CORRI-DOOR PROJECT: DID IT REALLY BOOST THE FRENCH ELECTRIC VEHICLE MARKET?

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Abstract

The decarbonization of the transportation sector needs a major rise in the electric vehicle (EV) market share in order to totally switch into electromobility. Boosting the electric vehicle market requires a cooperation between automotive industries by developing this technology especially batteries, charging infrastructure by installing more charging points especially fast ones and EV owners by giving them subsidies and offers. We collected data from different sources to analyze PEV sales in French departments and to know the reason that has the highest impact on the client's choice (from 2015 to 2018). Based on existing literature, we identified the most important factors and tried to build the French econometrics model using RStudio. Our model found that the autonomy, department's population density, charging infrastructure and the diesel price to be significant and correlated to local PEV sales. However, descriptive analysis suggests that vehicle's price, number of models and model year had negative impact. Results suggest boosting the study on a more detailed concept such as cities and suburbs as well as adding factors that reflect a department's and a client's characteristics in order to conclude with results that are more accurate.

Key words: Charging infrastructure, Electric vehicles, Econometrics study, Subsidies, Incentives

1. Introduction

In order to totally decarbonize the transportation sector, a total shift into electromobility is necessary. Frade et al. (2011) pointed out that motorized transportation is responsible for 40% of carbon dioxide emissions and 70% of other greenhouse gas emissions in urban areas. Electromobility will mitigate the climate global change in order to stop the temperature's upward trend, especially in urban areas such as cities. Many European countries additionally to China, Japan, and The USA decided to boost the Electric Vehicle (EV) market. In November 2017, The European Commission updated their Clean Mobility package by changing their CO_2 standards for Low Carbone Vehicles (LCVs) for the period until 2030 (EC, 2018). The goal is to achieve 15% CO_2 reduction per km for new vehicles in 2025 and 30% in 2030 (EC, 2018). In addition, if a car manufacturer exceeded its specific emission targets, a 95 €/gCO2/km per newly produced vehicle penalty is fixed (EC, 2018). Therefore, EV has received increasing attention during the last decade. This technology can reduce greenhouse gases (GHG) emissions that is the direct cause of global warming. Electric Vehicles, regardless of their type, are promising eco-friendly ways of transportation that may reduce GHG transportation sector emissions. Regarding Europe, the objective is to achieve 95 gCO2/km in 2021, 80 gCO2/km in 2025 (-15% compared to 2017) and 60 gCO2/km in 2030 (-30% compared to 2017). EVs can be generally classified into five categories according to the need of fuel, including Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Range-Extended Electric Vehicles (REEVs) and Fuel Cell Electric Vehicles (FCEVs). An EV, which can be externally charged by an electric socket, is called Plug-in Electric Vehicle (PEV). This category groups BEV and PHEV.

In order to encourage people to purchase an EV, countries all around the world took various incentives. Regarding the EV market share, Norway has the highest value around the world (slightly more than 45%) (Zhang Q. et al., 2018). However, Iceland and Sweden have respectively approximately 15% and 6% of EV in their transportation sector. There are many ways to encourage people to purchase an electric vehicle: government initiatives by eliminating taxes, TVA and offering free access to road ferries such as Norway, France, and Ireland… Generally, European countries will start prohibiting the sales of ICEV by 2030 (Netherlands), 2032 (Scotland) and 2040 (France and the United Kingdom) (Auverlot D. et al., 2018).

These examples of encouragement are not sufficient to fastly increase the market share of electric vehicles. The research has ended with the necessity to boost the market from different key levels (CIED, 2018). They highlighted recommendations for automotive salespersons, automotive industry and original equipment manufacturers besides national policymakers. In the same time, governments should work on eliminating the driver's battery blackout fear. One of the main problems for the EV driver is to find a charger to fuel his battery with electricity in order to avoid blackout during the trip. This is a psychological problem called "Range Anxiety". On one hand, people do not want to buy electric vehicle because the charging infrastructure is not mature enough and because of the extremely high prices of these types of cars. In fact, the battery production cost is nowadays high, it can rise the vehicle's price. According to L. Wang et al. (2018), the price of 1 battery kWh is around 200 to 400 $. On the other hand, charging infrastructure operators will not invest in charging stations based on a low EV market share; especially that an EV is usually the second car of the family (Lepoutre J. et al., 2018). The location of charging infrastructures can greatly influence the charging demand, which is usually higher in urban areas than in rural ones. A solution to the "*Electromobility chicken and egg dilemma*" (Lepoutre J. et al., 2018, Serradillaa J. at al., 2017) problem is to develop a method to efficiently deploy electric vehicles charging stations. According to ICCT (2017), there is a strong correlation between public charging infrastructure and electric vehicle uptake. Having more available charging points will give the driver more confidence to use the full range of the vehicle's battery. Regarding the French case, "Corri-Door" is one of the projects that has been lunched in 2012 in order to install a larger number of public EV chargers. The European Commission and many other parties such as EDF S.A., Sodetrel, BMW, Volkswagen, Renault, Nissan and ParisTech engineering schools, fund this project. Its goal is to place 200 fast chargers (50 kW power) on highways, motorways and in the shopping centers nearby, approximately every 80 km across France, in order to make inter-urban travel possible on main roads. Charging to reach 80% of the State of Charge (SoC) will take around 30 minutes, which can be considered as a coffee break during the trip. In addition, the Corri-Door intelligent charging points are universal and compatible with all commercially available PEVs. The Corri-Door network means that France is now one of the world's most advanced countries for the deployment of EV fast charging points. In 2018, an increase of over 80% is recorded regarding the charging frequencies compare to 2017. This remarkable upward trend proves that drivers accepted the Corri-Door network and used the chargers to fuel their vehicles. 300 additional fast charging (100 kW power) will be deployed from 2020 by IZIVIA with the support of the European Commission. The sites will be located primarily off-highway, in commercial areas or on the outskirts of major cities, to complete the existing territorial network.

The purpose of the paper is to identify the reason(s) why clients switch into PEV in France, since it is a rarely studied country (Pierre et al., 2015). Section 2 will present a literature review about some papers analyzing the EV market. Section 3 will resume some important points and information about EV and recharge infrastructure. Section 4 will reflect a benchmark about governments' incentives for some countries. Data and methodology are elaborated in Section 5, followed by the study's results and discussion in Section 6 and a conclusion in Section 7.

