/day, between 150 and 200 km/day and above 200km/day. The interesting contribution of this paper resides in its input parameter – that are not determined deterministically – but to which a probability distribution is associated. Thanks to that, a Monte Carlo simulation is run in order to evaluate the results variability. Two main results emerge from the data. First, alternative powertrains outperform ICE vehicles in term of TCO/km depending on the vehicles segment and use case. In case of short distances, ICE vehicles outperform EV in all segments and for every year. For long distances instead, EV are more efficient in term of TCO/km – especially for A/B segment – due to the bigger benefits coming from operational costs (e.g. fuel costs).

Hagman et al. (2016) research paper aims to define the most realistic possible TCO model when purchasing new car and test it on the Swedish market to identify potential implication over the BEV diffusion. The interesting contribution of this paper is to tailor the TCO calculation according to the specific buyer profile. Therefore, the elements taken into consideration for the TCO computation are depreciation, fuel cost, interests (supposing to purchase the vehicle with the aid of a loan), insurance, maintenance and repair and taxes and subsidies. This study compares the TCO of two ICE vehicles, one PHEV and one BEV in the Swedish market, supposing a three-year holding period. Here again, only incentives at the country level are considered and not at the municipality or regional ones. This analysis leads to the conclusion that BEV's TCO is smaller than the one of its counterpart cars, suggesting that the TCO – by himself – it is not able to explain the diffusion of EV in Sweden.

In Bjerkan et al. (2016) an analysis of which incentives are critical for BEV adoption in Norway as well as a categorization of the buyers, according to their sensitivity to the different types of incentives, is presented. The study has been conducted by interviewing 3400 BEV owners belonging to the Norwegian EV association. The main conclusions have been that "exemption from purchase tax and VAT" are critical for most of the BEV adopters but "exemption from road tolling" seems a decisive factor for subjects not sensitive to the former incentive. Furthermore, the paper suggests that people interested in incentives reducing the car fixed costs (purchase tax and VAT exemption) are men, above 45 years old, Tesla owners but whose income level is not significant. Instead, respondents with low income and university education were sensitive to incentives reducing use costs (e.g. free parking), while respondents with an elementary education were perceptive to priority incentives (e.g. access to bus lane). The main limitations of this study come from neglecting the impact of cognitive factors and recharging infrastructure when evaluating the diffusion of EV.

Mitropoulos et al. (2017) calculate for the US market the TCO and externalities of ICE vehicles, PHEV and BEV. This paper does not solely aim at studying the customer point of view when confronted with the adoption choice but makes a Life Cycle Assessment of the three types of car to understand from an environmental point of view the costliest one. To assess the total externality costs, the emissions and costs of five pollutants were considered: CO, NOx, VOC, SOx, and PM10 during four phases of the car life cycle (manufacturing, fuelling, operation and maintenance). Interestingly enough this study is the only one that considers opportunity costs for the time spent refuelling or recharging the car. The paper finds out that despite BEV have the lowest externalities costs, the TCO of PHEV is the lowest – followed by BEV and ICE – for total mileages above 60.000 and considering 11 years of car lifetime. For inferior mileages, BEV total cost of ownership is bigger than ICE one. Therefore, in the short-term PHEV should diffuse greatly as no specific complementary assets are required. In the long-term – once a sufficient recharging infrastructure is in place – BEV have the potential to become the dominant design and reduce the environmental impact. Therefore, policies should focus on lowering PHEV price while technology and infrastructure advance.

Palmer et al. 2017 work is one of the few that looks at how the TCO for HEV (hybrid electric vehicles), PHEV, BEV and ICE evolves through time, across different geographies and tries to assess the relationship between HEV TCO and adoption through a regression analysis. The studied regions are California, Texas, Japan and United Kingdom, while the cars used to conduct the TCO analysis are a Toyota Prius – in its HEV and PHEV versions – a Nissan Leaf (BEV) and a Toyota Corolla (ICE). This paper highlights the general growth of incentives, across time, for PHEV and BEV while the same has not happened for HEV. The regression analysis showed that by using a model made of two explanatory variable – the former representing initial costs, including subsidies and the latter the running costs – the model was able to explain fairly well the HEV's market share evolution across regions. The study found out that the biggest influence is played by incentives and subsidies – aimed at lowering initial costs – but running cost also have an important impact in explaining HEV adoption, even if of a lesser extent.

In this paper, Liu D. et al. 2018, study the diffusion of EV in China throughout the time horizon 2010-2040. Four scenarios are evaluated in this study: no policy support; only direct policy; only indirect policy and direct and indirect policy. Direct policies are state provided incentives that reduces the EV cost of production, the selling price and foster the development of recharging infrastructure. On the other side, indirect policies include the energy policy – aiming at reducing the environmental pollution – and the environmental policy – focusing on the reduction of greenhouse gasses emissions. In order to assess the impact of each of the four scenarios on EV adoption, this paper uses a SD (system dynamic) model. An SD model is a methodology to represent complex scenario, characterised of several variables, impacting one another. The structure of this SD model in the paper is represented by 5 sub-systems: two costs sub-systems – one for the EV and one for the fuel vehicles – an R&D sub-system, an investment sub-system and a carbon emission and trading scheme sub-system. Each one of them was characterized by several internal variables. The result of this paper is that the diffusion of EV in 2040 will be 4,03; 8,61; 4,2 and 8,85 million vehicles respectively in scenario 1, 2, 3 and 4, leading to the conclusion that direct policy support has the greater impact on EV diffusion. Nonetheless, a sensitivity analysis has been conducted on the policy variables, leading to the result that a 20% cut on direct policy leads to a 24% reduction on EV diffusion in 2040 – with respect to the base-case scenario – whereas a 20% improvement of direct policies leads to a 17,95% improvement on EV adoption. Therefore, cutting subsidies has a bigger impact then increasing them.

In Langbroek et al. (2016), the authors study how effectives several policy incentives are on EV adoption in Sweden. To do so, they conducted a two-stage survey, collecting 294 responses, using stated-choice experiment and applying the Transtheoretical model of Change

(TTM) and the Protection Motivation Theory (PMT). EV range, price after subsidies, public charging infrastructure availability, free and paying public charging, parking benefits and use of bus lane, were the variables considered is this study. The TTM is a framework that divides people's behavioural change into 4 stages: Pre-contemplation (people that do not have considered behaviour changes); Contemplation stage (think of changing their behaviour), Preparation change (plan to change behaviour); Action stage (actual behaviour change) and Maintenance stage (people that have changed their behaviour in the past). An expected general rule comes out from this study, incentives increase the probability of choosing an EV. Interestingly enough, the effectiveness of incentives changes according to the TTM stage. People that are more advanced in the behavioural change process are less price sensitive. This implies that subsidizes are less effective for this group of people. On the other side, this group perceives a smaller gap in utility between traditional vehicles and EV.

The main limitation that all these authors have pointed out in their studies, is the impossibility to completely explain the diffusion of EVs in the different countries they have analysed by just considering financial incentives and TCO calculation. All of them underlined the recharging infrastructure diffusion, social norms as well as range anxiety as other important aspects to study in order to have a more complete understanding of the diffusion phenomena. On the other side, not only these studies have been conducted considering various markets but – as it is clearly identifiable in table 1.1 – all of them have used different approaches to calculate the TCO, making the results comparison difficult.

	Lévay et al. (2017)	**Mock and Yang (2014)**	**Propfe et al. (2012)**	**Wu et al. (2015)**	**Hagman et al. (2016)**	**Mitropoulos et al. (2017)**	**Palmer et al. (2017)**
Vehicles	18 cars: 9 ICE, 6 BEV, 3 PHEV	BEV, PHEV, ICE	HEV, PHEV, EREV, FCEV BEV and ICE	BEV, PHEV, HEV, ICE	ICEV, HEV and BEV	BEV, PHEV, ICE	BEV, PHEV, HEV, ICE
Car segment comparison	Yes	Yes	None	Yes	Yes	None	None
Geographies	8 EU countries	11 countries - worldwide	Germany	Germany	Sweden	USA	UK, USA Japan
Purchase year	2014	2013	2020	2014, 2020, 2025	2012	2015	1997/2000–2015
TCO calculation							
Ownership duration(years)	4	4	4	6	3	10,6	3
Annual kilometres travelled	12.000	10.000	4 scenarios: 2.500, 5.000, 7.500 and 10.000	3 scenarios: 7.483, 15.184, 28.434	10.000	0-12.000	16.640, 17.713, 25.025, 9.941
Subsidies	Yes	Yes	None	Yes	Yes	None	Yes
Annual & acquisition taxes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fuel price	Yes (assumed constant)	Yes (assumed constant)	Yes (DRL analysis based on IEA Energy Outlook 2011)	Yes (BDEW, 2013)	Yes	Yes (EIA 2016b)	Yes (Spritmoniter)
Electricity price	Yes	Yes	Yes (BMU study 2010)	Yes (BDEW, 2013)	Yes	Yes (Davis et al. 2012)	Yes (The Idaho National)
Resale value	Yes	None	Yes (regression model)	Yes	Yes	None	Yes
Insurance	None	None	None	Yes	Yes	Yes	Yes
Maintenance and repair costs	None	None	Yes	Yes	Yes	Yes	Yes
Discounted TCO (discount rate)	Yes (1%)	None	Yes (5%)	Yes (4,1%)	Yes	Yes (2,4%)	Yes (3,5%)
Borrowed money (interest rate)	None	None	None	None	Yes (4.2%)	None	None
Opportunity cost (car recharging)	None	None	None	None	None	Yes	None

Table 1.1: TCO literature overview

1.1.2. Cognitive Factors

In their paper, Barth et al. (2016) explore whether social norms and collective efficacy can foster the EV adoption. To do so, they first interviewed a panel of experts – people working in a field related to EV – and non-expert asking for the most relevant elements that according to them would impact this new technology adoption. Both experts and non-experts have suggested the same factors: acceptance of EV is pushed by its low environmental impact and reduced maintenance cost compared to ICE vehicles. On the other side, factor limiting EV adoption are purchasing price, limited range and missing recharge infrastructure. None of them identified social norms or collective efficacy as relevant factors. Social norms are a broad term that encompasses several types of norms (Cialdini et al. 1990). Descriptive norms refer to the perception of "what is": how people do behave (e.g. Italians do not drive EV). Injunctive norms regard the perception of "what must be": how people should behave, and so which behaviours are approved or disapproved in a group (e.g. Italians approve EV driving). Finally, we can identify provincial norms – the effect that others' behaviour can have on ours when those others occupy a comparable setting – and subjective norms that differentiate from the former as the others can influence our behaviour without necessarily occupying a comparable setting (e.g. to live close by). To evaluate the effect of these norms on EV adoption, the authors conducted a survey in which respondents had to evaluate the degree to which several statements would impact their EV adoption. The grading scale went from 1 to 7, with 7 meaning "absolutely agree". A total number of 548 responses from German was collected. The statements were divided into four categories: personal costs (e.g. purchase price), personal benefits (e.g. maintenance costs), social norms and collective efficacy. The results were studied through a hierarchical regression. As experts and non-experts predicted, cost-related disadvantages were negatively correlated to EV adoption, while cost-related benefits were positively correlated. On the other side, significant importance was also found with regard to injunctive norms – what people value - whereas descriptive norms were not significantly impacting EV adoption.

Caperello et al. (2013) in "Do You Mind if I Plug-in My Car? How etiquette shapes PEV drivers' vehicle charging behaviour" analyse the importance of etiquette – rules defining how EV drivers should behave – when recharging their PEV (plug-in electric vehicle) in away-from-home conditions. For the authors "away-from home" recharging includes any public charging, work charging or any other charging occasion that is not performed at the driver's home. According to Martin (1993) etiquette plays three roles. The first is a regulative function aiming to manage social behaviour to create harmony in a community. The symbolic function of etiquette creates a system of signs that reduce the uncertainty of social situations, especially among strangers. Finally, the sacred function aims at providing ceremonies and traditions to transform chaotical emotional occasions into more orderly one, such as weddings and funerals. This study has been conducted by interviewing 29 Nissan Leaf drivers, leaving in California. The recurring elements that came up from the interviews were: i. the lack of information when approaching free recharging lots (e.g. how long am I allowed to park there?) ii. the lack of information when finding a busy parking lot (since how long the car is charging? Can I un-plug to recharge mine?). On the other side, respondents revealed the existence of a charging etiquette – the Electric Vehicle Courtesy Charging Protocol – but the lack if its adoption from the vast majority of PEV driver made it useless. Furthermore, respondents were frustrated by car-sharing PEV – occupying public recharging stations – and by shopping malls and large retailers' employees, for occupying the charging stations located in the customer parking area.

The relevance of this paper with the aim of this thesis reside in the way in which innovative product diffuse in the market. According to Bass (1969) the demand of an innovative product in the early stage is subject to the Diffusion Phenomena. This theory models the demand according to two parameters: p the innovative adoption parameter and q the imitative adoption parameter. In case of durable product, whose adoption involves a significant expense the diffusion curve will be characterized by a very small p with respect to q. If this would be the case, consumers will hesitate and wait for confirmation of the product validity coming from early adopters. In such a context word of mouth becomes a powerful tool that can foster the technology diffusion. Therefore, a lack of etiquette when recharging PEV away from home generate frustration that prevents a positive word of mouth in the community and therefore might inhibit the EV diffusion at a larger scale.

1.1.3. Range anxiety and charging infrastructure

In their paper, Thiel et al. (2012) evaluate the drivers' perception and willingness to adopt electric vehicles in France, Germany, Poland, Italy, Spain, and the United Kingdom through a stated preference (SP) survey. The survey – structured in two sections – aimed initially to assess how much drivers were familiar with BEV and then to evaluate how much they agree with several statements, covering several features of BEV (e.g. their range, purchasing costs, operational costs…). This study highlighted that drivers needed to be more educated on the electric vehicles topic as they stated not to be really familiar with it. Despite this, they were interested in the technology but purchasing price and range were the two most cited reasons explaining their adoption reticence.

Gomez et al. (2017) study is based on the analysis previously conducted by Thiel et al. (2012). The same survey submitted in 2012, was provided to new respondents in 2015 belonging to the same countries. The main purpose of this study is to understand how the user's perception toward BEV has evolved with time as well as which are the major elements that still prevent the BEV diffusion at the European level. From a comparative analysis of the surveys result form 2012 and 2015, the authors discovered that the proportion of customers strongly agreeing with the statement that BEV are quite expensive has decreased. This could result from the introduction of subsidies and other financial incentives at the national level. Moreover, customers are more and more aware of the lower operational costs that BEV have in comparison to ICE, compared to 2012 but the proportion of people unable to state that BEV having a better environmental impact than ICE might suggest that customers are more aware of the concept of life cycle emission. Finally, the reasons reported by respondents for not buying a BEV were the purchase price, the car autonomy, the recharging infrastructure and a too limited number of available models.

In this paper, Lieven (2015) examines the importance of seven different incentives that can be clustered into three major categories: monetary measures, traffic regulation and investments in charging infrastructure. To do so, it conducted a survey in 20 different countries and assessed the consumer preferences with a choice-based conjoint analysis and used the Kano method to understand the level importance of the seven different incentives. The main finding coming from this study is that monetary measures – subsidies and tax exemption – are "delighters": if present, users are extremely satisfied, if not they do not complain. Traffic regulation – use of bus/fast lane and free city centre parking – are indifferent attribute: their presence of absence does not generate satisfaction nor dissatisfaction in the respondents' eyes. Finally, charging infrastructure is a must have attribute/basic need. Therefore, its presence does not generate satisfaction for the customers; but its absence generates great dissatisfaction, thus preventing EV adoption.

Sierzchula et al. (2014) seek to identify the link between financial incentives and several socio-economic factors (education level, fuel price, environmentalism…) to electric vehicle adoption. The study comprises both battery electric vehicles as well as plug-in hybrid vehicles. To do so, a multiple linear regression analysis was performed considering 30 different countries for the year 2012. The authors have decided not to conduct a state preference study – as many beforementioned authors have done – to evaluate the impact of socio-economic factor on vehicle adoption as they believe that consumers responses are not really representative of their real purchase behaviour: there is an "attitude-action gap". From the regression, Sierzchula et al. identified a positive correlation between financial incentives and EV diffusion. Nonetheless, some countries with high level of financial incentives had little EV penetration and the other way around, suggesting that there are other factors that foster EV diffusion. Also, the existence of local manufacturer producing EV and the number of charging station were positively correlated to EV adoption, with the latest being the one with the highest correlation factor among these three factors. In conclusion, this study suggests that the number of recharging stations per 100.000 residents drives the diffusion phenomena.

1.2. *Research method*

This section presents the research methodology used in order to develop the Italian value-chain around electromobility, to map the public recharging stations in Italy and their business model and to develop the regression model

In order to understand the EV ecosystem in Italy and therefore to identify all the corporations offering either the final product or services or assets necessary to its development, the internet websites of these companies and their annual reports have been studied. In this way it was possible to identify the offered services, business models and corporate strategy for the following years. The analysis started with the most well-known companies operating in this field. By doing so, more companies in the same field were coming to the surface, allowing a broader analysis. An important number of companies have been analysed but, after a thorough review aimed at discarding companies that were not directly operating in Italy, 99 companies – international and not – were retained to define the EV Italian ecosystem. The biggest challenges faced at this point were related to the different actors operating around the recharge of plug-in electrical vehicles. Indeed, since the diffusion phenomena in Italy is still limited, theoretical roles, company definition and actual activities were not always matching. In order to identify recent alliances, mergers, acquisition or joint-ventures that could have a significant impact on the ecosystem evolution and the dominant players' identification, several articles reporting the news of the selected companies have been analysed. In addition to this, some interviews with managers operating in Italian utilities companies were conducted. A major category of players that has not been included in the beforementioned value chain are Tier2 companies as, for the moment, they hold the same role they had in the traditional combustion engine ecosystem. It is important to highlight that this ecosystem analysis does not aim to be a perfect representation of the current EV value-chain state, but it provides a sufficient level of detail in order to perform macro analysis.

The evolution of the recharging infrastructure in Italy has been made by mapping only the public and semi-public recharging stations, as information relative to the private ones are difficult to access and of limited interest. No public database containing information related to the year of installation and the actors in charge of the charging stations are available. Furthermore, the few existing open databases do not guarantee data accuracy, especially related to the year of installation as record are added by the users who might discover the station long after its inauguration. Hence, the data regarding these stations were obtained by reading articles of specialized Italian reviews in the electro mobility (e.g. Greenlandmobility.it), major local newspapers (e.g. Il Sole 24 Ore) and announcements made from municipalities (e.g. commune.roma.it). Out of the 2108 existing recharging stations in Italy at the end of 2017 (Omniauto), this analysis studies 1105 public and semi-public recharging stations, covering the period 2012-2018. Here again, the objective was not to give complete map of the existing Italian infrastructure, but to provide a general a sufficiently detailed study allowing to identify the macro trends through the years.

For what concerns the cross-country regression analysis, four models have been defined. A basic multiple linear regression model to study the PEV diffusion, a transformed model for PEV and two other transformed models; one specific to the BEV diffusion and the other for the PHEV one. The first step was the identification of the dependent variable and the explanatory ones. In order to identify which independent variables could be interesting to study, a thorough review of the literature presented in this chapter has been made in order to identify the results that seems to be in contradiction from one study to another. For example, the level of education was included in the regression model as several authors – among which Thiel et al. (2012) – claimed that higher level of education would lead to a higher PEV diffusion. On the other side, Li et al. (2017) had the opposite affirmation. Some explanatory variables that have been included in other regression models, studying the macro-economic factors influencing the PEV diffusion, have been neglected as they were not satisfying the falsifiability criterion[2] (Popper (1983)). An example of such variable is the number of public charging stations in each country. Finally, the last explanatory variable that has not been included in the model is the CO2 per capita. Despite the before mentioned criteria being satisfied, the variable was ignored as a more complete indicator of the country environmental performance was used. The explanatory variable used in the basic model was the ration between the number of newly registered PEV per year over the total number of new cars in a year, for each country. In the second model, the response variable was a logarithmic transformation of the dependent variable used in the former model, in order to maximise the model fitting. Finally, the explanatory variables used in the third and fourth model were the same used in the second one but either specific to BEV or PHEV sales. The third step of the analysis was the identification of the country for which the demand would be analysed. The criteria used to select them, was to cover most of the European territory as the focus country of this study comes from there. Furthermore, also North America and Asia had to be considered in order to give an international perspective to the study. Within those regions the most important ones in term of PEV diffusion have been selected. For what concerns the sources used to retrieve the data for each of the mentioned variables, several open databases have been used, such as the European Alternative Fuel Observatory (EAFO), or the OECD library (OECD). A complete overview of the sources used for each variable is available in table 3.1. Finally, the regression analysis has been conducted with the Excel software thanks to the “Analysis ToolPak” add-in.

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[2] The falsifiability criterion will be briefly explained in the sub-section 3.2.2

2. The Italian EV ecosystem

2.1. *Introduction*

This chapter aims at responding to the following research question: "Are Italian companies ready to support the diffusion of PEV?"

In order to provide and answer to such a broad problematic, the question has been broken down in three sub-questions: i. "How the EV ecosystem is articulated in Italy?"; ii. "Which actors will likely be the winners?"; iii. "How does the recharge infrastructure has evolved throughout the years?". The goal of this introduction is to provide several theoretical frameworks explaining the importance of an ecosystem analysis, when studying the diffusion phenomena.

According to Foster (1986) when the performance of a new technology overcomes the performance of the old one, then substitution would take place. If the technological performance of PEV is compared with the one of ICE vehicles, it is clear that a rapid take-off of electric vehicles will not happen. Despite a significant improvement in the battery energy density, going from 65Wh/L in 2008 to 295Wh/L in 2015 (Department of Energy (2014)), the gap with the energy density of Gasoline and Diesel fuels is huge: around 10.000Wh/L. Figure 2.1 presents the technology S-curve of the battery energy density and the battery cost evolution. (IEA (2016)).

