2010 ITF-KOTI Joint Seminar on
Green Growth in Transport

ELECTRIC VEHICLES: A TENTATIVE ECONOMIC AND ENVIRONMENTAL EVALUATION[1]

by

Rémy PRUD'HOMME[2]

November 25, 2010

OECD Conference Centre, Paris, France

[1] Prepared for a KOTI (Korea Transport Institute) – ITF (International Transport Forum) meeting, November 25, 2010. This research did not benefit from any research grant or contract.

[2] Professor (emeritus), University Paris 12. (prudhomme@univ-paris12.fr)

Introduction

Electric vehicles are often presented as a green solution to the transport problem. They offer, it is argued, the benefits of the private car without its costs. They make it possible for individuals and families to move around easily, rapidly, comfortably, at any moment in time, which makes them more consumer friendly than public modes of transportation. Yet, unlike classical cars, they do not consume scarce and dwindling fossil fuel resources and do not reject greenhouse gases, nor local pollutants.

The idea is not new, but the record of enthusiastic statements is not encouraging. One century ago, the press was already asserting: the electric car "has long been recognized as the ideal solution" because it "is cleaner and quieter" and "much more economical (*The New York Times*, November 2, 1911); and: "prices of electric cars will continue to drop until they are within reach of the average family" (*The Washington Post*, Halloween 1915). For many years, however, the electric car remained a dream, or a concept, or a curiosity.

Things might be changing. At the 2010 Paris Motor Show, several automobile companies presented electric vehicles models for mass sales. This makes it possible to go beyond literary and qualitative appraisals of the electric car potential. It gives us access to the (or rather, to some) cost and performance numbers necessary to undertake a quantitative evaluation of the economic and environmental achievements of an electric car.

This paper sets out a methodology, which takes the form of a computerized model, to do that. It uses it to appraise the costs and performance of an electric car, relative to a fuel-powered car. Because of the uncertainties attached to some of the parameters utilized, a sensitivity analysis is conducted to find out how robust are the outcomes of the model. This round of simulations relates to 2010 electric cars, which are likely to evolve over time. The same model can be used to simulate the impacts of important or major changes in vehicle characteristics.

The data used in this paper relates mostly to France. But there are good reasons to expect the analyses conducted and the conclusions arrived at to be significant for most countries. The paper tries to evaluate a new technology, which, by nature, is not country-specific. Vehicles are internationally produced and traded products competing with each other.

Methodology

This evaluation is comparative. It compares an electric car with a classical car providing about the same level of service during a similar period of time. It does this from three important viewpoints: consumer costs, socio-economic costs and CO2 emissions. Consumer costs are what consumers pay to use our two types of cars. Socio-economic costs are consumer costs minus specific taxes (which are not an economic cost, but a transfer) plus externalities. The externalities concerned are those caused by fuel car usage, to the exclusion of road maintenance or accident costs, which are common to both the fuel car and the electric car and would therefore cancel each other in comparison. CO2 emissions are an externality, of course, but one which is difficult to price; we prefer to evaluate the difference in CO2 emissions, and relate it to the difference in socio-economic costs, to find out the marginal cost of a ton of CO2 saved thanks to an electric car.

There are three main outcomes of the exercise. The first is the difference between the consumer electric cost (CEC) and the consumer fuel cost (CFC). Because we assume that CEC>CFC, we call it the consumer surcost (CS) of the electric car:

$$CS = CEC - CFC$$

For the electric car to have a market, CS must be reduced to zero by some form of subsidy.

The second outcome is the difference between the socio-economic electric cost (SEC) and the socio-economic fuel cost (SFC). We call it the socio-economic surcost (SS) of the electric car:

$$SS = SEC - SFC$$

The third is the difference (G, as in greenhouse gas) between the CO2 emissions of the fuel car (GF), and the CO2 emissions of the electric car GE), or rather of the electricity consumed by it. Because we assume that that GF>GE, we call it the CO2 gain of the electric car.

$$G = GF – GE$$

A fourth outcome of interest is the ratio of the socio-economic surcost (SS) to the CO2 gain of the electric car (G). It is the unit or marginal cost of a ton of CO2 saved (g):

$$G = SS/G$$

Car usage is characterized by k, the number of km driven per year, and by n, the lifetime of the car, which are, as mentioned, identical for the two types of cars.