2. Literature review

Nowadays, the PEV market share in European countries seems to be extremely modest. In fact, it accounts for 1.84% for Germany, 2.04% for France, 2.05% for Belgium, 7.21% for Sweden and 39.81% for Norway (Groupe PSA database). These countries have put plans for the future years especially 2030 and 2050 in order to stop the ICEV sales, to switch into pure electromobility and to accelerate the downward trend of CO2 emissions. However, some numbers are too optimistic and require some revisions. In reality, the client willingness to purchase a PEV is low. Many countries rely on traditional automotive industry intermediaries such as car dealers to promote EV uptake among consumers. However, dealers could in fact be a barrier to EV penetration (Zarazua de Rubens et al., 2018). The study was made on the Nordic region and it shows that PEV typically take longer to sell and consumers tend to ask many questions to dealers. Some countries developed business models to enable EV uptake, which include targets on economy, energy and environment. Thus, this model can include the EV industry to participate in the full EV supply chain. On the other hand, all forms of EV remain more expensive to purchase than ICEV. The second-hand EV remain somewhat uncertain because of its immaturity partly due to the uncertainty over the technical part such as lifetime of batteries (McKinsey 2017). Moreover, range anxiety presents an important psychologic barrier, which limits the development of the EV market share. The fear of blackout is in a direct relation with the battery capacity and technology, the distribution of the charging infrastructure and the changing in the driver's habits. For this reason, it is important to solve the barriers in sequence to boost the EV market. There are several studies that used revealed preference data to investigate factors that influenced consumer uptake for those automobiles (Sierzchula et al., 2014). Li et al. (2017) categorized the factors, which influence the client to buy an EV, into three main types: demographic, situational and psychological. According to their study driving range, charging problem and purchasing cost are the main situational barriers. These barriers can be surpassed by boosting the studies that focus on how to guide consumers plan their travel time and distance, how they charge to satisfy their demand, and how to calculate total cost according to their driving habits. Sierzchula et al., 2014 considered that socio-demographic variables such as income and education level have no significance to purchase an EV; whilst, these factors play a role in determining uptake because studies have identified levels of education, income, and environmentalism to all be positively correlated to likelihood to purchase an EV (Hidrue et al., 2011). For Sierzchula et al., 2014, financial incentives and charging infrastructure were statistically significant factors but they are not enough to ensure high EV adoption rates. Mersky et al. (2016) also found that access to charging infrastructure; being close to big cities as well as regional income are the most significant factors. Fearnley et al (2015) studied BEV incentives in Austria and Norway. They found direct financial incentives to be effective. However, the subsidy level and duration must be high enough to achieve a major adoption. Chandra et al. (2010) found that the way rebates were granted was not the most effective way of introducing HEVs. Freanley at al. (2015) found that free parking for BEV is the least effective policy. Lieven (2015) found that the installation of fast charging networks on freeways to be a necessity while high vehicle subsidies can be replaced by lower subsidies providing additional charging infrastructure. In addition, the availability of the charging stations play a role in the driver's choice (Egbue and Long, 2012; Tran et al., 2012). Other factor that are studied in the literature are the fuel and electricity prices. In fact, they are recognized as two of the most powerful fact especially if they have sight upward trends (Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011). Additionally to the previous studies, the degree of urbanity of the studied area could facilitate the PEV adoption (IEA, 2011). Finally, the number of PEV models available on the market can help the client to be more convinced in this technology (Van den Bergh et al., 2006).

3. Electric vehicles and recharge infrastructure types

As a definition, electro-mobility is the act to use electricity as a main source of energy for the vehicle. The EV is a promising alternative way of transportation. Actually, adoption of an EV can have positive consequences by reducing carbon dioxide emissions, especially in urban area. Usually, an ICEV use the diesel or the fuel to turn on. However, for en EV, it may depends on the type. This section will present a comparison of all different types of EVs on different scales: technical, economic, environmental.

3.1. General introduction on Electric Vehicles

There is a variety of electric vehicles types in the market. As mentioned in the introduction, there are five types.

i. **Battery Electric Vehicle (BEV)**: This type of EV uses electricity stocked in batteries as main energy source. It does not contain an internal combustion engine, nor a fuel cell or a fuel tank. The driver can charge the battery by plugging in a socket to a charging point. There is a variety of sockets that will be elaborated later in the section 3.2.

ii. **Hybrid Electric Vehicle (HEV)**: This second type of EV is powered by both electricity and fuel. Thus, it contains a fuel tank and a battery which is charged by the car's breaking system as well as an internal combustion engine. The HEV uses the electric part based on an internal computer order when the load or speed rises. It cannot be charged externally by a socket.

iii. **Plug-in Hybrid Electric Vehicle (PHEV)**: is an upgraded version of HEV. It has the same specifications. However, it includes a new battery charging system that can be fueled by an external charging point.

iv. **Range-Extended Electric Vehicle (REEV):** It can be charged using a filler or an electric charger. However, the fuel is converted into electrical power and stocked in a battery via a small internal combustion engine (less than 2 liters of fuel per 100 km, Flah A. et al., 2014).

v. **Fuel Cell Electric Vehicle (FCEV):** This type of EV is developed to operate for long distances. It can be fueled using a filler and its main energy source is Hydrogen. Therefore, it contains no fuel tank but high pressure Hydrogen tank. It contains an electric battery that is fueled by a fuel cell stock in the intermediary of a charger.

Regarding the main object of the paper, we will discuss only BEV, PHEV and REEV. Only electric and hybrid vehicles will be compared in this part of the paper; thus, FCEV or Hydrogen vehicles concept will not be developed. In fact, these types of EV can be externally charged using a charger. Thus, they can be named as PEV or Plug-in Electric Vehicles.

3.2. General introduction on recharge infrastructure

One of the main problems for the EV driver is to find a charger to fuel his battery with electric energy in order to avoid blackout in the middle of this trip. A study was made on 10 two-car households; they replaced one of their conventional cars with a Volkswagen e-Golf battery electric vehicle for 3 to 4 months (Jakobsson, N. et al., 2016). The goal was to identify the changes in the driving behavior of these German and Swedish households. They concluded with the lower variance driving distance of the EV than the first car. Charging infrastructures can greatly influence the charging demand, which is usually higher in urban areas than in rural areas.
Regarding the charging infrastructure, this section will elaborate the charging levels and specifications. There are many charging technics: Energy to vehicle, such as battery swapping, wireless charging, and supply while driving, (Grauers A. et al., 2013). This paper will cover only the charge while parked charging technic by cable, or in other words "charging points" or "charger". We can identify a charging point by its location, power, socket model, maximum voltage (AC/DC, single or triple phase). Table 1 will resume the charging points' specifications: (*only unidirectional charging points are elaborated in this section; V2G adaptability is not taken into account in the domain of this paper*).

It should be noted that the charging time of an EV depends primarily on the State of Charge (SoC), the size of the battery, on the technology of the battery (Lithium-Ion, Plomb, etc.) as well as the charging point technical specifications (connector, cable, power, current type AC/DC). (Serradillaa J. et al., 2017) *IEC 61850* is an international standard defining communication protocols for intelligent electronic devices at electrical substations. This standard define four modes (1, 2, 3 and 4), three levels (1 for slow, 2 for fast and 3 for extra-fast) of charging. In order to develop the public recharge infrastructure, there is a necessity to identify the location of the charging event. According to the international standard IEC 61850, there are three "main" locations for the charging point: private (home), semi-public (supermarket, work, cinema, etc.) and public (highways, corridors, etc.). Table 1 resumed all the information about the charging points and sockets.

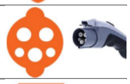
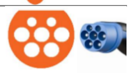
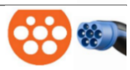
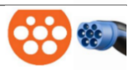
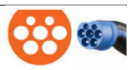
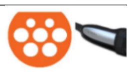
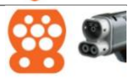
Connector Type	Charging Level (1,2,3)	Mode [IEC 6185]	Charging Speed	Charging time	Location	Power (kW)	Current Type	Single/Three phase	Photo
3 PIN	1	1	Slow	Hours	Private	2.8	AC	Single phase	
Type 1	1	1	Slow	Hours	Private	3.7	AC	Single phase	
Type 1	2	2	Fast	Hours	Semi-public	7	AC	Single phase	
Type 2	1	1	Slow	Hours	Private	3.7	AC	Single phase	
Type 2	2	2	Fast	Hours	Semi-public	7	AC	Single phase	
Type 2	2	3	Fast	Minutes	Semi-public	22	AC	Three phase	
Type 2	3	3	Extra fast	Minutes	Public	43	AC	Single (can carry three phase power)	
Type 2 (Tesla)	3	4	Extra fast	Minutes	Public	120	DC	-	
Commando	1	1	Slow	Hours	Private	3	AC	Single phase	
Commando	2	2	Fast	Hours	Semi-public	7	AC	Single phase	
Commando	2	3	Fast	Minutes	Semi-public/Public	22	AC	Three phase	
CCS	3	4	Extra fast	Minutes	Public	50	DC	-	
ChaDeMo	3	4	Extra fast	Minutes	Public	50	DC	-	

Table 1 Electric vehicles charging points technical specifications; *Sources: https://pod-point.com/guides/driver/ev-connector-types-speed and https://www.zap-map.com/charge-points/connectors-speeds/*

4. Government incentives to boost the EV market

According to the Global EV Outlook 2018, the global stock of EV reached 3.1 million in 2017 after an increase of 57% from 2016. China has the highest sales volume of EV around the world, followed by the USA and Europe. However, Norway accounts for the highest EV market share globally. PEV are supported by monetary and non-monetary policies put by worldwide governments: several studies have shown that direct purchase initiatives can boost the EV market (Plötz P. et al., 2017). Although the EV economic interest seems to be acquired mobility needs, actual EV adoption by mass market still raises questions (Pernollet et al., 2019).