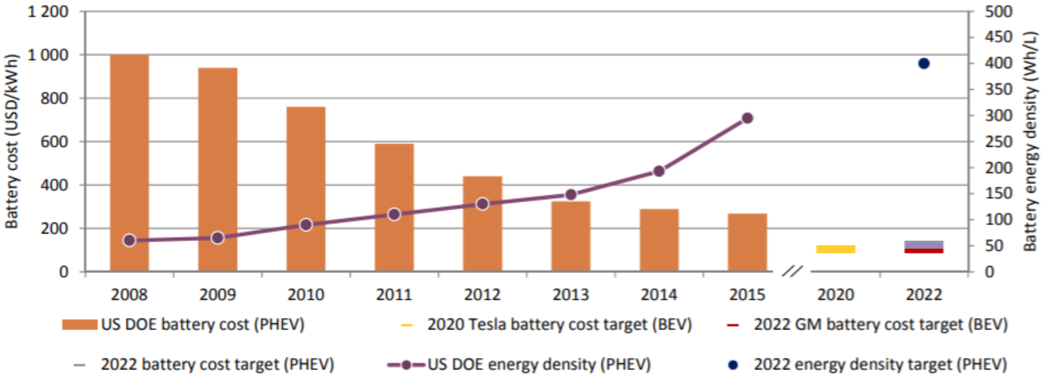

Figure 2.1: Technology S-curve of EV battery and its cost evolution[3]

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[3] Source: IEA (2016) Global EV Outlook. All rights reserved

Even if technological performance is a determinant factor when looking at the speed with which the old technology is replaced by the new one, there are several other elements that can influence its take-off. The theory of Localized Technological Change (Antonelli (1995)) states that when individuals consider adopting a new technology, they will continually evaluate whether to remain loyal to the old one or move to the new. This decision is based on the perceived utility that the innovation will generate, against the utility provided by sticking with the old technology. This evaluation is based not only on objective factors – such as the technological performance – but also on subjective ones, such as: investments in complementary assets, expertise level and so on. This implies that individuals considering whether to keep a thermal engine car or move to a PEV will evaluate factors that are not strictly linked to the car autonomy. For example, Barth et al. (2016) found out that what injunctive norms – how people should behave – influences the diffusion of EV. Adner and Kapoor (2016) also stress the importance of the ecosystem (figure 2.2) when considering the pace of substitution of a new technology over the old one. The idea behind this theory is that bottlenecks existing in the ecosystem supporting the new technology can slower the speed at which the substitution takes place.

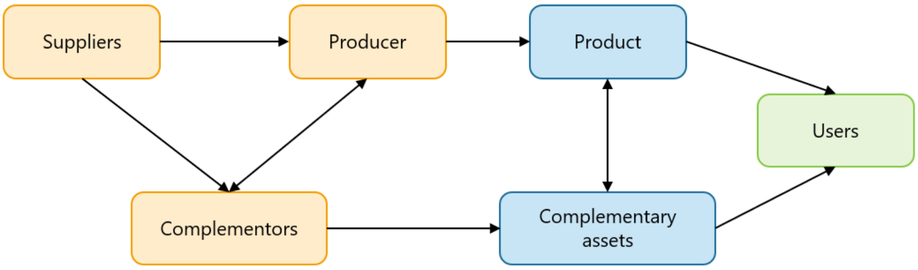

Figure 2.2: Graphical representation of an ecosystem

On the other side, extensions of the ecosystem supporting the old technology increase the period during which this technology will remain relevant (figure 2.3). Based on this, four different situations have been developed by Adner and Kapoor (2016): i. Creative Destruction: when both the challenges for the ecosystem supporting the new technology and new opportunities coming from the extension of the ecosystem supporting the old technology are low. In this case a rapid substitution is expected; ii. Illusion of Resilience: when there are many bottlenecks slowing the emergence of the new ecosystem and few ecosystem extension opportunities for the old technology. In this situation the substitution will stagnate until the bottlenecks in the new ecosystem are resolved and then a rapid substitution will take place; iii. Robust Coexistence: the challenges for the ecosystem supporting the new technology are low but the extension opportunities for the old technology ecosystem are high. In such a case, the market will be characterized by a gradual substitution. The new technology will make its appearance in the market but opportunities coming from the old ecosystem allow incumbents to defend their position; iv. Robust Resilience: when challenges are high for the new technology ecosystem and the old ecosystem has strong opportunities to improve, leading to the slowest substitution pace of the old technology by the new one.

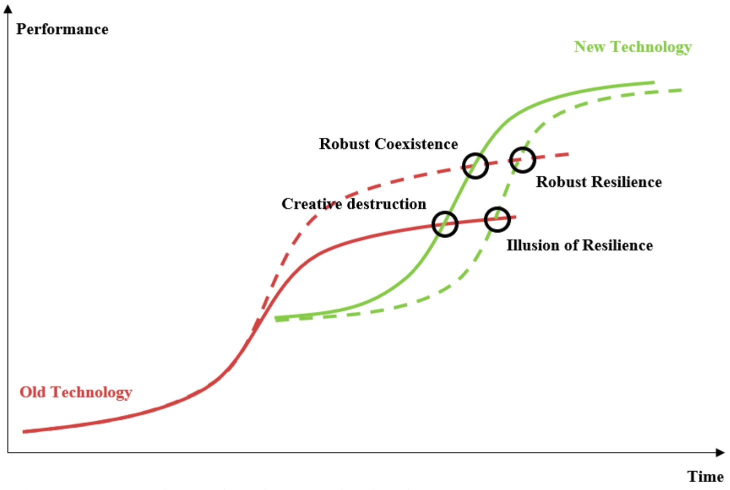

Figure 2.3: Role of ecosystems in technology substitution

From this later theory it becomes clear how the competition between ICE vehicles and hybrid electric vehicles is a Robust Coexistence case. Indeed, traditional thermal engine cars, force by the European Union, are reducing their CO2 emissions and technological development is increasing their consumption efficiency. On the other side, if we look at plug-in electric vehicles, not only the substitution of ICE vehicles by BEV and PHEV is slowed down by the expansion of the thermal engine ecosystem, but high challenges prevent the development of the PEV one. In particular, the inexistence of a widespread diffusion of recharging stations is limiting the diffusion of these technologies. Therefore, the substitution is at its lowest possible rate: Robust Resilience. With these premises, the role of this chapter becomes clear. Identifying and studying the structure of the new ecosystem supporting the PEV technology, is necessary in order to assess the Italian readiness in replacing ICE vehicles with greener from of mobility.

This chapter will start by giving a brief overview of the PEV diffusion at a Worldwide and European level in order to see how Italy position itself in this context. It will then follow by presenting the main findings of the research that has been conducted in order to identify the EV Italian value chain structure and its implications. The last section of this chapter will be dedicated to analysing how the actors involved in the recharge business has evolved over the years, in Italy.

2.2. *The diffusion of PEV: a worldwide and European perspective*

This section will analyse the sales evolution of both battery electrical vehicles (BEV) and plug-in hybrid vehicles (PHEV) as these two technologies have a very similar product architectures (figure 2.4) and require the same type of complementary assets in order to ensure their take-off. All the data presented in the following pages comes from the IEA (2018), the OICA and the EAFO. The countries considered for these analyses are 44[4] and represent 94% of the PEV vehicles sold worldwide.

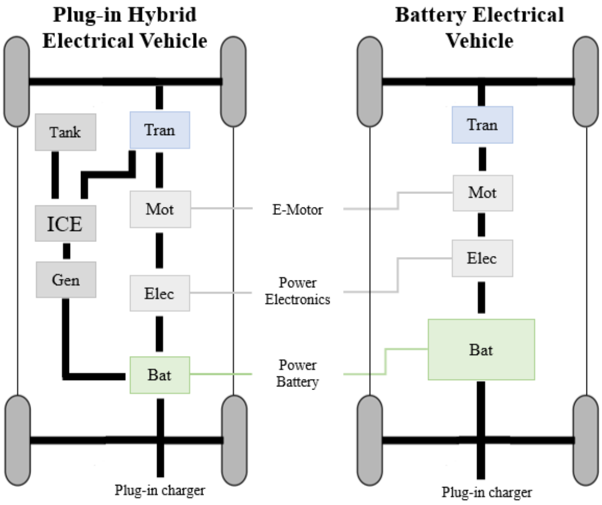

Figure 2.4: Architectures of PHEV and BEV cars

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[4] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malaysia, Malta, Poland, Romania, Slovakia, Slovenia, Spain, Australia, Brazil, Canada, Chile, China, Finland, France, Germany, India, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Portugal, South Africa, Sweden, Thailand, United Kingdom and United States

On a worldwide perspective, since 2010 the number of PEV hasn't stopped to increase. They moved from less than 10.000 newly registered cars in 2010 to more than 110.00 cars in 2017. During this period, the sales of BEV worldwide constantly remained higher than the PHEV ones. The gap between these two types of vehicles became always more important and in 2017 reached its maximum: 65% of the PEV sold worldwide were BEV (figure 2.5 left). Furthermore, the substitution of ICE vehicles by PEV is increasing even if at a very slow rate. In 2010, just 0,02% of the newly registered cars were PEV whereas in 2017, the diffusion of PEV was at 1,87% (figure 2.5 right).

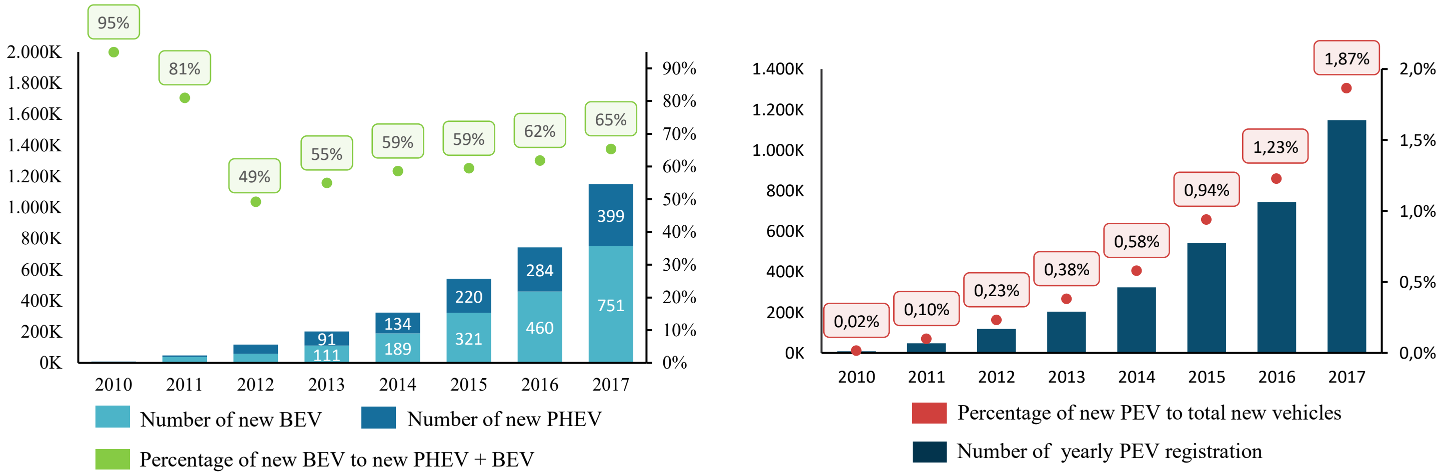

Figure 2.5: Evolution of PHEV and BEV sales worldwide over the period 2010 – 2017

China, Norway and the United States are the biggest worldwide PEV markets. With 579.000 units sold in 2017, China is in absolute term the country where the highest number of plug-in electric vehicles have been sold. Despite this, the penetration of PEV is still limited as just 2,2% of the car sold in 2017 were either BEV or PHEV. The United states represents the second biggest market in term of volumes with 198.000 sales in 2017. Due to the limited size of the Norwegian market, the number of BEV sold in 2017 is one order of magnitude lower than in China (62.000 units sold). Nonetheless, the penetration rate is much higher, with 39% of the car registration in 2017 being either full electric or plug-in electric vehicles (figure 2.6). Furthermore, in Norway, since September 2018 the ratio of new PEV to total car registration is constantly above 50% (Insideevs.com).

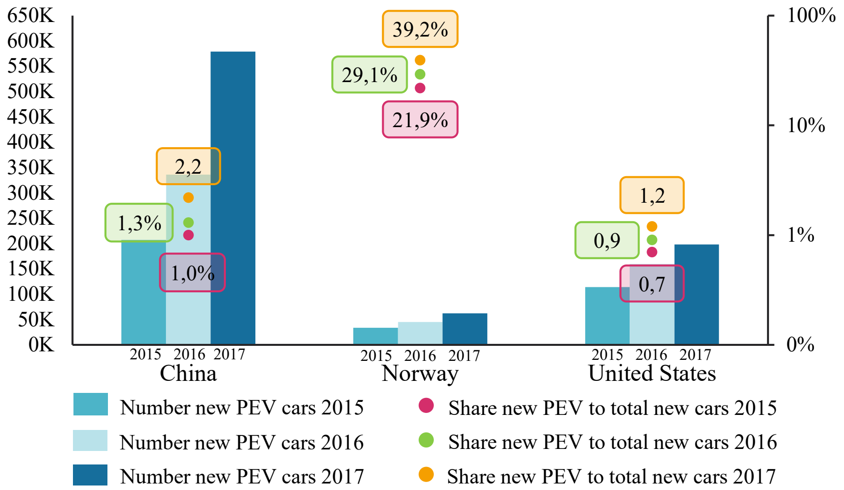

Figure 2.6: Evolution of PEV sales and penetration in China, Norway and US over the period 2015 – 2017

Looking at the European 28 and EFTA (Norway, Island, Liechtenstein, Switzerland and Turkey) countries, the number of PEV sold has continuously increased during the period 2010-2017. Moreover, apart from the year 2016 during which there has been no grow in term of new PEV over total new car sold, in all the other years this ratio has improved. Therefore, the substitution of ICE vehicles by PEV is happening both at a European level (figure 2.7 left) and at a world one (figure 2.5 right).

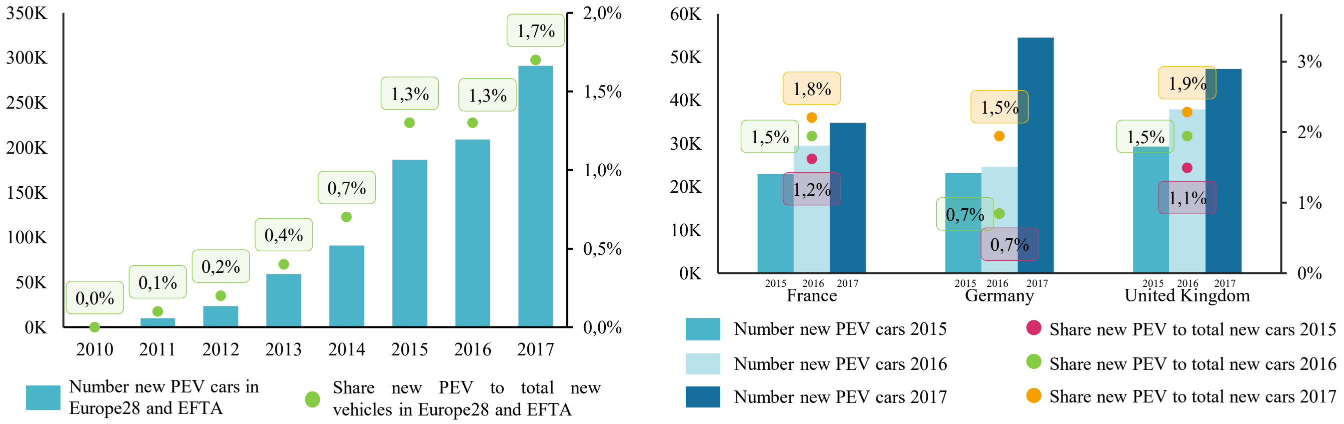

Figure 2.7: Evolution of PEV sales in Europe (left) and top selling European countries (right)

In Europe, despite Norway that has been analysed before, the other three most important markets in term of PEV volumes are France, Germany and United Kingdom. For all of them, throughout the period 2015-2017 the number of PEV sold has constantly increased (figure 2.7

right). Germany had a sharp PEV volume increase moving from 2016 to 2017. Sales went from 24.000 units sold to 54.000 units. Furthermore, the share of newly registered BEV to total new cars improved for all these countries. This indicator shows that the sales growth of PEV is not due to an increase of the automotive market per se, but by a substitution of ICE vehicles by PEV ones (figure 2.7 right). In Italy (figure 2.8), despite the share of new PEV to new cars in 2016 decreased, the overall trend is the same that has been observed at a global and European level. Sales of PEV vehicles as well as the ration of registered PEV to registered cars are both increasing. The year 2016 was a particular year for the Italian car market as sales of traditional cars increased by more than 15% with respect to the previous year (Repubblica.it (2017)), leading to a PEV market share decrease. Nonetheless, despite the Italian car market being the fourth biggest in Europe, after Germany, UK and France (ACEA (2018)), the number of PEV sold is not comparable with the one in the top EU markets. In 2017, the PEV sales in Italy were around 4.800 units, one order of magnitude smaller than the sales in the three biggest European markets. Therefore, despite a positive trend in term of PEV diffusion, it is clear how Italy is lagging with respect to what is happening in comparable markets.

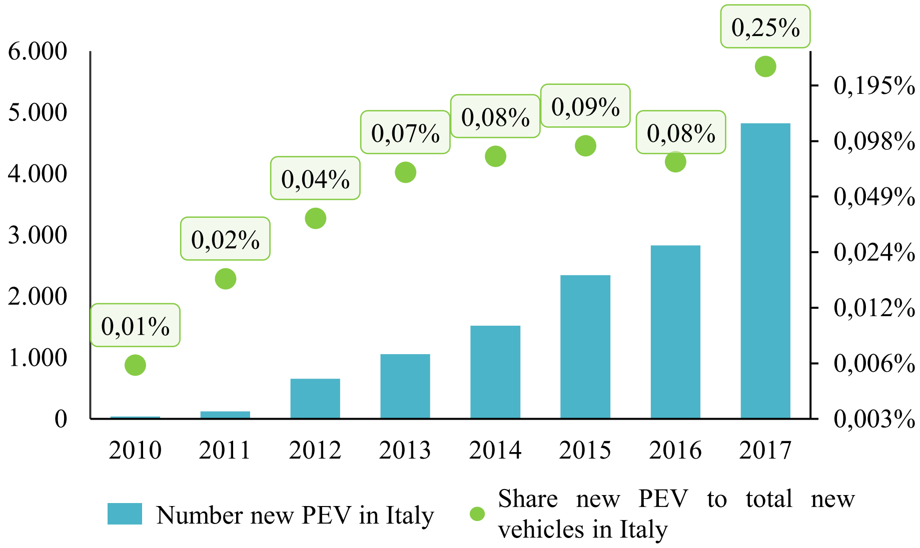

Figure 2.8: Evolution of PEV sales in Italy during the period 2010-2017

2.3. *Characterization and study of the EV Italian ecosystem*

As it has been highlighted in the previous section, not only at a global level the substitution of the ICE vehicles by PEV is slow, but it is even slower in Italy. We are therefore in the robust resilience situation defined by Adner and Kapoor (2016) and an analysis of the emerging Italian ecosystem becomes interesting. In order to model it, 99 companies from several industries have been analysed (figure 2.9). Three quarter of these companies were incumbent while 25% were new entrant. Of the incumbent companies, 49 were operating into their traditional market (e.g. Volvo keeps operating in the automotive sector) and 26 were defined as "new entrants from other industries". This latter term identifies, for example, the case of an incumbent utility company entering the business of operating charging stations.

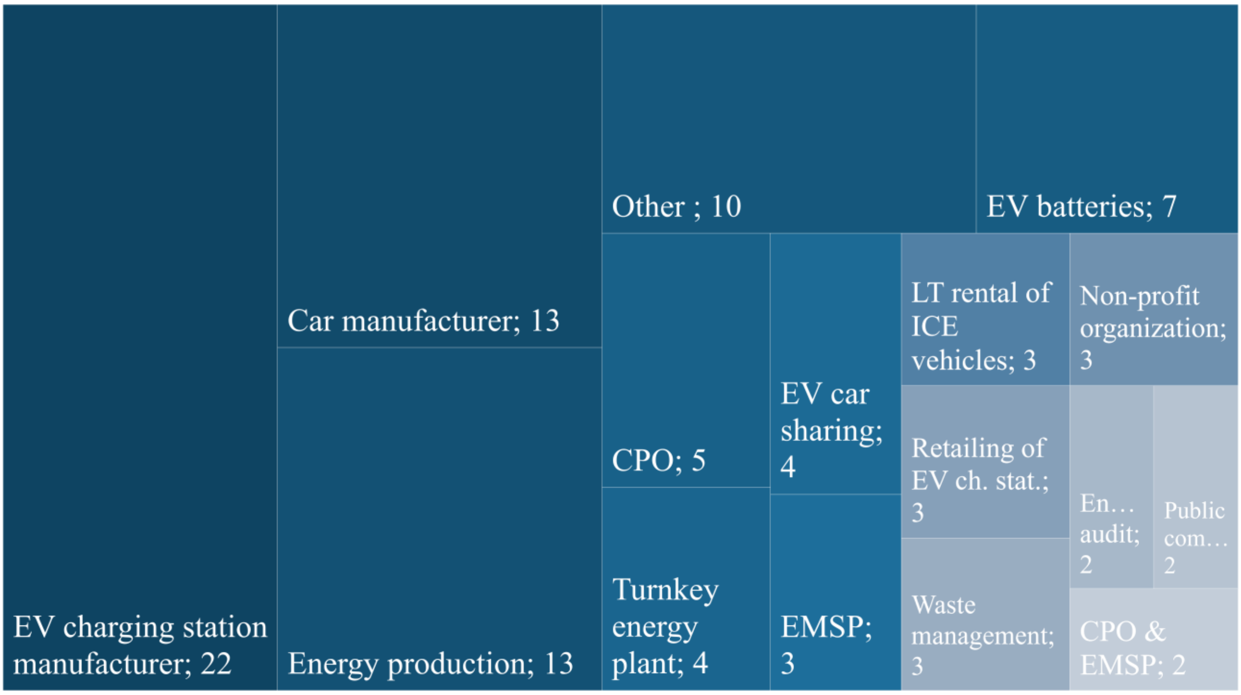

Figure 2.9: Industries analysed; number of companies per category[5]

Before presenting how the Italian ecosystem around the electric vehicles is structured, it is important to briefly introduce two roles that will be extensively used in the following pages: the Charging Point Operator (CPO) and the Electric Mobility Service Provider (EMSP). This latter actor is in charge of offering the recharge service to the final users (i.e. the PEV driver).

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[5] "Other" includes: Energy transmission, Electric appliances, EV battery recycling, EV on demand charging service, Fleet management services, Maintenance services, Power converter, Shopping mall, Tourism and Roaming platforms

His activity includes managing the recharge payment or subscription with the final users, offering personal assistance services and the visualization of available charging stations on a map. EMSPs generally offer also other added value services, as charging station booking, even though this is not true for all of them. The CPO, instead, oversees the recharging infrastructure. It will therefore define the term of use of the charging stations (price, opening hours, who as access to it…) with the infrastructure owner (e.g. condominium, hotel, shopping mall, municipality…) and will transfer the payment from the EMSP to the station owner. The CPO will also be responsible of all the technical operation related to managing a network of charging stations (e.g. installation, maintenance, firmware updates…). In addition to this, it will be responsible for defining the contracts with different EMSPs, to grant the service provider's userbase access to the stations that the CPO is managing. Finally, a CPO can also own be the recharging stations owner and one actor can decide to perform both CPO and an EMSP roles. These two actors will be extensively analysed in section 2.4.