Cost is defined as the present value, calculated with a social rate of discount r, of all costs incurred during the lifetime of the cars. With a flow of costs y_t over the 1 to n time period, the present value Y of this flow is:

$$Y = \sum_t y_t(1/(1+r)^t$$

The fuel car is characterized by its fuel efficiency (xf), which is the number of km driven per unit of fuel consumed (km/litre). The electric car by its electricity efficiency (xe), that is the number of km driven per unit of electricity consumed (km/kWh). Just a word on these units: efficiency, or productivity, is generally defined as an output/input ratio, and increases in productivity or efficiency are considered desirable. This is in conflict with the European fashion of measuring the performance of a car in litre/100km or in kWh/100 km (but not with the US fashion of measuring it in miles/gallon). Our concept of efficiency will therefore be the inverse of the European practices.

The cost of the electric car usage consists of the initial construction cost Ie, plus the battery cost B, plus the electricity consumption cost E. The battery cost is expressed in cost per year, because several car companies intend to rent batteries on a monthly or annual basis. E is the present value of the flow of yearly expenditures e_t. e_t is the quantity of electricity consumed (itself a function of the electric efficiency xe and of the distance driven k) multiplied by the price of electricity in year t pe_t:

$$e_t = k*(1/xe)*pe_t$$

The cost of the fuel car usage (If) consists of the initial construction cost plus the fuel consumption cost (F), which is the present value of the flow of yearly expenditures (f_t). It is useful for the analysis to decompose f_t into three components: an oil cost, a specific tax cost, and other costs.

− The oil cost for a given year t is a function of the quantity of oil consumed (itself a function of k, the number of km driven, of the fuel efficiency (xf) of the car, of the price of oil (po) on international markets expressed in US dollars per barrel, and of a coefficient l:

$$\text{Oil cost}_t = k*(1/xf)*l*po_t$$

− The tax cost for yeat t is simply the quantity of fuel consumed yearly multiplied by the unit tax t_t expressed in euros per litre.

$$\text{Tax cost}_t = k*(1/xf)*t_t$$

− The other costs (oil transport, refining and distribution), which are assumed to be constant over time, are also the product of unit costs z by quantities of fuel consumed yearly.

CO2 emissions of the fuel car for a given year t are defined as the product of the number of km driven (k) by the quantity of fuel consumed multiplied by the CO2 content of a litre of fuel (gf). The damages caused by CO2 are a function of the total quantity of CO2 emitted, irrespective of the date at which CO2 has been emitted. The yearly emissions of CO2 are therefore additive, and should be added without any discounting. The CO2 emissions over the life of the car GF are therefore simply:

$$GF = k*n*gf*(1/xf)$$

Similarly, the CO2 emissions associated with the electric car GE over the lifetime of the car are the number of km driven (k) multiplied by the number of years considered (n), multiplied by the electric efficiency (xe), multiplied by the CO2 content (c) of the electricity consumed:

$$GE = k*n*(1/xe)*c$$

CE and CF do not include all the car usage costs. They ignore insurance costs and parking costs. These costs are assumed to be equal for the two types of cars, and therefore not to influence the surcost.

It is reported that the yearly maintenance costs of an electric car are lower that those of a fuel car, by an amount M, which has to be taken into account.

Finally, in the calculation of the socio-economic cost, one must take into consideration the local pollution costs associated with the fuel car

It appears that SC and SS functions of about a dozen variables: Ie, If, B, xf, pe_t, xf, pb_t, x, t_t, z, r, n, k, M. For cars to be purchased in 2011, most of these variables can be known with a certain degree of certainty, although three (those with a subscript t) might change over the period considered: electricity prices, oil prices and oil taxes. For cars to be purchased in subsequent years, several of the parameters, such as electricity and fuel efficiency, purchase prices, battery costs, are also susceptible to change over time.

