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DISSERTATION

BATTERY ELECTRIC AND HYBRID ELECTRIC VEHICLES – AN ECONOMIC AND ENVIRONMENTAL EVALUATION

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ELECTRIC BATTERY AND HYBRID ELECTRIC VEHICLES – AN ECONOMIC AND ENVIRONMENTAL EVALUATION

By Ana Carolina Sousa

This paper aims to estimate the costs and the performance of an electrically powered and a hybrid electric vehicle (HEV) in relation to a conventional internal combustion engine car in the consumer, society and the exhaust Well-to-Wheel (WtW) carbon dioxide (CO2) emissions, using portuguese data. This goal will be achieved by building a total ownership cost model. A sensibility analysis is also conducted to assess the impact of alterations on the values of the key parameters. The results of this study suggest that neither the hybrid electric vehicle neither the battery electric vehicle (BEV) are yet competitive with the internal combustion engine vehicle (ICEV) in the Portuguese market.

Keywords: Battery electric vehicle, hybrid electric vehicle, cost-benefit analysis, CO2 emissions, taxes.

1. INTRODUCTION

Although a variety of clean vehicle technologies and fuels have been developed over the past years, electric vehicles represent one of the most promising: electrifying a country's vehicle fleet seems to be a key factor towards promoting a more sustainable, smarter and more inclusive growth. Electrically powered cars are the best technological pathway for cutting oil use leading to an increase in energy security due to the fuel mix diversification and to a reduction of external dependency on petroleum, and consequently to a decrease in the oil import bill. E-mobility also has a significant impact on the environment since electric vehicles (EV) usage may diminish greenhouse gas emissions such as CO2 and other pollutants. Furthermore, this green and fresh technology can also stimulate innovation and as a result create new industries and jobs subsequently improving economic growth.

In order to obtain these positive effects, a successful market introduction and penetration of electric vehicles is crucial. To do so, suitable targets must be set as well as appropriate strategies to reach them and research on consumer needs and behaviour and research and development initiatives ought to be promoted.

With these aspects in mind, this paper proposes to evaluate the economic and the environmental viability of electric transportation in Portugal. Therefore, the first goal is to determine if electric generation cars are an attractive option to consumers today through the definition of the point in which BEVs and HEVs become as attractive to consumers as conventional internal combustion engine cars. Another aim is to analyze whether this vehicle technology is a better choice to society by the assessment of the net impacts not only on the owners but also on the other aspects, especially regarding CO2 emissions and public finances.

Only with these metrics clearly identified is it possible to determine and implement effective policy plans and incentives.

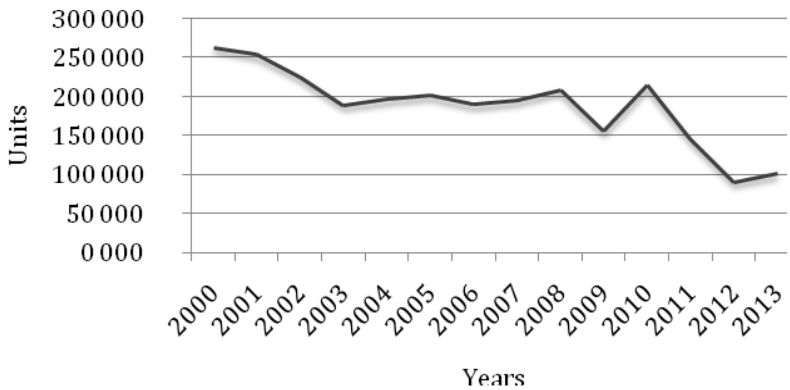
As a methodology, a simple complete life cycle ownership costs model is developed to estimate the costs associated over the vehicle's entire lifetime (not only the purchase price but also the running costs) to the consumer as well as to the society and the to determine the exhaust CO2 emissions too. The costs of each type of technology depend on the following variables: the specific capital cost, energy use, energy price, taxes and other operating costs, local air pollution cost, annual travelled distance, vehicle life and discount rate. As taxes are an important component of this assessment it also allows for the determining of the impact of electric generation cars on public treasury.

The results indicate that both hybrid and the battery electric vehicles are more costly than the conventional car from a private and a social perspective, because the fuel savings do not compensate the price premium, neither the air pollutant emissions. This analysis also finds that tax revenues from the HEV are higher than the ICEV ones because HEV *Imposto Único de Circulação* (IUC) is higher than ICEV, whereas the government loses money with the electric car. Regarding the exhaust CO2 emissions assessment, as long as HEV consumes less energy per kilometre than a conventional car it will always emit less CO2; with the assumed electricity-mix generation and thus the carbon content of electricity, the CO2 emissions produced by the electric car are also lower than ICEV.

Finally, the report is structured as follows: Section 2 characterizes the electric mobility in Portugal. Section 3 includes a literature review of previous economic research on electric mobility. Section 4 explains the methodology and presents the data used in the analysis. Then, Section 5 shows and discusses the results. Lastly, Section 6 summarizes and presents the conclusions of this study.

2. BACKGROUND

2.1. Sales



GRAPH I –NEW PASSENGER CAR SALES IN PORTUGAL

Source: ACAP, ICCT Europe

The new passenger vehicle sales in Portugal have been in a continued downward path since the beginning of the XXI century - from year 2000 to year 2013, new passenger car sales have fallen from 263381 million to 101126 million. As new vehicles sales are a mirror of the economic climate, in 2008 an even sharper downward trend started and the year of 2012 was the worst of the past 13 years: only about 90792 new passenger cars were sold. Moreover, during this period, a unique brief sales spike in 2010 interrupted the downward trend. New passenger car sales are now resuming. (ICCT, 2013 and ACAP, 2014)

The majority of new passenger cars in Portugal remain powered by gasoline or diesel: in 2012, diesel cars accounted for 71% of new passenger car registrations and gasoline vehicles for 27,21%; and all the other technologies– natural gas, hybrid and electric combined, make up the remaining 1,79%. (ICCT, 2013 and ACAP, 2014)

Hybrid electric vehicles were introduced into the Portuguese auto-market in 2004 and at that time only two models were offered. Until now more than 10000 cars have been sold and a diversity of hybrid models is available to consumers. However, HEV make up only 1% of new vehicle sales in Portugal. (ICCT, 2013 and ACAP, 2014)

The first 100% electrically powered vehicle was sold in Portugal in November 2010 and until the end of 2013 the total Portuguese vehicle stock numbered over 400 cars. In 2010, only two EV models were commercialized in the Portuguese auto-market and only six are still offered. At the beginning of electric transportation in Portugal, the national government established a deployment target for Electric Vehicles: EV sales should represent 10% of all vehicle sales in 2020. Every year this goal has become a greater challenge as today the EV market share is only 0,12% and therefore bigger adoption rates are essential to reach the defined target. (ICCT, 2013 and ACAP, 2014)

These low sales are probably justified because most consumers prefer to wait and see how new technology and its markets develop. Moreover, the limited choice for the consumer also had an influence on these numbers since as there is a strong correlation between sales and product variety (CEM, EVI & IEA, 2013). As a result, it is likely that with both consumers' trust and producers' experience gains the Portuguese EV sales will increase.

2.2. Charging Infrastructure

The development of a charging infrastructure is crucial for improving the market introduction of Electric Vehicles. Accordingly, as part of its demonstration project, during 2010 and 2011, the Portuguese government installed an intelligent network which primarily provides charging but also other background facilities (*Decreto-Lei* nº39/2010, April 26th).

This platform has 1350 chargers across the country - including 1300 slow charging points and 50 fast charging points that can be used by all electrically fuelled cars regardless of the auto-manufacturer (www.mobie.pt researched in April 2014). In the slow mode the charging time varies from 6 to 8 hours for a full charge whereas in the fast mode charging time ranges from 20 to 30 minutes for a complete charge.

It is important to note that there is no ex ante best solution concerning the charging infrastructure, rather the number of charging stations as well as its combination should be based on local needs and thus a well-designed system is the one that is the most suitable for the region. (CEM, EVI & IEA, 2013)

2.3. National Policy Initiatives

The success of electric-drive vehicles strongly depends on government support, mainly in making vehicles cost-competitive with conventional cars and ensuring an adequate recharging infrastructure is in place. The Portuguese government is fostering this market transformation by providing sizable investments in infrastructure as well as support to demand (*Decreto-Lei* nº39/2010, April 26th).

National authorities have supported the charging infrastructure installation cost across the country as explained in *2.2. Charging Infrastructure*.