2.3.1. The structure of EV Italian ecosystem

The structure of the ecosystem of international and Italian companies operating around electrical vehicles is presented in figure 2.10. This figure has been created by thinking at the lifecycle an electric vehicle. In the horizontal axes are presented the major steps of a PEV lifecycle while the vertical one identifies three distinctive value-chains supporting the rise of PEV in Italy. With production are identified all those activities where something is created or produced. This phase starts with the extraction of raw materials necessary to build components, includes the assembly of batteries for EV, the production of the vehicles itself, the generation of electricity from different sources as well as the production of complementary assets such as charging stations. Within the macro-category sales, are included all those activities that are necessary to make the main output of each value-chain available to the final user. It includes the distribution of EV and the dealers' activity, the transmission and distribution of electric energy and the retailing of charging stations. The third life-cycle stage of the PEV is the use. Within it, one of the main activities that the driver will perform is the vehicle recharge. If public and semi-public recharges only are considered, figure 2.10 shows the players (i.e. CPO, EMSP and roaming platforms) involved in this activity. The term "other services" encompasses all the activities that the vehicles will undergo during the use stage (e.g. maintenance, car sharing, long term rental, battery swapping, purchase of aftermarket parts…). The last step of the car lifecycle is the end-of-life and recycle. Many car components can be recovered or recycled (e.g. tire, glass, steel) yielding in a 95% reuse, recovery or recycling of it (Eurostat (2016)). For the purpose of this study a particular attention was given to the players operating in the field of EV battery reuse and recycling. This activity is of great importance as in order for EV vehicles to keep the promises of being more environmentally friendly, not only the production of electricity must come from renewable sources but also its components should ensure a limited environmental impact.

An ecosystem structure that mimics the PEV lifecycle has been used as it allows to understand in a clear way how different actors coming from very different value chain have decided to enter different PEV lifecycle phases. This visualization method allows to assess strategic decisions taken by companies such as: companies entering in phases that require different competencies from their core one or the decision to get closer to the final user so to have higher margins or increase customer loyalty. In the following parts of this subsection each value chain will be analysed independently.

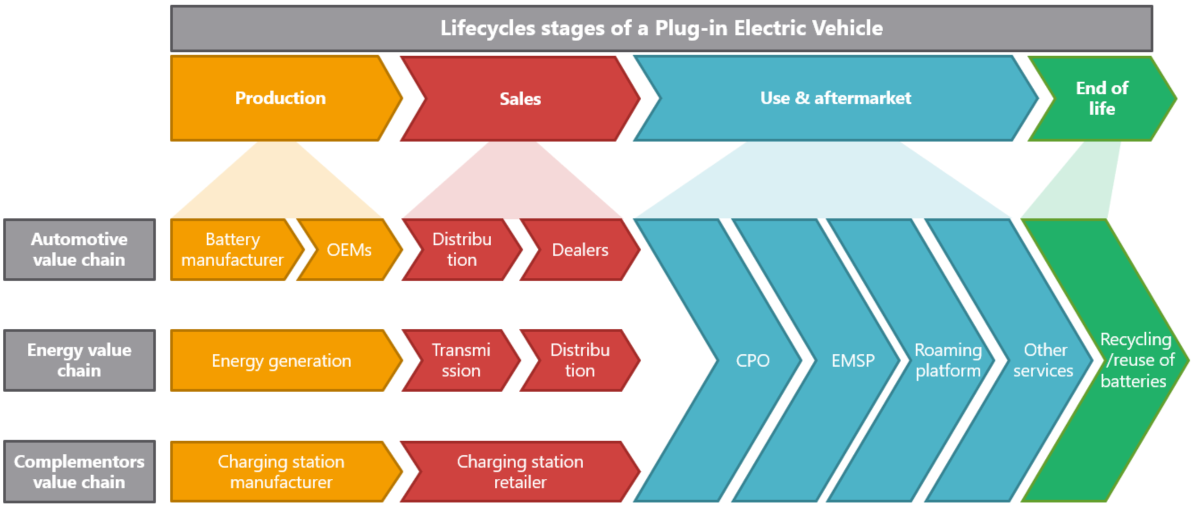

Figure 2.10: The ecosystem of companies supporting the PEV emergence in Italy

2.3.2. The Automotive Value Chain

The main actors that will be analysed in the automotive value chain are OEMs, EV battery manufacturers and players operating in the recycle and reuse of batteries.

Starting from the carmakers, the analysis has been made by looking at the group strategies and not at the single company one. For example, the strategy of the Volkswagen group has been analysed and not the singles brands' one (Audi, Volkswagen, Seat, Skoda, Ducati…). Thirteen groups have been studied as they represent the main players operating in Italy and offering electric mobility. It is interesting to notice almost all of them are incumbents (11) while just two are new entrants: Tesla and the Shanghai-based company NIO. Despite being founded more than ten years ago, Tesla is considered as a new entrant as it still has problems related with the production process that are typical to new players in an industry characterized by very important learning curve effects. Furthermore, Tesla is a very young company with respect to the other players, that are at least 25 years old. On the other side, NIO is a Chinese company, founded in 2004, that started its adventure by producing an electric supercar and then moved, in 2017, to the production of the ES8, a luxury SUV. Despite not being yet available in Italy, NIO has been included in this analysis as it is expected to launch its BEV soon there (vaielettrico). From a geographical perspective, 39% of the analysed groups are European, 15% are North American and the remaining 46% are Asian. Of these latter, two groups are Japanese, one is Indian (Tata motors operates in Europe with the Jaguar and Land Rover brands) and there are three Chinese companies. What is important to notice is that while most European groups have introduced into their offering electric vehicles and make them available in the European market, the number of Chinese EV manufacturers is very high and just few of them are selling their models in Europe.

In figure 2.11 are presented the set of activities that the different carmakers perform in Italy. As of 2018, most of the carmakers (60%) are just concerned by the production of electric vehicles and are not directly involved in other businesses related to them. On the other side, the remaining 32% has perceived the strategic importance that batteries play in this type of vehicles and therefore have decided to start producing them. For example, BYD owns several battery plants, providing a total capacity of 36GWh, and is finalizing one that is expected to have a capacity of 24GWh, making it the world biggest (Electrek). The reason why so many car manufacturers have entered this activity are multiple. First of all, it is important to know that no clear battery composition has yet emerged as the dominant one. Nickel-Cadmium, Aluminium-ion, Lithium-sulphur, Lithium-ion (Li-on) batteries and Solid-state technology all differentiate in term of performance and cost. For the moment, the preferred composition in term of both capacity, weight and production cost is the lithium-ion one. Nonetheless, this type of battery uses cobalt as one of the main cathode materials. The issue with this mineral is that it is almost exclusively extracted in Congo, a region politically unstable which could impact on the raw material supply and hence price (Statista). By producing their own lithium-ion batteries, car makers can therefore start to build the set of knowledge and competencies that will grant them a competitive advantage in the future, should this technology remain the dominant one. If economies of scale and learning curve effect are pushing down the cost of batteries (figure 2.1), this component still remains one of the most expensive. For example, the Tesla Model 3 battery pack costs around 9.500€[6]. Therefore, through vertical integration, car manufacturer would be able to reduce the cost of the battery as they would no longer have to pay for the manufacturer mark-up. Finally, while many brands have decided to solely invest in battery R&D, other car manufacturers decided to enter the production stage as they fear a lack of battery supplier. While PEV sales are increasing at an important rate, the production capacity of the battery suppliers is limited. Therefore, to avoid the embarrassing situation of having a PEV demand that is higher than what the battery supplier can provide, some OEMs decided to turn themselves into this activity. This issue will be extensively treated when talking about battery manufacturers.

Of the companies not just focused on the production of PEV, 80% of them are also involved in the production of charging stations. BMW decided to focus in the production of inductive (i.e. wireless) recharging stations only for private use. On the other side, Nissan and Tesla offer several types of conductive recharging stations (i.e. with a cable), both for domestic and public use and with different power ranges. It is interesting to notice how the strategies differentiate for those companies. BMW works on a more sophisticated technology (wireless charging) and uses private recharge as a test field for it; while it prefers not to enter the already very crowed inductive recharging sector. If this strategy limits the sales in the short term, it could provide BMW with a strategic advantage should this the technology become mature enough to be used in a public environment.

Referring to figure 2.11, it can be seen how the CPO role has been divided in two. This was necessary as the theoretical definition of the CPO activities does not always correspond with what the companies are doing. By observing the market, some actors are just in charge of the installation and maintenance of the charging stations, some solely manage the network of stations from an IT standpoint while other actors integrate both activities. The first case is Nissan one. The Japanese car manufacturer installs and performs ordinary maintenance of its recharging stations but does not manage them from an IT perspective. For example, in 2016 Nissan supplied A2A, an Italian electric utility, with 13 charging stations it produced. The most advanced car manufacturer under this aspect is Tesla. Indeed, the US-based new entrant is undergoing both CPO (maintenance and control of the charging stations) and EMSP roles. It provides a map of the charging points in all its cars, ensures that only Tesla owner can access

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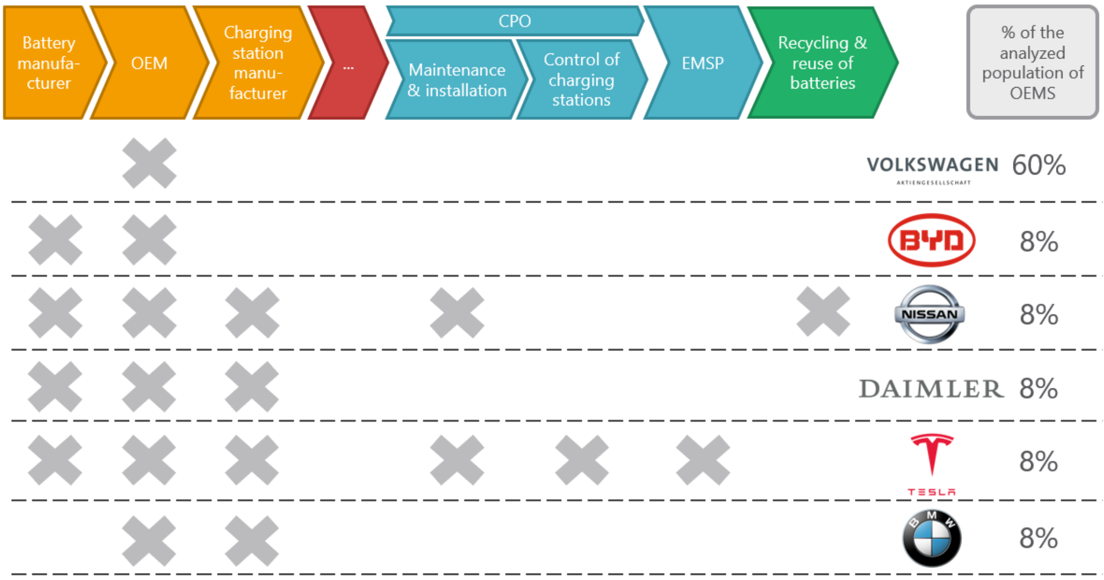
[6] Own calculation based on the 190€/kWh battery cost for tesla and 50kW battery capacity of the Model 3

them and manages the payment to the charging stations owners. Tesla has developed two distinctive charging networks free to use for Tesla owners. The former, the Supercharger network, is made of fast charging stations mostly placed on highways. The latter is the Tesla Destination Charging, a network of slow charging stations positioned in specific POI (point of interest) were drivers will stay for longer duration (e.g. hotels, shopping mall, restaurants…). If Nissan, by mainly producing and branding charging stations is trying to develop a new image for the company while supporting the development of complementary assets. On the contrary, Tesla uses a more aggressive strategy for several reasons. Many plugs exist for the recharge of electric vehicles (figure 2.13). The CCS (Combined Charging System) allows with one single socket to recharge from both direct current (fast recharge) and alternating current (slow charge). This type of plug is preferred by European automakers. Japanese OEMs use instead the CHAdeMO fast charging plug, that is generally combined with a type 1 or type 2 for the slow recharge. Tesla instead uses a modified version of the type 2 socket. Since Tesla adopted an altered version of the type 2 socket and as no universal standard has yet emerged, by producing and operating the recharge infrastructure, Tesla in supporting the diffusion of its own plug. Furthermore, as the car market is two-sided, an increase in the number of charging stations will have positive cross-sided network externalities. As Tesla was the first automaker really committed in changing the traditional mobility, it had to develop and operate by itself the charging network. This happened because PEV require specific complementary assets, therefore no company was willing to bet on a new technology whose success was uncertain. Nonetheless, Tesla's CPO and EMSP roles start to pay off, as they are generating positive network externalities for the drivers. Indeed, should a consumer be interested in a BEV, she might perceive a higher utility in adopting a Tesla rather than a competing alternative due to the private charging network it offers.



				CPO				
Battery manufacturer	OEM	Charging station manufacturer	...	Maintenance & installation	Control of charging stations	EMSP	Recycling & reuse of batteries	% of the analyzed population of OEMS
	✗						VOLKSWAGEN AKTIENGESELLSCHAFT	60%
✗	✗						BYD	8%
✗	✗	✗		✗			✗ NISSAN	8%
✗	✗	✗					DAIMLER	8%
✗	✗	✗		✗	✗	✗	TESLA	8%
	✗	✗					BMW	8%

Figure 2.11: OEMs activities in the PEV lifecycle in the Italian market

It is important to notice that in figure 2.11 are presented the activities in which the company is directly involved. This means that of the companies producing only PEV (60%), they might also be active in other part of the value chain, but in an indirect way (e.g. joint venture). Several interesting joint venture and mergers and acquisitions occurred in this sector. Back in 2009 Daimler together with RWE AG started testing EV and charging stations in Germany. In 2010 it formed a joint venture with BYD and launched the BEV brand Denza in China. In 2013 Daimler acquired a 12% stake of BAIC, one the largest BEV manufacturers in China. BMW and Brilliance Auto formed, in 2003, BMW Brilliance an electric vehicles manufacturer that leverage the already existing BMW platform to produce EV for the Chinese market. These equity-based alliances show how incumbent carmakers were not waiting to be disrupted by PEV. They instead undergo a period of testing before deciding to introduce the technology into more mature markets. In 2018, five year after the Israeli-based start-up Better Place, went bankrupt, Honda and Panasonic entered into a strategic agreement to test a battery swapping service for electric vehicles. Should the tests prove to be viable, it would be a major revolution in the BEV market as recharging time would become comparable with the one of traditional cars. Nonetheless, this technology has several problems with compatibility being one of the biggest. OEMs use for BEV different batteries and for the moment the cars' architecture is not conceived to allow the rapid substitution of batteries. Nissan, instead, entered in a joint venture with Sumitomo Corp. with the objective reducing the battery foot print. To do so, the joint venture uses the 4R approach: i) Reducing the primary sources extraction ii) Re-using already existing component or the final product at the end of its first life iii) Recycling the batteries allowing the re-introduction into the supply chain and iv) Redesign them. As it has been discussed above, the EV battery business is still very young as no clear winning technology has yet emerged. Therefore, companies not producing batteries might do so to avoid overcommitting in an uncertain technology or are betting on a technology that is not yet ready. This is the case of Volkswagen. The German automaker believes that solid-state batteries will be the future as they provide a higher energy density then the Li-on ones. Their commitment to this technology is proven by the recent 100 million USD investment made is QuantumScape, a US-based company specialised in this field. Finally, there have been two strong commitment signals from automakers and other players of the automotive value chain into PEV. The first one is the creation of Hubject, a joint venture between BMW, Daimler, Bosch, and others, whose purpose is to create a roaming platform[7] for EV drivers. Indeed, as of today, in order to charge their vehicles in different stations, PEV drivers need to have different contracts with EMSP, and of course this complexifies the user experience and inhibits the PEV diffusion. The second signal is the creation of Ionity in 2017. The company is a joint venture between BMW, Daimler, Volkswagen and Ford and aims at creating a network of ultra-fast charging station (350 kW) throughout Europe. This joint venture shows how automakers are willing to push the PEV sales as they are investing into the ecosystem development that will enable the substitution of ICE vehicles.

Within the Tier1 companies, a particular focus was given to EV battery manufacturers because of their strategic role. Seven companies have been identified as they represent the main players operating in this sector. It is interesting to notice almost all of them are incumbents (72%) while just only two are new entrants: Northvolt and CATL. The former is Swedish company that has been founded in 2015 and the it is still building its first manufacturing plant. CATL instead, is a Chinese battery manufacturer founded in 2011. It rapidly imposed itself as a major player and in 2018 reached a market share of 41% in China. From a geographical perspective, all the EV battery producer come from Asia except for Northvolt that is European. Within the Asian companies, two come from South Korea, two are Chinese and two are from Japan. As of today, the company with the highest production capacity is CATL with 40GWh of yearly output. From a regional perspective, China is once again leading, with a total of 135GWh of plants installed. Other Asian countries (excluding China) are in second place with 46GWh, followed by North America (21GWh) and Europe (20GWh). It is clear how Chinese

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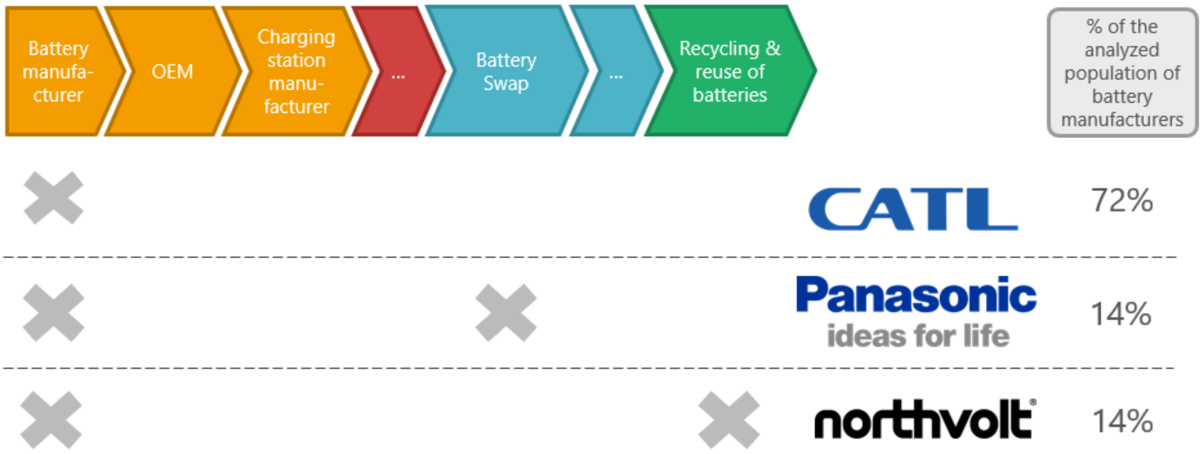
[7] The concept of roaming will be explained in more detail in the section 2.4

companies and China in general are leading the electrification race. By looking at the company statements and plans, in 2023, the situation will be very similar. The biggest battery manufacturer will remain CATL (88GWh) closely followed by the South Korea LG Chem (85KWh) and the third place will be the of car manufacturer BYD with 60GWh. Here again China will be the leading region with 61% of the total world installed capacity, followed by North America with 14%, Europe (13%) and the rest of Asia with 11%. Table 2.1 summarizes the production capacity of today and the expected one in 2023 for the main players.

Battery Manufacturer (Country)	**Supplied OEM**	**Capacity (2018)**	**Planned Capacity (2023)**
CATL (China)	Daimler, Volvo, BMW, Volkswagen	40GWh	88GWh
AESC (China)	Nissan	7,5GWh	27,5 GWh
LG Chem (South Korea)	Renault, Volkswagen, GM	18GWh	85 GWh
NEC (Japan)	Nissan	10GWh	10GWh
Samsung LDI (South Korea)	BMW, Volkswagen	33,5GWh	45 GWh
Northvolt (Sweden)	-	-	32 GWh
Panasonic	Tesla	22GWh	50 GWh
BYD	BYD	36GWh	60 GWh

Table 2.1: Main battery manufacturer, their actual and expected production capacity and supplied OEMs

As it has been made for OEMs, it interesting to study whether battery manufacturers are involved in other activities in the PEV lifecycle. From figure 2.12 it can be noticed how the vast majority (72%) are solely involved in this activity while just two players seem to pay attention to the other stages. Of this latter group, one company is investing in reducing the battery footprint. Indeed, today if Li-on batteries are not re-used, they are sent to the incinerator. To overcome this problem, Northvolt is working on the development of batteries that allow to easily dismantle and recycle its components. Panasonic instead, as previously introduced, is working with Honda on a battery swapping solution.



2.12: Tier1 activities in the PEV lifecycle in the Italian market

Three macro trends can be noticed. First of all, most of the battery manufacturer and battery production happens in China. Furthermore, battery manufacturers seem solely interested in their activity and are not looking to other opportunities, as instead some carmakers (e.g. Nissan or Tesla) have done. Finally, it can be noticed how no European carmakers are producing batteries. The reason behind the Chinese geographic supremacy is the size of their market. As we have seen in the section 2.1 China is by far leading the PEV sales at a worldwide level (figure 2.6). Therefore, not only some of the biggest battery manufacturer are Chinese, but also non-Chinese companies settle their plants there. The reason behind European carmaker not entering in the battery production[8] is justified by the high investment required, the lack of competencies in the field and the uncertainty around the winning technology. Nonetheless, this strategy could turn out to be very dangerous. Recently Volkswagen stated that it will produce 3 million PEV per year in 2025. Considering a that the average PEV battery has capacity of 50kWh, the carmaker would need 150GWh of batteries per year. If we compare this number with the planned production capacity of battery manufacturer in 2023 (table 2.1) it is clear how there might be a supply problem. This observation is supported by the Benchmark Mineral Intelligence, forecasting a total battery production capacity of 564,5GWh in 2023 (BMI (2018)). This number includes BYD production capacity (60GWh in 2023), that is solely used for its cars, so the available capacity for the other OEMs would be around 500GWh. Furthermore, not only European and North American OEMs will need batteries but there are many EV Chinese manufacturers. Therefore, the risks for European companies to remain without batteries is very

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[8] BMW produces batteries for EV through the joint venture BMW Brilliance. Nonetheless, these batteries are produced only for the Chinese market and do not aim at serving BMW global PEV sales.

high, especially because Chinese battery manufacturer might give precedent to compatriot OEMs, should there be a battery scarcity. This trend is already visible in South Korea, were an increasing amount of batteries is being kept for local sales (Bloomberg (2018)).

In conclusion it can be noticed that if some automakers have decided to enter other stages of the PEV lifecycle (mainly production of charging stations), very few have decided to enter into the battery production. In particular, European carmakers might pay the consequences for this choice in the close future. On the other side, the predominance of China as both preferred place for settling gigafactories and as mother country of the largest battery manufacturers is due to the combination of a very large number of Chinese PEV producers and the size of the market. Finally, as it has been presented before, some of the biggest European carmakers are commonly developing a network of charging stations. Therefore, by leveraging the infrastructure they manage and own, they could be pushed to become EMSP in the near future, entering therefore the use stage of the PEV. This would grant them to go down in the value chain, where margins are higher, integrate in their car a map showing their charging points and improving the driver recharging experience.