Baseline Case

What values should be attributed to our variables in order to determine the surcost and the gain caused by the replacement of a fuel car by an electric car? We constructed a baseline case by comparing an electric car presented by Renault under the name of Zoe at the October 2010 Paris World Motor Show with a Renault Clio diesel car. The two cars seem to be roughly comparable in size and comfort. We shall assume they are used mostly for daily commuting purposes, for 15 years (n=15), and cover 10 000 km per year (k=10 000), two generous estimates. At the end of this period, the cars are assumed to be scrapped. We use a 4% social rate of discount.

The sale price of the Clio diesel car (If) is reported to be "from 11 700 €" on the official Renault site (www.renault.fr)[3]; we retained 12 000 €. The sales value of the electric car (Ie) is reported to be 20 000 €, before a 5 000 € French government subsidy. These numbers are sales values, when we are interested in cost values. Can they differ much? Most probably not. The automobile industry is extremely competitive, with very small profit margins, and sales prices (before subsidies) are probably a fair reflection of economic costs.

It is usually difficult to find estimates for the cost of batteries. This case is an exception. Renault offers batteries on a rental basis, at 75 € per month, or 900 € per year. This makes it possible to calculate B, the present value of battery usage, at 10 000 €. What was said in the preceding paragraph about the cost representativeness of sales values applies probably to batteries.

The car and battery prices of the electric car selected appear to be relatively low. Peugeot also offers an electric car on a rental basis, at a price of 6 000 € per year, a much higher price in present value terms. Other models, quoted in *The Economist* (Oct. 9, 2010), are reported to be on sale at about 27 000 €, with no detail about battery costs.

The fuel car considered is reported to consume less than "5 litres of diesel per 100 km"; this is a fuel efficiency of 20 km/litre (xf=20).

To price fuel, we started with a June 4, 2010 estimate of UFIP (Union Française de l'Industrie Pétrolière), a reliable industry source, that presents the structure of diesel oil prices as indicated in Table 1.

Table 1 – Diesel Oil Price Structure, France, 2010

			(in € per litre)
	Before tax	VAT	After tax
Crude oil (at 75 $/barrel)	0.375	0.073	0.448
Specific tax (TIPP)	0.428	0.084	0.512
Other (refining, distribution)	0.162	0.031	0.193
Pump price			1.153

Source : UFIP (www.ufip.fr)

The oil cost component will vary proportionately to the price of crude oil. The price in Table 1 corresponds to a crude oil price of 75 US$ per barrel. Over the course of time, it will be equal to 0.448*po/75. This assumes, for the sake of simplicity, a constant dollar/euro exchange rate, an hypothesis that could easily be abandoned. In the baseline case, we shall assume a 6% per year increase in the price of the barrel, which means oil at 170 $ a barrel in year 15 (2025).

The specific tax to be considered in France is obviously the TIPP[4], the rate of which is expressed in euros per litre. The VAT (19.6% in France) assessed on the TIPP, a tax on the specific tax, should also be treated as a specific tax. The tax is therefore 0.542 €/litre, and the option of an increase can be considered.

Other costs, i.e. refining and distribution costs, at 0.193, including VAT, are assumed to be constant over time.

[3] This is much more than the « from 8 900 € » reported for the Clio Campus, a model less comfortable than the Zoe electric car.