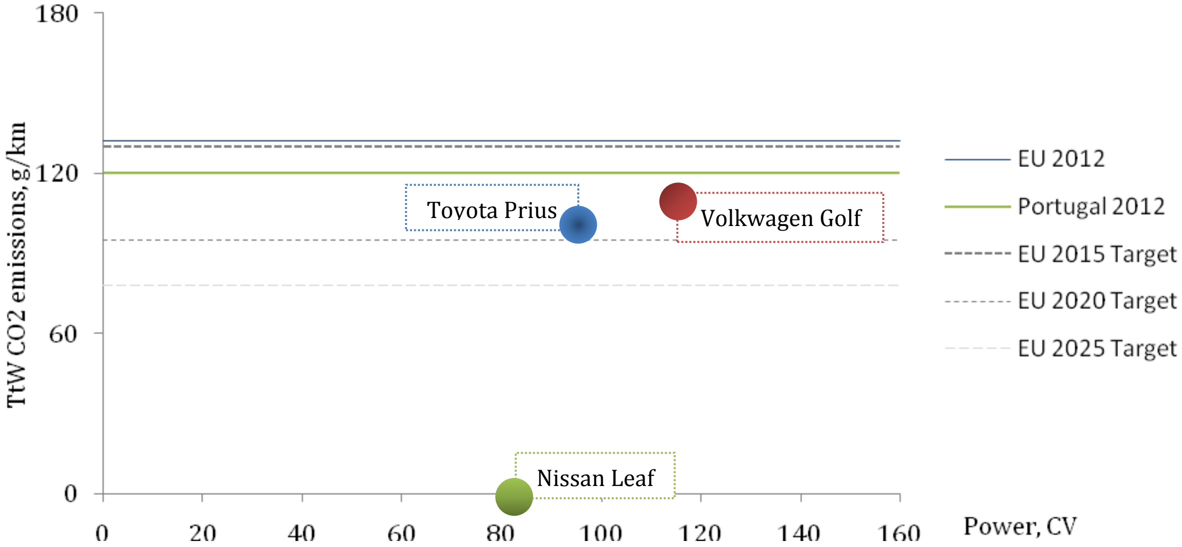
With regard to consumer incentives, the Portuguese government provides a combination of financial and non-financial incentives. Currently, electric vehicles are exempt from registration (ISV - *imposto sobre veículos*) and annual circulation (IUC - *imposto único de circulação*) taxes; and EV owners benefit from free electricity at public charging stations until the pilot phase is concluded. Regarding hybrid cars, a 50% ISV tax exemption is provided (*Lei* nº22-A/2010, June 29th). A set of other incentives were scheduled but they were cancelled given the present economic climate (*Lei* nº64-B/2011, December 30th).

2.4. CO2 emissions

Already in 1960s, the ICEV was identified as one of the largest causes of air pollution problems and the electric car as a solution to help them.

One should keep in mind that vehicles emit CO2 not only during use but also upstream. In other words, CO2 is produced over the fuel cycle, that is, through all the steps necessary to turn a feedstock into a fuel (Well-to-Tank CO2 emissions) and also over the vehicle cycle, that is, through fuel consumption (Tank-to-Wheel CO2 emissions).

Tank-to-Wheel CO2 emissions are better known and regulated. For instance, average CO2 emissions of newly registered cars in Portugal, normalized to the New European Driving Cycle (NECD) test, were 126 grams per kilometre in 2012, and 120 grams per kilometre, considering passenger cars only - Portugal has the lowest CO2 emission levels in the EU. This amount is already under the EU 2015 target of 130 grams of CO2 per kilometre. The European Commission has already established the target for 2020: 95 grams per kilometre; and puts forward an ambitious proposal to set a 2025 target of 78 to 68 grams per kilometre. Moreover, the TtW average CO2 emissions have been dropped for all engine technologies; in particular, the decrease in emission levels since 2005 has been particularly strong for gasoline vehicles. Despite that fact, hybrid and electric vehicles offer a significant possibility to further reduce the CO2 emissions in road transportation. (ICCT, 2013)



GRAPH II – TTW CO2 EMISSIONS

Source: Eurostat, ICCT Europe, Nissan, Toyota and Volkswagen Data

In what concerns WtT CO2 emissions, 100% electric vehicles can emit less or more than an ICE car, depending on the Portuguese electricity generation mix and specific on its carbon intensity. The environmental performance of battery electric cars strongly depends on the way that electricity is produced. Therefore, if supported by adequate policies to decarbonize electricity generation, they may have a positive contribution as far as lowering CO2 emissions is concerned.

2.5. Electricity grid and electric mobility

In recent past years, the Portuguese government bet strongly on renewable energies, particularly on wind-power. As a result, electricity generation from RES has been following an ascending pathway and in 2013 more than an half (57%) of the electricity generation results from hydro, wind, thermal and solar powers. (REN, 2013)

However, these energy sources are difficult to coordinate with existing power generation capacities and load curves: per example, wind energy is mostly available at night when demand is at its lowest. As a consequence, zero prices and even negative prices may occur and negatively affect electricity market.

Renewable generation and e-mobility are deeply connected and this relationship can accentuate the advantages of both: green power energies means less pollutant electricity generation which contributes positively to EV environmental performance; on the other hand, if consumers recharge their cars by night, electrical mobility may be an alternative to run offs the electricity produced by the wind at night at a very low price.

3. LITERATURE REVIEW

The literature has studied electric mobility from diverse perspectives: some studies focus on the factors that influence the adoption of EVs; others examine the private life cycle and the social costs of an EV in order to assess the benefits or the excess costs of having an EV rather than a conventional gasoline or diesel car; a more specific analysis emphasises the environmental benefits of e-mobility, namely the reduction of greenhouse gas emissions in general and CO2 emissions in particular and examines the effectiveness of governmental support of cleaner transportation.

Given the aim of the present study, this literature review focuses on the second type of studies mentioned.

A first paper by Prud'homme & Koning (2010) estimates the excess costs of an electric car relative to a similar fuel car, for the consumer and for society, as well as the CO2 gains it offers for France. The authors find that EV is not competitive: it will cost the consumer a further 12000 euros and 15000 euros more to society. They also find that if batteries are recharged at night, when CO2 content of electricity is close to zero, 19 tonnes are gained but at a high cost.

Similarly, Crist (2012) compared the lifetime costs of an internal combustion and a battery electric vehicle pair - sedan, compact and a van - providing about the same level of service during a given period of time from three viewpoints: consumer costs, socio-economic costs and CO2 emissions. The author finds that relative costs of electric vehicles remain elevated for consumers and even more for society, except in the case of the van.

Another study performed by Rusich & Danielis (2013) estimates the total private and social cost of seven different cars, including BEV and HEV, as well as their energy consumption using Italian data. From a consumer's point of view, the two analysed electrically-powered vehicles are the two most expensive cars as the conventional vehicles are the cheapest, followed by HEV. BEVs have zero emissions in the TtW but are highly pollutant in the WtT one; the opposite is true for the other cars. From a social point of view, the HEV performs as well as the BEVs and the absolute differences with conventional cars are quite small. BEVs become competitive when the vehicle life time and the annual distance driven rises and when battery costs decrease.

Nina (2009) performs an economic viability study of electric mobility in Portugal. The author employs a simple total ownership cost model to assess and compare the total life costs of an electric and a standard vehicle from consumer and social perspectives. Nina's findings show that under her baseline assumptions the electric vehicle is the most advantageous technology for the C-segment from a consumer's viewpoint. With regard to social costs, the electric vehicle incurs in a cost associated to externalities that are dependent on the source of the electricity used and may vary significantly.

Lastly, Fontaínhas (2012) also investigates the economic and environmental performance of two pairs of vehicles in the Portuguese market, an EV and the equivalent ICEV, using a similar methodology. According to his results, the electric vehicle is not yet competitive: the acquisition of an electric vehicle represents higher costs for the consumer and for society and the cost of tonne gained is also too high. He also concludes that the electric vehicle becomes more attractive as the number of kilometres driven per year increases.

It should be noted that only a few years later the reality was different and thus the results also changed. Given that, the study presented here evaluate the potential of electric mobility in Portugal in the current economy. This analysis is based on a different reality and so an update of all information was made; both BEV and ICEV models chosen were not already studied and a hybrid electric vehicle was considered; finally, the model also estimates the differential between the three technologies from public finances perspective.

4. METHODOLOGY AND DATA

A simple total ownership costs model is developed to estimate the lifetime costs of different powertrain C-segment vehicles (fuel-powered, hybrid electric and battery electric) from the user's and society's viewpoints in order to determine the additional costs of the replacement of a conventional vehicle with an electric generation car. Furthermore, the impacts of electric cars on government revenues and on CO2 emissions are also analyzed.

To compare the various technologies, a representative vehicle of each category has been considered based on market relevance (ICCT, 2013 and ACAP, 2014) and the best technology available (Nissan, Toyota and Volkswagen data), within the medium type: the petrol-fuelled vehicle is characterized by the Volkswagen Golf, while the Toyota Prius and Nissan Leaf were chosen to represent the hybrid electric vehicle and the electrically powered car, respectively.

Consumer costs represent the total cost of ownership including purchase, operating costs and taxes. Accordingly, the private cost of each vehicle is given by the sum of the following components: vehicle capital cost, battery cost, electricity or fuel consumption cost and other operating costs, namely, charge infrastructure costs and excise duty. The maintenance and repair, insurance and parking costs are not taken into account.

A car usage does not only involve private costs; in fact, there are some costs that are mostly supported by society rather than by vehicles' owners and this is the reason why an analysis from the perspective of society as a whole must be made. Therefore, the social cost of a vehicle represents the costs to the owners and to others and so it consists of the correspondent consumer cost plus externalities minus taxes. Only the external costs of local air pollution are considered here. Noise costs are overlooked since the electric vehicles' silence gave rise to some questions regarding safety and security. The emissions of carbon are examined in quantities as an alternative of monetary values given the importance of the goal lines defined by European Union.