These initiatives are divided into two categories: direct subsidies such as rebates, tax credits, state credits and indirect subsidies like fuel tax exemptions, charging equipment installation incentives, vehicle inspection exemptions, parking incentives, reduced license tax, reduced registration fees, vehicle-to-grid energy credits, idle reduction technology tax credits, reduced toll road rate. It is therefore important to identify the business model and to offer incentives to all parts: EV manufacturers, EV owners and recharge infrastructure. On the other hand, many governments are investing in the deployment of public charging stations.

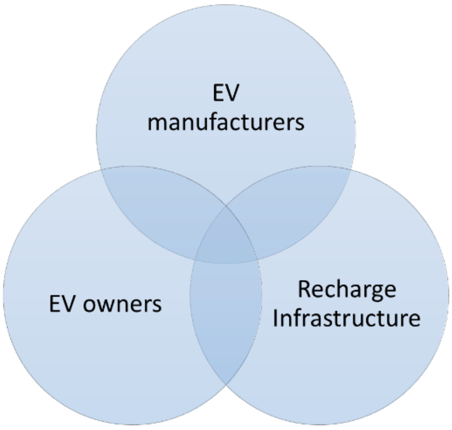


Fig. 1. Problem presentation

Hence, we will resume in this section, different incentives of China, The United States of America and some European countries. First, a series of policies are proposed aiming to boost the PEV adoption all over the country. It is obvious that clients make decisions by comparing the incentives as well as PEV technical characteristics. Based on a comparison between ICEV and PEV, the most recognised factors include vehicle prices, vehicle subsidies, refuelling/charging prices, refuelling/charging availability, driving range, municipal convenience, etc. (Langbroek et al., 2016). Thus, the regulation efforts released by the Chinese government are classified by the attributes according to the Fig. 2 (Ji & Huang, 2018).

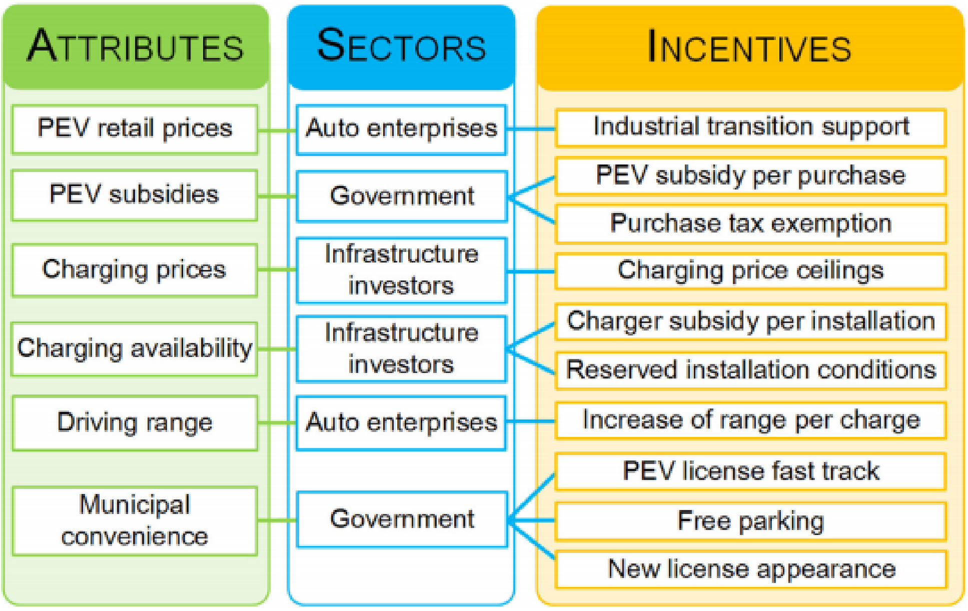


Fig. 2. Types of incentives; *Source: Ji & Huang, 2018*

- **China**:

In 2017, the Chinese government issued a New Energy Vehicle (NEV) credit mandate for 2018. This mandate has a clear object: to ensure a minimum requirement for the car industry on the produced ot imported EV number and it depends on the vehicle's range and the energy efficiency level. Therefore, the higher the distance is, the higher the NEV credits are.

On the other hand, the government gives subsidies, which depend on various parameters such as the vehicle's range, efficiency, battery capacity, battery technology…, for the purchase of electric vehicles in order to increase the market share. The Chinese target is to achieve 5 million EVs by 2020.

- **The United States of America**:

In 2018, the United States Environmental Protection Agency (EPA) announced a change in the 2012 standards for Zero Emission Vehicles (ZEV) sold between 2022 and 2025. The forecasted percentage of PEV for 2025 in the vehicle market share is 5%. The program gives each car manufacturer some points called "ZEV Credits" similarly to NEV credits in the Chinese case. Thus, these companies should achieve a certain number of credits by producing or by purchasing electric cars. It can be noted that the State of California accounts for almost half of the US market of PEV. The USA's target is to achieve 3.3 million ZEVs in 2025 (1.5 million for California). Regarding the recharge infrastructure deployment, California has announced to build 200 public fast-charging stations (Shahraki et al., 2015).

- **Europe**:

Generally, Europe is divided into two main groups regarding the evolution of electromobility. The first one is composed of Northern and Western Europe. The main barrier is there is a lack of EV to plug-in. However, the other part, which combines Southern, Central and Eastern Europe, has bottleneck in the growing procedure of the charging infrastructure. To better understanding the evolution of the EV market, Transport & Environment (2018) classified the European countries into three groups regarding the EV market development.

- **Front-runners**: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Sweden and the UK
- **Followers**: Italy, Portugal and Spain
- **Slow starters**: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia.

They assume that there will be two successive waves in the European world of electromobility. It is expected that Followers category will follow the front-runners' sales by 2025 and Slow starters by 2030. However, it is obvious that front-runners countries are investing in this technology in order to develop it. The annual investment in public charging reached till 2018 nearly more than 400 million € and it is forecasted to rise to slightly less than 2000 million € in 2030. The same reference estimates that the subsidy will gradually drain in the Front-runners' category between 2020 and 2025 thanks to the technological improvements in the vehicle and recharge infrastructure.

At present, the ratio between the number of EVs and the charging points is 5; whilst, the European Commission recommends a ratio of 10. Therefore, to reach this number, there should be 220,000 charging points.

The European Commission's goal is to achieve a 15% CO_2 emission reduction per km for 2025 and a 30% reduction for 2030 (EC, 2018). In order to provide for the transition from the current to the future framework, the proposal also includes the already established fleet wide target of 95 gCO2/km for cars and 147 gCO2/km for LCVs for 2020/2021. A penalty of 95 €/gCO2/km is fixed for every manufacturer which exceeds the standards. The EU's target in terms of GHG emissions is to have a reduction of 80% in 2050 compared to 1990 levels. Each European country has its own EV market shares as well as incentives.

i. Norway:

Norway accounts for the highest PEV market share in the world. The government has implemented several financial incentives to boost the EV market such as VAT and tax exemption, free access to road ferries… Therefore, a client would purchase an EV instead of an ICEV thanks to its low cost, obviously after the government subsidies. Reaching 100% EV market will probably be achieved in 2025, the year when new ICEV sales will be halted. Evidence from this country assumes that public urban charging stations are less used than predicted (Transport & Environment, 2018). Regarding the charging behavior, EV owners tend to charge their vehicle most frequently at home or at workplace (IEA, 2018). Thus, people tend to use more fast charging points, installed on roads, than slow ones. This is the reason of the upward trend in the number of fast chargers and the decrease in the slow chargers across Norway.

ii. Sweden:

Sweden's percentage reduction of the GHG emissions is fixed at 70% by 2030 compared to 2010 level (Government of Sweden, 2017). They do not have a fixed target for EV market share; whilst, they support the EV30@30 European campaign which goal is to reach 30% sales EV share by 2030 (EVI, 2017). In 2015, the Swedish government launched the "Klimatklivet" project for the problems related to climate change and supported the installation of various types of charging points: private, public, slow and fast. For the period between 2018 and 2020, the Swedish government allocated around 82 million dollars for public infrastructure and around 11 million dollars for private charging points' installation (IEA, 2018).

iii. Denmark:

Denmark has put clear targets for its future electric vehicles market: Fossil fuel-free goal by 2050 (Danish Energy Agency, 2017a). The government is investing on all directions: regulations, direct investment for chargers implementation, and fiscal advantages for both public and private infrastructure. Regarding the accessibility to the charging points, the Danish government revised the non-open protocols in order to let the drivers charge their vehicle whatever they want. Moreover, owners pay 50% less for their power fees if they use the public infrastructure, which will be upgraded into 150-350 kW as a plan (E.ON, 2017a). However, there is no official car deployment target.

iv. France:

France took many fiscal incentives in order to boost the PEV market. First, the government increased the subsidy value from 4000 to 6000€ in case of purchasing a BEV as well as an exemption of taxes and VAT. The value of the subsidy is 27% of the vehicle's price. The bought vehicle should be brand new and pure electric. Another subsidy is to offer 5000€ after a conversion from an ICEV to a PHEV/BEV. Regarding the blackout fear, a

reduction of 30% on the energy transition tax credit (Crédit d'Impôt Transition Energétique - CITE) is guaranteed in order to install a private charger in the house. Concerning the collective residences such as appartments, a subsidy of 50% of the price of the charging point is given.
Another stimulating procedure is to install 100,000 charging points by 2020. Corri-Door project mentioned in the introduction can be a way to eliminate the blackout fear in the driver's behavior especially for long trips. 2040 is the year when all new ICEV will be prohibited.

v. Germany:

"Nationale Plattform Elektromobilität" is the German program to develop the EV market. Its targets are not only to reach 1 million EV by 2020 and six million EV by 2030, but also to decrease the dependency on oil production and GHG emissions as well as to develop the vehicle's industry (Die Bundesregierung 2011, 2014, 2015). Similarly to all countries, the government exempted all types of taxes and gave a 4000€ (for BEV) and 3000€ as a subsidy for buying a PEV. The government pays half of this sum and the vehicle manufacturer pays the other half (Kemfert C., 2016).

Nevertheless, many European ultra-fast charging projects have been launched across European countries.

Project name	# stations/ # sites	Partners	Location
Ionity	400/~2400	BMW, Mercedes, Ford, VW Group	24 countries
Ultra-e	25/~100	Allego, Audi, BMW, Magna, Renault, Hubject	Netherlands, Belgium, Germany, Austria
E-Via Flex-E	14/~60	Enel, EDF, Enedis, Verbund, Nissan, Renault, Ibil	Italy, Spain, France
MEGA-E	39/322	Allego	20 countries
Central European Ultra charging	118/-	Verbund, CEUC, Enel X, Smartrics, Greenway, OMV	Austria, Czech Republic, Italy, Hungary, Romania, Bulgaria and Slovakia
NEXT-E	30/-	E.ON, MOL, HEP, PETROL, Nissan, BMW	Czech Republic, Slovakia, Croatia, Hungary, Slovenia, and Romania
E.ON x Clever	180/-	E.ON, Clever	Germany, France, Norway, Sweden, UK, Italy, Denmark
Instavolt network	-/200	Instavolt	UK
Fastned network	25	Fastned	GerUKmany, Netherlands, UK
Pivot Power and the National Grid	45/100		UK
EnBW	100-1000/800	EnBW and OMV	Germany

Table 2 European projects on recharge infrastructure ; *Source: Transport & Environment, 2018*

Another point to mention, the lower the price of an EV is, the higher the client is convinced to buy this type of vehicles. The most stimulating incentive is to offer subsidies to newly purchased EV. In addition, building an optimized charging infrastructure will play a role to eliminate the range anxiety in the driver's behaviour as well as solving the Chicken and Egg problem.
Regarding the charging infrastructure for European countries, we used the European Alternative Fuel Observatory (EAFO) website. In fact, this observatory is supported by the European Comission and has a goal to provide information and statistics about alternative fuels like Hydrogen, electricity and natural gas. This website provides general statistics, for all European countries, about the sales of vehicles (per type: PEV, FCEV, ICEV,… and per category according to the UNECE standards depending on the weight: passenger cars, light electric vehicles, busses, heavy duty, etc.) and the number of charging points (per power or speed: normal or fast and per socket type: ChaDeMo, CCS, etc.).
According to the databases collected from Groupe PSA and EAFO, it can be concluded from the ratio charging points/EV market share that the number of public charging points number is not the reason for the EV market share upward trend. In fact, taking the example of Belgium (27459 charging points for 1.84% EV market share in 2018), Germany (37093 charging points for 5.3% EV market share in 2018) and the Netherlands (45422 charging points for 2.05% EV market share in 2018), the increase in the number of charging points did not make a major change in the number of bought EV. Thus, other factors, to be identified, are the reason of an EV market boost.

5. Data and methodology

This section describes the data used in this study is collected and analysed using a set of techno-socio-economic variables.
Section 5.1 describes the data that were collected. Section 5.2 outlines the analysing methodology used in this paper. Section 5.3 provides the reader about a detailed descriptive analysis of the various databases used.

5.1. Data collection

We collected and analysed data from different sources. First, Groupe PSA (statistics department) provided us with the PEV sales data per department and per EV (type (PHEV or BEV), model, year of manufacturing) in France for the years 2015, 2016, 2017, and 2018 from ACEA (European Automobile Manufacturers Association) . This data was completed by several useful information such as battery capacity, autonomy and price of each vehicle. The government subsidy is fixed as 6000€ during this period of four years. The number of available number of EV models was also calculated. Additionally to the EV characteristics, we completed the database with the department code, density and regional subsidies from the municipalities over the same period of time (2015 – 2018) and for France.
Furthermore, we introduced the number of public accessible charging points in France from Groupe PSA. We will use the data for 2015, 2016, 2017, and 2018 to be coherent with the EV database. This data is divided into two parts: normal chargers (Power < 22 kW) and fast chargers (Power > 22 kW).
In order to reflect the driver's way of thinking, we decided to add the price of electricity and fuel throughout the period of four years. Therefore, we calculated the average price the driver is going to pay in order to drive 100 km using an EV or an ICEV.

Variable	*Definition*	*N*	*Type*	*Unit*	*Mean*	*Source(s)*
Sales	PEV sales per year "t", per department "i" and per vehicle "j"	10125	Integer	--	14.07	Groupe PSA/AECD
Sales year	Years of the study	4	Integer	--	--	--
Density	Human population density of department "i"	169	Integer	Pp/km²	1241	
Subsidies	Local subsidies of department "i"	3	Integer	€	2333	Automobile propre
Type	Type of vehicle "j"	2	Boolean	--	--	Groupe PSA
Model year	Model year of vehicle "j"	48	Integer	--	--	Groupe PSA
Battery capacity	Battery capacity of vehicle "j"	48	Integer	kWh	22.24	
Autonomy	Autonomy of vehicle "j"	48	Integer	Km	134.6	
Number of models	Number of models per year "t"	4	Integer	--	57.3	Own sources
Price	Vehicle price of vehicle "j"	48	Integer	€	55902.7	Groupe PSA
Normal CP	Number of normal chargers per year "t", per department "j"	380	Integer	--	82	EAFO, data.gouv.fr
Fast CP	Number of fast chargers per year "t", per department "j"	380	Integer	--	66	EAFO, data.gouv.fr
Cost EV 100km	Price paid by the driver to travel 100 km using an EV per year "t"	4	Integer	€	1.7	ADEME+Statista
Cost ICEV 100km	Price paid by the driver to travel 100 km using an ICEV per year "t"	4	Integer	€	6.4	ADEME+Statista

Table 3 Description of variables and sources

5.2. Methodology

We used panel data regression in order to analyse the effect of direct, indirect incentives as well as technical PEV parameters on the PEV sales share in France. RStudio © (version 3.5.3), which is used as an econometrics software tool, was run a HP laptop having Windows 10 Entrprise 2016 LTSB as windows version. Since the PEV parameters were added manually in order to boost the EV database, some vehicles did not have battery capacity nor autonomy information. Thus, these EV types were deleted from our database.

