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Willingness to pay for electric vehicles and their attributes: the impact on electric vehicles market diffusion in France

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Executive Summary

This paper examines electric vehicle diffusion in France taking into account monetary and non-monetary drivers. Barriers and levers to alternative fuel vehicle adoption are examined based on a discrete choice experiment. Willingness to pay for autonomy, charging time, charging point density, EV specific criteria were calculated for different household types. Then, these non-monetary attributes are included to a classic investment behaviour model based on generalized total cost of ownership, to estimate EV diffusion. The possibility to recharge EV at home, the EV trial, information on battery quality and charging solutions, EV incentives are important parameters to boost EV sales.

Keywords: EV (electric vehicle), market development, user behaviour, cost, simulation

1 Introduction

In France, the development of personal electric vehicles (EV) is often seen as one of the best ways to achieve significant CO_2 emissions reduction in passenger transport sector [1], which is necessary to achieve the ambitious climate goals set by the Paris Agreement [2]. Although the EV economic interest seems to be already acquired for certain mobility needs [3], actual EV adoption by mass market still raises questions. In France, in 2018, sales of light vehicles (passenger cars and light commercial vehicles), battery electric vehicle (BEV) and Plug-in hybrid vehicle (PHEV) only reached 2.05% market share. It is important to better understand key parameters which influence EV adoption, both monetary and non-monetary, to know how to reach France’s ambitious targets: 14%, 38% and 45 % EV passenger car sales market share in 2023, 2028 and 2030, respectively [4].

Some studies show barriers to EV adoption [5] [6] [7], other try to quantify these barriers (autonomy, charge time, charging point density…) thanks to willingness to pay (WTP) [8] [9] [10]. Other studies first examine total cost of ownership (TCO) comparing EV and internal combustion vehicle (ICV) investment cost and energy cost, sometimes maintenance and insurance cost and then model diffusion pathways [11] [12]. But few studies take into account both the monetary aspects and the non-monetary barriers to model EV diffusion [13] [14] [15] and no study was barely found to look at the EV diffusion model sensibilities to non-monetary parameters, which is the focus of our work.

First, this study explains willingness to pay to overcome some EV barriers (EV driving anxiety, autonomy, charging time, charging point density) differentiating by different household types. Then we study some EV diffusion model results taking into account monetary aspects and non-monetary barriers. Finally we analyse non-monetary barriers evolution and the impact on EV diffusion. We focus on private cars in France, a country rarely studied [16], and look at BEV, PHEV, natural gas vehicle (NGV) and ICV.

2 Willingness to pay

2.1 Methodology

A representative sample of 12,000 French future vehicle buyers answered an online survey in December 2016 and were asked to choose between 4 cars among different powertrains (ICV, BEV, PHEV, NGV), in 6 different configurations (see example on Table 1 and 1 bis). Each car gets different attributes levels for purchase price, fuel cost for 100 km, autonomy, distance to fuel station/public charging station, charging time, incentives. Table 2 shows the attributes' values. These values are chosen on purpose in a wide range in order to represent value possible from 2015 to 2050. One powertrain can be twice in the same trade-off (example table 1) but cars have different attributes levels. We then used a multinomial logit model (discrete choice based on declared preferences) [17] [18] to calculate each attribute level willingness to pay (WTP) [19]. The WTP is the maximum price at or below which a consumer will definitely buy one unit of a product. The WTP was determined for different household characteristics (standard of living, car rank, home charge possibility, long trip frequency, annual kilometers, BEV experience, age, owned vehicles number) in order to better understand alternative vehicle barriers and boosters among household segments.

Table 1et 1 bis: Example of 2 of the 72 000 trade-offs (one among 4 vehicles has to be chosen)

	ICV	BEV	NGV	BEV
Purchase price (bonus already deducted)(without battery for electric vehicle which are rented)	12 500 €	10 625 €	14 375 €	12 500 €
Autonomy	800 km	350 km	800 km	500 km
Fuel/electricity cost for 100 km (including battery location cost for EV)	11 €	8 €	7 €	10 €
Average distance in kilometer to fuel station/charging public station	fuel station at 6.5 km in rural zone, 2.5 km in urban zone	charging station at 7 km in rural zone, 1.5 km in urban zone (0 km if charge at home)	gas station at 16 km in rural area, 6 km in urban area	charging station at 7 km in rural zone, 2.5 km in urban zone (0 km if charge at home)
Charging time in a public station /fuel tank fulling time	About 10 minutes in fuel station for **800 km**	About 10 minutes in a public charging station for **200 km autonomy** (between 5 to 11h at home)	About 10 minutes in fuel station for **800 km**	About 90 minutes in a public charging station for **200 km autonomy** (between 5 to 11h at home)
Public incentive (free parking, access to some restricted city center, reserved lane on motorway, smaller motorway tolls)…	No	No	Yes	Yes

	ICV	PHEV	PHEV	BEV
Purchase price (bonus already deducted)(without battery for electric vehicle which are rented)	20 000 €	26 000 €	23 000 €	20 000 €
Autonomy	800 km	80 km electric and 720 km thermic	40 km electric and 720 km thermic	200 km
Fuel/electricity cost for 100 km (including battery location cost for EV)	7 €	2 €	6 €	8 €
Average distance in kilometer to fuel station/charging public station	fuel station at 6.5 km in rural zone, 2.5 km in urban zone	charging station at 7 km in rural zone, 1.5 km in urban zone and fuel station at 6.5 km in rural zone, 2.5 km in urban zone	charging station at 7 km in rural zone, 1.5 km in urban zone and fuel station at 6.5 km in rural zone, 2.5 km in urban zone	charging station 7 km in rural zone, 2.5 km in urban zone (0 km if charge at home)
Charging time in a public station /fuel tank fulling time	About 10 minutes in fuel station for **800 km**	About 20 minutes for 40 km with electricity	About 10 minutes for 40 km with electricity	About 20 minutes in a public charging station for **200 km autonomy** (between 5 to 11h at home)
Public incentive (free parking, access to some restricted city center, reserved lane on motorway, smaller motorway tolls)…	No	No	Yes	Yes