Therefore, exhaust CO2 emissions per vehicle were calculated. The focus of the CO2 emissions' assessment is on those which are emitted through the use of the vehicles rather than their full lifecycle as the CO2 emissions related to the car production and the end of life are ignored. Moreover, the analysis has a Well-to-Wheel basis, that is, it includes both the fuel cycle emission (Well-to-Tank) and the car usage emissions (Tank-to-Wheel).

In what concerns public finances, the aim is to quantify and to qualify the respective impact on the public treasury of a battery electric vehicle, a hybrid electric car and an internal combustion engine vehicle in order to evaluate the financial consequences of the emergence of electrical mobility. This evaluation ignores both the manufacturing and the vehicles' end-life phases, that is, it only covers the use of the vehicle by the consumer during its operating lifetime. Besides, all government revenues provided from insurance, repair and maintenance and parking are not accounted for.

4.1. Discount rate

All costs incurred during the lifetime of the vehicles are defined as their present value. The annual operation costs for each year are discounted assuming a discount rate equal to 5%.

Given the complexity of the calculation of value of this parameter, the 5% value is not a specific country's value but instead it is the value used in the majority of other studies, such as Prud'homme & Koning (2010) and Crist (2012). Moreover, keeping this value could allow the making of comparisons.

4.2. Vehicle lifetime

According to ACAP, the average passenger car age in 2012 in Portugal was 12 years and so it is presumed in the model that the vehicles' lifetime is 12 years.

4.3. Annual vehicle use

The baseline daily travel assumption is 35 kilometres a day for the three cars analysed here which corresponds to an annual vehicle use of 12800 kilometres. These facts are in line with the average kilometres driven per year in Portugal estimated by Azevedo (2008).

4.4. Ownership cost

The value of vehicle cost used equals the advertised retail prices in the Portuguese market minus any subsidy given by the national government on "green" vehicles.

According to the information available in brands' official websites, the ICE's purchase price is 22.654,50 euros (www.volkswagen.pt researched in April 2014); the sale value of the Toyota Prius is reported to be 29.375 euros (www.toyota.pt researched in April 2014); and the retail price of the EV excluding battery is stated at 29.000 euros (www.nissan.pt researched in April 2014).

The vehicles' price should include a specific tax, *Imposto Sobre Veículo*, and a 23% sales tax. Nevertheless, to promote more eco-friendly vehicle sales the Portuguese government offers fifty percent and a totally ISV tax exemption for HEV and EV, correspondingly.

4.5. Battery cost

With regard to Nissan Leaf battery, the lease option is considered - the economic agent only buys the car and rents the battery.

Accordingly, a 36-month leasing contract and a mileage of 12,500 kilometres per year are assumed. This results in a cost of 79,36 euros per month or in a yearly expenditure of 952,32 euros. Moreover, since the agreement's annual distance is less than 12.800 kilometres an adjustment has to be done every three years (www.nissan.pt researched in April 2014).

4.6. Fuel efficiency

The fuel-powered vehicles are characterized by their fuel efficiency which is the number of kilometres driven per unit of fuel consumed. Based on manufacturer data, the conventional car fuel efficiency is stated at 26,3 kilometres per litre. On the other hand, the Prius is reported to consume "3,9 litres of gasoline per 100 kilometres" which results in a fuel efficiency of 25,6 kilometres per litre. According to some studies (for instance, Prud'homme & Koning (2012) and Crist (2013)), there is a gap between the test and the real gasoline consumption of conventional vehicles by around 15% to 25% and even more in the case of hybrid cars. Even so, the fuel consumption calculated by the NEDC test, combined mode, is used since it is the standard driving cycle used in Europe and for which all analysed mobility options are evaluated.

4.7. Fuel price

The consumers' fuel price depends on five components: the price of oil on international markets expressed in US dollars per barrel, the dollar/euro exchange rate, the other costs, the harmonized consumer price index and the fuel specific taxes.

A projection has been used for the Brent oil price on international markets made by the U.S. Energy Information Administration: at the beginning, the price is set at 102,2 dollars per barrel and it reaches 129,8 dollars at the end of the life of the vehicles examined here. Even though it is a strong assumption, to simplify a constant dollar/euro exchange rate equal to 0,7236 is considered (www.bloomberg.com researched in 14th April 2014). Moreover, according to DGEG (2014), the costs related with oil transport, refining and distribution are assumed to be 0,141 euros for gasoline and 0,132 euros in the case of diesel and in the first year and in the following periods an increase is assumed: the yearly change equals the harmonized index of consumer prices forecast for the same year made by the International Monetary Fund. In the case of diesel, the Biodiesel incorporation is also accounted, that is 0,021 euros per litre.

4.8. Fuel taxes

The *Imposto Sobre os Produtos Petrolíferos* is the unique specific tax considered. This tax is established at 0,586 euros per litre of gasoline 0,369 per litre of diesel and it will not change in the analysed period. VAT is also taken into account which is a sale tax on the post-ISP price of fuel. This rate is currently set at 23% and the possibility of an increase is considered just for year 1.

4.9. Fuel cost

The fuel cost for a given year is a function of the number of kilometres driven per year, the fuel efficiency and the correspondent consumers' fuel price:

$$Fuel\ cost\ = Annual\ vehicle\ use \times Fuel\ efficiency \times Fuel\ price$$

The lifetime fuel consumption cost is the present value of the flow of yearly expenditures.

4.10. Electricity efficiency

The electric car is characterized by its electricity efficiency, in other words, the kilometres driven per unit of electricity consumed. In order to obtain the EV's efficiency, the claimed NEDC battery range of 199 kilometres has been divided by the battery capacity of 24 kWh: 8,3 km/kWh. It should be noted that neither auxiliary electricity consumption nor losses during charging are accounted for in this measure and so it probably underestimates the Nissan Leaf energy use.

Like conventional vehicles BEV's electricity use manufacturer data probably undervalues the real energy consumption: in agreement with some findings (Prud'homme & Koning (2012) and Crist (2013), per example), an electrically-fuelled vehicle consumes 20 to 25 kWh per 100 kilometres driven which means an electricity efficiency of 4 to 5 kilometres per kWh. However, for the same reason presented in sub-section *4.7 Fuel Use*, the NEDC values have been used in the calculations.

4.11. Electricity price

First of all, the household price of electricity depends on consumers' choices: nowadays, with energy market liberalization, each family can select their provider from a set of companies and can also choose the most advantageous contract too. Moreover, although at the present time public stations' charging is free, this situation is likely to change in a near future in agreement with MOBI.E information.

Given the uncertainty of how consumers prefer to recharge their BEVs, the price they face at home and the future price of public stations, it is assumed that the price of electricity of each year can be decomposed into three components: the average national price in euro per kWh without taxes applicable for the first semester of the previous year for medium size households (INE & DGEG, 2011 and European Commission, 2014), the consumer price index (IMF, 2014) and specific taxes on electricity.

Thus, for year 1, the ex-price of electricity assumed is 0,1218 € per kWh.

4.12. Electricity taxes

Regarding electricity taxes, two must be accounted for: the *Imposto Especial Sobre o Consumo de Electricidade* which is 0,001€/kWh and is presumed to be constant over the years, and VAT. As in the case of fuel, VAT is a 23% sales tax on the post-IESCE price of electricity.

4.13. Electricity Cost

The yearly expenditure with electricity is a function of the annual car use, its energy consumption and the price of electricity in the same period:

$$Electricity\ Cost = Annual\ vehicle\ use \times Electricity\ efficiency \times Electricity\ Price$$

The electricity consumption lifespan cost is the present value of the flow of annual expenses.

4.14. Other taxes

With regard to vehicle excise duty, cars' owners have to pay the *Imposto Único de Circulação,* whose annual amount depends on the year of registration of the car in Portugal, on CO2 emissions and on horsepower. Presently, the national government provides a tax break for EVs (*Lei* nº22-A/2010, June 29th).

In the first year, the fuel-powered car incurs in an excise duty of 98,8 euros and the hybrid vehicle should pay 196,25 euros. It is further assumed that this amount increases 1% per year.

4.15. Infrastructure costs

The cost of a home charger infrastructure is also accounted for, crucial for a BEV fast recharge: Nissan recommends a EFACEC fast-recharging technology which costs the owners 1217,7 euros.

4.16. Local air pollution

For external costs, only the monetary effects related to the main externality induced by combustion engine car use is accounted for, namely, local air pollution.

The externality cost has been calculated considering the amount of local air pollutant emissions reported by brands and the respective vehicle per kilometre cost provided by Carvalho (2013): for light passengers' cars, the average local air pollution cost in 2009 was 0,017 euros per vehicle-km. Moreover, a decline rate of 4,5% per year over the 12 analysed years is assumed and, consequently, at the base year the cost is about 0,014€/vehicle-km (Prud'homme & Koning, 2012).

4.17. WtW CO2 emissions for fuel cars

In the case of fuel-powered vehicles, carbon is produced not only as the fuel is used in the car but also upstream, during fuel extraction, production and transportation.