[4] Taxe Intérieure sur les Produits Pétroliers

Table 2 – Present Value of Fuel Consumption, Fuel Car, Years 1-15

	€	%
Oil cost O	3 704	51
Oil taxes T	2 846	37
Other costs Z (refining, distribution)	1 073	14
Total	7 623	100

Note: calculated on the basis of a 6% per year increase in the price of crude oil, with a price of 170 $ a barrel in 2025

It is not easy to find reliable estimates of the electricity efficiency of the electric car. The countless electric car propagandists seem not to be much interested in this key number. Producers usually do not communicate it in the abundant publicity they make about their products. The US Energy Policy Information Center (a project of an apparently reliable think tank committed to reducing oil dependency entitled "Securing America's Future Energy"), in 2010, evaluates the consumption of a "midsize plug-in electric vehicle" to be 27.5 kWh/100 km, a 3.64 (km/kWh) efficiency (http://energypolicyinfo.com). This number includes 7% transmission losses and 10% charging losses, which seem not to be included in most other estimates. ADEME, a French government Agency in charge of energy savings, an ardent and active supporter of electric cars, states that "a small electric car consumes about 25 kWh/100 km" in one place, and "15 to 25 kWh/100 km" in another place (ww2.ademe.fr). We shall use in our baseline case 20 kWh/100 km, *i.e.* a fuel efficiency of 5 km/kWh driven (xe=5), then test the impact more electricity-efficient cars in sensitivity analyses.

The price of electricity retained for year 1 (2011) is the retail price of electricity in France, which is lower than in most other countries, thanks to the high nuclear content of electricity in France: 0.11 €/kWh (pe=0.11). This assumes that the heavy investments required to offer electric cars an easy access to the grid would not be reflected in higher prices. With this low price, the present value of the electricity cost of the electric car is about 2 400 €.

Regarding local pollution costs, we can base ourselves on a French official commission report, known as the Boiteux report[5] (because it was chaired by Marcel Boiteux, a respected economist), the findings of which were endorsed by the minister of Transport in an official "directive"[6]. For private cars, in non-dense urban areas (as opposed to dense urban areas and rural areas), the local pollution cost to be utilized in cost-benefit analysis was 0.01 €/vehicle-km in 2000. To take into account the rapid decrease in car emissions, this value was to decline by about 4.5% per year over the 2000-2020 period. This means 0.006 €/veh-km in 2011. We retain this value, and this decline rate, for the 15 years period studied.

Table 3 sums up the value of the parameters used in the baseline case.

5 Commissariat Général du Plan. 2001. *Transport : choix des investissements et coût des nuisances. Paris. La Documentation Française*. 322p. (Report of a Commission chaired by Marcel Boiteux)

6 Ministère de l'Equipement, des Transports, du Logement, du Tourisme et de la Mer. 23.3.2004. *Instruction-cadre relative aux méthodes d'évaluation économique des grands projets d'infrastructures de transport*

Table 3 – Value of Parameters Used in the Baseline Case

Number of years (n)	15
Car usage (k), in km/year	10 000
Social rate of discount	4%
Fuel car :	
Purchase cost (If), in €	12 000
Fuel efficiency (xf), in km/litre	20
Oil price (po) in year 1, in $/barrel	75
Yearly change in oil price (%)	6%
Fuel taxes (t), in €/l)	0.512
Other fuel costs (z), in €/l	0.193
CO2 emissions (gf), in kg/l	2.6
Local pollution costs in year 2011 (€/km)	0,006
Yearly change in local pollution costs (%)	-4.5%
Electric car :	
Purchase cost (Ie), in €	20 000
Battery cost present value (B), in €	10 007
Electricity efficiency (xe), in km/kWh	5
Electricity price (pe), in €/kWh	0.11
Yearly change in electricity price (%)	0%
CO2 content of electricity (c), in g/kWh	90

Table 4 compares, in present value terms, the consumer cost of the two types of vehicle, for a similar usage.

Table 4 – Present Value of Fuel and Electric Car Usage, for Consumers over a 15 Years Period, Baseline Case

(in €)

	Fuel car	Electric Car	Difference
Purchase cost	12 000	20 000	+8 000
Battery cost	-	10 007	+10 007
Fuel or electricity cost	7 623	2 446	-5 177
Difference in repair costs	778	-	-778
Total cost	20 401	32 453	+12 053

Source :See text and Table 3 for the values given to the various parameters.
Note : The total cost is not quite total, since it does not include costs common to the two types of cars, such as parking, insurance or repairs (only the surcost for the fuel car is given) because we are only interested in differentials.