Table 2: Different attribute levels for each motorization in the trade-off

	ICV	BEV	NGV	PHEV
Purchase price (compared to wanted purchase price)	100%	70%; 85%; 100%; 115%; 130 %	100%; 115%; 130 %	115%; 130 %
Autonomy (in km)	800	200; 350; 500; 800	800	40;80;160
Fuel/electricity cost for 100 km (including battery location cost for EV)	3;7;11;16;20	2;4;6;8;10;12;14;16;18	3;7;12;16	2;6;9;12
Average distance in kilometer to fuel station/charging public station	6.5 km in rural area, 2.5 km in urban area	11 km in rural area, 3 km in urban area 7 km in rural area, 2.5 km in urban area 7 km in rural area, 1.5 km in urban area 7 km in rural area, 0.5 km in urban area	41 km in rural area, 16 km in urban area 16 km in rural area, 6 km in urban area 6.5 km in rural area, 2.5 km in urban area	No public station 11 km in rural area, 3 km in urban area for charging station 7 km in rural area, 2.5 km in urban area for charging station 7 km in rural area, 1.5 km in urban area for charging station 7 km in rural area, 0.5 km in urban area for charging station and fuel station 6.5 km in rural area, 2.5 km in urban area
Charging time in a public station /fuel tank fulling time	About 10 minutes for 800 km	About 90 min for 200 km About 20 min for 200 km About 10 min for 200 km	About 10 minutes for 800 km	About 20 min for 40 km with electricity About 10 min for 40 km with electricity About 5 min for 40 km with electricity
Public incentive	No	Yes or No	Yes or No	Yes or No

2.2 WTP for different motorizations and attributes

Figure 1 shows the different average WTP for different attributes (autonomy, charging time, station density) for the 3 powertrains BEV, PHEV and NGV (compared to ICV). The WTP_motorization attribute takes into account specific characteristics of the alternative fuel vehicles like image, performance (speed/acceleration), environmental impact, noise, battery lifetime, maintenance network, model variety …).

WTP_motorization from BEV to ICV is around 4300 €, it is the surplus price that people are ready to pay to have an ICV instead of BEV given that ICV and BEV have the same autonomy, charging time and charging station density. Since WTP_motorization for BEV, PHEV and NGV are positive, it means that this alternative fuel vehicle in 2016 are globally seen as less attractive than ICV. WTP_motorization_BEV is five times lower than WTP_motorization_NGV: BEV diffusion barriers and incentives to implement in order to help BEV diffusion are far lower than for NGV. WTP_incentives is equal to -3680 €, it means that people are ready to pay this amount to have access to incentives that could be implemented (free parking, access to some restricted city center, reserved lane on motorway, smaller motorway tolls). It almost compensated the disadvantage seen for BEV and PHEV motorizations (WTP_incentives ≈ WTP_motorization_BEV ≈ WTP_motorization_PHEV)

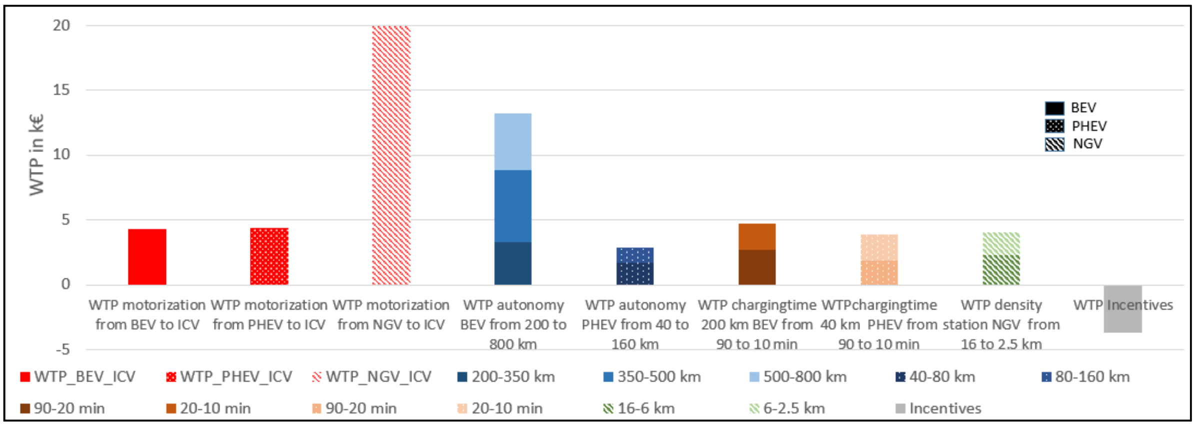

Figure 1: Average WTP for different attributes and different motorizations

For BEV, people are ready to pay an average amount of 13185 € to increase their autonomy from 200 to 800 km (respectively 3289, 5510, 4387 € from 200 to 350, from 350 to 500 and from 500 to 800 km). For BEV, we see that people are more interested in increasing autonomy than reducing charge time. As a matter of fact, WTP_autonomy is far higher than WTP_charging_time and WTP_motorization.