For the purpose of the study and in agreement with Edwards *et al* (2008), it is considered that extraction, production and transport of gasoline for use in Europe produces 12,5 grams of CO2 per MJ; it is assumed that gasoline contains 44 MJ per litre too; consequently, the corresponding upstream WtT CO2 emissions are 550 grams of CO2 per litre. With regard to diesel, it is assumed that diesel produces 14,29 grams of CO2 per MJ; it is assumed that diesel contains 34 MJ per litre too. Consequently the diesel ICEV emits 486 grams of CO2 per litre in the WtT phase.

For the usage phase, the TtW CO2 emissions stated by producers are considered.

4.18. Carbon content of electricity

Even though electric-vehicles are claimed to be zero-emission vehicles, this is not a completely true fact: EVs do not emit CO2 during the TtW phase but when the two phases are jointly considered EVs can emit less or even more CO2 than conventional vehicles, depending on the carbon intensity of electricity generation. For the analysis, 303 grams per kWh is assumed. (IEA, 2013)

Table I summarizes the values of the parameters used in the baseline case.

	ICEV *Golf 1.2 TSI 105cv 5P Trendline*	HEV *Prius 1.8 Hybrid 136cv Exclusive*	BEV *Nissan Leaf Acenta*
Vehicle life (years)	12	12	12
Annual car usage (km)	12.800	12.800	12.800
Social rate of discount (%)	5	5	5
Purchase cost (€)	22.654,50	29.375	29.000
Battery cost (€/ year)	-	-	952,32
Fuel efficiency (km per lt)	20,4	25,6	-
Electricity efficiency (km/kWh)	-	-	8,3
Oil price ($ per barrel)	102,199	102,199	-
$/EUR	0,724	0,724	-
Other costs (€ per lt)	0,132	0,141	-
Biodiesel Incorporation (€ per lt)	0,021	-	-
ISP (€ per lt)	0,369	0,586	-
VAT on diesel (%)	23	-	-
VAT on gasoline (%)	-	23	-
Electricity price (€/kWh)	-	-	0,1552
ISC (€/kWh)	-	-	0,001
VAT on electricity (%)	-	-	23
Other operating costs(€)		196,3	1217,7
Local air pollution cost (€ per km)	0,014	0,014	-
CO2 content of diesel (g per lt)	486	-	-
CO2 content of gasoline (g per lt)	-	550	-
CO2 content of electricity (g per kWh)	-	-	303
TtW CO2 emissions (g per km)	99	89	0

TABLE I – Baseline Case Parameters

Source: See 4. Methodology and Data

5. RESULTS

Table II shows that from a private point of view, the green technology cars are not yet competitive in the Portuguese auto market.

	ICEV *Golf 1.2 TSI 105cv 5P Trendline*	HEV *Prius 1.8 Hybrid 136cv Exclusive*	BEV *Nissan Leaf Acenta*	HEV Additional Consumer Cost	BEV Additional Consumer Cost
Purchase Cost	25.926,46 €	29.375 €	29.000 €	+ 3.448,54 €	+ 3.074 €
Battery Cost	-	-	8.996 €	-	+ 8.996 €
Fuel or Electricity Cost	5.197 €	7.097 €	2.338 €	+ 1.901 €	- 2.859 €
Other Operating Cost	1.410 €	1.919 €	1.218 €	+ 509 €	- 193 €
Total Lifetime Usage Cost	32.533 €	38.392 €	41.551 €	**+ 5.858 €**	**+ 9.017 €**

TABLE II – CONSUMER COSTS

Source: Annex 3 and Annex 4

Under the baseline case assumptions, it costs the consumer an additional 9017 Euros to use a BEV instead of a fuel-powered car; and besides that, the consumer excess cost of use of an HEV rather than an ICEV is about 5858 Euros. These results are assigned to significant differences in the sales prices and also the enormous battery costs in the electricity-powered car case. As far as energy costs are concerned, the electric vehicle is cheaper than the gasoline-fuel powered car since electricity price is lower than gasoline price; and the hybrid vehicle is more expensive than the ICE car given its fuel efficiency.

Another important achievement is that the monetary purchase incentive of 5000 Euros offered by Portuguese Government was not enough to make electric vehicles cost competitive from a consumer's perspective.

	ICEV *Golf 1.2 TSI 105cv 5P Trendline*	HEV *Prius 1.8 Hybrid 136cv Exclusive*	BEV Nissan Leaf Acenta	HEV Additional Social Cost	BEV Additional Social Cost
Consumer Cost	32.533 €	38.392 €	41.551 €	+ 5.858 €	+ 9.017 €
Air Pollution Cost	565 €	418 €	0 €	- 147 €	- 565 €
Taxes	11.005 €	12.969 €	7.801 €	+ 1.964 €	- 3.204 €
Social Cost	22.093 €	25.840 €	33.750 €	**+ 3.747 €**	**+ 11.656 €**

TABLE III – SOCIAL COSTS

Source: Annex 4, Annex 5 and Annex 6

As expected, the electrically-powered vehicle has a clear advantage on local air pollution costs over the convention vehicle, in a TtW perspective. The external costs are also lower in the HEV.

From a fiscal point of view, replacing of ICEV with HEV leads to a gain of approximately 1964 euros mainly because the higher VAT revenue from the higher vehicle's sale price. By contrast, public treasury loses about 3204 euros with an electric vehicle since the higher VAT revenue from the higher purchase price and battery are compensated by the lower revenues from taxes on energy and the current EV tax breaks. The differences among the three vehicles' technologies taxation are not only quantitative but also qualitative, specifically, in the sharing of energy use taxes.

Finally, society as a whole loses 11656 euros more with the BEV rather than ICEV usage and the economic differential between the hybrid and the conventional car is about 3747 euros.

With the values given to the annual vehicles use and the specific fuel efficiency, the internal combustion engine car examined here rejects 1.5 tonnes of CO2 per year, corresponding to 18 tonnes over the 12 years. On the other hand, the hybrid electric car emits 1.4 tonnes of CO2 per year and so 17 tonnes during its lifetime. The substitution of an ICEV with an HEV leads to a reduction of 1 tonne of CO2 emissions, which corresponds to a marginal abatement cost of 3508 euros per tonne.

As far as CO2 emissions are concerned, assuming a CO2 content of electricity of 303 grams per kWh, the electric car has a better performance than the fuel-powered vehicle: it emits 468 kg of CO2 per year and so 5,6 tonnes through the period analysed - approximately three times less than the ICE vehicle. However, the cut of a tonne of CO2 costs society 940 euros.

To sum up, both the representative battery electric car and the hybrid electric vehicle are not yet attractive to consumers neither to society as a whole. These findings are in accordance with other studies.

6. SENSITIVITY ANALYSIS

In order to test the robustness of the study and determine if, by how much and why the findings vary with changes in the value of some more uncertain parameters, a sensitivity analysis was developed.

6.1. Rate of discount

To begin with, the 5% rate of discount is one of the parameters with a contestable value. As already mentioned, the 5% rate of discount is not a country specific value but the value that is communally used.

If a discount rate equal to 7% was used both the consumer and the social excess costs of the electric car have a slight decrease whereas the hybrid ones have a slight increase. This happens because BEV yearly operating costs are higher than other vehicles' annual running expenditures. On the other hand, if a lower discount rate was assumed, the opposite happens.

6.2. Vehicles' production costs

A second issue concerns vehicles' production costs, which are assumed to be fairly represented by the corresponding sales price. In a model case, the electric vehicle capital cost decreased by 20% and so did its ex-VAT purchase price. In this scenario, holding all else equal, the BEV excess consumer cost was reduced by 73% and society losses by 41% relative to the base case. A change in the hybrid electric vehicle price was also analysed: a 10% decline in HEV sale price without VAT results in 60% diminution of the consumer excess costs (2351 euros) and in an even greater decrease of social excess costs such as HEV becomes more attractive to society than conventional vehicles (-164 euros). The impact of a 20% internal combustion engine vehicle ex-VAT sale price increase was also simulated. The consequences were the following: the excess costs of the two electric generation cars significantly decreased both in a consumer and in a society perspective;

although, the HEV benefits the most since now society saved with the replacement of ICEV with a HEV (50 euros).

6.3. Battery costs

According to some studies, battery costs are expected to decrease significantly in the near future. Would a 30% fall in the battery costs deeply change the findings? Consumer excess costs decrease almost 30% to 6606 euros and the excess societal costs decline by 17% to 9689 euros, *ceteris paribus*.

6.4. Oil price

A fourth question is about oil prices: are the results very sensitive to an oil price change? A rise of 10% per year over the vehicle lifetime is considered instead of IEA's projection, implying a 291,6 US dollars per barrel at the end of the period. As expected, this change affects both HEV and BEV excess costs in a positive way, and especially with regard to the electric car since an increase in oil prices means upper fuel costs to the HEV too.

6.5. Electricity price before taxes

Another plausible scenario is a 10% annual rise of ex-taxes electricity price which leads to an electricity price without taxes of 0,3476 euros in year 12. Keeping everything else constant, the differential between the costs supported by the owner of a BEV and an ICE increases to 10333 euros and the BEV social costs also rises to 12724 euros. This moderate effect is due to the small share of the electricity costs on BEV total operating costs.