With the values given to the relevant variables in this baseline case − that seem to reflect today's reality − the electric car is not competitive. For a given service (10 000 km per year of short trips during 15 years), it costs the consumer an additional 12 000 euros to use an electric car than a fuel car.

The level of service provided by the electric car is inferior to the level of service provided by the standard fuel car in at least one respect. The electric car can only be used for less than 150 km long trips. Unlike the fuel car it cannot be used for most vacation trips. The willingness to pay for the additional degree of liberty offered by the fuel car is difficult (although not impossible) to estimate, but most probably reaches several thousand euros.

This additional 12 000 € is the surcost for the consumer. From a socio-economic viewpoint, however, one should take into account the specific taxes paid by the fuel car. These taxes are a transfer, not an economic cost, not a consumption of scarce resources. Table 2 shows that such taxes amount to about 2 800 €. This should be deducted from the socio-economic cost of the fuel car, and increase the surcost. The economic differential, what society loses by utilizing an electric car, is about 14 000 €.

In terms of market penetration, what matters is the consumer surcost. Except for a few consumers who want to show they are very rich, and very green, there is not much of a market for the electric car at present. Sales require average subsidies of at least 12 000 € per car. Such subsidies might take the form of compulsory purchases by government or quasi-government bodies. This will take place at a high cost in terms of public finance. If, next year, 10% of car sales in France (2.3 million cars) were to be electric cost, this would require, or implies, a subsidy of 2.8 billion euros, as well as a tax loss of 0.7 billion euros; that is an increase in tax or in debt of 3.5 billions.

Can this drain on economic resources and on public finance be justified by the gain in CO2 emissions likely to be generated by the electric car?

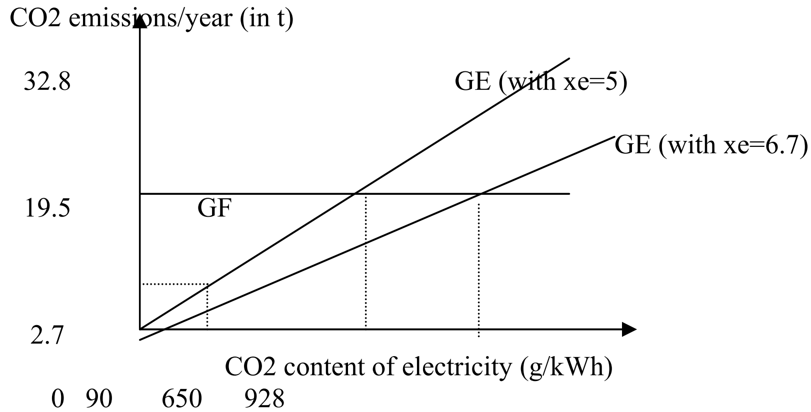
It is easy to figure out the CO2 emissions of our reference fuel car that will be saved. As mentioned above, they are equal to gf*(1/xf)*k*n. The CO2 content of a litre of diesel oil (gf) is 2.6 kg. With a fuel efficiency (xf) of 5 km/litre, and 10 000 km/year, the fuel car will reject 1.3 tons of CO2 per year (about half what is rejected by a cow in the form of methane), and 19.5 tons over its lifetime.