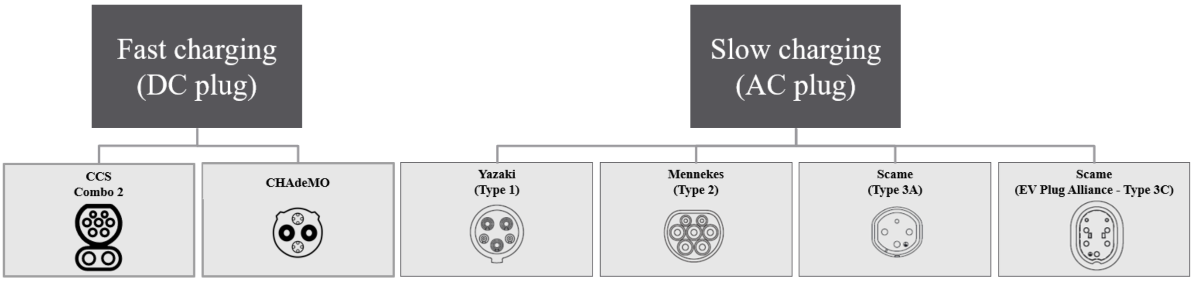


Figure 2.13: Existing PEV sockets

Before moving to the following part, as a matter of completeness, it is important to observe what other Tier1 suppliers are doing. The most active one in the electric mobility is Bosh that migrated into the complementor value chain and started producing charging stations, with the objective of reducing its dependency from OEMs. Another interesting case in the Bolloré Group. Initially born as a transportation group, with time it diversified its activities very well and remained strongly vertically integrated. As of today, it produces the batteries for its own full-electric vehicles and use these cars in its own car-sharing service, that operates in Italy under the BlueTorino and BlueRoma brands, France, USA and Singapore.

2.3.3. The Energy Value Chain

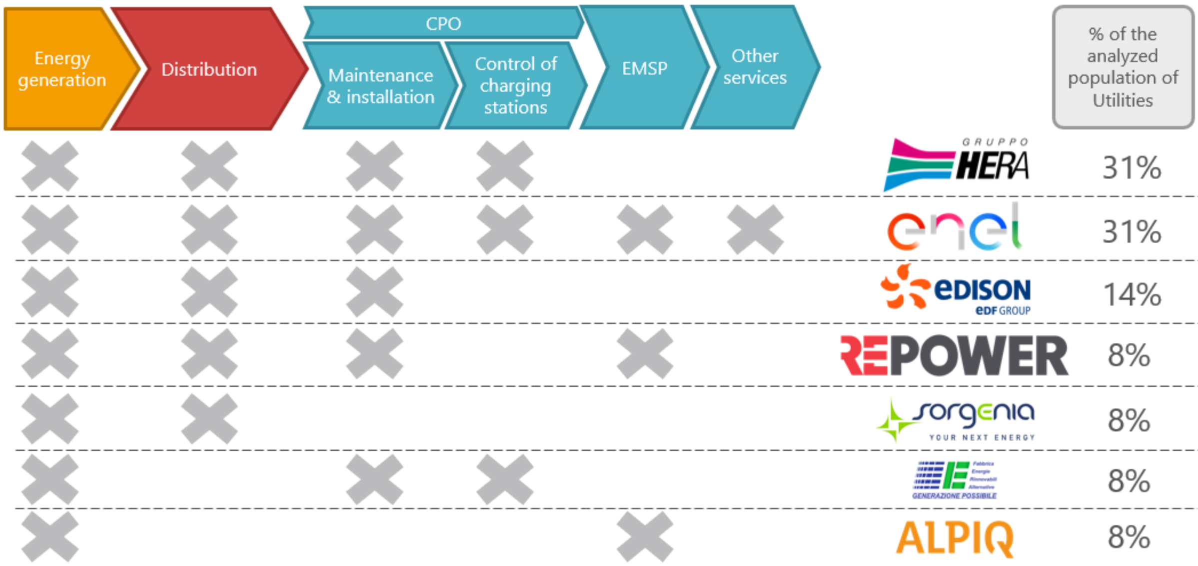
The main actors that will be analysed in the energy value chain are involved in energy generation, transmission and distribution.

It is interesting to notice how the situation is very different from the automotive value chain. While in the previous case most players where incumbents and there were few new entrants, here almost all players are new entrants from another industry (12) and two incumbents. This mean that there are no new entrants stricto sensu but, the majority of players are incumbents that entered in new businesses related to electric vehicles. From a geographical perspective, all the analysed companies are European. Of them, 77% are Italian and the remaining 23% Swiss. The core business of the analysed companies evolves around four activities: the energy generation, distribution, trading and transmission. One player is involved in the energy transmission, 14% are involved just in the production of electricity, 65% are electric utilities (i.e. they generate and distribute electricity) and 14% are also involved in trading activities.

Figure 2.14 presents the activities in the PEV lifecycle performed by the players operating in the energy value chain. The company operating in the energy transmission is a particular case and therefore is not included in the figure. Nonetheless, it will be analysed later in this sub-section. As of 2018, just few players (8%) are only operating in their core business, while the vast majority (92%) entered in new activities related to the electric vehicles' lifecycle. It is interesting to notice how almost all the new entrants from another industry decided to perform at least the most basic CPO activity: the installation and maintenance of the charging stations. This is for example the case of Edison that in partnership with rental car companies, offers long term contract for PEV. Within this agreement, Edison is in charge of supplying and installing the charging station that will be placed at the user's house. The second most performed activity is the control of charging station. Indeed, 62% of the analysed players are performing both CPO's activities. Hera is an Italian utility that since 2011 installs and manages charging stations, but its stations are accessible from the EnelX application and therefore does not perform the EMSP activity. The same type of activity is performed by Iren, an Italian utility, that has recently installed four public fast charging stations and controls them. A more particular positioning has been taken by Repower that performs the maintenance and installation of charging stations and the EMSP. The decision might seem strange as an electric utility has the competencies to manage a network of charging stations and might even have benefit in managing them, as it can better balance the grid load. The reasons behind this positioning is that the Swiss company decided to differentiate himself – from other utilities – by creating

Ricarica101: a network of hotel, restaurant, spa, where drivers can recharge their PEV. Since these recharging stations are not publicly available, there is no need to have a centralized entity managing them, but the POI can do it. On the other side, the installation and an application providing visibility and access to the recharging stations are important. Without the application, each time a new PEV driver arrives to the POI, she must ask the authorization to use the station (e.g. goes to the hotel reception and asks for the RFID card), leading to a frustrating charging experience. Furthermore, the application gives visibility to the POIs that are ready to host EV drivers. Meaning that final users might prefer to go to a restaurant that also allows them to recharge their vehicle rather than one they might have preferred but doesn't allow to do so. Also, Alpiq has a particular positioning. Through its application Easy4You it grants access to several CPO around Italy. Finally, 31% of the analysed players are the most vertically integrated. They perform both the CPO and EMSP activities and also other services related to PEV. An example is Enel, that with the EnelX division, installs and manages most of the publicly available recharging stations in Italy. The company has also launched an electric car sharing service for the students and professors of a Rome university and offers a package including a long-term rental of the Nissan Leaf together with the installation of a private station.

In Italy, the company Terna is responsible for the development of the electric grid transmission. Nonetheless, what is interesting is that earlier in 2016 the company started to work on smart grids, allowing a better electricity flow management. Furthermore, in 2018, Tesla and Terna reached an agreement to experiment the Vehicle to Grid (V2G) technology in Italy. The V2G allows a bidirectional flow of electricity – from the grid to the car and vice versa – depending on the necessity. This technology – that is based on a smart grid – would allow to cope with several problems related with the production of electricity and renewable energies. Indeed, during the night and weekend, the consumption of electricity is lower than during the day. With the V2G, plug-in electric vehicles would be recharged during these hours so to match the consumption with the production of electricity. Even a greater benefit could be achieved if this technology is used with renewable energy sources. Indeed, the problem of photovoltaic and wind turbines is their intermittence. Since the produced energy cannot be easily stored, with V2G, in production peak moment, PEV are recharged, whereas, when the consumption of energy is at its maximum and renewable energy sources are not, PEV are used as batteries, from which electricity is taken.



Energy generation	Distribution	CPO		EMSP	Other services		% of the analyzed population of Utilities
		Maintenance & installation	Control of charging stations				
✗	✗	✗	✗			GRUPPO HERA	31%
✗	✗	✗	✗	✗	✗	enel	31%
✗	✗	✗				EDISON EDF GROUP	14%
✗	✗	✗		✗		REPOWER	8%
✗	✗					sorgenia YOUR NEXT ENERGY	8%
✗		✗	✗			Fabbrica Energie Rinnovabili Alternative GENERAZIONE POSSIBILE	8%
✗				✗		ALPIQ	8%

Figure 2.14: Activities performed in the PEV lifecycle by companies belonging to the energy value chain.

In conclusion it can be seen how the situation in the case of the energy value chain is very different from what has been observed in the automotive one. Here, the majority of players are involved in many activities, far from their core business. The most performed, is the installation and maintenance of charging stations. The reason behind this is that the utility can leverage its customer base to becomes the interface through which the client can purchase a charging station while the competencies required for this activity are basic. The other very frequent activity performed by utilities is also the control and management of the charging infrastructure. Apart from being a more sustainable business in the long term than just the installation activity, if a utility company has many charging points and, for example, many PEV would be plugged at the same time, this could generate a grid overload and a blackout. Therefore, it becomes important for energy producer to have a control over the quantity of energy that is delivered in time by each charging station. Nonetheless, the challenges to do so are several. From an IT perspective there are several problems like the user identification, billing, the remote control of charging stations coming from different manufacturers, the management of the electrical grid, the interaction with other operators (roaming) and so on. In order to solve them utilities generally outsource the software development as they don't have the in-house competencies. For example, Enel's software has been developed by WellD and Softeco. Some players have decided instead to have a different approach and position themselves just as installer of charging stations and EMSP. This makes sense with respect to the particular offering they are proposing. Installing charging stations with private access does not require a centralized CPO, but the infrastructure owner car manage them as the number of charging stations will be limited. What is instead necessary to improve the user recharge experience and boost the POI visibility is an EMSP. Nonetheless, whether the underlying assumption of this strategy holds in the long term is not granted. Today, as the number of charging points in Italy is still limited, PEV drivers might prefer a restaurant or hotel with charging stations rather than one that doesn't. Instead, assuming that PEV will overtake ICE vehicles, having a charging station would no longer be a differentiating factor and probably users will prefer EMSP that grant access to a higher number of charging stations, so to have a limited number of cards and subscriptions. Finally, a significant number of players have the highest level of vertical integration by performing the both the CPO and EMSP activities. The advantages in this type of strategy is that mainly economic. As the technical difficulty for setting-up an EMSP is limited, avoiding this intermediary grants higher margins and limits the need of closing contracts with several EMSP. On the other side, if the company has a limited number of charging stations there is little interest for drivers to become clients or, if the company only uses its EMSP activity to make the charging stations available to the public, few PEV drivers might be aware of their existence. Therefore, it seems clear that there is not a clear preferred strategy. The place of recharge (public, semi-public or private) and the economic capacity of the company in installing charging stations can influence these decisions. If all these elements are positive with respect to the development of an ecosystem of companies supporting the BEV diffusion, as they show the interest and commitment utilities are putting in the development of a network of recharging stations, there is one issue that should be addressed: the grid capacity. This quantity represents the amount of energy that can flow at each moment in time. When a lot of BEV will be on the street, the current grid capacity is insufficient to supply both households and BEV. Therefore, utilities should not only focus on the development of a network of charging station but should plan important investment in improving the grid capacity, otherwise by looking at new business opportunities they might lose sight on their core business priorities.

2.3.4. The Complementors Value Chain

The term "complementor value chain" encompasses all the actors involved in the development of the most important complementary asset for the uptake of plug-in electric vehicles: the recharging infrastructure.

Due to the high diversity in term of core activity for the different players involved in the production of recharging systems, figure 2.15 show on one side the set of activity performed by them and their original business. It is interesting to notice how the great majority of players are incumbents (91%). Out of 22 analysed companies, 17 are incumbents (77%), 3 are new entrant from another industry (14%) and 2 are new entrants. Of these latter players, one is Witricity, a US start-up founded in 2007, based on a technology developed in the MIT laboratories for inductive charging. The other new player is EO, a UK-based company founded in 2015 with the vision of making PEV charging independent from the grid. From a geographic perspective, the situation is very different from what happened in the automotive value chain. The majority of players come from Europe (20) and just two are US-based. Of the European players, eight are Italian, four are French, two comes from Germany and the remaining are from Austria, Holland, Portugal, Spain, Sweden and United Kingdom. For what concerns the performed activities, it can be noticed that the majority of players are involved in the production of charging stations (64%) while the remaining 46% perform also other activities in the PEV lifecycle. Most of these, do the maintenance and installation of charging stations. Just one player: S&H, an Italian manufacturer of electrical equipment has decided to enter the EMSP business. Under the label RicaricaEV, the company offer access to the stations managed by the EVBility and Green Land Mobility operators. It is also interesting to notice how companies having as core business the production of charging stations are limited (18%) while the most significant number of the players come from other industries (82%). In particular, most companies producing charging stations are electrical equipment manufacturers (50%) while the remaining companies come from other industries[9].

As previously discussed in the subsection 2.3.2, the number of existing sockets to recharge PEV is great and no standard has yet arisen on a worldwide level. In 2010, Schneider Electric, Legrand and Scame created the EV Plug Alliance with the objective of promoting a new plug they developed: the type 3C (figure 2.13). This plug was becoming the standard in France as it was it was the only complying with the local legislation of having a physical cover to avoid involuntary electrocution. Nonetheless, in 2013 the European Union with the intent of harmonizing the recharge system decided to select the plug developed by Mennekes – the type 2 – as common standard for the slow AC charging. The imposition of the standard by law allows to speed up the PEV adoption process in Europe. Indeed, a standard war would have required a lot of time before one plug would emerge as a winner and in the meantime, PEV drivers had either to equip themselves with adapters or could use all the recharging stations. For what

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[9] The other industries do not include the OEMs already analysed in sub-section 2.3.2 but includes players operating in: Telecommunication, Turnkey Energy Plant and Energy Solution, Recycling of electronic devices, Pagoda Marquees and Automation Solutions

concerns the DC fast charging, no standard has yet arisen in Europe. For example, the Nissan Leaf uses the CHAdeMo socket while European carmaker prefer the CCS Combo2. Nonetheless, since 2017, the EU requires all DC fast charging station to be equipped with at least, but non exclusively, the CCS Combo 2 plug (Directive 2014/94/EU). The same standards are also used in Australia, South America, Africa and Asia (except for China and Japan). In North America, the preferred plugs are instead the Type 1 for AC, and CCS Combo 1 for direct current. Finally, in China a plug developed by a local company is used (GB/T) and in Japan, the CHAdeMO plug has the monopoly.

Several elements can be noticed from this analysis. First of all, it has been observed how just a minority of players have as core business the production of charging stations, while the majority of charging stations manufacturers come from the other businesses related to electrical equipment. This demonstrate how the skills required to produce conductive stations are similar to the ones that these players already possess. Furthermore, the fact that more than 30% of the players come from very diverse industry, show how in general developing the charging stations is not really complex. As a matter in completeness, a distinction in term of complexity has to be made between stations for private and public usage. The latter are more difficult to produce as they must resist any weather condition and should have a software that allows the CPO to communicate, control and monitor the performance of each one of them. Furthermore, it has been noticed that most of the players involved in other activities in the PEV lifecycle are performing the installation and maintenance of charging stations. This can be explained by the fact that the skills required to perform this type of activity are in line with the one that the company already possesses. Therefore, it is interesting to wonder why not all the companies are doing it. The reason behind might be two. On one side, for private charging, very little if no maintenance is required and the installation is generally easy. Instead, for public stations, it has been noticed in the previous section how already many players are performing this activity. Therefore, the potential market for the maintenance and installation in Italy is limited, hence players are not incentivized in setting-up teams for this activity.

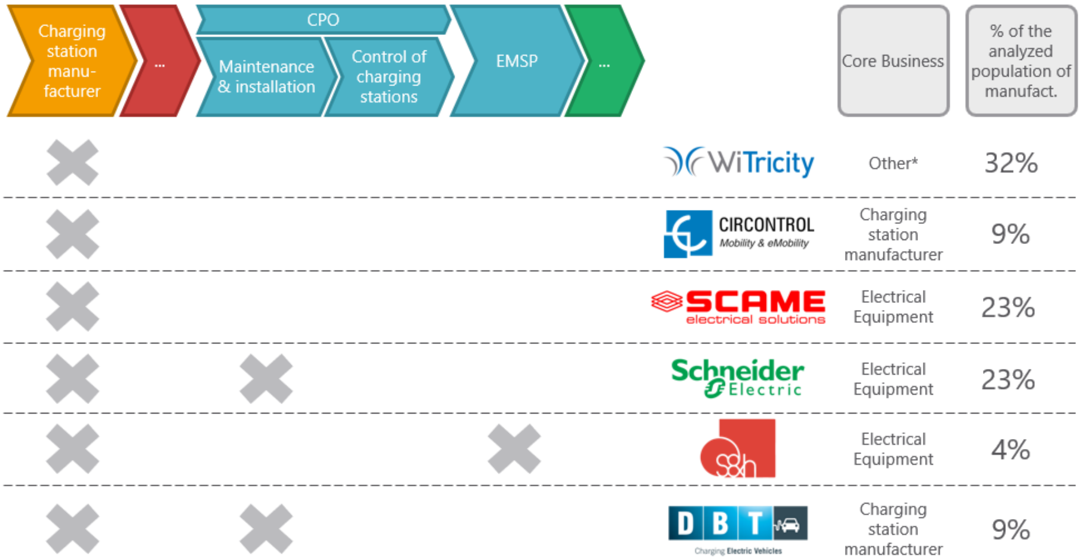


Figure 2.15: Complementors activities in the PEV lifecycle in Italy

2.3.5. Specialized CPO and EMSP

Until now an analysis of the players, coming from various industries, that have decided to enter in different activities belonging to the PEV lifecycle, has been made. It is now interesting to study the players that are specialized in the installation, maintenance, operation and access of the charging stations.

As the market for electric vehicles in Italy is at an infant stage (figure 2.7), all the companies that decided to specialise in either CPO or EMSP activities are naturally young. Indeed, out of the 10 analysed companies, all of them are start-ups. From a geographic perspective, the majority of them come from Italy (80%) while the remaining 20% comes from Germany.

Figure 2.16 presents the activities performed by the analysed start-ups. It can be notices how thirty percent of the players are specialized in the retailing/resell of charging stations and their installation and maintenance. Of these, the only players that differentiate its offering from these two simple activities is Driwe. The Italian start-up also offer a retrofitting (i.e converting an ICE vehicle into a full-electric one) and a V2H (vehicle-to-home) service. Driwe is a pioneer in Italy, as it is the only one offering PEV drivers to have a bidirectional exchange of electricity between their car and home. The interest of the V2H is that it can work as additional battery for the home and provide energy in case of a blackout. The second most performed activity is the specialized CPO, in charge of both the installation and maintenance and of the charging stations management. An example is EVbility, that manages a network of 10 charging stations, that are accessible thanks to the EMSP RicaricaEV. A smaller number of players are instead performing both the CPO and EMSP activities, such as Emobitaly. Finally, 20% of the analysed start-ups are positioned as specialized EMSP. They will therefore need to close deal with specialized CPO in order to facilitate the charging station access to PEV drivers. An example of specialized EMSP is Plugsurfing. The German start-up has reached a deal with EVway to allow its users recharge in their vehicles in the stations managed the CPO.

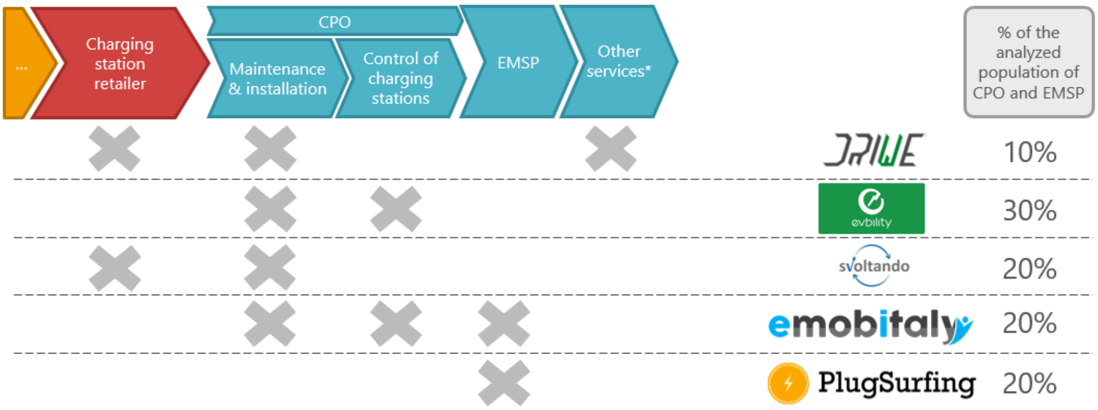


Figure 2.16: Activities performed by specialized CPO and EMSP actors in Italy

In conclusion, it can be said that each of these specialised actor plays a very important role in the PEV ecosystem. Companies performing only maintenance and charging station resale are very important for private users that want to purchase a charging station. Indeed, in general the players in the complementor value chain are born as B2B businesses and therefore less well-known to the larger public. Specialized EMSP are very good instead for privates or POI of interests that have few charging stations and therefore can manage the charging station by themselves but need of tools to make their infrastructure visible and easy to access by PEV drivers.

2.4. *The Italian recharge infrastructure*

From the previous section it has been noticed how many companies coming from different industries are including in their panel of activities also the CPO and/or EMSP ones. Indeed, in order to experience the take-off of plug-in electric vehicles over the traditional ones, not only the recharge infrastructure must be in place, but also the business models around it, have to be validated and appreciated by the customers. It is therefore important to have a particular focus on the CPO and EMSP theoretical roles, business model, and their utility.