6.6. Fuel and electric efficiency

It is likely that there will be improvements in the efficiency of cars. In the case of fuel-powered vehicles, it is mainly in an attempt to become more eco-friendly and to reduce the fuel bill, and in the case of electric vehicles, because of the freshness of technology and the public efforts to increase the range of the battery. A more efficient energy use has an impact on excess costs but also on the CO2 gains. If the number of kilometres driven per kWh of electricity increases by 30% both BEV excess costs reduce slightly: about 6% in the consumer excess costs and about 4% in society excess costs. A 30% increase of HEV efficiency implies a decrease of 28% on consumer HEV excess costs and even more on the society HEV excess costs. With a lower energy use, the WtW CO2 emissions emitted by HEV decline and as a result the CO2 gain increases to 1,8 tonnes. An increase in fuel efficiency of the ICEV results in an increase of both BEV and HEV additional lifetime expenditures, particularly the consumer costs as the conventional vehicle fuel costs decrease evidently more than fuel taxes. TtW CO2 emissions are less than in the base case and as a result both CO2 gains decline to 12 and 0,6 tonnes in the case of BEV and HEV, respectively.

6.7. Fuel Tax

Another possible case is that the specific fuel tax increases 10% per year instead of being constant throughout the analysed period. It benefits both BEV and HEV excess costs from a consumer's point which declines to 8309 and 6240 euros. As HEV is a gasoline-powered vehicle the impact of a rise in ISPP is surely lower. It has already been seen that EVs led to a loss in government revenues when compared with a conventional vehicle. Consequently, in order to compensate this loss an increase in the specific tax on electricity to the current amount of the specific tax on gasoline was estimated: 0,586 euros. As a result, EV energy costs dramatically rise and so EV user costs: from 9024 to 18260 euros.

This is a simple example of how different levels of taxation influence the results.

6.8. Annual mileage

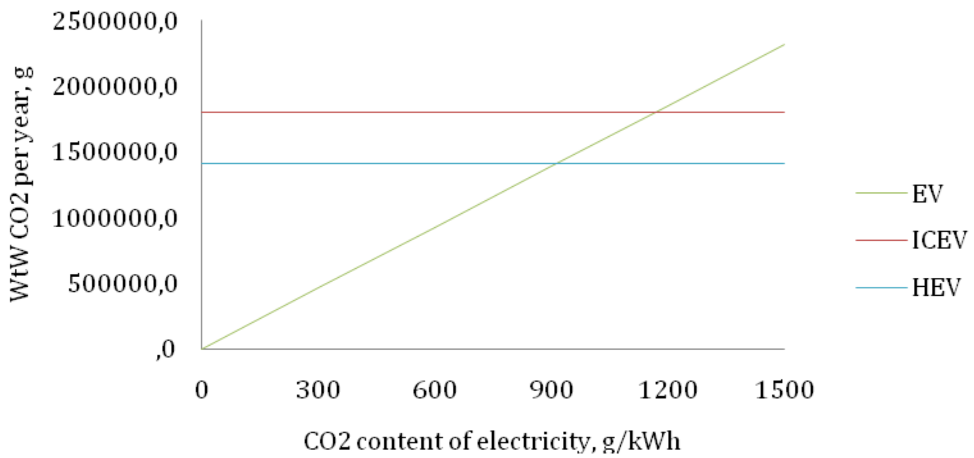
Given the uncertainty of the annual mileage, the findings are tested for a lower and a higher yearly distance driven.

To begin, a 30% decrease in the kilometres driven per day results in an increase of BEV excess cost for the consumer and for society. On the other hand, if a rise of 30% in daily vehicle travel was considered, the extra cost for the consumer and the economic differential for the society of having a BEV instead of an ICEV also increase but by less. These are very interesting outcomes, particularly if an urban mobility perspective was considered.

6.9. CO2 content of electricity

As noted previously, the marginal CO2 content of electricity varies over places and even through time. Hence, it is appropriate to test the sensitivity of the CO2 gains to changes in the grams of CO2 per kWh. With a CO2 intensity of 352 grams per kWh, EU27 average, the tonnes of CO2 cut down with the replacement of ICE with a BEV decreases to 11,5 tonnes and naturally the abatement of each tonne becomes more costly (1014 euros). Does the maximum level of CO2 that electricity could still have an advantage in an environmental perspective?

The electric vehicle considered emits as much CO2 as the fuel-powered



vehicle for a CO2 content of electricity of 1168 grams per kWh. Above this limit, the BEV's CO2 WtW emissions would be higher than those from the ICE vehicle. For a CO2 electricity intensity lower than 1169, BEV would always be the less pollutant. If the CO2 content of electricity decreases to a low carbon level like France (61 grams of CO2 per kWh), less 15 tonnes of CO2 would be emitted and marginal reduction cost would decrease to 690 euros.

GRAPH III–WELL-TO-WHEEL CO2 EMISSIONS

Source: Annex 7 and Annex 8

6.10. Best scenarios

A simulation is made of the impacts of the "most optimistic" scenario for EV: a decrease of the manufacturer costs by 20%, a decline of 30% on battery costs, an improvement of electricity use by 30% and a 10% yearly rise in the oil prices. In this case, the electrical powered vehicle is competitive with the conventional car from the user's perspective: there are no excess costs but instead consumers save money with a BEV option. Despite that, the replacement of a conventional vehicle with an electric one continues to represent a loss for society. It is evident that, the CO2 gain is even higher (about 15 tonnes) and it costs society 199 Euros to reduce one tonne of CO2 emissions.

Concerning the HEV best picture, a case is modelled where the capital cost of hybrid cars decreases by 10% and the energy use of the HEV declines by 30%. In this scenario, HEV becomes less expensive for consumers and even more attractive for society: the economic differential for users is 710 euros and it is cheaper to buy an HEV rather than an ICE in a social perspective. The government particularly benefits from HEV usage.

7. CONCLUSION

In conclusion, this paper estimates and analyses the total costs of ownership of a hybrid and a battery electric vehicles in comparison with a gasoline-fuel powered vehicle, as well as the impact of the three different energy efficiency cars on exhaust Well-to-Wheel CO2 emissions and on public treasury.

Under the assumptions employed throughout the study and the values given to relevant variables in the baseline case, which are believed to fairly reflect today's reality, the analysis shows that both the hybrid and the battery electric vehicles are uncompetitive with conventional gasoline cars, in Portugal; It also finds that the reality of HEV and EV is very different, with a less prominent place for the latter.

The main findings are the following:

- Assuming a vehicle's lifetime of 12 years and a car usage of 12800 kilometres per year, the HEV will cost about 5864 Euros more to the owner and the consumer's additional cost of using a BEV rather than an ICEV is about 9024 Euros.
- Lower fuel and electricity use costs seem to only compensate a small part of higher purchase prices and, in the case of the BEV, the higher battery costs.
- Under a set of assumptions, society loses 3549 Euros if an HEV is preferred instead of an ICEV and social excess cost of BEV is 11459 Euros.
- The findings also suggest that E-mobility is an opportunity to cut CO2 emissions; however, it is a costly way of doing so. For the Portuguese average of CO2 content of electricity and for the estimated providing service, an HEV emits less 4,7 tonnes of CO2 than a conventional car and the BEV CO2 gain is about 16 tonnes.
- From a fiscal viewpoint, the study demonstrates that the usage of a hybrid car leads to a higher tax revenue than a conventional gasoline vehicle and, by contrast, the replacement of an ICEV with an EV has a negative impact on public treasury.

As the present and the future values of several of the relevant parameters are often uncertain, a sensibility analysis was conducted: different rates of discount were tested, alterations on vehicles' capital cost were considered, crucial increases in energy prices were estimated as well as different taxation scenarios, higher levels of efficiency were analysed and, finally, a more detailed view was given to changes in the CO2 content of electricity and the annual usage of the vehicles.

Considered individually, the changes in the vehicles' cost capital and in the battery costs are the ones that have higher impacts on the excess costs because of the share of these two variables on the total costs of ownership; the remaining impacts are not too significant.

The major effects happen when some of the chances are jointly taken such as in the best scenarios. A simultaneous decrease in the HEV production cost by 10% and an increase by 30% in its efficiency makes the hybrid vehicle more attractive for the society than a gasoline-powered vehicle; however, it continues to be slightly more costly for the consumer. In the most optimist situation for the BEV, consumers saved money with the preference of an EV instead of an ICEV but the EV society excess cost still persists despite the drastic fall.

With regard to limitations, the study is restricted to a single combination of hybrid and battery electric and conventional vehicles. Besides that, the results are focused on the financial aspects of a choice of car even though there are other important variables that determine the selection of a vehicle. Finally, the analysis only reflects the operating life of the vehicles, and it ignores both the manufacturing and the end of its life.