It is much more difficult to evaluate the CO2 emissions associated with the electric car, defined as GE=ge*(1/xe)*k*n. The reason is that ge, the CO2 content of a kWh of electricity, varies greatly from place to place and moment to moment, from about zero to 1 000 (grams of CO2 per kWh). Rather than a number, it is best to offer a function:

$$GE = 0{,}030 * ge \quad (\text{with } xe=5)$$
$$GE = 0{,}021 * ge \quad (\text{with } xe=6.5)$$

Figure 1 represents this function. The break-even point appears to be a CO2 content of electricity of about 650 g/kWh, with an electric efficiency of 5 kWh/km). Beyond this limit, the electric car emits more CO2 than the reference fuel car. Before this limit, the electric car performs better, in terms of CO2, than the fuel car. For a greater electric efficiency, the break-even point is higher.

Figure 1 – CO_2 Emissions of Fuel and Electric Cars, as a Function of the CO_2 Content of Electricity



In many countries, the average CO_2 content of electricity is around, or greater than, 400 g/kWh. Table 4 presents 2007 estimates for a selection of European countries[7]. The average for Euro-15 countries is reported to be 330 grams. It is lower than 100 grams in Sweden and in France, because of the high share of nuclear and hydro in the electricity-mix. But it is higher than 400 grams in Germany, the United Kingdom, the Netherlands or Denmark, not to mention most Eastern European countries. In these countries, the substitution of a fuel car by an electric car would (in our baseline case) decrease CO_2 emissions by less than 6 tons – not per year, but over 15 years.

Table 4 – CO_2 Content of Electricity, Selected European Countries, 2003

	(in g of CO2 per kWh)
Sweden	40
France	90
Belgium	290
Italy	388
Spain	390
Netherland	405
Germany	427
UK	500
Czech Republic	558
Poland	668
Average Europe-15	330
Average Europe 27	362

Source : Ministère de l'Ecologie, 2010. *Chiffres-clés du climat France et Monde*, quoting IEA

What counts, however, is the *marginal* CO_2 content of the electricity used to recharge the electric car batteries. This varies greatly. It can be very low. In France, if electric cars were only recharged at night − when electricity is mostly produced by nuclear power plants emitting next to zero CO_2− the gain would be close to 19 tons per car. But if the cars were recharged at times when a larger share of electricity is produced by fuel or gas powered plants, the gain would be much reduced.

[7] Eurostat does not provide these statistics. Neither does WRI. The IAE does, but sells them.

Somewhat arbitrarily, we assumed 90 g/kWh, the average number for France in the statistics quoted[8]. It produces a CO2 gain of 16.8 tons per car. At an economic surcost of 14 400 €, this puts the CO2 abatement cost at 860 € per ton of CO2 eliminated. This is in the favourable French case. For most other countries, the unit cost would be much higher. For the United Kingdom, for instance, a gain of 3.1 tons would be obtained at a cost of 4 600 € per ton.

Short Term Sensitivity Analysis

Some of our parameter values are very well established; others are much less certain. It is therefore important to see if, why, and by how much, our outcomes are modified by changes in the value of these questionable parameters, in order to test the robustness of the analysis, and to identify the variables that could most affect outcomes. Table 5 presents how, for the present batch of vehicles, the consumer surcost, the economic surcost, and the CO2 gain could be modified as a result of such changes.

Rate of discount − A first question is: are our findings, which are expressed in present value terms, very sensitive to the rate of discount chosen (4% in the baseline case)? Not really: they change by about 500 €. One could have expected the electric car, which is supposed to be more costly at the time of purchase and less costly in fuel/electricity consumption, to be favoured by a low rate of discount. Actually, the opposite is true. The reason is that in our model (as in most cases in reality), battery costs are yearly costs, and the yearly costs of the electric car are higher than the yearly costs of the fuel car.