The recharge of electric vehicles happens thanks to 4 different actors. The first one is the station owner. This entity can either be a private person, a point of interest (e.g. hotel, shopping mall, restaurant and so on) or a municipality. The second actor that is necessary is the energy distributor: the entity in charge of ensuring that the electric energy will flow through the charging station. Finally, the remaining two roles are the EMSP (Electric Mobility Service Provider) and CPO (Charging Point Operator). The EMSP is the actor in charge of granting the PEV drivers access to the charging stations and managing the customer relationship. In general, the activity will include managing the payment, an application for the identification of available stations, and any other service that could be valuable to the PEV driver. The CPO activity from a theoretical perspective encompasses the all the tasks related to management of charging stations. From the physical installation and maintenance to the day-to-day remote control of the station (busy/free/broken), measurement of the energy supplied by each station, control of the access and possibility to activate and disactivate it and payment to the infrastructure owner. Figure 2.17 and 2.18 summarize in a visual way the relationship between the different actors together with the sustained costs and price definition. In practice, it has been seen that the CPO role can be divided in two subsets of activities. From the more basic installation and maintenance, to the more complex management of the infrastructure. Nonetheless, from now on, with the term CPO we will identify the players performing both activities.

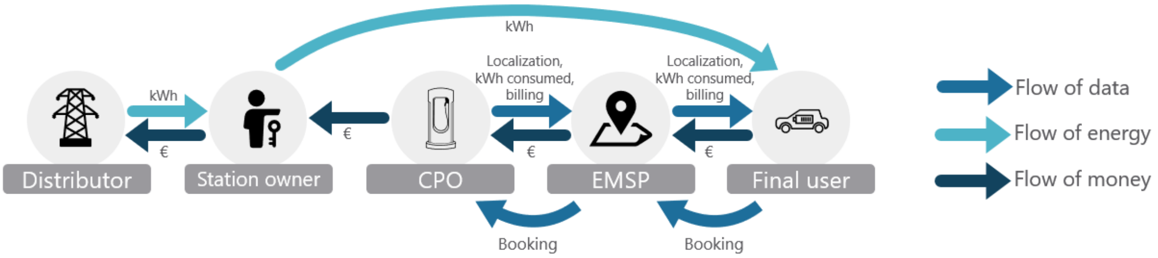


Figure 2.17: Exchange of information, money and electricity between the different actors.

From a theoretical standpoint, the CPO and EMSP are two different interdependent actors. The CPO needs an EMSP, not because without it, driver would not be able to start the recharge of the vehicles, but because it would be very painful. Indeed, all charging stations controlled by the same operator can be accessed with a common RFID card. This means that for each new driver willing to charge for the first time at the station, a CPO employee must provide the driver with the RFID card. This is of course impossible in case of network of charging stations that are spread over a territory. Furthermore, the EMSP is also in charge of acquiring new customers and ensuring the visibility of the charging point to a maximum number of drivers. On the other side, the EMSP needs the CPO as it services are based on the charging station it operates. It is also possible, when the number of charging stations to manage is very limited, that the owner also operates the stations and is not using a third-party CPO. This is, for example, the case of Repower. The utility performs the installation of stations to hotel and restaurant and the EMSP, while their operation is made by the POI. Therefore, normally an EMSP will close contracts with several CPO, so that its users can have access to a wider network of stations, and the CPO will close deals with EMSPs as a higher number of drivers can charge at its location (figure 2.19). Roaming between operators is also possible. Referring to figure 2.19, if CPO1 and CPO2 decide to allow the roaming between them, then the PEV driver1 without being client of the EMSP3, but by using its actual subscription to EMSP1 can recharge her car in the municipality (stations controlled by the CPO2).

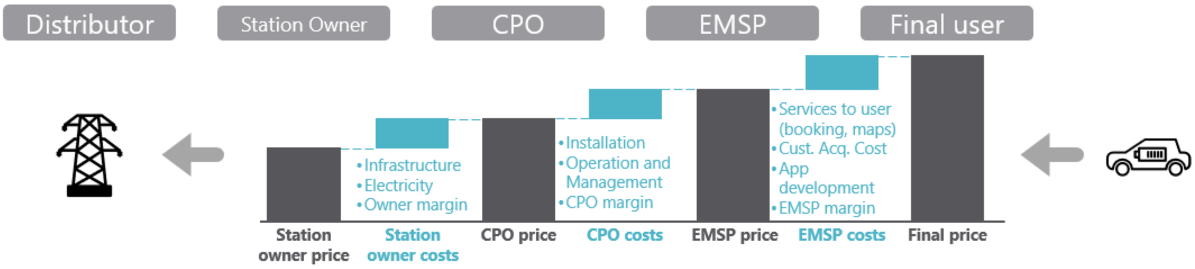


Figure 2.18: Costs and price definition in between the different actors in the recharge ecosystem

For what concerns price definition, figure 2.18 provides with a general idea of how they are made. In reality the situation is more complex and will depend from the bargaining power of the actors involved. Indeed, in some instances, the CPO might decide to pay for the whole or part of the infrastructure, despite not being the owner, because it believes that a station in this position, under his control might have a strategic importance. In an interview conducted with Mr. Pologruto (Iren), it came out that price definition is an issue that the players are trying to figure out. Should the station owner have bargaining power, it will be possible for him to define a tariff and based on this one the CPO and EMSP will add their mark-up. Otherwise, the CPO can impose a pricing to the station owner or the EMSP can impose a price to all the CPO.

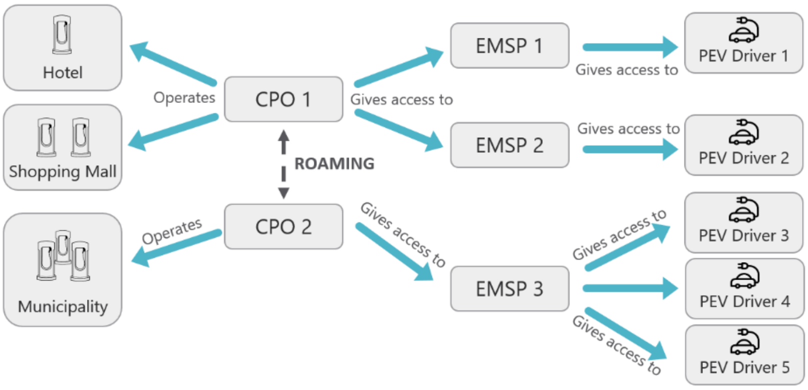
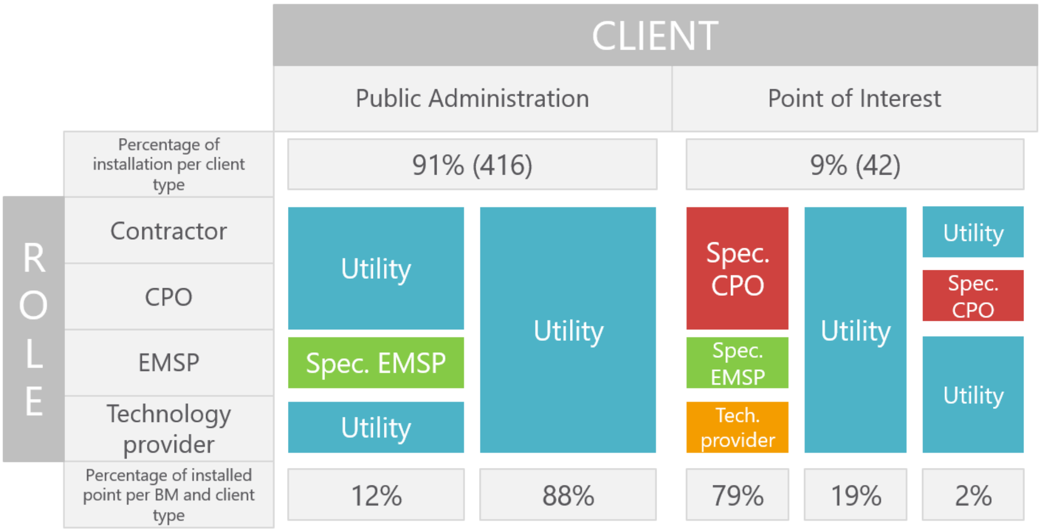


Figure 2.19: Contractual relationship between Station owner, CPO, EMSP and PEV drivers

Until now, the CPO and EMSP have been presented as two separate entities that depend the one from the other. Nonetheless, from the subsections 2.3.3 and 2.3.5, it is also known that some players (e.g. Enel for the energy value chain and Emobitaly as specialized player) are performing both the CPO and EMSP functions. It becomes therefore interesting to study which configuration is likely to become the winning one in the future. To do so, the evolution of the actors involved in the recharge infrastructure in Italy has been studied for the public and semi-public recharging. The analysis aims at identifying which players where performing which role across the years. The period of time considered starts from the year 2012 and ends in December 2018. This period of time has been divided in three phases. The first one includes the year 2012 and 2013, when the PEV diffusion was very low (figure 2.7), the second period goes from 2014 to 2016 and the third one includes the years 2017 and 2018. The charging points analysed are public and semi-public. Finally, out of the 2.108 existing recharging stations at the end of 2017 (Omniauto), 1105 have been studied. Before presenting the results of this research, the used terminology must be presented.

The figures 2.20, 2.21 and 2.22 present the entities involved in the charging business and their role, respectively for the period 2012-13, 2014-16 and 2017-18. In columns, the term client defines the actor that will pay for the project and hence also where the charging station will be installed. There are two types of clients: i) Public Entity, for example a municipality that will purchase and install stations on the public ground ii) Point Of Interest such as a supermarket that will install a station in its parking for the clients. In the first case, we will have public stations, whereas in the second semi-public. In the rows are shown the roles that the entity is performing. The contractor is the actor responsible for the whole project. It will be in charge of identifying the other necessary actors (e.g. CPO, EMSP and technology provider). The CPO is the entity in charge of managing the installed charging station, the EMSP manages the PEV recharge with the driver, and the technology provider is the entity that will provide the charging station. It is important to notice that the technology provider is not necessary producing the station, but a utility can operate as system integrator and provide by himself the technology.

During the period 2012-2013 (figure 2.20), it can be noticed that of the 458 installed stations, 416 (91%) were public while just the remaining 9% were installed in POI (Point Of Interest). It can also be noticed how the actors involved, whether in the case of a public or semi-public recharge, are different. If the client is a public administration, in 12% of the times, the Utility plays the role of contractor, CPO and technology provider, but the EMSP is left to a specialized player. This is for example the case of A2A or Hera (figure 2.14). Instead, in 88% of the cases, the utility becomes a system integrator, covering all the roles and becoming the single interface with the public administration. This is for example the case of Enel (figure 2.14). If instead, the clients are POI, the actors involved are different. In 79% of the cases, the contractor and CPO roles will be covered by a specialized CPO (e.g. EVbility, figure 2.6), the EMSP function will be taken by a specialized EMSP, such as PlugSurfing and the recharging stations will be provided by a company such as SCAME (figure 2.15). In 19% of the cases, the utility will take care of all the functions and in 2% of the times the utility will be the contractor, the EMSP and the technology provider, but the management of the station will be left to a specialized CPO. This is the case of Repower for example (figure 2.14), that has created Ricarica101: a network of luxury hotels, restaurants and other locations. In this particular situation, as the hotel is an isolated entity that will install no more than one or two stations, the management is made the clients himself and hence becomes a “specialized CPO”. This of course doesn’t imply that the hotel will become a CPO as a commercial activity. Instead, when the client is a POI and the utility takes care of all the roles or when the POI uses specific player for each function, it is the case of a large retailer (e.g. IKEA) that will install in all its parking a station. In this situation, the POI needs a “real” CPO, as EVbility or Enel, because of the complexity that comes from managing a network of stations spread over the territory. In conclusion we can see how for these two year most of the installed station were public with utilities playing all the roles. In case of semi-public stations, the preferred configuration was to has a specific player per each role.



		CLIENT				
		Public Administration		Point of Interest		
	Percentage of installation per client type	91% (416)		9% (42)		
ROLE	Contractor	Utility	Utility	Spec. CPO	Utility	Utility
	CPO					Spec. CPO
	EMSP	Spec. EMSP		Spec. EMSP		Utility
	Technology provider	Utility		Tech. provider		
	Percentage of installed point per BM and client type	12%	88%	79%	19%	2%

Figure 2.20: Distribution of public and semi-public installation and actors involved in the period 2012-13[10]

During the period 2014-2016 (figure 2.21), most of the stations installed were semi-public (73%). It can be noticed how the situation is reversed with respected to the 2012-13 period. Furthermore, there has been a proliferation of different configuration of actors. Indeed, for public administration there is the appearance of specialized players (CPO, EMSP and technology provider) taking care of the different roles, in 9% of the cases. Utility as system integrator remains the most popular one with 72% of the public stations being managed in that way. Finally, in 19% of the cases, the utility will be the CPO, contractor and technology provider, and will rely on an external EMSP. Also, for the semi-public stations, there is the appearance of a new configuration. In 7% of the cases, an entity performing both the CPO and EMSP appeared. An example of such an entity is Emobitaly (figure 2.16) that uses as technology provider ABB. The most popular configuration remains the one with a specialized player in each role. Nonetheless, the percentage of POI adopting this solution has decrease from the previous period: 79% in 2012-13 and 46% in 2014-16. Also, the utility as system integrator has been adopted in just 12% of the cases against 19% in 2012-13. The configuration where the utility being in charge of everything except of CPO activities has instead improved, moving from just 2% in the previous period to 35% in 2014-16.

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[10] The figure between brackets in the image represents the number of charging station installed for this type of client.

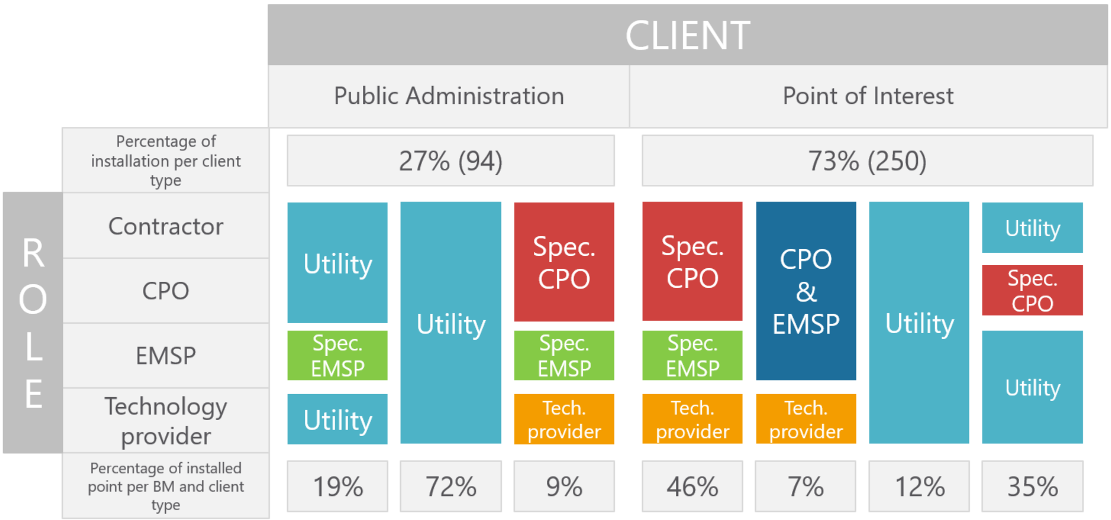

Figure 2.21: Distribution of public and semi-public installations and actors involved in the period 2014-16[11]

In figure 2.22 are presented the results for the period 2017-2018. In can be noticed how this time there is a more even distribution of stations for public and semi-public use. Indeed, 55% of them were commissioned by public administrations while 45% by POI. For what concerns public stations, a configuration that was previously used only by POI has been used also by public administrations: a single actor performing both the CPO and EMSP roles. Despite being still present, the number of public stations installed and managed by specific actors decreased. From an initial 9% in 2014-16, they now represent only 1%. At the expenses of this setting, the number of stations using utilities as CPO and technology provider and, having a specialized EMSP has steadily risen, moving from 12% in 2012-13 to 19% in 2014-16 and reaching 27% in 2017-18. Nonetheless, the preferred configuration by public administrations – 71% of the cases – is the utility playing all the roles, from the CPO to the technology provider. In the POI case, it can be noticed the disappearance of the business model were there was a specialized player for each role. In the same way, it can be noticed that the percentage of installations were the utility was a system integrator is steadily decreasing since the first period of study. In 2012-13, 19% of the installations adopted this setting, in 2014-16 they were 12% and in 2017-18 reached 6%. On the other side, since its appearance in 2013, the configuration in which the utility is in charge of the CPO and technology provider role, but the CPO is performed by the POI itself, hasn't stopped to increase, reaching 82% of installed charging stations in 2017-18.

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[11] The figure between brackets in the image represents the number of charging station installed for this type of client.

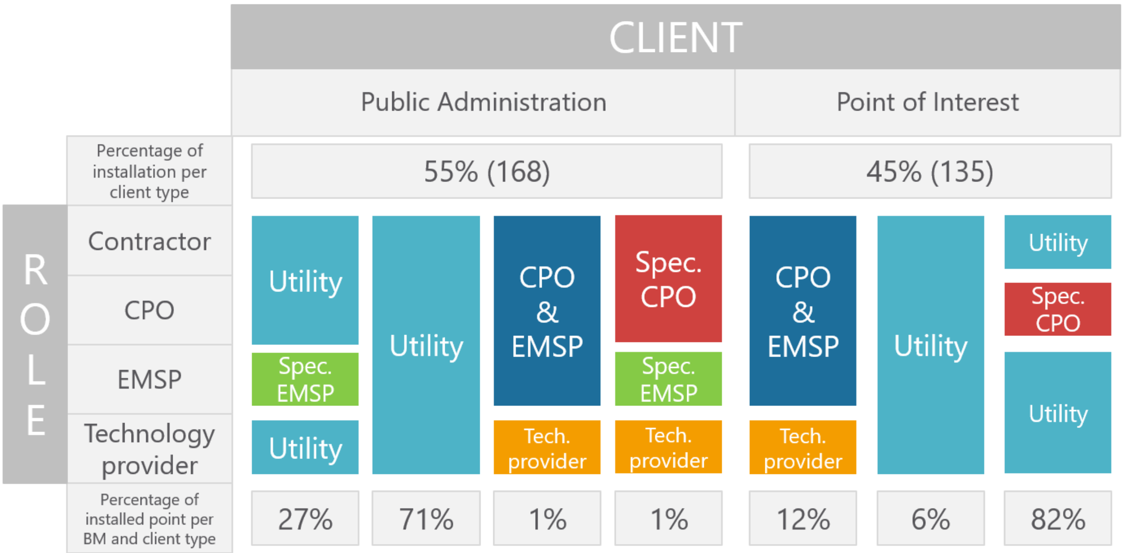

Figure 2.22: Distribution of public and semi-public installations and actors involved in the period 2017-18[12]

Several considerations can be made from these observations. The strengths of having a specialized player for each role, is that it ensures the highest level of competencies in each activity and the management of the charging stations is for sure better then when the POI does it. On the other side, the drawbacks are related to the infrastructure interoperability. As shown in figure 2.19, a specialized CPO will close contracts with different EMSP, to maximise the likelihood of the station to be used. Nonetheless, each EMSP can define its tariff and access methods which lead to a cumbersome recharging experience. Furthermore, specialized players are generally small, while public administrations tend to install several stations at the same time. Therefore, these players might lack of the financial and human resources to manages such quantities. This setting is adapted in case of small town or single shops that want to install one or two charging stations and expect to have always the same drivers using them.

The case of having a player performing both the CPO and EMSP role, is financially interesting for the player, as an intermediary is eliminated, leading to higher margins. The main advantage for the clients (public administration or POI) is that these actors have generally a larger userbases, which means a higher station utilization rate and higher earnings for the infrastructure owner. This configuration is used a lot in case of large shopping mall, retailers and supermarket chain (e.g. Esselunga) as the integrated players ensure that players will be present in all the territory and therefore offer homogeneity to the final users. Moreover, the POI

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[12] The figure between brackets in the image represents the number of charging station installed for this type of client.

will tend to prefer this configuration rather than the utility as system integrator, as in the former case it has higher bargaining power and can therefore obtain better prices.

If the utility performs the EMSP function and provides the technology but, the CPO is performed by the clients, PEV drivers will have a homogeneous recharge in all the stations installed by the utility. This situation is possible for hotels, restaurants, SPA, as the number of stations installed per location is limited (i.e. one or two). Therefore, the management of the infrastructure is easy and being in charge of it, reduces the station owner costs. On the other side, this configuration is not seen for other type of POI or public administrations as the utility proposing this solution target luxury locations to create an exclusive network of recharge (e.g. Repower).

Finally, the case in which the utility is a system integrator or when the utility is the CPO and provides the technology, is good when the client has a large number of stations and wants a single actor that takes care of the situation. This is why utilities are winning when the clients are medium and large public administrations. These actors will make call for tenders for the installation for many stations. Therefore, only utilities have the financial and human capacity to answer these requests. Furthermore, utilities are better suited to manage an important number of stations as they can monitor the load on the grid an deactivate the recharge, should it lead to a blackout. Finally, utilities have for sure an advantage in comparison to other players with public administrations as they already know how to deal with this type of entity.

In conclusion it can be noticed that different configurations are suited to different case (figure 2.23). Utilities as system integrator are better off when dealing with large public administrations. Integrated CPO and EMSP or specialized CPO with the utility in charge of the rest are suited wit POI clients. Nonetheless, the former configuration is work well in case of large shopping mall and retailers whereas the latter is good to create an exclusive network of locations where tourist can travel. Finally, it can be noticed how the configuration of having a specialized player for each activity is suited for very peculiar situations and might disappear in the future.

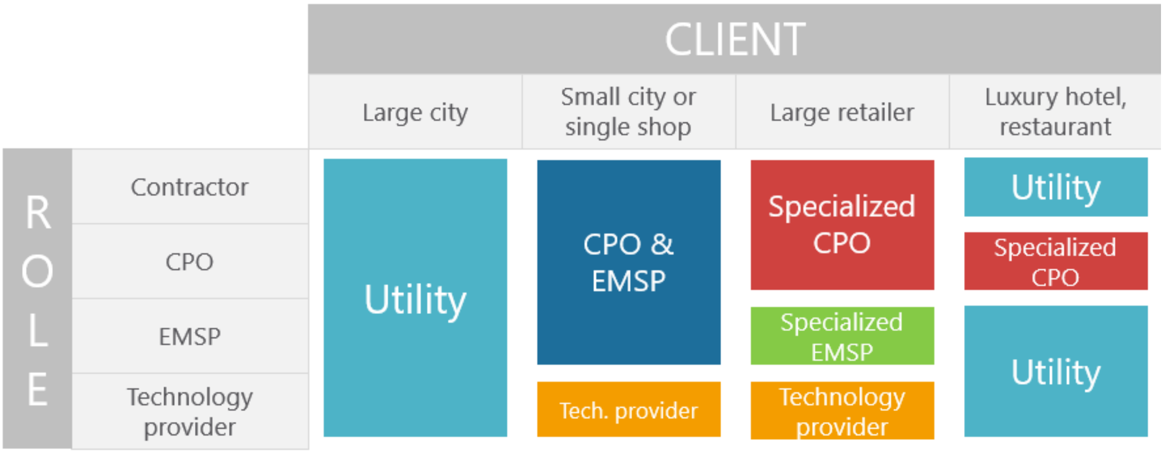

Figure 2.23: Preferred configuration of players managing the recharge infrastructure depending on the client type

2.5. *Conclusions*

In the introductory part of this chapter several theoretical frameworks have been explained in order to show the importance of an ecosystem analysis, when studying the diffusion of an innovation. Following to this section, the PEV diffusion at a worldwide level has been provided. The aim being to provide the reader with an understanding of the global and the Italian situation. Finally, the core of chapter has been treated: the identification and analysis of the ecosystem supporting the PEV diffusion in Italy. The ecosystem has been divided according to three different value chain: the automotive, energy and complementors. For each player, the activities that it is performing in the PEV lifecycle has been mapped. This led to several observations.