5.3. Descriptive analysis of databases

5.3.1. EV Database

Groupe PSA provided us with PEV sales of all departments in France for the years 2015, 2016, 2017 and 2018. First, according to Fig. 3, it can be seen that Ile-de-France region (especially Hauts de Seine and Yvelines Departments) followed by Hauts-de-France and Provence Alpes Côte d'Azur account for the highest sales for the selected years.

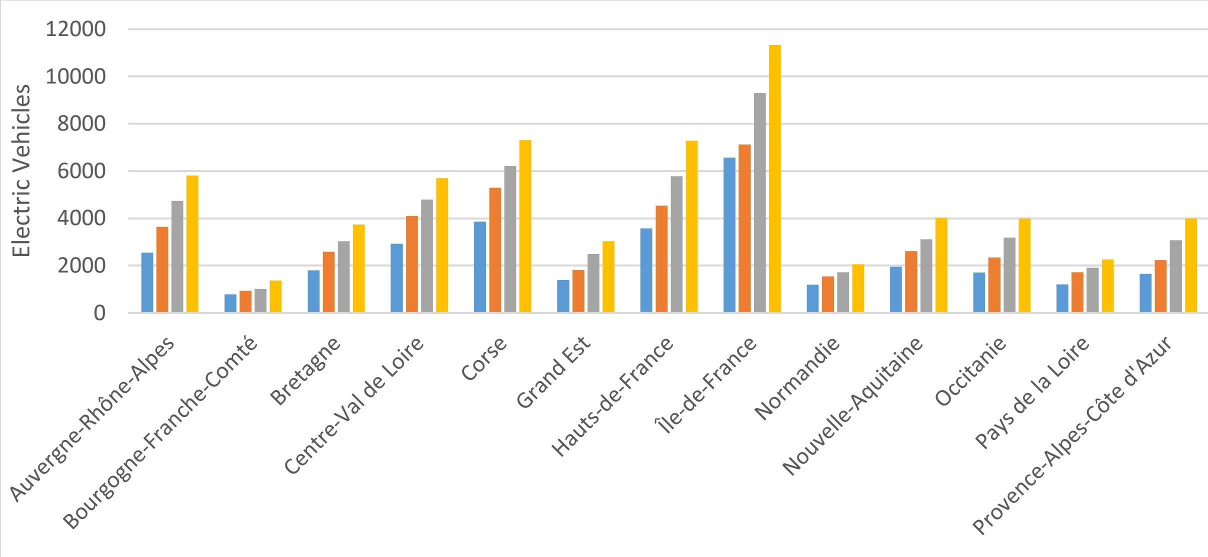


Fig. 3. Evolution of the EV sales across the French departments

Regarding the technical parameters and as mentioned in the data Collection section (Section 5.1), we completed the database with some useful information about battery capacity and autonomy for all vehicles. Therefore, we can group the PEV into six groups depending on their battery capacity and type (BEV or PHEV). It can be concluded that there is a variety of models on the market, which may affect the choice of the client. 44 models for both BEV and PHEV were available for purchase on the French EV market in 2015. This number increased to 66 for 2018. Therefore, it can be seen that the French PEV market combines a variety of models and different technical specifications that should be taken into account in further studies.

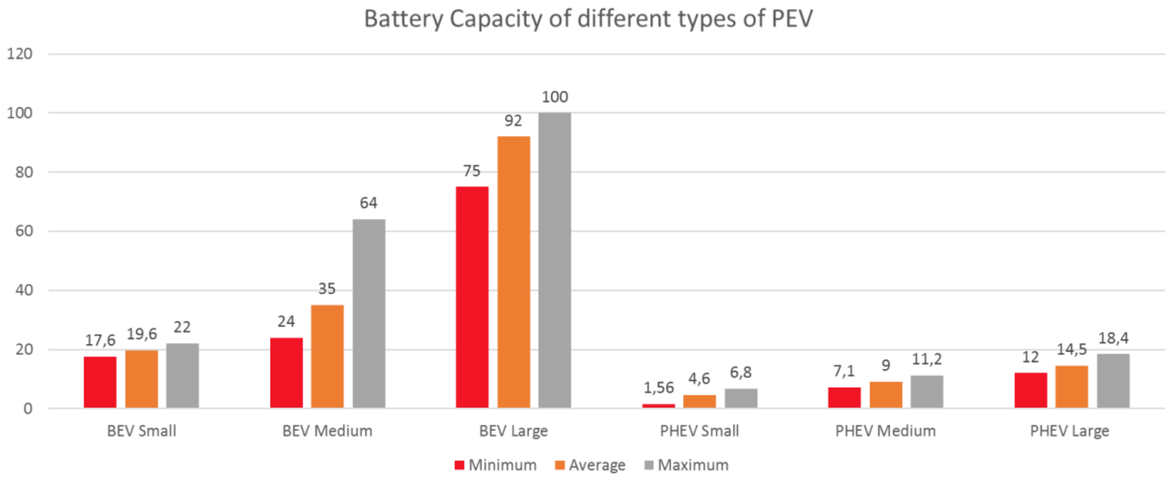


Fig. 4. Types of PEV depending on their battery capacity and type

On the other hand, in order to integrate the autonomy factor, an analysis of the collinearity between this variable and the battery capacity is a must. From a simple analysis of the Fig. 5, it can be concluded that these two variables are highly correlated: we can identify a positive and significant relationship (P-value of.000). Using RStudio, we can build the equation, which connect them. Moreover, Fig. 5 appears to be two groups of vehicles. The first is the vehicles with battery capacity less than 10-20 kWh, which are mostly PHEV, and the other group combines BEV. In fact, the main source of mileage of a PEV is electricity, which is stocked in battery cells. Therefore, the battery capacity can be used to define the vehicle's autonomy. Obviously, the vehicle's weight an influence this equation since every vehicle has its own consumption rate.

$$Autonomy = 5.6 * Battery\_Capacity - 2.345 \quad (R^2=93.23\%)$$

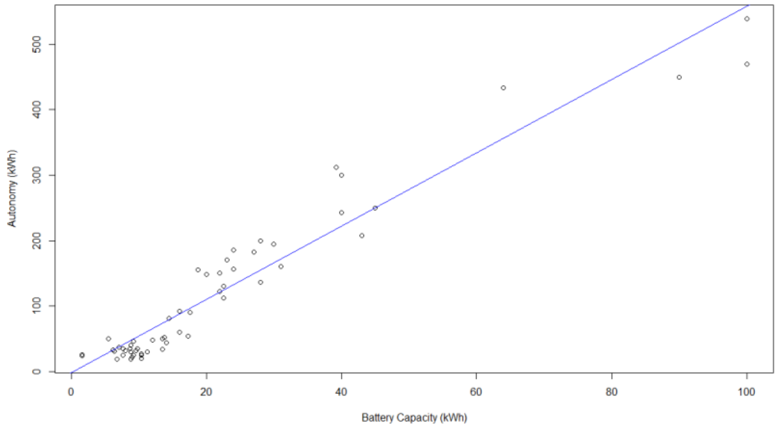


Fig. 5. Autonomy and battery capacity correlation

In addition to the PEV technical parameters, the price of the vehicle plays an important role. It has a negative significance (p-value of < 2.2e-16) since it may affect the clients choice. In reality, PEV are more expensive than normal ICEV, even though after the subsidy and tax exemptions for the French case.