WTP_autonomy_PHEV from 40 km to 160 km is lower than WTP_autonomy_BEV from 200 to 800 km, however people are ready to pay to have more electric autonomy with PHEV in order to have extra fuel economy on their bill.

Our calculation shows that public charge point density should not be a significant factor for BEV or PHEV. This means that people who choose BEV/PHEV are already satisfied by the number of existing charging points, whereas people who never choose BEV/PHEV do not pay attention to charge density criteria since they eliminate BEV for other reasons, particularly charge time and autonomy. Trade-off method requires that BEV must be chosen in order to determine attributes by differentiating price with ICV motorization. People who do not have possibility to charge at home, automatically discard the electric vehicle which prevent from quantifying public charging station density. However for NGV, people are ready to pay more to increase gas station density. We suppose two majors reasons. First, today gas station density is far lower than fuel station density or public charging station density. Secondly, for most of the people, it is more difficult to fill NGV at home than to charge BEV/PHEV at home.

However, all the results can vary a lot according to households. That is why, we looked major household characteristics influence on different WTP attributes focusing on BEV in order to better understand barriers and levers for different household segments.

2.3 BEV WTP_motorization according to household type

The WTP for motorization takes into account all other vehicle motorization characteristics than those already tested: autonomy, charging time, charging point / fuel station density. The reluctance to buy BEV appears to be mainly due to charging issues and uncertainties about batteries (see Figure 3). Hence to help BEV diffusion, the importance of communicating on battery lifetime, offering battery guaranty, explaining how to charge and finally helping people to install a charging solution at home. This BEV perceived extra cost varies widely across households (Figure 2). with different characteristics: standard of living, car rank, home charge possibility, long trip frequency, annual kilometers, BEV experience, age, owned vehicles number)

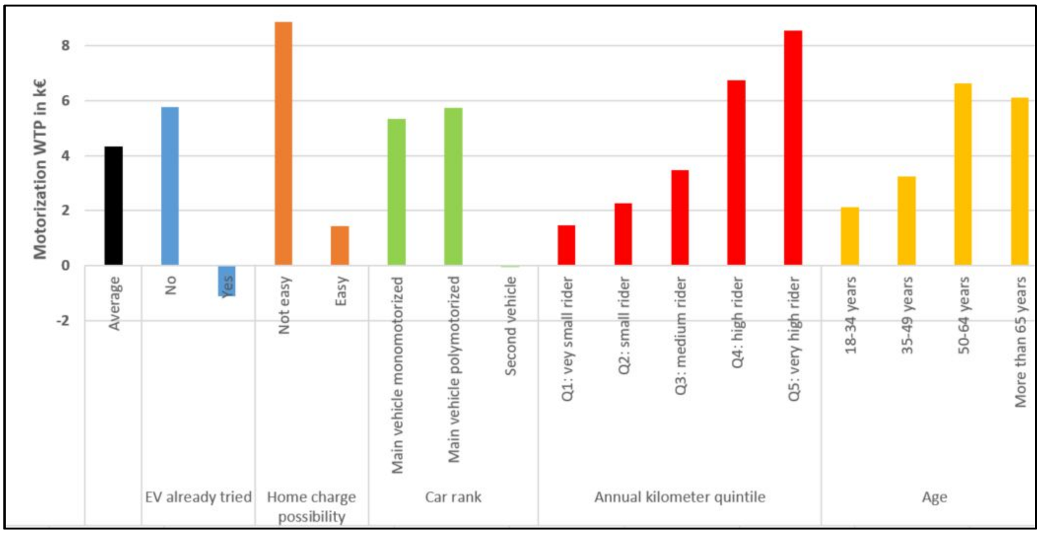

Figure 2: BEV WTP_motorization according to household type

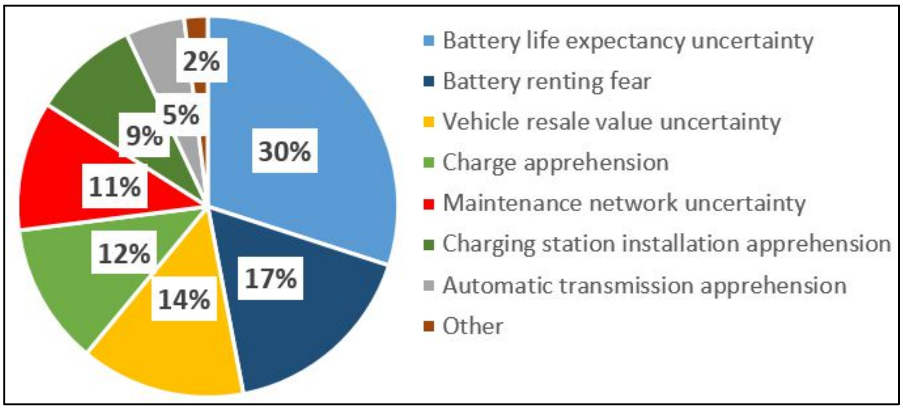

Figure 3: Main apprehensions (except for autonomy, charge time and public charging station density) for BEV cited by surveyed people

For example, for people who have never tried EV, BEV purchase cost should be in average 5800 euros cheaper than ICV in order BEV to be chosen, given similar use cost, autonomy, charging point density and charging time for households to purchase it (Figure 2), whereas people having already tried an EV are ready to pay 1100 euros more. Every solution offering people to test BEV, will change BEV vision and will help BEV diffusion, for example car-sharing with BEV, BEV taxi, BEV courtesy car, BEV tests organized by car manufacturers.