First of all, it has been noticed how among OEMs, the vast majority are incumbents while two are new entrants. Furthermore, 60% of the car manufacturers are solely involved in the PEV production and not in other activities. It has also been noticed how German OEMs despite not being directly involved in stages of the PEV lifecycle, through joint ventures they are developing a network of ultra-fast charging stations (Ionity) and also a roaming platform (Hubject) to improve interoperability. On the other side, it can be noticed how no Italian OEMs have yet produced PEV vehicles. The first one will be FCA with a BEV model of the FIAT 500, that will be launched in 2020. But, the fact that first automakers in term of sales in Italy (FIAT) is not producing PEV, is for sure limiting their diffusion in the country. This observation has also been confirmed by Sierzchula et al. (2014) in their study. Furthermore, since the initiative aimed at supporting the diffusion of PEV are developed by German carmakers (Ionity and Hubject), the later and in smaller quantity they will arrive in the Italian market, slowing even more the PEV diffusion. Indeed, Ionity will install just 30 stations in Italy against 80 in France. Furthermore, the first Ionity stations arrived in Italy in October 2018, very late with respect to the other European countries. It has also been noticed how due to the very slow evolution of the ecosystem supporting the PEV diffusion, no market disruption will happen, and incumbent players will remain in dominant position.

For battery manufacturers, it has been instead noticed how all the companies except for two are incumbents. The Chinese CATL, and the Swedish Northvolt are the only new entrants. Furthermore, from a geographic perspective, the biggest battery producers are Asian – with Chinese companies in the first place – and the biggest manufacturing plants are located in China too. This geographic concentration could become problematic for the PEV diffusion as there are signs of a potential battery shortage in the near future. The situation could lead to several possible scenarios: i) the diffusion of PEV in Italy and Europe is slowed due to battery shortage, ii) battery manufacturers will sell batteries to European OEMs at a premium price, leading to PEV final price increase, slowing down their diffusion; iii) battery manufacturers could supply only compatriot countries, leading to the entry of several Chinese and Asian players in the European market. There signs are already visible in South Korea, were an increasing amount of batteries is being kept for local sales (Bloomberg (2018)).

For the energy value chain, it has been noticed how utilities are very active in the PEV environment. Indeed, 92% of the analysed companies are performing other activities from their core one that pertain to the PEV lifecycle. In particular, most of them perform the two CPO activities (maintenance and management) or even both the CPO and EMSP roles. Some utilities, such as Repower, have instead a more peculiar positioning, offering only EMSP services. This ferment is positive as Italian utilities are supporting the development of the recharge infrastructure. As electric vehicles are a two-sided market, the wider is the stations network, the higher will be the PEV adoption. This positive correlation between the infrastructure density and the electric vehicle diffusion has been validated by many studies (Thiel et al. (2012), Gomez et al. (2017), Lieven (2015)).

Charging station manufacturers are mostly made of incumbent players (77%), followed by new entrants from another industry (14%) and then by new entrants (9%). This observation together with the fact that most manufacturers come from the electrical equipment business, lead to the conclusion that the type of innovation required to develop these stations is mostly incremental. From a geographic perspective, a lot of the charging terminal sold in Italy come from European companies – 36% of which are Italian – showing once more the ease with which they can be produced and therefore no need to use non-European supplier. If the development of a station is not influencing the diffusion of PEV, what has instead a significant impact is the existing sockets. It has been seen how the European Union has *de jure* imposed a standard for AC recharge (type 2) and is suggesting one for the DC one (CCS Combo 2). This homogeneity in the recharging socket will speed up the adoption process in Italy and throughout Europe as driver will no longer need to worry if a station is compatible with their car.

By looking at what specialized EMSP and CPO are doing, it has been noticed how all these players are new entry companies. Thirty percent of them are specialized in the resell, installation and maintenance of charging terminals. Another 30% is performing both CPO activities, while 20% are doing both EMSP and CPO roles and the remaining 20% is a specialized EMSP. Within these players there are some excellences that experiment innovative solutions. An example is Driwe, the only player in Italy offering vehicle-to-home and retrofitting of ICE vehicles.

Finally, from the recharging infrastructure analysis, it was possible to notice how no clear configuration of actors has emerged as winning either in the public of semi-public recharge. It is true that the preferred configuration for municipalities seems to be the one exploiting the utility competencies and letting them be in charge of all the roles, from the CPO to the technology provider. Instead if the client is a POI, two configurations are preferred depending on the client type. On one side, if the client is a large retailer, a specialized player performing both the CPO and EMSP is generally used, whereas if the POI is a luxury hotel, the utility will be in charge of the EMSP role, while the CPO one will be performed by the POI itself. If on one side, having all these possible combination of actors in the recharge ecosystem is positive as it demonstrates a great interest form companies to operate in this sector, on the other side in can slow down the PEV diffusion process. Indeed, this multitude of players creates problems of interoperability for drivers. Final users will need to have a different contract with each EMSP – either utility or specialized one – in order to make sure that they can recharge in most of the territory. Furthermore, most of the actors operate at the city level. For example, A2A installs and operates stations mainly in Milan and Brescia, which means that people travelling a lot need to be aware of the CPO and EMSP operating in the interested location but also create the necessary subscriptions. Actors like Hubject allow to recharge at whichever station without needing an EMSP subscription or the operator's RFID card. While they are widely diffused in the rest of Europe, in Italy only few CPO are partnering with these roaming platforms.

Therefore, it becomes evident how these difficulties in the recharge methodology are creating a major barrier to the PEV diffusion in Italy. This observation is also being supported by Caperello et al. (2013) research work that studied how difficulties in recharging could frustrate PEV driver and slow down diffusion.

In conclusion it can be said that the ecosystem supporting plug-in electric vehicles in Italy is very young and, in its development stage. Hence it is slowing down its diffusion. The lack of Italian automakers producing EV, the lag with which European initiatives reach the Italian ground (e.g. Fastned, Ionity…), the limited number of public recharging stations available in the territory together with the problem of interoperability are discouraging the diffusion of PHEV vehicles in Italy and are symptomatic of an Italian ecosystem that is not yet ready to support the PEV diffusion. Furthermore, it can be noticed how all these elements are creating a vicious circle. Indeed, the low diffusion of PEV in Italy is explained by before mentioned factors. In turn, low sales numbers push even more Italian OEMs and complementors coming from other countries (e.g. PlugSurfing, Ionity, Hubject, Fastned…) to enter late in the Italian market. Which slows down even more down the substitution of ICE vehicles by PEV. Finally, it can be noticed how the gap created between European battery manufacturers and Chinese ones could become problematic for the PEV diffusion, not only at an Italian, but European level. Nonetheless, while the Italian companies are not ready to support the PEV diffusion and are lagging behind with respect to what happens in major European countries, the direction that has been taken is the correct one. Indeed, the great number of Italian utilities involved in the PEV ecosystem and the presence of many new entrants in some businesses show interest and dynamism around this innovation.

An interesting point that should need further exploration is related to the winning entities in the recharging business. Indeed, it seems that utility will be the winners in the recharge business for public administrations, as it has been explained in section 2.4. Nonetheless, since PEV are different from ICE vehicles in term of utilization, it is not sure whether the recharge business will be where the profits are. Indeed, since PEV can be charged at home, it is not yet sure if public stations are really necessary in the long term. For sure in the short term a wide recharging infrastructure is necessary to cope with new adopters' range anxiety. Nonetheless, once drivers are used to the electric mobility, public stations usage might become limited, recharge at POI more common while most of the recharge will be performed at home.

3. Regression Analysis: the impact of macro-economic factors on Electric Vehicle adoption

3.1. *Introduction*

This chapter aims to respond to the following research question: i. “What are the macro-economic factors that are driving the Electrical Vehicles diffusion at an international level?”; ii. “Are there significant differences between the variables having a positive impact on BEV demand and those on PHEV?”; iii. “What policy measures can the Italian government put in place in order to foster their diffusion?”

This chapter has an important place in this research paper as, after having deeply analysed the Italian value chain of electrical vehicles and therefore the readiness of the country to adopt this new technological paradigm, it is important to give an international perspective to this paper. Indeed, the country readiness to adopt a new technology cannot be the only diver influencing its diffusion within it. For this reason, an international perspective has been taken, analysing the impact of macro-economic factors on the Electrical Vehicles diffusion. To do so, a cross-country multiple linear regression study for the year 2017 is made. This type of analysis aims at representing the relationship between an independent variable – the share of newly registered PEV over the total number of new car registrations – and several other dependent variables, by fitting a linear equation. Once the coefficients of each explanatory variables are identified, a statistical analysis is necessary in order to understand which of them have a significant impact on the response variable. The analysis is based on a panel of 35 selected countries, representing 94,3% of all 1.223.600 units of Electric Vehicles – both battery electric vehicles and plug-in hybrid electric vehicles – sold worldwide in 2017. This year has been chosen for conducting the regression analysis for several reasons. First of all, it represents the most recent year for which definitive sales level for all the analysed countries and for all engines type were available. Furthermore, it is the closest year for which macro-economic indicators – such as education level, electricity prices and so on – were accessible. Despite the number of available macro-economic indicators for the selected countries being wider for older years, this analysis has been made considering the diffusion level in 2017 as the number of both battery electric vehicles and plug-in hybrid electric vehicles sold was too low for many countries in previous years. This would have negatively impacted the results of our analysis as the number of observations would have been drastically reduced. On the other side, in 2017 the number of electric vehicles on the roads increased by 54%. Furthermore, for that same year, the number of PEV sold represented 58% of the total number of PEV circulating in the world, showing the real explosion that this type of vehicles had in 2017. The figure 3.1 shows the cumulated number of BEV and PHEV circulating worldwide from the year 2009 to 2017.

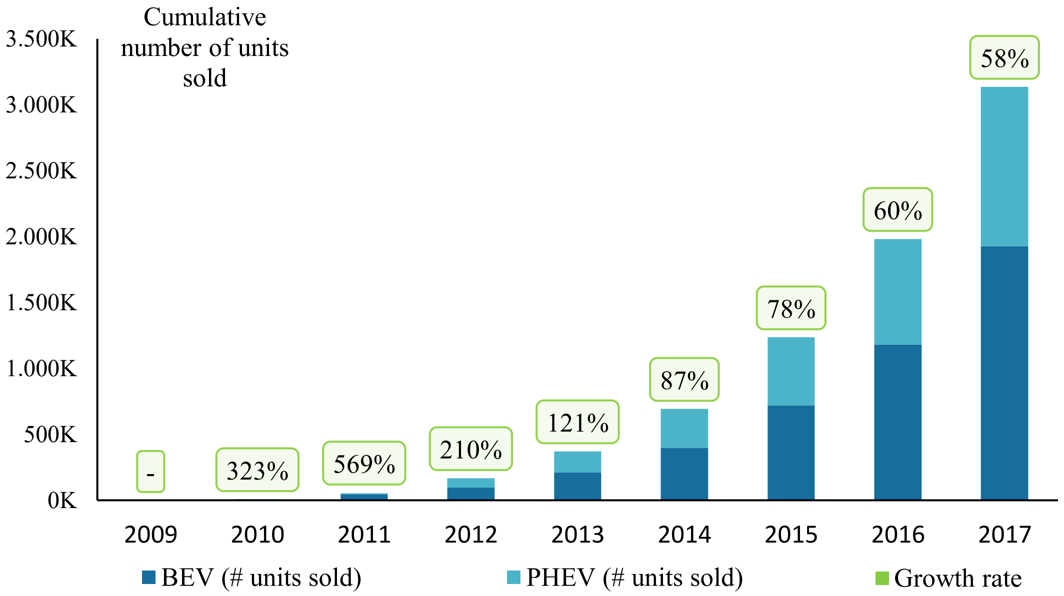

Figure 3.1: Cumulative number of PEV circulating worldwide[13]

This chapter will initially start by presenting the explanatory variables that have been selected for this regression study, why we have decided to omit some potential variables as well as the main hypotheses. It will follow by presenting for which countries the data has been collected and the models used. Section 3.3 will present the study results and in following one will contain the collusion and policy suggestions. Before starting it is important to make a precision. The purpose of this regression model is not to develop a forecasting tool for PEV sales, but it aims at assessing how macro-economic factors can influence plug-in electric vehicles diffusion.

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[13] Own elaboration of EAFO and IEA data

3.2. *Variables identification*

3.2.1. Response and Explanatory Variables

The Response variable whose evolution is being studied is the diffusion of electric vehicles in each country. It has been modelled as the fraction between the number of newly registered battery electric vehicles and plug-in hybrid electric vehicles over the total number newly registered passenger car in each country for the year 2017. For European and EFTA countries data has been retrieved from the European Alternative Fuel Observatory (EAFO) whereas for the non-European one the data comes from the Global EV Outlook (IEA (2018)).

The first explanatory variable that is being investigated is the education level. Several studies have identified educational level as a variable not influencing electrical vehicles adoption. Thiel et al. (2012) in the survey they conducted to assess the attitude of European car drivers towards electric vehicles, concluded that the people most likely to purchase an PEV where the one with the highest knowledge on this field or that wanted to change vehicles in the short term (in the next six months). Despite being considered, education did not seem to be a driving factor to PEV purchase. Similar results were obtained in Sierzchula et al. (2014) regression study. Nonetheless, Gomez at al. (2017) used "educational attainment as surrogate for propensity to adopt PEVs". Caperello et al. (2013) by analysing the demographic characteristics of the sample they surveyed, found out that PEV owners had higher level of education in comparison to the general population of San Diego. Similar results, suggesting that the higher the level of education, the bigger the propensity to adopt electric vehicles were obtained in Li et al. (2017) regression study. Given these contrasting results it is interesting to study the impact of educational level. The statistic used in order to represent the education level of each country is defined by share of population by educational attainment. Just the share of population having at least a tertiary education (bachelor, master and doctoral education) has been considered for this study, as for lower level of study, differences in share of population per educational level among countries would have been too small. This statistic comes from the OECD dataset for what concerns non-European countries whereas Eurostat has been used for European ones. The first hypothesis formulated is: the higher will be the education level the higher the diffusion of PEV in the country.

Electricity prices is the second variable that is being investigated. The consideration of this variables seems absolutely normal as, it represents one of the main operating costs that comes from the PEV usage, especially the longer is the holding period or the higher are the number of driven kilometres per year. Depending on the country and the type of vehicles – BEV or PHEV – the cost of refuelling over the whole vehicle's life ranges from 31% to 97% of refuelling costs that an ICE vehicle would have (Lévay et al. (2017)). Furthermore, in their study Palmer et al. (2017) concluded that the lower is the total cost of ownership the higher is the adoption rate. On the other side, the TCO has been found not to be representative on how people make decision (Wu et al. (2015)). Bounded rationality also plays an important role in the purchase decision of electric vehicles (Lévay et al. (2017)). Higher PEV upfront costs negatively influences consumers while the benefit that would have come from the ownership of it in the long term (i.e. lower operating costs) are not accounted during the purchasing decision. Therefore, it becomes interesting and non-banal to study the impact electricity prices on electric vehicles diffusion. The energy price considered is the one paid by households. Data for the analysed countries has been retrieved from several sources: Eurostat, Globalpetrolprices.com, Statista.com. All data has been converted in €/kWh using the February 2019 euro-to-currency exchange rate. The second hypothesis is that the lower will be the electricity price, the higher will be the diffusion of PEV in the country.

For similar reasons, gasoline pump price has been included into the independent variables aiming to explain PEV diffusion in a cross-country analysis. If, during the last decades, gasoline pump prices were not affecting the diffusion of car with thermal engine, as no other real alternatives were available, today, the situation might not be the same. Higher gasoline prices might push customers to move to oil-free alternatives (Li et al. 2017) while lower prices could delay the development of more performing batteries (Xiao Fu 2018), the range autonomy parity between PEV and ICE vehicles and therefore the diffusion of PEV. The data used comes from the World Bank open data, where the US-dollar/litre price has been converted in Euro/litre, using the February 2019 euro to US-dollar exchange rate. For this variable, it is expected that the higher will be the gasoline pump price, the higher will be the adoption level of PEV.

Greenhouse Gasses (GHG) are the main responsible for the global warming, with CO2 being one of the major components. Indeed, CO2 represented 82% of the GHG emissions in the US in 2016 (EPA – United States Environmental Protection Agency). On the other side, the transportation sector emits 27% of the GHG, and 44% of them are produced by passenger cars

(EEA (2018)). Therefore, not only PEV would help to decentralise the emission of CO2 from cities, but should they be recharged by using energy that has been produced through renewable sources, then they would also help in the overall reduction of GHG emissions. On the other side, consumers also have the possibility to install solar panels at their house in order to produce electric energy for free. Should this individual also own a PEV, she could recharge it for free. Within this context, it is interesting to study the percentage of energy that is produced from renewable sources for each country, expecting that an increase of it would lead to a wider diffusion of PEV as, on one side environmentally friendly consumer select it as a green option while other type of consumer could choose it in order to reduce the operating costs associated to the PEV ownership (Axsen et al. (2013)). The percentage of electrical energy produced from renewable sources over the total production of energy has been obtained by collecting and adapting data from several sources. The BP Statistical Review of World Energy (BP (2018)) was used to obtain the total energy (Terawatt-hours) generated by non-European countries. Total production for European countries was retrieved in the European Environment Agency (EEA) database. Two different databases have been used as neither of the two sources included data for all the analysed countries. Nonetheless, consistency between the numbers has been checked for the common countries. Finally, the information regarding the quantity of energy produced form renewable sources has been collected from the International Renewable Energy Agency (IRENA) open database. For Iceland the percentage has been directly obtained from the national center of statistics (Hagstofa Islands). The fifth hypothesis is that the higher is the quantity if energy produced from renewable sources, the higher the diffusion level of PEV.

Despite being in continuous improvement, the range provided by battery electric vehicles it is not yet comparable with the one provided by traditional, thermal engine cars. The former provides on average 200 km of range, while the latter 800 km (Gustafsson et al. 2015). In addition to this, the number of recharging stations per PEV is still not comparable with the one of ICE vehicles. The IEA (2018) in its Global EV Energy Outlook has identified for the year 2017 a ratio from 0,06 to 0,27 stations per electric car. In his paper Lieven (2015) showed how range anxiety is a real issue when considering PEV adoption. The paper reveals that independently from the driving distance, charging stations are an “absolute necessity” for PEV drivers. The problem of PEV range as limiting factor to its widespread diffusion is supported by many paper (Thiel et al. 2012, Gomez el at. 2017, Tsakalidis et al. 2018). On the other side, as Markkula et al. (2013) highlight, PEV owners might never use a public charging station as they can charge their vehicle at home. Therefore, comparing the charging infrastructure of EV and of ICE vehicles, as it has been made by the IEA (2018), is not correct. Furthermore, Donati et al. (2015) have studied the driving behaviour of PEV owners. Their study revealed that in 80% of the cases, PEV drivers where making trip shorter than 10km, lasting less than 22 minutes and the total number of kilometres driven per day were smaller than 50km. This last study, in conjunction with the limited range of PEV seems to suggest that these vehicles are well suited for the urban mobility. This claim is also supported by Bjerkan et al. (2016). For this reason, the percentage of urban population will be considered as an explanatory variable. The importance of this variable in explaining the PEV diffusion is not granted at all, as several studies suggest that limited range is a barrier to adoption regardless the driving distance. The data for this variable has been retrieved from the World Bank open data for the year 2017. The sixth hypothesis is the higher the percentage of population leaving in urban area the higher is the adoption rate of PEV.

If we consider the mere acquisition cost, electrical vehicles in general, but BEV in particular are more expensive than their ICE counterpart. Figure 3.2 compares the acquisition cost of two segment C cars – the full electric Nissan Leaf and the petrol engine Volkswagen Golf – and of two segment J cars – the thermal engine and plug-in hybrid version of the Mitsubishi Outlander – for selected countries. Several studies seem to support the claim that BEV and – in general PEV owners – have a high personal income (Langbroek et al. (2016), Bjerkan et al. (2016), McKinsey (2014)). Therefore, it is interesting to explore the possible relationship between personal income and electrical vehicle diffusion. At a country level, this indicator is translated into a correlation between the Gross Domestic Product (GDP) per capita and the PEV market penetration. The statistic used in this case is the GDP at Purchase Price Parity (PPP). This index makes the comparison fairer as it takes into consideration the difference in prices that exist for the same product among different countries. The data has been collected from the World Bank open database and values were converted in euro through the euro-to-US dollar exchange rate of February 2019. The seventh hypothesis is: the higher the GDP at Purchase Price Parity, the greater is the PEV diffusion.