5.3.2. Department Databases

Since Groupe PSA provided us with the sales per department, we decided to add variables which reflects the area of study. Thus, the evolution density can be an important variable because it reflects the degree of urbanity of the department. This data was collected from the site of the "Institue National de la Statistique et des Etudes Economiques (INSEE)". The evolution of human population density within a department is modest throughout the four years. and Hauts de Seine departments, both in the Ile-de-France region, are overcrowded because their density level score more than 9000 persons/ km² (respectively 9210 and 21067 persons/km²) for 2018. The density factor have a positive and strong significancy over the EV department sales (P-value of 0.0001).
On the other hand, as identified in the Section 4, each department has the right to offer subsidies and incentives to the future PEV drivers additionally to the 6000€ national bonus, based on their strategies and future plans. Since, this act was not be applied in all departments; it can be interesting to include the subsidies as a variable. Referring to the www.automobile-propre.com site, all departments of the region Haute-Normandie and Alsace offered 5000€ as a bonus; whilst, the subsidy in Lorraine region reached 2000€. Furthermore, the subsidies to purchase an electric vehicle can reach 11000€ (5000€ + 6000€). Giving subsidies can encourage client to buy and to switch into electromobility. *Other type of incentives such as free parking, are not taken into account in this model.* From a first analysis with the EV sales, we can conclude that regional subsidies have no significance on sales (P-value of 0.739).

5.3.3. Charging infrastructure

As mentioned in Section 2 and 4, installing new charging points can boost the EV market. Range anxiety can be solved either by increasing the battery capacity of the vehicle; thus, adding more mileage into the electric range, or by installing more charging points on roads. We decided to divide the charging points into two main groups: normal chargers (Power < 22 kW) and fast chargers (Power > 22 kW). Fig. 6 reflects the distribution of charging points all over France at the end of 2017. It can be seen that Ile-de-France, Pays de la Loire as well as Côte d'Azur regions presents high densities of charging stations. Because of a comparison between Fig. 3 and Fig. 6, we can conclude about a solution of the Chicken and Egg Problem. Unfortunately, we do not have access to a detailed data about charging points in France per department. On one hand, we decided to aggregate different files of charging points from www.data.gouv.fr,which is supported by the French Government and has a goal to provide information and

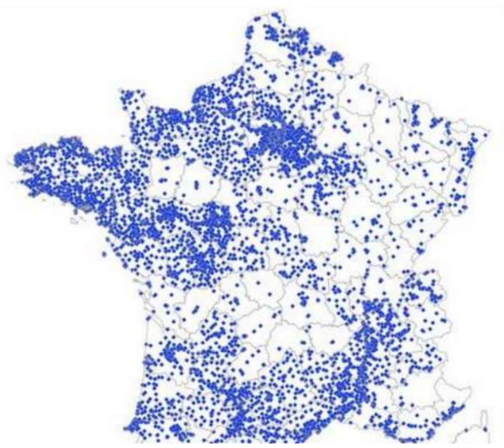


Fig. 6. Charging points in France ; *Source: Territoire d'Energie*

statistics about different topics including electromobility, and where we found only data for the end of 2018 without the installation year. On the other hand, the site www.eafo.eu provided us the percentage of growth of these chargers on the national basis. Thus, in order to re-build the data for previous years, we applied these percentages on the French government data.

5.3.4. Externalities

In addition to EV technical factors such as battery capacity and autonomy, we added to our database two important variables that reflect the increase of the electricity and fuel price. We decided to calculate the price that will be paid by the driver if he wants to travel using either an EV or an ICEV to travel 100 km.

On one hand, we collected the annually average electricity and fuel prices from Statista website (https://fr.statista.com). On the other hand, the average consumption of fuel and electricity per vehicle to travel 100 km is respectively 5L/100km for an ICEV and 10 kWh/100 km (https://www.energuide.be). The electricity price remained unchanged throughout the period around 1.7 €; whilst, the fuel price slightly fluctuated during these four years from 6 € to 7.3 € for 100 km. It should be stressed on the fact that additional taxes were put on the fuel price during 2018. Since the price of electricity remained constant during this period, it did not encourage drivers to switch into electromobility. Nevertheless, the price of fuel played a role in this transition.

6. Results and discussions

This section includes a correlation matrix of variables used in the model (Section 6.1), a descriptive analysis of the model (Section 6.2), a comparison between different tested models (Section 6.3) as well as sensitivity tests on the variables in order to determine the general robustness of the model and the relative impact of specific variables (Section 6.4).

6.1. Correlation analysis of model variables

Looking at relationships between variables can help to highlight dynamics that cannot be reflected in linear regression models. As mentioned in Section 5.3.1., we already identified the relationship between autonomy and battery capacity and concluded about the high correlation level between them. We used RStudio © to create the correlation matrix (Fig. 7). One of the patterns that appears when analyzing the correlation matrix is that Cost_EV_100km, Cost_ICEV_100km and Number of models are also strongly correlated. Therefore, battery capacity, number of models additionally to Cost_EV_100km were eliminated in order to minimize the uncertainty level in the model. Since the data of this study is aggregated for only four years; thus, we have only four values for these variables. In this case, the risk of multicolinearity is extremely high. Multicollinearity reduces the precision of the estimate coefficients, which weakens the statistical power of your regression model. Therefore, eliminating these variables will reduce this risk.

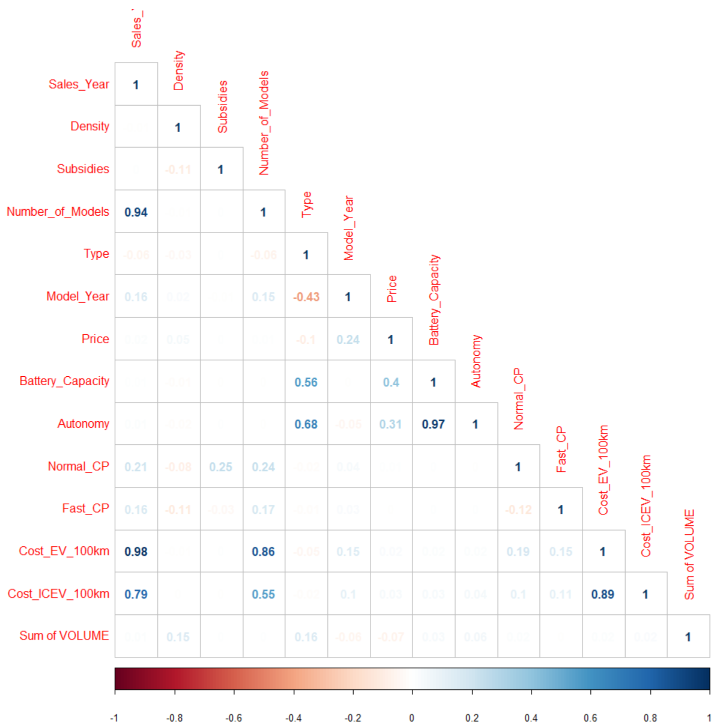


Fig. 7. Mutlicolinearity between the model's variables

6.2. Model regression

The pooling panel data model do not only take into consideration the evolution throughout the 4 years of study but also the variation within the parameters of the departments and the vehicles. The final model specification is given as:

$$\begin{aligned} Log(Sales_{i,j,t}) = \alpha + \beta_1 Vehicle\_Price_{\ i} + \beta_2 Autonomy_i + \beta_3 NormalCP_{j,t} + \beta_4 FastCP_{j,t} \\ + \beta_5 CostICEV100km_t + \beta_6 Subsidies_{\ j} + \beta_7 Density_{\ j,t} + \beta_8 Number\_of\_Models_{\ t} \\ + \beta_9 Model.Year_i + \varepsilon \end{aligned}$$

Where the subscript i denotes the vehicle,
j for the department
t for the year of sales
ε the error term.