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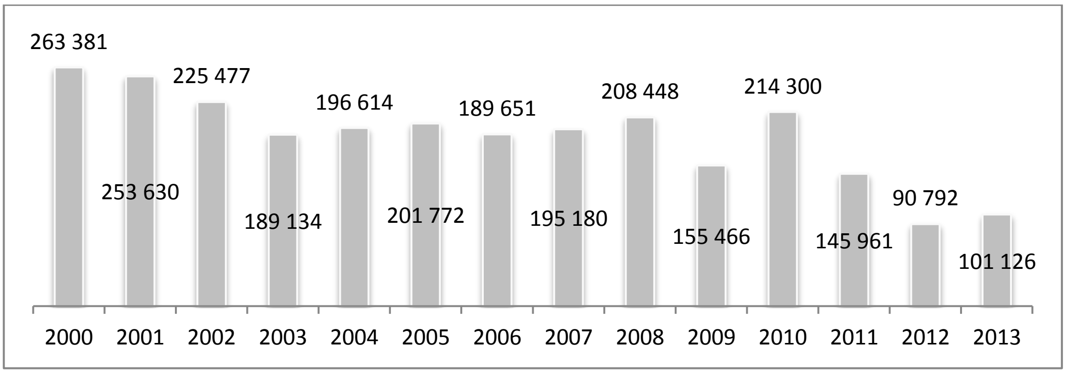
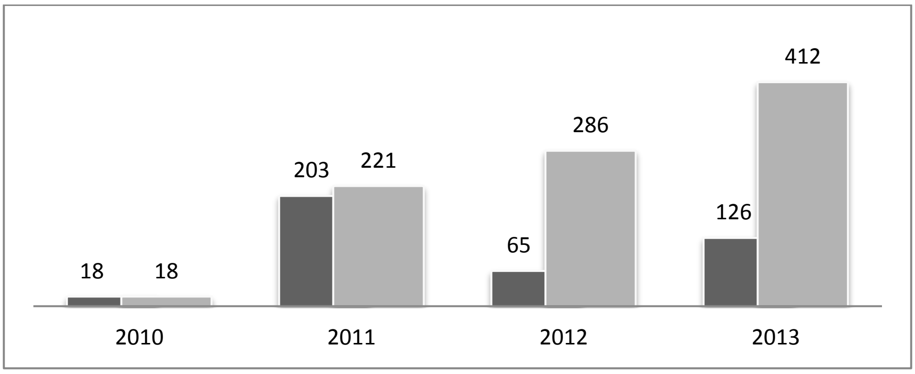
ANNEXES

ANNEX 1 – SOME FIGURES ABOUT VEHICLE SALES IN PORTUGAL



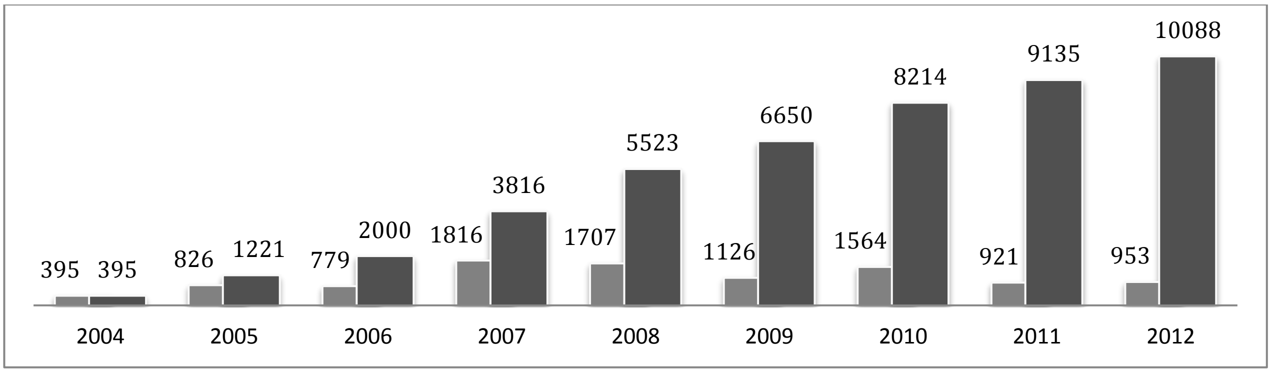
GRAPH I – NEW PASSENGER VEHICLE SALES IN PORTUGAL, IN UNITS

Source: ACAP, ICCT Europe



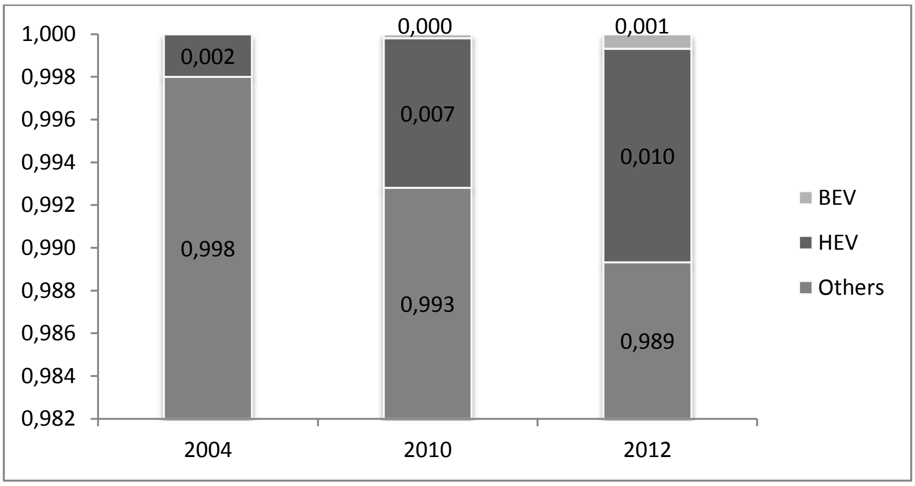
GRAPH II – BATTERY ELECTRIC VEHICLE SALES IN PORTUGAL, IN UNITS

Source: ACAP, ICCT Europe



GRAPH III – HYBRID ELECTRIC VEHICLE SALES IN PORTUGAL, IN UNITS

Source: ACAP, ICCT Europe



GRAPH IV – MARKET SHARE

Source: ACAP, ICCT Europe

ANNEX 2 – CO2 EMISSIONS PER KWH DATA

	2006	2007	2008	2009	2010	2011
Portugal	431	396	394	379	255	303
OECD Europe	368	374	365	340	331	334
World	543	546	539	533	529	536

TABLE I – CO_2 EMISSIONS PER KWH FROM ELECTRICITY GENERATION, G CO_2/KWH

Source: ICCT Europe

Annex 3 – Fuel Prices

	0	1	2	3	4	5	6	7	8	9	10	11
Brent Oil Price ($/Barrel)	102,20	101,95	99,57	99,30	101,54	105,21	109,37	114,03	118,88	124,06	129,20	134,25
Exchange Rate ($/€)	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242	0,7242
Brent Oil price (€/Barrel)	74,0125	73,8344	72,1108	71,9102	73,5353	76,1945	79,2072	82,5798	86,0951	89,8428	93,5631	97,2218
Brent Oil price (€/lt)	0,4655	0,4644	0,4536	0,4523	0,4625	0,4792	0,4982	0,5194	0,5415	0,5651	0,5885	0,6115
Biodiesel Incorporation (€)	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210	0,0210
Other costs (€)	0,132	0,134	0,136	0,138	0,140	0,142	0,144	0,146	0,149	0,151	0,153	1,132
Inflation (%)		1,2	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
ISPP (€)	0,278	0,278	0,278	0,278	0,278	0,278	0,278	0,278	0,278	0,278	0,278	0,278
Contribution (€)	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091	0,091
Price without IVA (€)	0,988	0,875	0,866	0,867	0,879	0,898	0,919	0,942	0,966	0,992	1,018	1,043
VAT Rate (%)	23	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25
VAT (€)	0,227	0,203	0,201	0,202	0,204	0,209	0,214	0,219	0,225	0,231	0,237	0,243
Price (€/lt)	**1,215**	**1,078**	**1,067**	**1,068**	**1,083**	**1,106**	**1,132**	**1,161**	**1,191**	**1,223**	**1,254**	**1,286**

Table I – Diesel Price

Source: Bloomberg, IEA, IMF

	0	1	2	3	4	5	6	7	8	9	10	11
Brent Oil Price ($/Barrel)	102,20	101,95	99,57	99,30	101,54	105,21	109,37	114,03	118,88	124,06	129,20	134,25
Exchange Rate ($/€)	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724	0,724
Brent Oil price (€/Barrel)	74,012	73,834	72,110	71,910	73,535	76,1945	79,207	82,579	86,095	89,843	93,563	97,222
Brent Oil price (€/lt)	0,466	0,464	0,454	0,452	0,463	0,479	0,498	0,519	0,542	0,565	0,589	0,612
Other costs (€/lt)	0,141	0,143	0,145	0,147	0,149	0,151	0,154	0,156	0,158	0,161	0,163	0,166
Inflation (%)	-	1,2	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
ISP (€)	0,586	0,586	0,586	0,586	0,586	0,586	0,586	0,586	0,586	0,586	0,586	0,586
Price without VAT (€)	1,192	1,193	1,184	1,185	1,198	1,217	1,238	1,261	1,286	1,312	1,338	1,363
VAT Rate (%)	23,00	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25
VAT (€)	0,274	0,277	0,275	0,276	0,278	0,283	0,288	0,293	0,299	0,305	0,311	0,317
Price (€/lt)	**1,467**	**1,470**	**1,460**	**1,461**	**1,476**	**1,500**	**1,526**	**1,555**	**1,585**	**1,617**	**1,649**	**1,680**