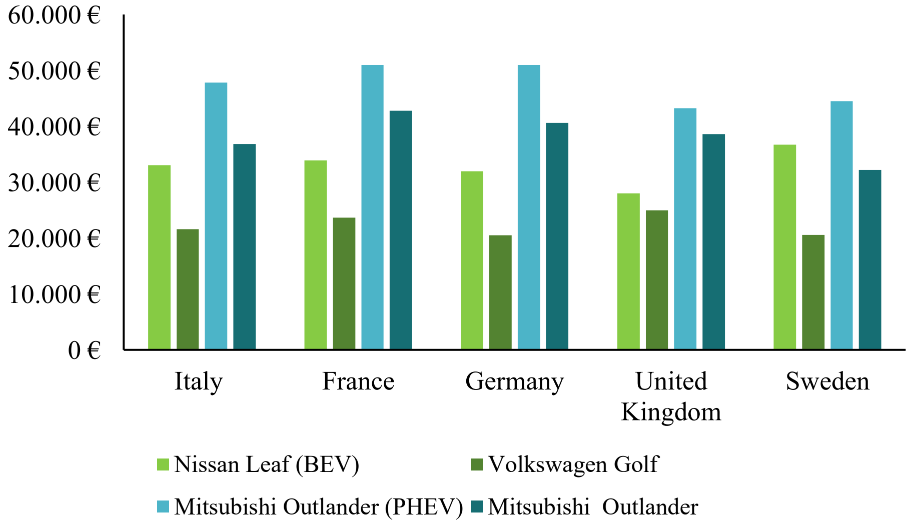

Figure 3.2: Purchase price comparison between competing alternatives of BEV, PHEV and ICE vehicles, across selected countries

As it has already been discussed, should PEV be recharged from electricity produced from renewable sources, the environmental impact of urban mobility is greatly reduced. Therefore, it is possible that PEV adopters are environmentally conscious users. Some studies seem to agree with this statement (Liu H. et al. (2015), McKinsey (2014)) while others have found that the absence of tailpipe emissions was not a relevant purchasing factor (Thiel et al. (2012), Gomez et al. (2017)). In order to evaluate this variable at a country level, the Environmental Performance Index (EPI) has been used. This score comes from a study jointly performed by the Yale Center for Environmental Law & Policy and The Center for International Earth Science Information Network (Columbia University). The EPI score compares the performance of different countries with respect to two macro policies objectives: environmental health and ecosystem vitality. From that, 10 major issues categories are identified, and 24 different indicators measured. Figure 3.3 illustrates for each macro objectives the sub-issues considered by the study and between bracket their weight[14]. Based on these, a score is calculated, representing the overall environmental performance of a country. This indicator is more interesting than just using as explanatory variable one environmental indicator (e.g. CO_2 per capita) as it gives a more comprehensive and exhaustive view of how well a country is doing from an environmental standpoint. Therefore, the higher is the EPI score, the better the country is performing from an environmental perspective. The data has been retrieved form the EPI 2016 study. The last hypothesis is that higher is the EPI score and therefore, the better is the

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[14] The size of each block in the figure is representative of the block weight.

country performing from an environmental standpoint, the higher is the diffusion of PEV in the country.

Table 3.1, at the end of this section gives an overview of the response and explanatory variables that have been used in the cross-country multiple regression model as well as the source used to retrieve the data.

Figure 3.3: Sunburst representing in the inner circle the policy objectives and in the outer one the addressed issues in the EPI study (weights into bracket)

3.2.2. Neglected variables

Many other variables could have been considered in the multiple linear regression model. This part presents a brief explanation of why some explanatory variables have been neglected.

The first and probably most obvious one is the vehicle cost, or the Total Cost of Ownership associated to it. Almost all studies related to the electrical vehicle diffusion show the TCO importance (Barth et al (2016), Liu D. et al. (2018), Mitropoulos et al. (2017), Mock and Yang (2014)). Within it fall studies trying to understand if direct subsidies are more effective then fiscal incentives – VAT exemption, one time registration tax, annual circulation tax – when looking at the EV diffusion (Lévay et al. 2017). This variable has not been included in the cross-country regression model as it does not satisfy the falsifiability criterion (Popper (1983)). Popper claims that any theory, in order to be considered scientific, should be refutable in logic terms. From this basic premises it should be possible to deduce the condition for at least one experiment that, should the theory be wrong, would demonstrate its wrongness. In this case, the statement "the lower is the TCO of PEV, the higher is the PEV diffusion" is not falsifiable. Therefore, it would not make sense to formulate any hypothesis on the relationship between this variable and the PEV diffusion.

The recharging vehicles infrastructure diffusion is another variable that is often cited to explain the diffusion of electric vehicles (Gomez et al. (2017), Lieven (2015), Sierzchula et al. (2014)). Here again, this variable has not been considered as it does not satisfy the falsifiability criterion.

The las last variable that is not directly present in the regression analysis is the emission of CO2 per capita. This variable is interesting to study as higher level of pollution might trigger the population to turn to more sustainable mobility alternative as electric vehicles. In reality this variable has not been neglect, but it is already included in the EPI (Environmental Performance Index) within the Air Quality section. Therefore, introducing CO2 emission per capita as a new variable would have made the regression model wrong since explanatory variables would no longer be independent. The EPI has been preferred to the simpler CO2 emission per capita as it gives a more comprehensive view of how the country is performing overall form an environmental standpoint.

Variable	**Description of the variable**	**Source**
PEV Diffusion	Diffusion of electric vehicles as the ration between the number of newly registered BEV and PHEV over the total number of newly registered car, %	EAFO (2017), IEA, Global EV Outlook 2018
Education	Percentage of the population having at least a tertiary education (bachelor, master and doctoral education), %	OECD, Eurostat
Electricity price	Price of electricity to household expressed in €/kWh	Eurostat, globalpetrolprices.com, Statista.com
Gasoline price	Price of gasoline at the filling station expressed in €/liter	World Bank
Share renewable energy	Percentage of energy that has been produced from renewable sources (including hydroelectric) over the total quantity of electric energy produced, %	European Environment Agency (EEA), BP Statistical Review of World Energy (BP (2018)), International Renewable Energy Agency (IRENA), Iceland National Center of Statistics (Hagstofa Islands)
Urban population	Percentage of the population living in urban areas over the total population, %	World Bank
GDP	GDP per capita measured at Purchase Price Parity, €	World Bank
EPI	Environmental Performance Index, index evaluating the overall performance of a country form an environmental standpoint	EPI

Table 3.1: Response and explanatory variables and sources

3.3. *The regression analysis*

Regression analysis are conducted in several steps. First of all, there is the formulation of the hypothesis and the identification of the explanatory variables. To this initial part follows the individuation of the data, for both the response variable and the explanatory ones. These parts have been covered in the former section. After that, there is the identification of the model (simple model, linear model, non-linear models), the estimation of the parameters, the verification of the model and the interpretation of it.

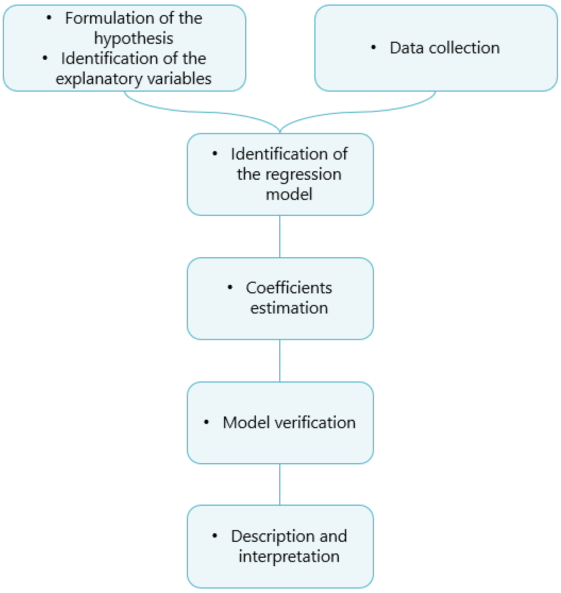

Figure 3.4: Steps involved in a regression analysis

This section will start by briefly presenting theoretical concepts behind the regression. It will then follow by testing the explanatory variables independence and finally will presenting, one after the other, the models used and their results.

3.3.1. Theoretical reminder: The Multiple Linear Regression

The objective of a regression analysis is to study the dependence of a quantitative variable Y with p quantitative variables X_1, X_2, X_3, X_4, …, X_p and a constant. Therefore, the available data will be presented in the following manner:

$$\begin{bmatrix} y_1 \\ \dots \\ y_n \end{bmatrix} ; \begin{bmatrix} x_{1,1} & \cdots & x_{1,p} \\ \vdots & \ddots & \vdots \\ x_{n,1} & \cdots & x_{n,p} \end{bmatrix}$$

- The symbol Y represents the dependent variable or response variable and is the one that the model tries to explain.
- $X_1, X_2, X_3, X_4, \dots, X_p$ are the variables used to explain the evolution of the response variable and they are called explanatory or independent variables
- n is the number of observations or the sample size

Supposing that a relationship between Y and $X_1, \dots, X_p$ exists, is known and linear, it would be represented by the following equation:

$$Y = f(X_1, X_2, X_3, \dots, X_p) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_p X_p + \varepsilon \quad (3.1)$$

Where β_0 represents the Y-intercept, $\beta_1, \dots, \beta_p$ are respectively the coefficients of the explanatory variables $X_1, \dots, X_p$ and ε is the casual error.

The multiple linear regression uses n observations to determine the best possible estimation (equation 2.2) of the regression line by minimizing the sum of the squared casual errors (equation 2.3) between the values of the response variable Y and the predicted values by the line in correspondence of the values of the explanatory variables $x_{1,1}, \dots, x_{n,p}$.

$$\hat{y} = b_0 + b_1 x_1 + \dots + b_b x_p \quad (3.2)$$

$$\varepsilon_i = Y_i - \hat{Y}_i \quad (3.3)$$

Where $b_0, b_1, \dots, b_b$ are estimates of the coefficients $\beta_0, \beta_1, .., \beta_p$ and ε_i is the casual error.

Once the estimated line of regression (equation 3.2) has been obtained, several elements must be analysed in order to understand how well this line is able to represent the observations. Residuals are defined as the difference between the regression line and the estimated one (equation 2.4).

$$Residual_i = y_i - \hat{y}_i \quad (3.4)$$

By developing this equation, it is possible to obtain the coefficient of determination R^2 – always included between 0 and 1 – that measures how much of the total observed variability for the response variable Y, that is being explained with the explanatory variables $x_{i,1}, \dots, x_{n,p}$, can be attributed to the estimated line of regression (equation 3.2). As shown in the following formula, the coefficient of determination is expressed as the ration between the variability due to the regression line and the total variability:

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (3.5)$$

Should R^2 be equal to 0, then there is no variability due to the regression line, meaning that the regression line has no capacity in explaining the data. On the other side, should R^2 be equal to 1, the variability due to the regression line coincides with the total variability observed. In this case the residual variability is zero and therefore all the estimated points (and so also the observed ones) are exactly on the regression line.

When performing a simple linear regression – there is just one explanatory variable – the coefficient of determination is the correct indicator to understand how well the regression line fits the observed data. The problem with this indicator when performing a multiple linear regression – more than one explanatory variable – is that R^2 increases automatically as new variables are added, independently if these latter improve or not the explanatory power of the equation. Therefore, in multiple linear regression analysis the adjusted coefficient of determination – adjusted R^2 – should be used. This indicator is once again included between 0 and 1, but its value will increase only when a variable that improves the explanatory power of the model is inserted. The adjusted R^2 equation is the following:

$$Adjusted\ R^2 = 1 - (1 - R^2)\left[\frac{n-1}{n-(p+1)}\right] \quad (3.6)$$

With p being the number of explanatory variables used in the model and n the number of different observations.

3.3.2. Independence test on the explanatory variables

As presented in figure 3.4, prior to the identification of the regression model it is necessary to assess whether the explanatory variables are independent. A preliminary test to verify the independence between the explanatory variables is to plot the correlation matrix. This matrix is presented in table 3.2 and shows in each cell the Pearson's correlation coefficient (equation 3.7). This indicator is included between -1 and +1 and measures the extent to which a linear relationship exists between two variables. Therefore, a coefficient of +1 indicates perfect increasing linear relationship between the two variables whereas a value of -1 indicate a perfect decreasing linear relationship. The limit of this test is that it is only able to represent the extent to which two variables are correlated to one another while it doesn't give information on the dependence between them.

$$\text{Sample correlation coefficient} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (3.7)$$

Where X and Y are two variables for which n different observations, respectively represented by x_i and y_i, and whose average value are indicated with the symbols are $\bar{x}$ and $\bar{y}$.

	Education	**Electricity prices**	**Gasoline prices**	**Share renewable energy**	**Urban population**	**GDP per capita**	**EPI**
Education	1						
Electricity prices	0,12	1					
Gasoline prices	-0,04	0,48	1				
Share renewable energy	0,17	0,13	0,38	1			
Urban population	0,50	0,25	0,28	0,04	1		
GDP per capita	0,51	0,32	0,20	0,21	0,44	1	
EPI	-0,26	-0,35	-0,39	-0,40	-0,20	-0,30	1

Table 3.2: Correlation matrix of the explanatory variables

Since for all the explanatory variables the correlation coefficients are low (<0,6) it can be assumed that they are weakly correlated. Nonetheless, a pairwise correlation analysis to spot multicollinearity might be insufficient. Indeed, a correlation between two factors may not exist, but a linear dependence among more variables could. In order to tackle this eventuality, a further test is performed. This test consists in calculating the Tolerance and VIF – Variance Inflated Factor – for the different coefficients of the regression model. It can be shown that the variance of the generic estimated factor b_k (equation 3.8) can be represented as follow:

$$Var(b_k) = \frac{\sigma^2}{\sum_{i=1}^{n}(x_{ik}-\bar{x}_k)^2} \times \frac{1}{1-R_k^2} \quad (3.8)$$

And the minimum possible value for this variance is:

$$Var(b_k)_{min} = \frac{\sigma^2}{\sum_{i=1}^{n}(x_{ik}-\bar{x}_k)^2} \qquad (3.9)$$

Where R_k^2 represents the R^2 (equation 3.5) when the explanatory variable X_k is regressed on the remaining explanatory variables (the response variable is not considered). Therefore, R_k^2 represent how much of the variability for the variable X_k is being explained by the remaining explanatory variables. Hence, the higher is R_k^2 , the higher is the linear dependence between X_k and the other explanatory variables.

As its name suggests, the VIF (Variance Inflation Factor) represents how much variance of the estimated factor is inflated. This inflation is represented by the ratio between the factor variance (equation 3.8) and the minimum value it can take (equation 3.9). Therefore, the VIF formula for a generic k^{th} explanatory variable is:

$$VIF_k = \frac{1}{1-R_k^2} \qquad (3.10)$$

From what has just been said, it naturally follows that the higher is the VIF_k the more the explanatory variable X_k is correlated with the other explanatory variables in the model (i.e. the higher is the multicollinearity). The Tolerance is just the reciprocal of the VIF but has the same meaning: the smaller is this number, the higher is the correlation of the evaluated explanatory variable with the remaining ones. In table 3.3 are reported the value of Tolerance and VIF for the explanatory variables that have been identified in the subsection 3.2.1.

	Education	**Electricity price**	**Gasoline price**	**Share renewable energy**	**Urban population**	**GDP per capita**	**EPI**
Tolerance	0,55	0,69	0,55	0,70	0,60	0,62	0,70
V.I.F.	1,82	1,45	1,82	1,43	1,66	1,60	1,42

Table 3.3: Tolerance and Variance Inflated Factor (VIF) of the explanatory variables

As stated by Hair et al. (2010), a general threshold for VIF values is 10 (or 0,1 for tolerance). Higher level of VIF (or lower for tolerance) always indicate a problem with multicollinearity. Nonetheless, problem might also appear at lower level of VIF (higher level of tolerance). Indeed, the authors suggest taking as threshold values between 3 to 5 for VIF, especially when the number of observation available are limited. From the table above, it is possible to notice that for all the explanatory variables the VIF values do not exceed neither the 10 nor the 3 thresholds. Therefore, it is possible to conclude that the considered variables are not subject to multicollinearity.

3.3.3. Basic multiple linear regression model

Since it has been shown that the explanatory variables are independent, it is possible to continue in the flow presented in figure 3.4 and proceed with the identification of the regression model. For this initial cross-country multiple linear regression analysis, data has been collected for the variables presented in table 3.1 for 35 countries comprising both European countries and non-European one. The countries considered in this analysis are the following: Austria, Belgium, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom and United Stated of America. The model used in this initial analysis is the following one:

$$\begin{gathered} Diffusion\ PEV = \beta_0 + \beta_1(EDUCATION) + \beta_2(ELECTRICITY\ PRICE) + \\ \beta_3(GASOLINE\ PRICE) + \beta_4(SHARE\ RENEWABLE\ ENERGY) + \\ \beta_5(URBAN\ POPULATION) + \beta_6(GDP\ PER\ CAPITA) + \beta_7(EPI) + \varepsilon \end{gathered} \tag{3.11}$$

In table 3.4 several key indicators are computed for the response and explanatory variables. For the Electric vehicles diffusion, the maximum value is 39,2% (Norway), the minimum 0,2% (Czech Republic), the average 3% and the coefficient of variation (CV) is 235%. The coefficient of variation is the ration between the standard deviation and the mean and shows the dispersion of the data. For the share of population having at least the tertiary education, the average is 35%, the CV 29% with a maximum value of 56,7% (Canada) and minimum of 9,7% (China). The electricity prices to households are on average 0,17€/kWh, with a maximum price of 0,30€/kWh (Germany), a minimum price of 0,07€/kWh (China) and a CV of 34%. The gasoline prices at the gas station goes from a maximum of 1,56€/l in Norway, to a minimum of 0,62€/l in the United States. The average value for the selected countries is of 1,14€/l and the coefficient of variation of 18%. The percentage of energy that has been produced from renewable sources (including hydroelectric) over the total quantity of electric energy produced, is on average at 34% and has a CV of 71%. The maximum share is reached in Iceland where 100% of the energy comes from renewable sources whereas the minimum is attained in South Korea with 2,8%. The percentage of urban population over the total population is on average 76% with a CV of 17%, a maximum value of 98% in Belgium and a minimum of 53,8% in Slovak Republic. For the GDP per capita the average number is 37.897€ and the CV is of 38%. The highest GDP per capita is of 91.004€ in Luxembourg while the smallest is 14.743€ in China. Finally, the EPI score goes from a maximum of 91 for Iceland to a minimum of 65 for China. The average value is of 85 and the CV of 6%. From these numbers it can clearly be seen that the "diffusion of PEV" variable has one with highest dispersion (CV) while all the explanatory variables present a coefficient of variation of one order of magnitude lower. This fact stresses the importance of running a multivariate regression as no single variable would be able to explain by himself the variability of the electric vehicles' diffusion from a cross country perspective.

	Diffusion PEV	**Education**	**Electricity prices (€/kWh)**	**Gasoline prices (€/l)**	**Share renewable energy**	**Urban population**	**GPD per capita (€)**	**EPI**
Max	39,2%	56,7%	0,30	1,56	100,0%	98,0%	91.004	91
Min	0,2%	9,7%	0,07	0,62	2,8%	53,8%	14.743	65
Average	3%	35%	0,17	1,14	34%	76%	37.897	85
Standard Deviation	7%	10%	0,06	0,21	25%	13%	14.571	5
CV	253%	29%	34%	18%	71%	17%	38%	6%

Table 3.4: Statistical variations for the explanatory and response variables

By running the regression analysis, it can be seen that this model presents an R^2 of 57% and an adjusted R^2 of 46%. As expected, the R^2 is higher than the adjusted one. This value of adjusted R^2 shows that the considered explanatory variables are able to explain 46% of the variability of the response variable. This value is good enough as the aim of this regression is not to develop a forecasting tool for the diffusion of electric vehicles for different countries, but it is to assess which variables impact the diffusion of PEV at a macroscopic level. Regression statistics are summarized in table 3.5.

Regression statistics	
Multiple R	0,75
R Square	0,57
Adjusted R Square	0,46
Standard Errors	0,05
Observations	35

Table 3.5: Fit statistics for the basic regression model

Referring to table 3.6, the F-test can be performed. This test compares the specified model with one that uses no explanatory variables (intercept-only model). The intercept only model is a model in which the coefficients of the explanatory variables are all set equal and identical to zero; that is: $\beta_1 = \cdots = \beta_7 = 0$. The null hypothesis of the F-test is that the used model and the model with no predictors provide the same fit level. The alternative hypothesis says that the used regression model fits better the data then an intercept only model. By setting a significance level 5%, it can be seen that the p-value is of 0,0008 and therefore the null hypothesis is rejected. It can be then concluded with a confidence level of 95% that the model presented in equation 3.11 fits better the data than the intercept-only model.

	Degree of freedom	SS	MS	F	P-value
Regression	7	0,089	0,013	5,12	0,0008
Residuals	27	0,067	0,0025		
Total	34	0,156			

Table 3.6: ANOVA results

Referring to table 3.7, most of the initial hypothesis are confirmed. The education coefficient is positive, meaning that to a share of population with tertiary education corresponds a higher level of PEV diffusion. The electricity prices coefficient is negative therefore a higher electricity costs pushes down the diffusion of EV. Whereas the higher is the gasoline price the higher the PEV demand as it presents a positive coefficient. The same is valid for the share of renewable energy: the higher is the proportion of clean to total energy produced, the higher is the penetration of PEV. Finally, also for Urban population the initial hypothesis has been confirmed: the higher the share of the population leaving in cities, the higher is the PEV diffusion. Differently from the initial hypothesis, the EPI score is negative, meaning that the worse a country is doing from an environmental perspective the higher is the diffusion of electric vehicles.

By setting a significance level at 5%, just the gasoline price and the share of energy produced from renewable source happen to be statistically significant; with P-values of 0,017 and 0,001 respectively. Thus, only these two variables affect positively the diffusion of PEV. These results are in line with what Li et al. (2017) and Axsen et al. (2013) stated in their studies. On one side, a higher gasoline price will push people to adopt plug-in electric vehicles as they would no longer rely – in case of BEV – or rely on a lesser extent – in case of PHEV – to gasoline and therefore reduce the car operating costs. On the other side, the reason why a higher share in electric energy produced from renewable sources is correlated to higher diffusion of PEV might be attributed to the fact that drivers can produce the electric energy by themselves – through solar panel – and therefore reduce even more the car operating cost. Another reason could be that, in order for PEV to keep their promises to reduce air pollution, they must be recharged with energy produced form renewable sources. Hence PEV are adopted where a real improvement for the air quality is possible.

	Coefficient	**P-value**
Intercept	0,059	0,707
Education	0,064	0,568
Electricity prices	-0,331	0,076
Gasoline prices	0,141	0,017
Share renewable energy	0,148	0,001
Urban population	0,030	0,731
GDP per capita	7,41E-07	0,327
EPI score	-0,003	0,128

Table 3.7: Regression coefficients

Referring to table 3.5 we can see that the multiple R score is of 0,75. This indicator measures how well how well the response variable can be predicted by using a linear function. This result might seem good enough given that our purpose is not to forecast the diffusion of PEV but just to identify the macro-variables that influence its adoption. Nonetheless, if this result is read together with the Adjusted R Square of the model (0,46) and the graphical representation of the diffusion of PEV for the analysed countries (figure 3.5), it is visible that the model that has been presented in equation 3.11 is not appropriate. Once again, the choice to improve the regression model through a transformation does not aims to improve the forecasting accuracy, but to understand whether other variables play a significant impact in the PEV diffusion.