6.3. Results

Table 4 shows the model of regression from the PEV sales in France over a period of four years. We used the logarithm transformation of PEV sales on vehicle price, autonomy, number of normal charging points, number of fast charging points, subsidies, density, number of available models and model year. We used the RStudio © software in order to build the econometric model and to analyze the results. The model has an R^2 (8.33%) and adjusted R^2 (~10%) which can explain that almost 10% of the PEV sales were explained by the tested variables. Regarding the model, the coefficients for vehicle such as price, autonomy, number of available models are strongly significant with p-value .000 for both. We can stress on the information that the price's coefficient is negative, which can support the non-client's willingness to pay for expensive cars. However, for the reason of the autonomy's coefficient positivity, we can conclude that drivers tend to buy PEV with long ranges. The department density has also a high significance on the PEV sales in the same area (p-value of 0.000). In fact, high density means that more people live in the same area. The probability of purchasing a vehicle increases with the rise of population. However, number of normal and fast charging points has a high significance (p-value of 0.000). It should be stressed that they have both positive coefficients. From the first conclusion, drivers investigate about the nearest charging stations before adopting a PEV. This can be due to the non-installation of private chargers in the derivers' houses especially in urban areas. In the same time, the price of diesel (all taxes included) has a positive impact on the PEV sales and is highly significant. On the other hand, subsidies do not boost the electromobility market. Consequently, not all departments gave direct financial subsidies during the four-year period of this study. Finally, clients do not buy the last model of the vehicle's brand. Usually, new vehicles are much more expensive than old ones especially if they are recently released. According to the three variables: model year, number of available years and vehicle's price, that have negative coefficients, they have a reverse effect on the market.

	Model ***Pooled panel data regression***
Intercept	7.566e+01 (8.6e00) ***
Vehicle_Price (in Euros)	-6.95e-6 (4.69e-7)***
Autonomy (in km)	1.38e-3 (1.06e-4)***
Normal_CP	8.03e-4 (9.46e-5)***
Fast_CP	5.55e-4 (1.01e-4)***
Cost_ICEV_100km (in Euros)	1.097e-1 (2.719e-2)***
Subsidies (in Euros)	1.31e-5 (9.87e-6)
Density (pp/km²)	1.06e-4 (4.31e-6)***
Number of models	-2.058e-3 (2.38e-3)
Model Year	-3.72e-2 (4.28e-3)***
N	10125
Year fixed effects	Yes
Department fixed effects	Yes
Vehicle fixed effect	Yes
R^2	9.78%
Adjusted R^2	9.7%
P-value	< 2,2e-16

Table 4 Regression results for PEV sales in France

*Signification codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'*

6.4. Sensitivity test and robustness check

In addition to the economic results in Table 4, we also performed several sensitivity tests for different variables (especially the number of normal and fast chargers) additionally to the model's overall robustness. Table 5 resumes the results on the variables' coefficients of the Model. We switched the variables with their modified versions in order to test their effect on the model. Each variable was changed to another version of it depending on different scales. For instance, we increased vehicle price by 10000 (€), autonomy by 50 (km), number of models by 50, subsidies by 2000 (€) and density by 200 (persons/km), the charging infrastructure both normal (by 1000) and fast (by 200).

As a first interpretation, we can conclude about the robustness of the model. The R^2 is fixed around 10% and stable with the variation of the different variables. The base model remains robust to this sensitivity test. However, the model did not remain robust with the sensitivity test of charging points (both normal and fast) variables. Their coefficients dramatically plummeted; whilst, the R^2 and adjusted R^2 remained constant. Yet the coefficients of all regression models changed only slightly, implying that either there is no big difference in the effect of incentives between innovators and early adopters or that the market is still dominated by innovators. The results are similar to the initial model discussed above, yet the explanatory power is much smaller. The latter suggests that a finite difference model is not suited to describe the PEV market and more data should be introduced in order to integrate more externalities that can influence on the PEV clients' opinions.

	Vehicle_Price	*Autonomy*	*Normal_CP*	*Fast_CP*	*Cost_ICEV_100km*	*Subsidies*	*Density*	*Nb of Models*	*Model year*
Intercept	7.57e+01 (8.6e00)***	7.55e+01 (8.6e00)***	7.48e+01 (8.6e00)***	7.55e+01 (8.6e00)***	7.54e+01 (8.6e00)***	7.56e+01 (8.6e00)***	7.56e+01 (8.6e00)***	7.57e+01 (8.59e00)***	7.57e+01 (8.61e00)***
Vehicle_Price	-6.9e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***	-6.95e-6 (4.69e-7)***
Autonomy	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***
Normal_CP	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***	8.03e-4 (9.46e-5)***
Fast_CP	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***
Cost_ICEV_100km	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***	1.09e-01 (2.71e-2)***
Subsidies	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)	1.31e-5 (9.87e-6)
Density	1.01e-4 (4.3e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***
Number of Models	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)	-2.05e-03 (2.38e-03)
Model year	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***	-3.71e-02 (4.28e-03)***
N	10125	10125	10125	10125	10125	10125	10125	10125	10125
R^2	9.78%	9.78%	9.78%	9.78%	9.78%	9.78%	9.78%	9.78%	9.78%
Adjusted R^2	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%

Table 5 Model sensitivity analyses by changing variables

Sensitivity analyses of the Table 6 consists on the elimination of each variable in order to conclude the model's robustness.

	Vehicle_Price	*Autonomy*	*Normal_CP*	*Fast_CP*	*Both Normal & Fast*	*Cost_ICEV _100km*	*Subsidies*	*Density*	*Nb of Models*	*Model Year*
Intercept	1.09e+02 (8.38e00)***	9.07e+01 (8.59e00)***	7.5e+01 (8.63e00)***	7.54e+01 (8.6e00)***	7.49e+01 (8.6e00)***	7.53e+01 (8.6e00)***	7.57e+01 (8.6e00)***	7.57e+01 (8.59e00)***	7.64e+01 (8.55e00)***	1.00e+00 (1.54e-01)***
Vehicle_Price		-4.935e-6 (4.47e-7)***	-6.92e-6 (4.71e-7)***	-6.94e-6 (4.69e-7)***	-6.92e-6 (4.69e-7)***	-6.93e-6 (4.7e-7)***	-6.95e-6 (4.69e-7)***	-6.36-6 (4.83e-7)***	-6.94e-6 (4.69e-7)***	-8.05e-6 (4.54e-7)***
Autonomy	8.68e-4 (1.02e-4)***		1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.4e-3 (1.06e-4)***	1.38e-3 (1.06e-4)***	1.30e-3 (1.09e-4)***	1.38e-3 (1.06e-4)***	1.5e-3 (1.05e-4)***
Normal_CP	7.92e-4 (9.56e-5)***	8.00e-4 (9.54e-5)***		7.12e-4 (9.46e-5)***		7.89e-4 (9.46e-5)***	8.34e-4 (9.18e-5)***	6.23e-4 (9.71e-5)***	7.83e-4 (9.17e-5)***	7.99e-4 (9.50e-5)***
Fast_CP	5.49e-4 (1.02e-4)***	5.54e-4 (1.02e-4)***	4.04e-4 (1.00e-4)***			5.58e-4 (1.01e-4)***	5.55e-4 (1.01e-4)***	2.37e-4 (1.03e-4)***	5.4e-4 (1.00e-4)***	5.52e-4 (1.01e-4)***
Cost_ICEV_100km	1.05e-01 (2.74e-2)***	1.26e-01 (2.73e-2)***	1.01e-01 (2.72e-2)***	1.10e-01 (2.71e-2)***	1.02e-01 (2.71e-2)***		1.05e-01 (2.71e-2)***	1.08e-01 (2.71e-2)***	9.72e-02 (2.30e-2)***	1.04e-01 (2.72e-2)***
Subsidies	1.23e-5 (9.98e-6)	1.27e-5 (9.87e-6)	3.35e-5 (9.6e-6)	1.31e-5 (9.87e-6)	3.18e-5 (9.6e-6)***	1.35e-5 (9.87e-6)		-8.17e-6 (1.01e-5)	1.36e-5 (9.87e-6)	1.38e-5 (9.91e-6)
Density	1.02e-4 (4.3e-6)***	1.06e-4 (4.31e-6)***	1.03e-4 (4.31e-6)***	1.03e-4 (4.28e-6)***	1.01e-4 (4.29e-6)***	1.06e-4 (4.31e-6)***	1.06e-4 (4.31e-6)***		1.06e-4 (4.31e-6)***	1.06e-4 (4.33e-6)***
Number of Models	-7.96e-04 (2.4e-03)	-2.41e-03 (2.38e-03)	2.97e-03 (2.31e-03)	2.21e-03 (2.35e-03)	4.25e-03 (2.29e-03)***	3.06e-03 (2.028e-03)	-2.22e-03 (2.38e-03)	-5.05e-04 (2.45e-03)		-4.42e-02 (2.37e-03)***
Model year	-5.4e-02 (4.17e-03)***	-4.46e-02 (4.28e-03)***	-3.69e-02 (4.29e-03)***	-3.71e-02 (4.29e-03)***	-3.69e-02 (4.28e-03).	-3.68e-02 (4.28e-03)***	-3.72e-02 (4.28e-03)***	-3.63e-02 (4.41e-03)***	-3.76e-02 (4.25e-03)***	
N	10125	10125	10125	10125	10125	10125	10125	10125	10125	10125
R^2	7.8%	8.2%	9.10%	9.5%	8.9%	9.6%	9.7%	4.3%	9.77%	9.10%
Adjusted R^2	7.7%	8.1%	9.03%	9.4%	8.9%	9.5%	9.6%	4.2%	9.7%	9.03%