TABLE II – GASOLINE PRICE

Source: Bloomberg, IEA, IMF

	0	1	2	3	4	5	6	7	8	9	10	11
Price t-1 (€)	0,121	0,122	0,123	0,125	0,127	0,129	0,131	0,133	0,135	0,137	0,139	0,145
Inflation (%)	0,7	1,2	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Price t without Taxes (€)	0,122	0,123	0,125	0,127	0,129	0,131	0,133	0,135	0,137	0,139	0,141	0,147
ISE (€)	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001
Price without VAT (€)	0,123	0,124	0,126	0,128	0,130	0,132	0,134	0,136	0,138	0,140	0,142	0,148
VAT Rate (%)	23,00	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25	23,25
VAT (€)	0,028	0,029	0,029	0,030	0,030	0,031	0,031	0,032	0,032	0,033	0,033	0,034
Price (€/kWh)	**0,151**	**0,153**	**0,155**	**0,158**	**0,160**	**0,163**	**0,165**	**0,167**	**0,170**	**0,172**	**0,175**	**0,182**

TABLE III – ELECTRICITY PRICE

Source: IEA, IMF

Annex 4 – Consumer Costs

	0	1	2	3	4	5	6	7	8	9	10	11
Battery Cost per month (€)	79,36	79,36	79,36	79,36	79,36	79,36	79,36	79,36	79,36	79,36	79,36	79,36
Battery Cost per year (€)	952,32	952,32	952,32	952,32	952,32	952,32	952,32	952,32	952,32	952,32	952,32	952,32
Adjustement (€)	0,00	0,00	45,00	0,00	0,00	45,00	0,00	0,00	45,00	0,00	0,00	45,00
Final Battery Cost per year (€)	952,32	952,32	997,32	952,32	952,32	997,32	952,32	952,32	997,32	952,32	952,32	997,32
PV Final Battery Cost per year (€)	952,32	906,97	904,60	822,65	783,48	781,43	710,64	676,80	675,03	613,87	584,64	583,11
Battery Cost (€)	8.995,53											

Table I – Battery Costs

Source: Nissan

	0	1	2	3	4	5	6	7	8	9	10	11
Purchase Price (€)	29.000											
Final Battery Cost per year (€)	952,32	952,32	997,32	952,32	952,32	997,32	952,32	952,32	997,32	952,32	952,32	997,32
PV Final Battery Cost per year (€)	952,32	906,97	904,60	822,65	783,48	781,43	710,64	676,80	675,03	613,87	584,64	583,11
Battery Cost (€)	8.995,53											
Annual usage (km)	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800
Electric efficiency	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3
1/Electric Efficiency	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12
Electricity Price (€/kWh)	0,151	0,153	0,156	0,158	0,160	0,163	0,165	0,167	0,169	0,172	0,175	0,182
Electricity Cost per year (€)	233,02	236,28	239,79	243,36	246,98	250,66	254,39	258,18	262,02	265,92	269,88	281,32
PV Electricity Cost (€ per year)	233,02	236,16	239,68	243,24	246,86	250,54	254,27	258,05	261,89	265,79	269,75	281,19
Electricity Cost (€)	3.040,45											
Other costs (€)	1.217,70											
∑ Yearly Costs (€)	31.403,04	1.188,60	1.237,11	1.195,68	1.199,30	1.247,98	1.206,71	1.210,50	1.259,34	1.218,24	1.222,20	1.278,64
PV ∑ Yearly Costs (€)	31.403,04	1.132,00	1.122,10	1.032,87	986,67	977,82	900,47	860,28	852,37	785,29	750,33	747,60
BEV Consumer Cost	41.550,84											

Table II – Battery Electric Vehicle Consumer Costs

Source: Nissan, Annex 3 – Table III

	0	1	2	3	4	5	6	7	8	9	10	11
Purchase Price (€)	29.375											
Annual Usage	12.800	12.800	12.800	12.800	12.800	12.800	1.2800	12.800	12.800	12.800	12.800	12.800
Fuel Efficiency	25,60	25,60	25,60	25,60	25,60	25,60	25,60	25,60	25,60	25,60	25,60	25,60
1/ Fuel Efficiency	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Gasoline Price	1,47	1,47	1,46	1,46	1,48	1,50	1,53	1,55	1,58	1,62	1,65	1,68
Annual Fuel Cost	733,37	735,21	729,85	730,41	738,07	749,75	762,83	777,32	792,39	808,38	824,29	839,98
PV Annual Fuel Cost	733,37	700,20	661,99	630,96	607,21	587,45	569,24	552,43	536,32	521,09	506,04	491,12
Fuel Cost (€)	7.097,41											
IUC	196,25	196,25	198,21	200,19	202,20	204,22	206,26	208,32	210,41	212,51	214,64	216,78
Yearly change, %		0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Yearly change, €		1,96	1,98	2,00	2,02	2,04	2,06	2,08	2,10	2,13	2,15	2,17
Annual IUC	196,25	198,21	200,19	202,20	204,22	206,26	208,32	210,41	212,51	214,64	216,78	218,95
PV Annual IUC	196,25	188,77	181,58	174,67	168,01	161,61	155,45	149,53	143,84	138,36	133,09	128,02
Other Costs (€)	1.919,17											
∑ Annual Costs	30.304,62	933,42	930,04	932,61	942,29	956,01	971,15	987,73	1.004,90	1.023,02	1.041,07	1.058,93
PV ∑ Annual Costs	30.304,62	888,97	843,58	805,62	775,22	749,06	724,69	701,96	680,16	659,45	639,13	619,13
HEV Consumer Cost	38.391,59											

TABLE III – HYBRID ELECTRIC VEHICLE CONSUMER COSTS

Source: Toyota, Annex 3 – Table II

	0	1	2	3	4	5	6	7	8	9	10	11
Purchase Price	25.926,46											
Annual vehicle use	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800
Fuel efficiency	26,30	26,30	26,30	26,30	26,30	26,30	26,30	26,30	26,30	26,30	26,30	26,30
1/ Fuel efficiency	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Diesel Price	1,22	1,08	1,07	1,07	1,08	1,11	1,13	1,16	1,19	1,22	1,25	1,29
Yearly Fuel Cost	591,40	524,75	519,44	519,88	527,24	538,51	551,14	565,14	579,71	595,16	610,54	625,70
PV Yearly Fuel Cost	591,40	499,76	471,14	449,10	433,76	421,94	411,27	401,64	392,37	383,65	374,82	365,83
Fuel Cost (€)	5.196,68											
IUC	142,92	144,35	145,79	147,25	148,7	150,21	151,71	153,23	154,76	156,31	157,87	159,45
Yearly change, €	-	1,44	1,46	1,47	1,49	1,50	1,52	1,53	1,55	1,56	1,58	1,59
Annual IUC	142,92	145,79	147,25	148,73	150,21	151,71	153,23	154,76	156,31	157,87	159,45	161,05
PV Annual IUC	142,92	138,85	133,56	128,47	123,58	118,87	114,34	109,99	105,80	101,77	97,89	94,16
Other Costs	1.410,21											
∑ Annual costs	26.660,79	670,55	666,69	668,61	677,45	690,23	704,37	719,91	736,02	753,04	769,99	786,75
PV ∑ Annual costs	26.660,79	638,61	604,71	577,57	557,34	540,81	525,61	511,63	498,17	485,42	472,71	460,00
ICEV Consumer Cost	**32.533,35**											

TABLE IV – DIESEL INTERNAL COMBUSTION ENGINE VEHICLE CONSUMER COSTS

Source: Volkswagen, Annex 3 – Table I

Annex 5 – Taxes Assessment

	0	1	2	3	4	5	6	7	8	9	10	11
Purchase VAT	5.422,76											
Battery Rental VAT	178,08	179,65	188,14	179,65	179,65	188,14	179,65	179,65	188,14	179,65	179,65	188,14
PV Battery Rental VAT	178,08	171,09	170,64	155,19	147,80	147,41	134,06	127,67	127,34	115,80	110,29	110,00
∑ PV Battery Rental VAT	1.695,35											
Electricity Taxes per kWh	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,04
Electricity Taxes per year	45,12	46,11	46,78	47,45	48,13	48,83	49,53	50,25	50,97	51,71	52,45	54,61
PV Electricity Taxes (€ per year)	45,12	43,92	42,43	40,99	39,60	38,26	36,96	35,71	34,50	33,33	32,20	31,93
∑ PV Electricity Taxes	454,94											
Homecharger VAT	227,70											
Annual Taxes	5.873,65	225,76	234,91	227,10	227,78	236,96	229,18	229,89	239,11	231,35	232,10	242,75
PV Annual Taxes	5.873,65	215,01	213,07	196,17	187,40	185,67	171,02	163,38	161,84	149,13	142,49	141,93
PV Total Taxes	7.800,75											