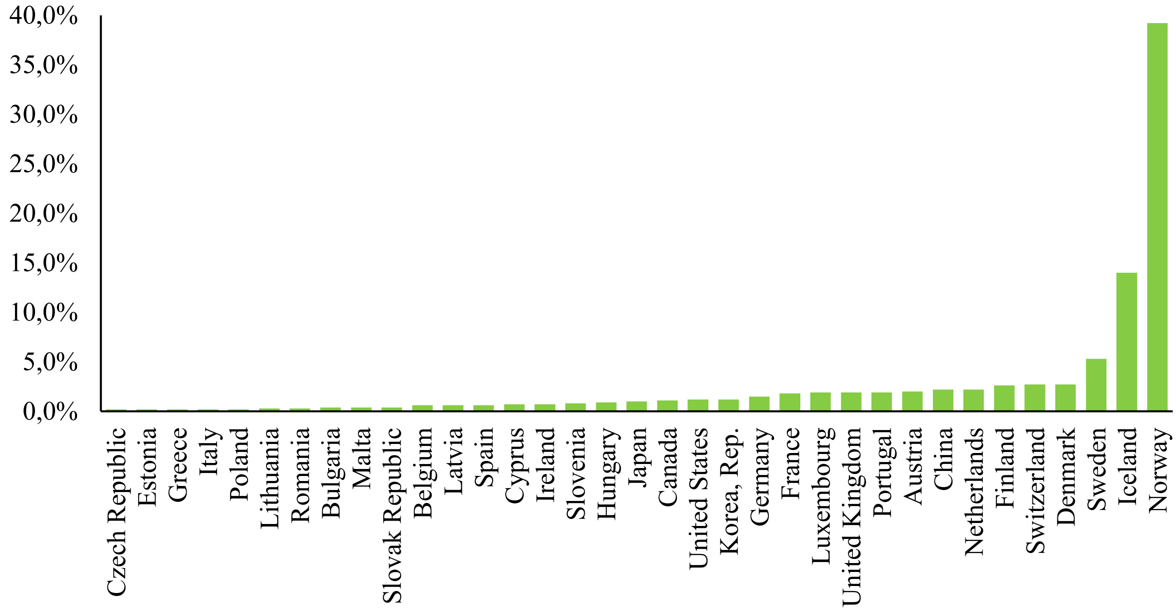

Figure 3.5: EV diffusion for the different countries under evaluation

3.3.4. Logit transformation

In order for the multiple linear regression to better fit the PEV diffusion data, a logit transformation of the dependent variable is made. This procedure aims to normalize the distribution of the EV diffusion. This type of transformation is possible when the data is defined on a bounded outcome score – that is a finite interval – and is U-shaped or J-shaped (Lesaffre et al. 2007). In this case, the PEV diffusion data, being a ratio between the number of newly registered BEV and PHEV over the total number of newly registered car is defined on a [0;1] interval (i.e. a bounded outcome score) and the data, as shown in figure 3.5, are skewed to the left. Hence the transformation can be applied. The resulting model is the following:

$$\begin{gathered} LN(Diffusion\ PEV) = \beta_0 + \beta_1(EDUCATION) + \beta_2(ELECTRICITY\ PRICE) + \\ \beta_3(GASOLINE\ PRICE) + \beta_4(SHARE\ RENEWABLE\ ENERGY) + \\ \beta_5(URBAN\ POPULATION) + \beta_6(GDP\ PER\ CAPITA) + \beta_7(EPI) + \varepsilon \end{gathered} \tag{3.12}$$

Apart from this transformation all the other aspects presented in the previous model remain the same. Indeed, the data collected, and the countries analysed remain unchanged. By running the multivariate regression analysis with the new model, R^2 is of 65% against a 57% of the previous model, the adjusted R^2 goes from 46% with the simple model to 56% with the transformed one. Therefore, an improvement of the model in explaining the variability of the transformed response variable can be noticed. Once again, this value is more than enough for the purpose that defined for the regression analysis. As expected, also the multiple R statistic, increased its value, reaching 0,8. Showing an improvement in how the response variable can be predicted by using a linear function.

Regression statistics	
Multiple R	0,80
R Square	0,65
Adjusted R Square	0,56
Standard Errors	0,79
Observations	35

Table 3.8: Fit statistics for the transformed regression model

Referring to table 3.9, the F-test can be performed. By setting a significance level 5%, it can be seen that the p-value is of 6,67E-5 and therefore the null hypothesis is rejected. It can be concluded with a confidence level of 95% that the model presented in equation 3.12 fits better the data than the intercept-only model. Furthermore, it can be noticed that the sum of square (SS) of the regression model is almost twice as the one of the residuals. The smaller is the Residual SS compared to the Total SS, the better the model fits the data. This statistic proves once more how the transformed model is better at explaining the data then the simpler version.

	Degree of freedom	SS	MS	F	P-value
Regression	7	32	4,57	7,22	6,67E-5
Residuals	27	17,08	0,63		
Total	34	49,08			

Table 3.9: ANOVA results for the transformed regression model

Referring to table 3.10, it can be seen how the explanatory variables that are now statistically significant changed from the previous model. The variable “gasoline prices” is no longer statistically significant while it was for the basic model. This observation is consistent with what has been found by Sierzchula et al. (2014) and Li et al. (2017). A potential reason behind this change is that gasoline price might be a decisive factor to choose a full electric vehicle (BEV) while the demand for PHEV is not influenced by this variable as this car still runs on gasoline. GDP per capita has instead become a statistically significant variable. Therefore, to a higher country wealth leads a higher diffusion of EV. The coefficient in this case is very small as the GPD in comparison to the diffusion is several orders of magnitude bigger. The EPI score becomes also statistically significant, with a P-value of 0,0279. What is interesting to notice is that the coefficient of the EPI score in negative, meaning that an increase in it will lead to a decrease of the EV diffusion. This result goes against the initial hypothesis as it was expected that to a higher environmental performance would follow a higher in diffusion of EV. In order to assess whether the sign of this coefficient was due to an outlier, the whole dataset as been analysed. China has been identified as a potential outlier as it presents one the higher EV diffusions while having the smallest EPI score of the whole dataset (table 3.4). Despite a new regression being run after eliminating this record, the sign of the EPI score regression coefficient remained negative. In order to be sure of this counterintuitive result, the importance of the EPI score for explaining the diffusion of EV has been tested. The model presented in equation 3.12 has been modified by eliminating the explanatory variable “EPI score” and the regression has been run again. The resulting regression statistics for this latter regression shows that the absence of the EPI variable reduces the adjusted R^2 by 7 percentage points (table 3.11). As it is known the adjusted R^2 increases only if a variable with explanatory power is added. It can then be concluded that the EPI score is a relevant variable that cannot be excluded and that the negative sign of its coefficient cannot be associated to an outlier. Therefore, one possible reason behind this sign could be that countries that are lagging behind from an environmental standpoint try to put in place incentives to push a more sustainable way of moving. This is for example what is happening in China, where incentives are granted to EV producer and consumers (Forbes (2018)).

Nonetheless, it is important to notice that several non-negligible differences exist between BEV and PHEV. As it has already been pointed out, gasoline is one of them as the former don’t use it while the latter still heavily relies on gasoline. Furthermore, as shown in figure 3.6, comparable models are consistently more expensive in the full electric version if compared with the plug-in hybrid one. As of today, range is also an important differentiating factor between these two technologies. It interesting therefore to study what are the statistically significant variables if we increase the level of detail and distinguish between the BEV diffusion and PHEV diffusion.

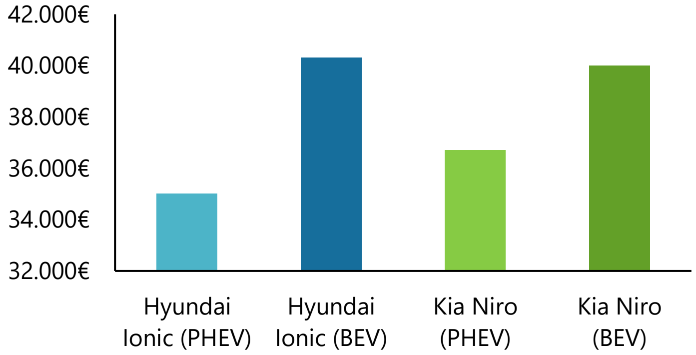

Figure 3.6: Price comparison between PHEV and BEV belonging the same segment for the Italian market

	Coefficient	**P-value**
Intercept	-3,34	0,1937
Education	1,22	0,4934
Electricity prices	-2,47	0,3950
Gasoline prices	1,51	0,0975
Share renewable energy	2,83	0,0002
Urban population	1,74	0,2229
GDP per capita	2,43E-05	0,0495
EPI score	-0,07	0,0279

Table 3.10: Regression coefficients of the transformed regression model

Regression statistics	
Multiple R	0,76
R Square	0,58
Adjusted R Square	0,49
Standard Errors	0,85
Observations	35

Table 3.11: Fit statistics for the transformed regression model without the “EPI score” explanatory variable

3.3.5. BEV and PHEV regression models

The model that will be used to study the diffusion on BEV and PHEV is an adaptation of the one presented in equation 3.12, where the PEV diffusion is replace by the diffusion of BEV and PHEV respectively. Therefore, in the full-electric case the model is:

$$\begin{aligned} LN(Diffusion\ BEV) = {} & \beta_0 + \beta_1(EDUCATION) + \beta_2(ELECTRICITY\ PRICE) + \\ & \beta_3(GASOLINE\ PRICE) + \beta_4(SHARE\ RENEWABLE\ ENERGY) \\ & + \beta_5(URBAN\ POPULATION) + \beta_6(GDP\ PER\ CAPITA) + \beta_7(EPI) + \varepsilon \end{aligned} \tag{3.13}$$

In this model, not all the 35 countries have been considered as for Greece in 2017 no BEV were sold and the logistic transformation does not allow to deal null values. Therefore, the regression has been made with 34 observations.

While for the PHEV case, the model is:

$$\begin{aligned} LN(Diffusion\ PHEV) = {} & \beta_0 + \beta_1(EDUCATION) + \beta_2(ELECTRICITY\ PRICE) + \\ & \beta_3(GASOLINE\ PRICE) + \beta_4(SHARE\ RENEWABLE\ ENERGY) \\ & + \beta_5(URBAN\ POPULATION) + \beta_6(GDP\ PER\ CAPITA) + \beta_7(EPI) + \varepsilon \end{aligned} \tag{3.14}$$

A similar situation happened for the PHEV case. In 2017, no plug-in hybrid cars were sold in Malta and therefore the regression has been made with 34 observations.

The table 3.12 presents the regression statistics for both models. The adjusted R^2 is of 53% for the BEV model and of 50% for the PHEV model. These values show a good fit of the models with respect to the variability of the data and considering the purpose of this analysis. Table 3.13 ad 3.14 presents the ANOVA results for the BEV and PHEV models respectively. In both cases, by setting a significance level of 5% the null hypothesis of the F-test can be rejected. It can be then concluded – with a confidence level of 95% – that the models presented in equation 3.13 and 3.14 fits better the data than the intercept-only model.

	BEV	**PHEV**
Multiple R	0,79	0,78
R Square	0,63	0,60
Adjusted R Square	0,53	0,50
Standard Errors	0,76	0,93
Observations	34	34

Table 3.12: Regression statistics for the transformed BEV and PHEV regression models

The coefficients of the two regressions are presented in table 3.15 and 3.16. For the BEV case we can notice how the Gasoline price variable is statistically significant with a confidence interval of 95% (P-value 0,0228), while it is not in the case of the PHEV. This result supports the observation that while gasoline price is a key driver to push the diffusion of BEV, it is not for PHEV as in any case this technology relies on gasoline. In both model the share of energy that is produced from renewable sources is statistically significant. For the BEV model, the P-value is 0,001 while for the PHEV is 0,0028. This result is in line with what has been found by Axsen et al. (2013). The possibility to autonomously produce electric energy through solar panels brings a financial incentive that pushes the adoption of BEV and PHEV. By setting a level of significance of 5%, the explanatory variable "GPD per capita" is also statistically significant in the BEV model, with a P-value of 0,0322. On the other side, this same variable is not statistically significant for in the PHEV model (P-value 0,2355). This result supports the observation that by BEV being systematically more expensive than PHEV their adoption will more pronounced in more wealthy country. This conclusion can be made only because the GDP per capita considered as explanatory variable is calculated at Purchase Price Parity. It is possible to notice how the EPI score is statistically significant in the BEV model with a level of significance of 5% (P-value 0,0029) while it is not in the PHEV one (P-value 0,6508). This result supports the reason provided in the previous sub-section. Countries lagging behind from an environmental standpoint put in place incentives to push more sustainable way of moving: BEV. Finally, it can be noticed how the "urban population" variable is statistically significant in the PHEV model. The authorization granted to these vehicles to transit in restricted area of the city center, while providing enough range in full electric mode to perform the daily activities make this type of car a preferred choice in crowded cities.

	Degree of freedom	SS	MS	F	P-value
Regression	7	26,32	3,76	6,47	1,78E-4
Residuals	26	15,09	0,58		
Total	33	41,41			

Table 3.13: ANOVA results of the BEV regression model

	Degree of freedom	SS	MS	F	P-value
Regression	7	35,2	5,03	5,7	4,4E-4
Residuals	26	22,8	0,87		
Total	33	58			

Table 3.14: ANOVA results of the PHEV regression model

	Coefficient	P-value
Intercept	-1,21	0,6187
Education	0,69	0,6847
Electricity prices	-5,17	0,0703
Gasoline prices	2,07	0,0228
Share renewable energy	2,35	0,0010
Urban population	1,05	0,4368
GDP per capita	2,62E-05	0,0322
EPI score	-0,09	0,0029

Table 3.15: Regression coefficients of the BEV regression model

	Coefficient	P-value
Intercept	-9,46	0,0051
Education	-0,31	0,8923
Electricity prices	-0,52	0,8817
Gasoline prices	0,08	0,4462
Share renewable energy	2,59	0,0028
Urban population	4,43	0,0234
GDP per capita	1,69E-05	0,2355
EPI score	-0,017	0,6508

Table 3.16: Regression coefficients of the PHEV regression model

3.4. *Conclusions and policy suggestions*

By identifying seven explanatory variables and collecting data from the sources summarized in table 2.1, it has been possible to study the diffusion of PEV across thirty-five countries. Several models have been utilized and each of them highlighted interesting points. The transformed model studying the PEV diffusion (equation 3.12) identified three variables that have positive effects: percentage of energy produced from renewable sources, GDP per capita and EPI score. The latter models (equation 3.13 and 3.14) where instead able to grasp the differences between BEV and PHEV, showing how gasoline price becomes a significant factor in case of BEV while it is not for the PHEV diffusion. Similarly, GDP per capita and EPI have positive effect only on the BEV demand and not on the PHEV one. Nonetheless, the share of energy produced from renewable sources remains a significant variable for both BEV and PHEV.

Based on these results some policies suggestions can be provided. First of all, as renewable energy appears to be always significant, governments should promote the diffusion of these sources of energy together with electric vehicles. For example, Vehicle-to-Grid (V2G) systems could be experimented and put in place. In such a system, BEV and PHEV communicate with the power grid and exchange electricity. This technology would allow to tackle one of the biggest problems of renewable energies while generating value for PEV drivers. Intermittence and timing at which the electric energy is produced are some of the biggest limits of green energy. Indeed, most renewable energy plants produce higher quantities of energy during the day (e.g. solar panels), missing the consumption peak of the morning and evening. This is problematic for governments as of today they cannot store in an effective way the energy produced from these sources. The V2G system, would therefore enable to use plug-in electric vehicles (BEV and PHEV) as batteries when the production of energy from renewable sources is higher than the consumption and take it back during peak hours. This system combined with dynamic electricity prices would push the EV drivers to recharge their vehicles during the day, when production of electricity is higher than consumption and so prices are lower and sell the energy back during the evening when the opposite situation happens. Of course, in order for this system to work a wide network of recharging stations must be in place. Therefore, a second suggestion for government would be to incentivize the installation of charging stations throughout the country and in strategic places (e.g. highway, hotels, offices…). The third suggestion that can be made is related to gasoline prices. As this variable is significant for the diffusion of BEV, governments could increase the taxes on gasoline in order to push this technology. The substitution of combustion engine cars with BEV one could also provide savings to public administrations as lower level of pollution would also lead to a smaller number of respiratory problems and hence a decrease in sanitary spending.

4. Conclusions

The aim of this thesis was to understand why the diffusion of plug-in electric vehicles in Italy is far behind the one in other major European countries, despite Italy being the fourth biggest European car market. To provide an answer to this problematic, the question has been divided in two. First of all, it has been wondered “How ready are Italian companies in supporting the diffusion of EV?”. The second chapter aimed instead at providing a more international perspective and assessing: “Which are the macro-economic factors driving the PEV diffusion and policies that can be put in place to support it?”.

To provide an answer to the first question, it has been initially highlighted through theoretical frameworks (Antonelli (1995), Adner and Kapoor (2016), Dosi (1982)) how a study of the Italian ecosystem supporting PEV is of paramount importance in order to identify the speed at which the substitution of ICE vehicles will take place. Following to this, the PEV diffusion at a worldwide level has been provided. The aim being to provide the reader with an understanding of the global and the Italian situation. Once these premises settled, the core analysis has been made. Through market observation and research, the ecosystem of companies supporting the PEV diffusion in Italy has been identified. It was structured in a way that mimics the lifecycle of a PEV, as it allows to understand in a clear way how different actors coming from very different value chain have decided to enter different PEV lifecycle phases. This visualization method allows to assess strategic decisions taken by companies. Later in the chapter, the evolution of the actors involved in the recharge business has been studied, in order to assess the configuration of actors that was likely to be the winning one in the future. These studies led to several observations. First of all, it has been noticed how the OEMs market was mostly made of incumbent players, that will not be disrupted by this innovation, as the rate of substitution of ICE vehicles by PEV is very low giving them the time to prepare for the S-curve jump. Furthermore, the majority of car manufacturers were not directly involved in other activities if not the production of PEV. Nonetheless, through joint venture, most German automakers were tackling the recharge problem from two sides: the development of the recharging infrastructure – with Ionity – and the interoperability between operators – with Hubject – showing their commitment in the electric mobility. Nonetheless, as these initiatives are promoted by foreign automakers, their entry and the investment made in the Italian market are either delayed in time, limited in quantity or both. On the other side, it has also been noticed how no Italian OEMs are instead producing PEV and the first one, will be launched in 2020.

This latter element has a negative effect on the PEV diffusion in Italy. The battery manufacturers analysis has shown instead how this key component for electric vehicles is in the hand of Asian – and mainly Chinese – companies. Furthermore, a battery supply shortage could become reality in the near future, should the demand of PEV continue to grow at the current pace. This would either limit the diffusion of plug-in electric vehicles not only in Italy, but in Europe, or lead to a massive entry of foreign car manufacturers as battery manufacturer will give precedence to compatriot OEMs. In the energy sector instead, Italian utilities are very active in the PEV environment. Indeed, many companies perform either the CPO, the EMSP or both roles. This element is positive as utilities are supporting the recharge infrastructure development that allow to cope with the range anxiety of non-adopters. Finally, through the analysis of charging stations manufacturers, specialized CPO and EMSP players and the evolution of the actors involved in the recharge business, it has been shown how hardware interoperability exists. Indeed, recharge sockets have been selected by the European Parliament, with the type 2 plug as standard for alternate current and the CCS Combo 2 as mandatory, but not exclusive, direct current recharge socket. On the other side, in Italy, software interoperability is problematic. Due to the existence of a high number of CPO and EMSP actors and a limited penetration of roaming platform – such as Hubject – the public and semi-public recharge activity is cumbersome, creating a major barrier to PEV adoption. In conclusion it was noticed how the Italian ecosystem is characterized by several internal challenges preventing the diffusion of plug-in electric vehicles.

Nonetheless, companies by themselves cannot drive the diffusion of PEV. Governments must also put in place policies to support this phenomenon. Therefore, the second chapter aimed at identifying the macro-economic factors that foster the PEV diffusion and provide some policy suggestions. To do so, a cross-country multiple linear regression model has been developed. The analysis started with the identification of the dependent and explanatory variables. The former ones were selected by reviewing the literature and identifying contradicting results from one study to another. For example, the level of education was included in the regression model as several authors – among which Thiel et al. (2012) – were supporting that higher level of education would lead to a higher PEV diffusion whereas Li et al. (2017) had the opposite claim. The explanatory variable used in the basic model was the ration between the number of newly registered PEV per year over the total number of new cars in a year, for each country. In the second model, the response variable was a logarithmic transformation of the dependent variable used in the former model, in order to maximise the model fitting. Finally, the explanatory variables used in the third and fourth model were the same used in the second one but either specific to BEV or PHEV sales. The transformed model for the PEV diffusion identified three statistically significative variables: the percentage of energy produced from renewable sources, GDP per capita at Purchase Price Parity and the EPI score. The models specific to the BEV and PHEV diffusion allowed to identify the differences in terms of factors influencing their diffusion. It was hence possible to identify how gasoline price became a significant factor for the BEV diffusion – a price increase would boost the full-electric vehicle penetration – while it was not for PHEV. Similarly, GDP per capita and EPI have a positive effect only on the BEV demand. Instead, the share of energy produced from renewable sources remained a significant factor from the initial model to the transformed specific model for BEV and PHEV. Based on these observations it was possible to provide several policies suggestion to further support the diffusion PEV in Italy. As renewable energy appears to always be statistically correlated to the diffusion of electric mobility, governments should support the diffusion of these plants. In Italy, 37% of the energy produced comes from renewable sources, behind Spain (38%), Romania (41%), Portugal (54%) and other countries but before Germany (29%). This result could seem satisfying, nonetheless, the Italian performance in this field could be much better thanks to its geographic positioning and weather conditions. Furthermore, the utilization of the V2G technology, could tackle the intermittence and timing problem that come from the production of energy through renewables sources. The V2G system, would therefore enable to use plug-in electric vehicles (BEV and PHEV) as batteries when the production of energy from renewable sources is higher than the consumption and take it back during peak hours. This system combined with dynamic electricity prices would push the EV drivers to recharge their vehicles during the day, when production of electricity is higher than consumption and so prices are lower and sell the energy back during the evening when the opposite situation happens. In Italy V2G is being tested by Enel and ACEA in 2010 and nowadays only Terna is working on it. On the other side, many tests have been made in other European countries (e.g. Denmark, Holland…). Therefore, national incentives should be put in place to support the development of such projects. Furthermore, in order for the V2G system to work, a large network of recharging station must be in place. Therefore, governments should put in place incentives to push the installation of charging stations. In Italy, until March 2019 no incentives for private stations existed, which was limiting the infrastructure diffusion. Since then, the government has put in place the possibility to have a 50% fiscal deduction on the cost of purchase and installation of a private charging station, for a maximum of 3000€. For public charging instead, incentives are decided at the regional level. This can create a great disparity in the distribution of charging stations in the Italian territory, with wealthier regions pushing more the infrastructure diffusion and poorer lagging behind. Finally, the last suggestion that can be made to push the diffusion of BEV, it to increase the taxes on gasoline.

In conclusion, it has been noticed that the Italian ecosystem supporting plug-in electric vehicles is emerging. Therefore, several internal challenges must be solved in order to foster the substitution of ICE vehicles with PEVs. Furthermore, companies cannot push the electric mobility adoption by themselves, but need the government to put in place policies that incentivize this form of mobility. Support for the production of renewable energy plants, further V2G experiments, centralized from of incentives for public charging and an increase of gasoline prices are the points were the Italian government could do better.

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