Table 6 Model sensitivity analyses by eliminating variables

*Signification codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'*

Generally, according to Table 6, we applied another robustness check to our model by eliminating the studied variables to investigate the impact on the model. Removing all the variables did not have any impact on the R^2 value of the model it was approximately maintained around 10%; except the density that dramatically decreased R^2 to 4%. We can conclude from above that the density have the most important impact on the model. However, it does not influence on the client's opinion to adopt a PEV. It is a pure demographic variable. On the other hand, eliminating both charging infrastructure variables have an impact on the other variables coefficients but not on the R^2. From these sensitivity tests this is possible to conclude that in our model, the charging infrastructure have an influence on the PEV purchasing but is not the responsible of the PEV growth. Thus, it can be concluded that drivers charge their vehicles using private chargers. Before buying a PEV, the client will investigate about the number of charging points in the department where he/she lives as well as about the technical specifications of the vehicle. Regarding their coefficients, both normal and fast chargers have the same value. Therefore, they have the same impact on the model.

6.5. Discussions

These empirical results provide a useful comparison with the literature review section. The regression results on PEV sales in France confirm the expected outcomes: higher autonomy, higher fuel prices, higher density as well as higher number of near charging points lead to higher sales. While most of these variables are significant and have the expected signs, this was the case for local subsidies that the literature has anticipated to be influential because of their non-significance (Van den Bergh et al., 2006; Sierzchula et al., 2014; Fearnley et al., 2015). Also, an increase of fuel or diesel prices can boost the PEV market. Drivers will start comparing electricity to fuel prices and will be convinced about electromobility. However, the effect of charging points is interesting: both normal and fast have the same impact on the model. Regarding the clients' choice, they are not interested about the charger's speed. They are not interested about waiting so long in order to fuel their batteries. This could be justified by the installation of private charging points at homes that can be used only by the owner. These studies should be developed by adding the private charging point effect on the model, because according to many clients, they charge their PEV during night in order to leave their house with 100% of SoC. Moreover, the degree of urbanity plays a role in the private chargers installation: it is difficult to install private sockets if a parking is not provided. In addition to this, we can conclude that local subsidies do have a negative impact on the driver's choice: the price of a brand new PEV will be more expensive than an ICEV even though more subsidies are taken into account. Different lessons can be conducted from these variables. First, operators should investigate more about the drivers points of views in order to cover all their needs in terms of accessibility, location, offers for different types of payment, etc... Second, regulators, governments and policy makers should put more rules in order to manage the installation of charging points, especially elaborate the "Right to install a private charger" or "Le droit à la prise". Third, since the main problem is to convince drivers to switch into electromobility and according to these variables, PEV manufacturers should release vehicles with high autonomy (or battery capacity) with affordable prices. Thus, a collaboration with the government/municipalities is a must in order to fix logical subsidies that may lower the vehicle's price. However, there are fundamental differences between the literature review and our model that could help to understand some conflicting results. Thus, further studies on details vehicles parameters are necessary. The strategy of these regions is to help their citizens to purchase an EV with the cheapest price. For this reason, many departments decided to apply these local bonuses in France but stopped after a while. Indeed, direct and indirect incentives could have been included in the model via several ways. We only took into account subsidies as financial incentives. At the same time, and as mentioned in the previous sections, tax exemption, reduction in toll road rate, free parking, charging facilities, etc. could be other forms of financial subsidies that were not taken into consideration in this study because of the difficulty to obtain below states and nations consistent data.

We can conclude that the model is given as:

$$\begin{aligned} \boldsymbol{Log(Sales_{i,j,t})} = \boldsymbol{\alpha} + \boldsymbol{\beta_1 Vehicle\_Price_{\,i}} + \boldsymbol{\beta_2 Autonomy_i} + \boldsymbol{\beta_3 NormalCP_{j,t}} + \boldsymbol{\beta_4 FastCP_{j,t}} \\ + \boldsymbol{\beta_5 CostICEV100km_t} + \boldsymbol{\beta_6 Subsidies_{\,j}} + \boldsymbol{\beta_7 Density_{\,j,t}} + \boldsymbol{\beta_8 Number\_of\_Models_{\,t}} \\ + \boldsymbol{\beta_9 Model\_Year_i} + \boldsymbol{\varepsilon} \end{aligned}$$

7. Conclusion

The purpose of this paper was to explore the relationship between several socio-demographic-techno-economic parameters with the evolution of PEV sales in France. We analyzed the PEV sales depending on the French departments and based on collected data from different sources: Groupe PSA, EAFO, www.datagouv.fr, Automobile propre, Statista, etc. over a period of four years (from 2015 to 2018). First, we cleaned our data and eliminated the correlated variables (Battery capacity and electricity price). Then, we built a pooled panel model using RStudio. Our results show that PEV parameters (autonomy, price), local subsidies, density, chargers as well as the fuel price are highly significant and have positive impact on the sales. However, of the variables used in the model, the vehicle's price, number of available chargers and model year have an inversely impact on the sales. People are interested about the installation of normal public charging points. We also checked the model's robustness by applying sensitivity tests on variables either by changing or by eliminating them. We concluded about the robustness of the model with the most factors' variation. This study also provides some notes of caution for the different parties that are directly or indirectly responsible of the PEV market. Some recommendations are elaborated in Section 6 for PEV manufacturers, recharge infrastructure operators and the policy makers. Therefore, we suggest for future studies to focus on the sales within the same department such as city and suburbs. Additionally, it is possible that the used variables concealed important factors. Thus, as mentioned in the previous sections, tax exemption, reduction in toll road rate, free parking, charging facilities, etc. could be other forms of financial subsidies that were not taken into consideration in this study. Some factors can be developed by adding more variables such as GDP (Gallagher and Muehlegger, 2011; Sierzchula et al., 2014), all types of local incentives, renewable energy production (Li et al.; 2017), percentage of citizens who vote with the green part (per department), family sizes, education level (Sierzchula et al., 2014), ages (Egbue and Long; 2012), the variation within the same year (months or seasons), etc.

As a general conclusion, the development of the electromobility remains open for further researches that require additional methodologies to deal with the complexity of the problem as well as up-to-date and detailed databases for other countries.

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