BEV WTP_motorization reaches 9,400 euros for people considering difficult to install charging point at home while it is only 1,250 euros for households that can easily install charging point at home. The fact of not being able to charge at home appears prohibitive for electric vehicle adoption, enhancing the importance of supporting people to get access to nearby charge points, particularly in multi-family building (43% of main dwellings in France).

BEV WTP_motorization may fall to 0 for second vehicle whereas it is more than 5000 € for main vehicle. For second vehicle, in case of failure, people can use their main vehicle reducing anxiety. Some solutions like free courtesy vehicle in case of BEV vehicle failure, could help people to feel more confident to buy BEV for their main vehicle.

This trade-off shows also that the lower annual mileage drive the smaller WTP_motorization, certainly because they are less dependent on car. Young people are less reluctant to BEV than the elderly. Knowing that in France, the average age to buy new vehicle is 56 years old, more communication to decrease BEV fears must be done particularly for 50 to 64 years-old people.

2.4 BEV WTP_autonomy according to household type

For BEV, WTP_autonomy varies widely across households, in particular the value is influenced by the standard of living and the annual mileage. However, in proportion, the variation is smaller than for WTP_motorization.

WTP for switching from 200 to 350 km BEV for households is relatively low (Figure 4) compared to WTP for switching from 350 to 500 km. The latter is much higher than WTP for switching from 500 to 800 km. It means that 200 km is sufficient for usual daily trips but people want more than 350 km autonomy for their long trips, but 500 km seems enough.

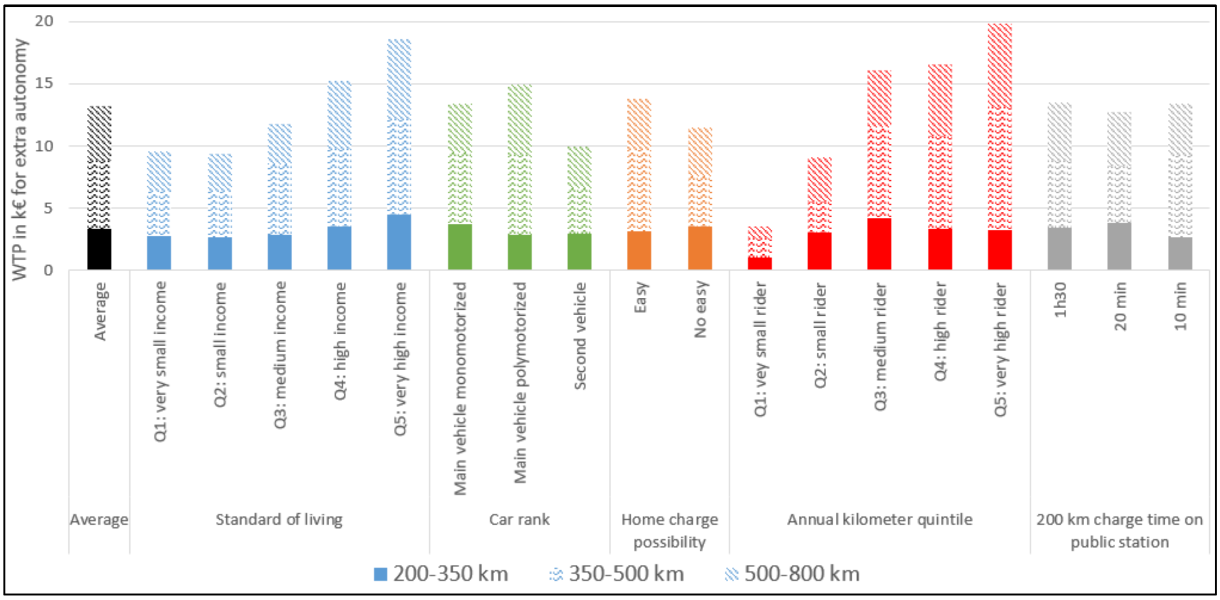

Figure 4: BEV WTP_autonomy according to household type

The standard of living strongly influences this average result: the value given to one extra kilometer in the range of 200 to 500 km of autonomy reached an average amount of 29 € / km for a 500 km autonomy vehicle but it is 33 € / km and 40 € / km for households with the highest standard of living quintiles (Q4 and Q5).

However, these households are the most likely to acquire new vehicles. Indeed they represent respectively 28% and 42% of new vehicles sales. This average value granted per kilometer of autonomy is to be compared to battery price production[1] (around 24 € / km with a 17kWh / 100 km consumption and 160$/kWh [20]). So except for small rider, since WTP_autonomy from 200 to 350 is smaller than WTP_autonomy from 350 to 500 km, people should buy BEV with more than 350 km autonomy (≈ 60 kWh) if their autonomy willing do not change, and battery price should allow soon to propose vehicles offering an autonomy compatible with more than 2/3 of future car purchasers budget and willing.

When people buy a BEV as a second vehicle, the WTP for extra autonomy above 350 km is lower than when it is their main vehicle. As a matter of fact, for their long trips they can use their main vehicle. What is more surprising is that people polymotorized are ready to pay more to gain autonomy for their main vehicle than people monomotorized. We can find two main reasons: first they are richer, secondly they want to use more their main vehicle and less their second one.