Table I – Battery Electric Vehicle Taxes Assessment

Source: Own calculations

	0	1	2	3	4	5	6	7	8	9	10	11
ISV	1.493,15											
Purchase VAT	5.492,89											
Fuel Taxes per litter	0,860	0,863	0,861	0,862	0,864	0,869	0,874	0,879	0,885	0,891	0,897	0,903
Fuel Taxes per year	430,11	431,67	430,65	430,76	432,20	434,41	436,88	439,61	442,45	445,47	448,47	451,43
PV Annual Fuel Taxes	430,11	411,11	390,62	372,11	355,58	340,37	326,00	312,42	299,47	287,15	275,32	263,94
∑ PV Annual Fuel Taxes	4.064,20											
IUC	196,25	196,25	198,21	200,19	202,20	204,22	206,26	208,32	210,41	212,51	214,64	216,78
Yearly change, %	-	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Yearly change, €	-	1,96	1,98	2,00	2,02	2,04	2,06	2,08	2,10	2,13	2,15	2,17
Annual IUC	196,25	198,21	200,19	202,20	204,22	206,26	208,32	210,41	212,51	214,64	216,78	218,95
PV Annual IUC	196,25	188,77	181,58	174,67	168,01	161,61	155,45	149,53	143,84	138,36	133,09	128,02
∑ PV Annual IUC	1.919,17											
Annual Taxes	7.612,39	629,88	630,85	632,96	636,42	640,67	645,20	650,02	654,96	660,10	665,25	670,38
PV Annual Taxes	7.612,39	599,88	572,20	546,77	523,59	501,98	481,46	461,95	443,30	425,51	408,41	391,96
PV Total Taxes	12.969,40											

Table II – HEV Taxes Assessment

Source: Own calculations

	0	1	2	3	4	5	6	7	8	9	10	11
ISV	2.094,28											
Purchase VAT	4.848,04											
Fuel Taxes per litter	0,60	0,57	0,57	0,57	0,57	0,58	0,58	0,59	0,59	0,60	0,61	0,61
Fuel Taxes per year	290,38	278,78	277,78	277,86	279,25	281,37	283,76	286,40	289,15	292,06	294,96	297,82
PV annual fuel taxes	290,38	265,50	251,95	240,03	229,74	220,46	211,74	203,54	195,70	188,27	181,08	174,13
∑ PV Annual Fuel Taxes	2.652,52											
IUC	142,92	144,35	145,79	147,25	148,73	150,21	151,71	153,23	154,76	156,31	157,87	159,45
Yearly change, %	-	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Yearly change, €	-	1,44	1,46	1,47	1,49	1,50	1,52	1,53	1,55	1,56	1,58	1,59
Annual IUC	142,92	145,79	147,25	148,73	150,21	151,71	153,23	154,76	156,31	157,87	159,45	161,05
PV Annual IUC	142,92	138,85	133,56	128,47	123,58	118,87	114,34	109,99	105,80	101,77	97,89	94,16
∑ PV Annual IUC	1.410,21											
Annual Taxes	7.375,62	417,63	411,34	406,33	402,83	400,25	398,10	396,39	394,94	393,83	392,85	391,98
PV Annual Taxes	7.375,62	404,36	385,51	368,50	353,32	339,34	326,09	313,53	301,50	290,03	278,97	268,29
PV Total Taxes	11.005,05											

TABLE III – ICEV TAXES ASSESSMENT

Source: Own calculations

ANNEX 6 – EXTERNAL COSTS

	Pollutants (g/km)						
	CO	**HC**	**NOx**	**PM**	**Total**	**Annual Use (km)**	**Local Air Pollution (g/year)**
BEV	0	0	0	0	0	12.800	0,00
HEV	0,258	0,058	0,006	0	0,322	12.800	4.121,60
ICEV	0,153	0,282	0	0,0004	0,436	12.800	5.574,40

TABLE I – LOCAL AIR POLLUTION COST

Source: Carvalho (2011)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Local Air Pollution Cost (€/v-km)	0,00061	0,00058	0,00055	0,00053	0,00051	0,00048	0,00046	0,00044	0,00042	0,00040	0,00038	0,00037
HEV												
Local Air Pollution Cost per year	55,66	53,15	50,76	48,48	46,30	44,21	42,22	40,32	38,51	36,78	35,12	33,54
PV Local Air Pollution Cost per year	55,66	50,62	46,04	41,88	38,09	34,64	31,51	28,66	26,06	23,71	21,56	19,61
Total Local Air Pollution Cost	418,037											
ICEV												
Local Air Pollution Cost per year	75,28	71,89	68,65	65,57	62,61	59,80	57,11	54,54	52,08	49,74	47,50	45,36
PV Local Air Pollution Cost per year	75,28	68,47	62,27	56,64	51,51	46,85	42,61	38,76	35,25	32,06	29,16	26,52
Total Local Air Pollution Cost	565,39											

TABLE II – LOCAL AIR POLLUTION COST ASSESSMENT

Source: Koning & Prud'homme (2012), Annex 6 – Table I

Annex 7 – CO2 Emissions

	ICEV	HEV	BEV
Well-to-Tank			
Carbon Intensity (CO2g/MJ)	14,29	12,5	-
Energy Intensity (MJ/lt)	34	44	-
CO2 (g/lt)	486	550	303
1/Fuel efficiency (lt/km)	0,0380	0,0391	0,1206
WtT CO2 emissions (g/km)	18,46	21,51	36,55
Annual Use (km)	12.800	12.800	12.800
WtT CO2 emissions per year (g)	236.322	275.264	467.841
Tank-to-Wheel			
TtW CO2 emissions (g/km)	99	89	0
Annual Use (km)	12.800	12.800	12.800
TtW CO2 emissions per year (g)	1.267.200	1.139.200	0
Well-to-Wheel			
WtW CO2 emissions (g/km)	117	111	37
WtW per year (g)	1.503.522	1.414.464	467.841
WtW Lifetime (g)	**18.042.268**	**16.973.568**	**5.614.089**

Table I – CO2 Emission Analysis

Source: ICCT Europe, Volkswagen, Toyota and Nissan

	HEV	BEV
CO2 emissions gain (ton)	-1.068.700	-12.428.178
Additional Social Cost (€)	3.746,529	11.656,394
Abatement Cost (€ per ton)	3.507,985	940,032

Table II – CO2 Emissions Abetment Cost

Source: Own calculations

Annex 8 – Sensitivity Analysis

	HEV Additional Consumer Cost	HEV Additional Social Cost	HEV C02 Gain	BEV Additional Consumer Cost	BEV Additional Social Cost	BEV CO2 Gain
Baseline Case	5.858,23 €	3.746,53 €	1 Ton	9.017,49 €	11.656,39 €	12,4 Ton
6.1 Discount rate: + 2%	5.641,59 €	3.710,20 €	1 Ton	8.612,13 €	11.125,78 €	12,4 Ton
6.2 Vehicle Production Cost						
ICEV Sale Price: + 10%	1.188,13 €	-50,30 €	1 Ton	4.347,39 €	7.859,57 €	12,4 Ton
HEV Sale Price: - 10%	2.350,79 €	163,80 €	1 Ton	9.017,49 €	11.656,39 €	12,4 Ton
BEV Sale Price: - 20%	5.858,23 €	3.746,53 €	1 Ton	2.406,28 €	6.940,95 €	12,4 Ton
6.3 Battery Costs: - 30%	5.858,23 €	3.746,53 €	1 Ton	6.604,52 €	9.689,37 €	12,4 Ton
6.4. Oil price: + 10%/year	5.901,73 €	3.481,90 €	1 Ton	7.426,69 €	10.065,60 €	12,4 Ton
6.5. Electricity price: + 10%/year	5.858,23 €	3.746,53 €	1 Ton	10.333,05 €	12.723,79 €	12,4 Ton
6.6 Cars' Efficiency						
ICEV Efficiency: + 30%	6.729,83 €	4.173,24 €	0,62 Ton	9.889,08 €	12.083,10 €	12 Ton
HEV Efficiency: + 30%	2.292,46 €	705,61 €	1,8 Ton	9.017,49 €	11.656,39 €	12,4 Ton
BEV Efficiency: + 30%	5.858,23 €	3.746,53 €	1 Ton	8.479,84 €	11.223,39 €	13,7 Ton
6.7 Fuel Taxes						
+ 10% ISPP/year	6.239,82 €	3.746,53 €	1 Ton	8.308,84 €	11.656,39 €	12,4 Ton
6.8 Annual mileage						
41 km/day	6.184,92 €	4.073,22 €	1,3 Ton	9.174,98 €	11.789,87 €	15 Ton
6.9 CO2 content of electricity:						
CO2g/kWh = EU27	5.858,23 €	3.746,53 €	1 Ton	9.017,49 €	11.656,39 €	11,5 Ton
CO2g/kWh = France	5.858,23 €	3.746,53 €	1 Ton	9.017,49 €	11.656,39 €	16,9 Ton
6.10 Best scenario	710,30 €	-737,75 €	1,8 Ton	-2.097,29 €	2.987,95 €	15 Ton

Table I – Sensitivity Analysis

Source: Own calculations