People who do not have easy access to charge are willing to pay a bit more to gain autonomy from range 200 to 350 since it facilitates them their usual trip by decreasing their public charge frequency, however they are willing to pay less for next ranges than people with easy charge. It could be that most of people with no easy charge at home consider only BEV purchase as a second vehicle.

Charge time on public station seems to have no influence on the willing to have autonomy. It means that, even if there is a huge development of public fast charging station, BEV diffusion won't happen if BEV autonomy do not increase. However, it is usefull to develop public fast charging station since people are ready to pay to reduce charge time (see 2.5)

2.5 BEV WTP_charging_time according to household type

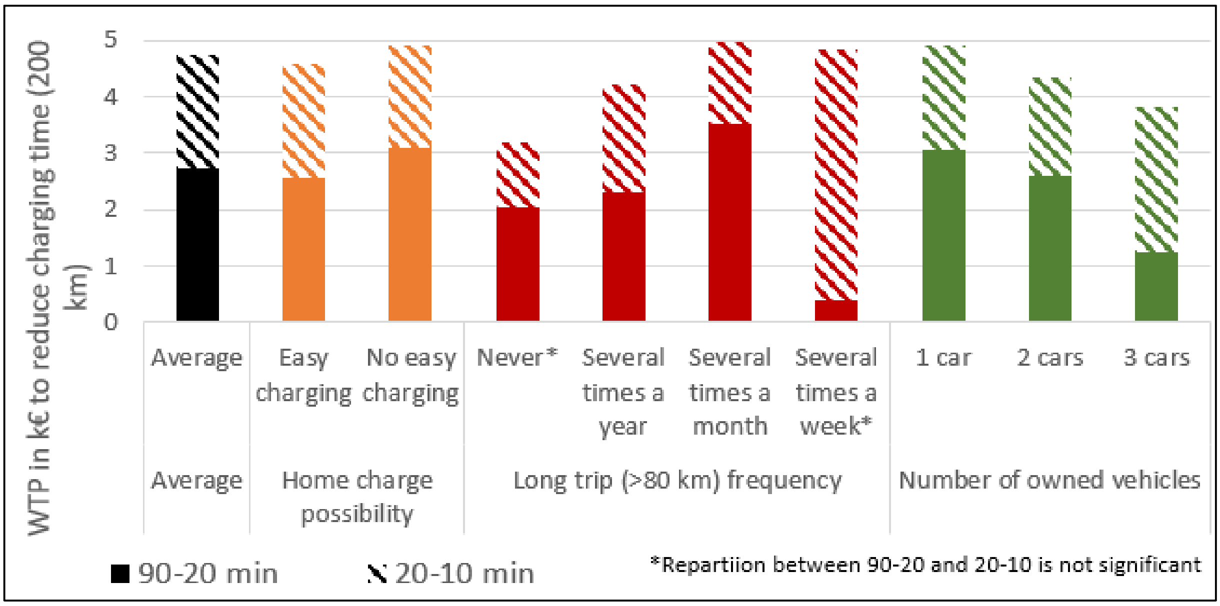

Figure 5: BEV WTP_charging time according to household type

Strong public charging station density doesn't seem to be a requirement for most of household to buy a BEV (2.2). However, charging time on public station seems important. Globally, people are ready to pay 2 700 € to reduce the time to charge 200 km from 90 minutes to 20 minutes (that is to say shifting charging point from 22 kW to 100 kW) and 2 000 € from 20 minutes to 10 min (charging point at 200 kW). People driving few long trips are ready to pay more to reduce from 90 to 20 than 20 to 10 min since they barely use public station and are ready to wait. This is not the case of people frequently driving long trips which refuse to wait longer than with ICV and are only ready to pay to reach 10 minutes charge.

[1] cell price is higher including guaranty, battery builder margin, car constructor margin… battery price should be around 45 €/kWh

People monomotorized are ready to pay more than multimotorized people since they cannot use a second ICV vehicle for long trips.

To reduce charging time, people without accessible charging are only ready to pay a bit more than people with easy charging what is surprising. It can be explained by the fact that they do not project to buy BEV if they do not have charge at home or really near home. Consequently with this proximity, charge time is not crucial.

3 EV market diffusion model

3.1 Immove-pbm methodology

To follow, we developed a model to better understand the personal private car sales diffusion of different motorizations in the long term for different household segments. We thus combined a traditional investment behaviour model based on TCO with WTP for non-monetary attributes. We then studied 90 car buyer household segments by considering annual mileage (5 classes: very small rider, small rider, medium rider, high rider, very high rider), income (3 classes: low, medium, high income), dwelling type (2 classes: easy access to charge at home and difficult access to charge), car type (3 classes: small, medium, large). 14 motorization were studied (Table 3)

Table 3: Motorization modelled in IMMOVE-PBM

ICV	BEV (autonomy estimated for large and small car in 2030)	PHEV	NGV
Stop-start gasoline Stop-start diesel Full hybrid gasoline Full hybrid diesel	BEV 30 kWh (160-240 km) BEV 40 kWh (210-310 km) BEV 60 kWh (305 - 445 km) BEV 80 kWh (395 - 570 km) BEV 100 kWh (481-688 km) BEV 120 kWh (560 - 795 km)	PHEV 40 km electric autonomy PHEV 80 km electric autonomy PHEV 120 km electric autonomy	NGV

For each year, from 2015 to 2040, for each household segment and for each motorization, we calculate the generalized TCO (Figure 6): it includes the traditional monetary TCO and the value of the additional non-monetary constraints (autonomy, load point density, load time and other attributes) to reach ICV performance (equation 1).

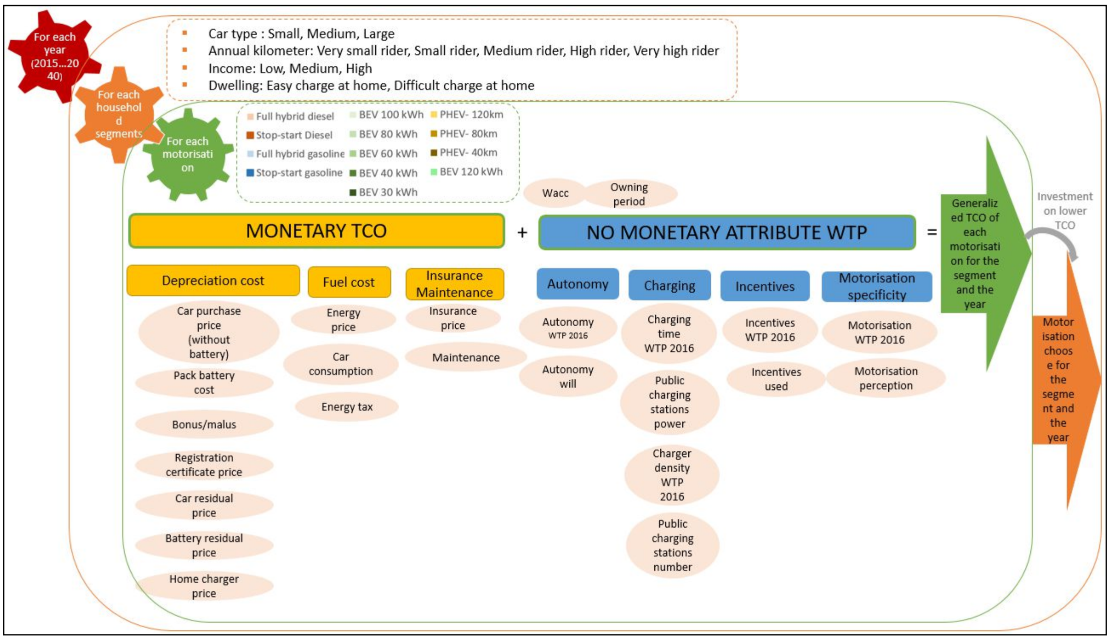

Figure 6: Global methodology for market share sales (IMMOVE-PBM model)

As the population is divided into small market shares, to simplify the model, households are supposed to invest in the type of vehicle that presents the lower generalized TCO. Model and the different assumptions are described in details in this study [21]. The assumptions taken in the selected scenario, rely on a scenario in which French regulatory context helps to develop EV to try to respect environmental agreements targets.

$$TCO_{generalized} = TCO_{monetary} + WTP_{autonomy} + WTP_{charge\ point\ density} + WTP_{charge\ time} + WTP_{motorization} + WTP_{incentives} \quad (1)$$

3.2 Results

Figure 7 shows EV diffusion provided by the model in a traditional monetary TCO taking into account or not non-monetary constraints, and shows the interest to take into account the different WTP to better model the diffusion. With the traditional monetary TCO, 30 kWh BEV reach almost 100% of market share in 2020, it means that 30 kWh BEV TCO is cheaper than ICV TCO. However BEV won't develop so fast because of the no monetary constraints.

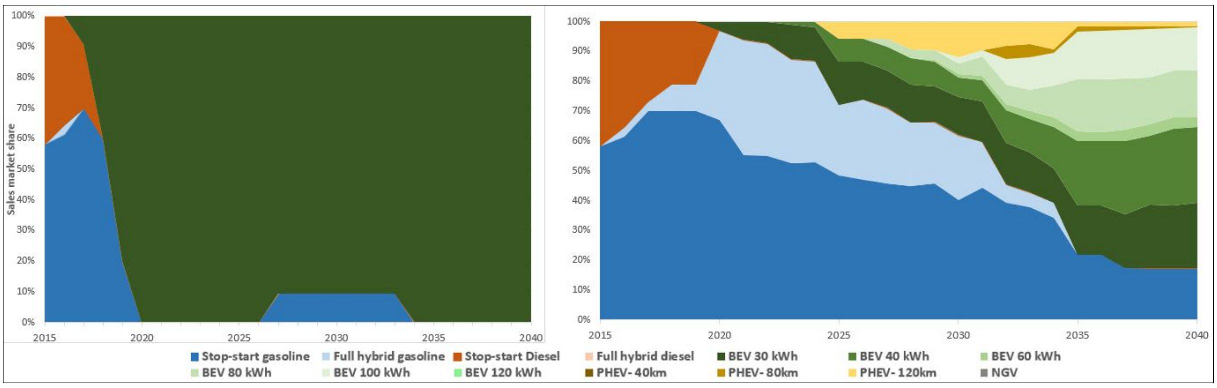

Figure 7: Private vehicle sales evolution with (right) or without (left) taking into account non-monetary constraints

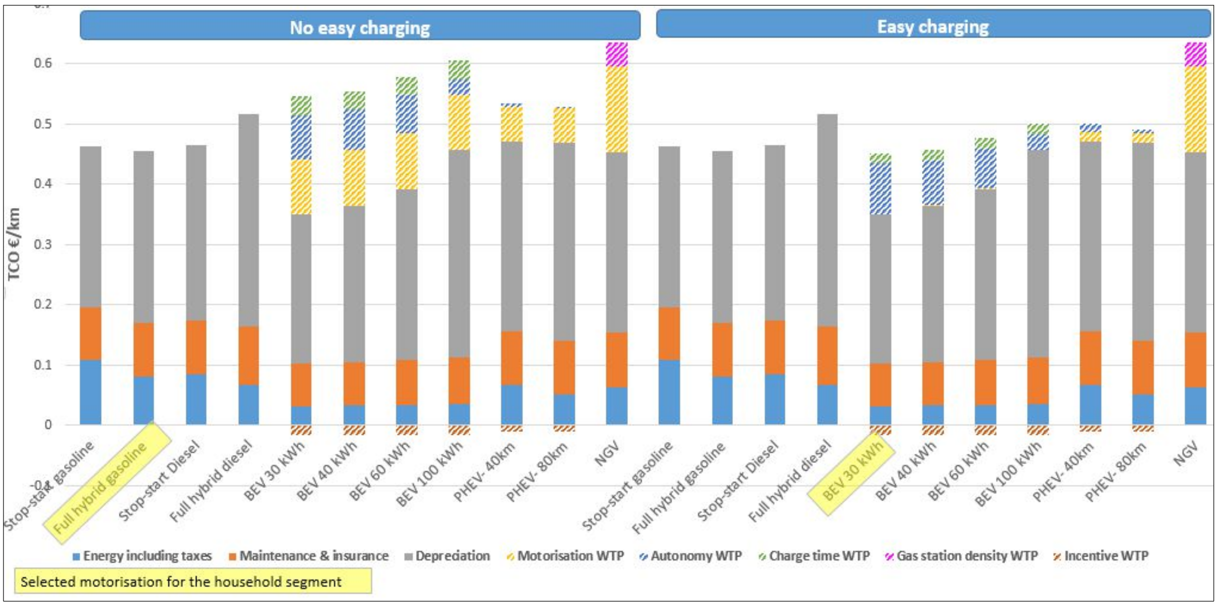

Figure 8: Generalized TCO for different vehicle technologies for large segment vehicle in 2025 for an average driver (11800 annual km) and medium income class

Figure 8 shows results obtained from generalized TCO model, including non-monetary attributes valorization for two household segments. On average, monetary TCO (filled parts) for EV 30, 40, 60 kWh appear to be lower than ICV monetary TCO, which should lead to a massive diffusion of EV after 2025 for these segments. But by taking into account autonomy limit, charging point availability at home, charging time and BEV apprehension, generalized TCO could be lower for ICV (example on figure 8 for the household without easy charging). Hence, the market share of EV would be 28% in 2025 at this time horizon (Figure 7) in the chosen scenario.

3.3 Sensitive analysis

The survey allows us to calculate WTP at present time, however these different WTP will evolve in the future and subsequently change EV diffusion by changing EV barriers level. Of course, in parallel, the different costs will change (battery cost decrease, fuel…), charging infrastructure will develop. We considered some evolutions in our scenario [21]. Figure 9 show sensitive analysis for different parameters on the WTP evolution.

Table 4 shows the main EV apprehensions, and the decrease considered in different scenarios. We see that by communicating on battery life expectancy and reassuring people, by explaining battery rental system, educating people on charging systems and helping them with home charge installation we can gain 20 points on EV sales in 2025 (Figure 9), enhancing the crucial role of car manufacturers and association on these points.

Table 4: Main apprehensions (except for autonomy, charge time and public charging station density) evolution considered in medium scenario for BEV and WTP_motorization_EV_ICV evolution

		Value compared to 2015			
	Main apprehension repartition in 2015	**2015**	**2020**	**2025**	**2030**
Battery life expectancy uncertainty	30%	100%	90%	75%	0%
Battery renting fear	17%	100%	90%	50%	0%
Vehicle resale value uncertainty	14%	100%	50%	0%	0%
Charge apprehension	12%	100%	0%	0%	0%
Maintenance network uncertainty	11%	100%	50%	0%	0%
Charging station installation apprehension	9%	100%	0%	0%	0%
Automatic transmission apprehension	5%	100%	50%	0%	0%
Other	2%	100%	50	0%	0%
WTP_motorization_EV_ICV medium		100%	58%	31%	0%
WTP_motorization_EV_ICV high		100%	50%	0%	0%
WTP_motorization_EV_ICV low		100%	80%	60%	30%

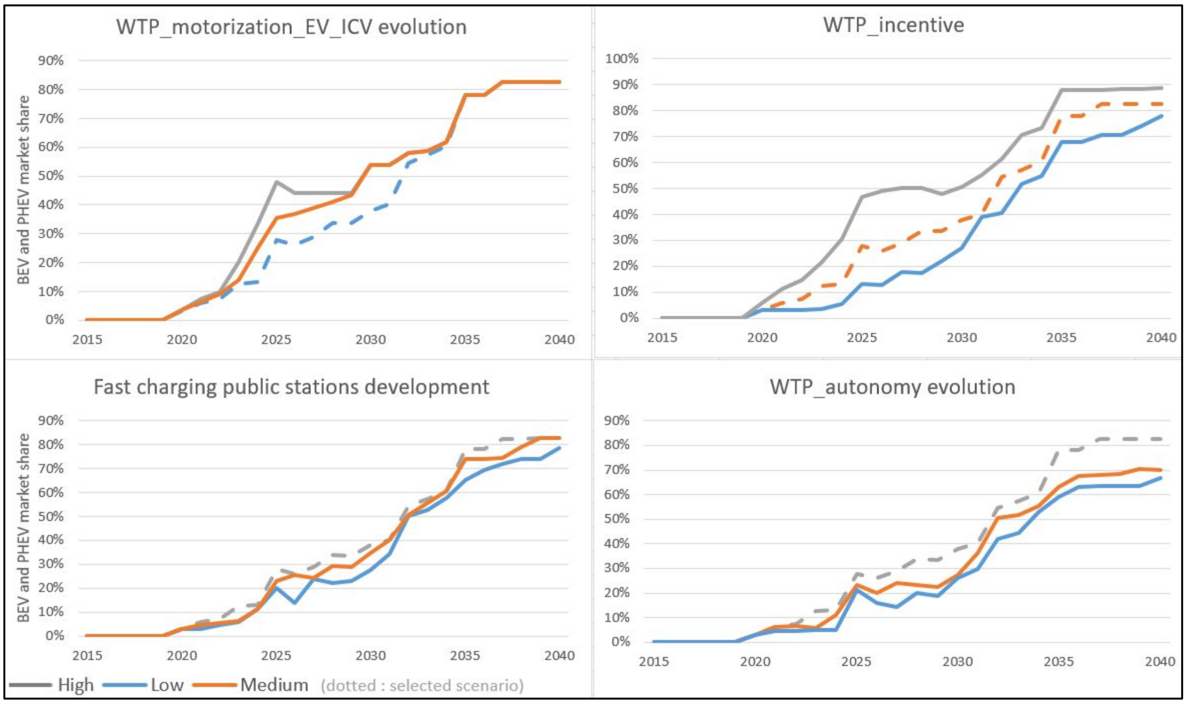

Figure 9: BEV and PHEV market share from 2015 to 2040 according to different parameters levels

Table 5 and Figure 9 show incentives influence on EV diffusion on market. These parameters are particularly crucial on the medium term (2020-2025) and really help the market to develop, and become less influent by 2040. For example in 2025, it can improve EV sales by 37 points in a scenario with high incentives compared to a scenario with low incentives. Hence the huge government role on implementing incentives to boost EV sales

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Table 5: For 3 scenarios, share of implemented incentives compared to free parking, access to some restricted city centres, reserved lane on motorway, smaller motorway tolls

	2015	2020	2025	2030	2035	2040
Medium	50%	50%	50%	29%	25%	25%
High	80%	80%	80%	55%	50%	50%
Low	30%	30%	10%	10%	10%	10%

Table 6 and Figure 9 show the fast charging development influence. In the coming years, it can influence a bit EV development. For example, in 2025, it can improve EV sales by 5 points in a scenario with high development of fast charging stations compared to a scenario with low development.

Table 6: 20000 fastest charging stations power repartition (there is around 10 000 fuel stations in France) in 3 scenarios L: Low; M: Medium; H: High

	2015			2020			2025			2030			2035			2040		
	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Station - 200 kW or more	0	0	0	0	0	0	0	2	4	2	4	15	7	15	25	10	35	25
Station - 100 kW	2	2	2	6	10	20	8	15	30	10	20	40	14	28	60	20	65	35
Station 40 kW	9	9	9	18	20	30	24	30	50	30	40	30	50	50	15	60	0	40
Station 22 kW	44	44	44	35	70	50	68	53	16	58	36	15	29	8	0	10	0	0
Station 7 kW	45	45	45	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Today, WTP for autonomy is linked to people mobility habits using ICV with large autonomy. However, given the cost to have more autonomy, we assume that people are likely to adjust their mobility habits and that some solutions should appear for long trips (superfast charging, ICV car rental, auto-train, range extenders …) hence the evolution of WTP for autonomy. Explaining to people their real autonomy need and showing them some solutions available for the few times they need more autonomy, will help to reach this objective. For example in 2030, it can improve EV sales by 12 points in a scenario where people begin to understand their real need compared to a scenario with people do not understand their autonomy needs (Table 7 and Figure 9).

Table 7: WTP_autonomy evolution considered compared to WTP_autonomy in 2015 in 3 scenarios

	2015	2020	2025	2030	2035	2040
Medium	100%	95%	90%	85%	80%	75%
High	100%	91%	82%	73%	64%	55%
Low	100%	98%	96%	94%	92%	90%

Conclusion

This study shows the importance of taking into account non-monetary constraints (range, charge density and new technology fear) associated with EV in diffusion models in order to improve their realism, particularly in the coming years. It shows what can be done to remove some EV diffusion constraints and the influence on EV market. First, the possibility of charging at home, especially in multi-family buildings, must be facilitated since it appears to be a prerequisite to consider the EV purchase. Second, people should try the EV to reassure themselves and discover its assets, this can happen for example with trial offered by car manufacturers, EV car-sharing, BEV courtesy car. Third, people have some strong apprehensions on BEV. To decrease these fears, people need to be informed on how to charge and how to install a charging point at home. They also need to be reassured on battery lifetime for example with a battery warranty and with a courtesy car in case of failure. Then government should help EV diffusion by implementing EV incentives like free parking, access to some restricted city centers, smaller motorway tolls. Finally we see that people are really willing to have a huge autonomy even if a fast charging network is built. Some car models with large autonomy must be developed to answer this demand however people must also be helped to really understand their real autonomy needs and solutions for occasional long trip must be explained to them and developed: public fast charger, ICV-car rental, auto-train, or trailer with extra-autonomy battery. This study also shows that NGV seems not to be a solution since people are far more reluctant to buy NGV than BEV.

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