Table 5 – Outcome Changes Generated by Possible Changes in the Value of Key Parameters

	Consumer surcost (€)	Economic surcost (€)	CO2 gain (Tons)	Cost of CO2 gain (€/ton)
Baseline case	12 100	14 400	16,8	860
Rate of discount: 2%[a]	12 600	15 300	16,8	910
Rate of discount: 6%[a]	11 600	13 600	16,8	811
(a) Fuel taxes: +100%[b]	9 200	14 400	16,8	860
Oil prices: +12%/year[c]	10 000	12 400	16,8	740
Electricity prices: +10%/year[d]	14 400	16 800	16.8	1 000
(b) Electr. efficiency: +30%[f]	11 500	13 800	17.6	790
(c) Yearly mileage: +30%[g]	10 500	13 000	21,8	620
(a)+(b)+(c)+changes car prices[h]	2 564	9 283	22,7	410

Notes: All cost numbers have been rounded to the nearest 100, to facilitate the reading of the results. [a]As opposed to 4% in the baseline case. [b]From 0.512 to 1.024 €/litre. [c]From 75 $/barrel in year 1 to 285 $/barrel in year 15. [d]From 0.11 €/kWh in year 1 to 0.42 in year 15. [e]400 g/kWh as opposed to 90 in the baseline case. [f]6.5 km/kWh instead of 5. [g]13 000 km/year instead of 10 000. [h]Lower electric car price (19 5000 instead of 20 000) and higher fuel car price (15 000 instead of 12 000)

Oil prices − A second question is: would a rapid increase in the price of oil in the next 15 years drastically change the picture? In the baseline case, we assumed a 6% per year

[8] A direct calculation dividing the 2008 CO2 emissions produced by electricity generation (29 M tons, according to the authoritative CITEPA report) by the 2008 electricity production (575 TWh), one obtains 50 g/kwh.

increase, already a substantial increase. A 12% per year increase (implying a price of 370 US$ in year 15) would decrease our two surcosts by about 2 000 euros.

Fuel taxes − A third question relates to fuel taxes. We simulated the impact of a doubling of the present fuel taxes in year 1, a radical (and unlikely) measure. It obviously does not affect the economic surcost, which remains above 14 400 €. It only lowers the consumer surcost by about 3 000 €, to 9 200 €, which remains high enough to prevent mass purchases of the vehicle.

Electricity price − Fourthly, the electricity price used in the baseline case (0.11 /kWh), the present price paid by households in France, is low by international standards. It is much lower than the cost of solar electricity, which presently in France is sold to the network at more than 0.50 €. We simulated the impact of an electricity price increase of 10% per year, implying a price of 0.41 /kWh in year 15 (below the present cost of solar electricity). The result is an increase of both surcosts of more than 2 400 €[9]. The marriage of electric cars and solar electricity would not be a happy one.

Electric efficiency − A fifth issue concerns the electric efficiency of the electric car. The one assumed in the baseline case is 5 km/kWh (20 kWh/100 km). We simulated the impact of a 30% more electric efficient car (6.5 km per kWh, or 14 kWh/100 km). It reduces the surcosts by only about 700 € − not a radical change in the overall picture. It also improves the CO2 gain by only about 1 ton over the 15 years period.

Car mileage − A sixth question relates to the mileage driven annually. The base line case assumes a yearly car usage of 10 000 km. Were this number to be increased by 30%, to 13 000 km, the surcosts would decrease, by about 600-800 €, the CO2 gains would increase by 5 tons, and the cost of a ton of CO2 saved decrease to about 600 €.

This raises an important issue. The interest of an electric car (relative to a fuel car) varies significantly with the number of km driven. The more km that are driven per year, the more attractive it is. Yet, because of their short range, electric cars are only suited to short daily trips. Is there a contradiction here? In average terms, yes; in market terms, no.

The average number of km per year driven on daily trips is low. In France, a 2008 nation-wide transport survey gives the number of local trips (of less than 80 km) per week, as well as the average distance of each trip[10]. Since we know the number of cars, we can calculate the *average* yearly mileage of each car on local trips: 2 000 km. Many cars (for instance the second car in a number of households) are not used every day, or only for very short distances per day.

The electric car, however, does not target the average car, or the entire market. It focuses only on those car owners that drive many kilometres in the form of short-range trips. Industry believes that cars driving at least 13 000 km per year on such trips represent about 10% of the market. It is therefore legitimate to consider the advantages of the electric car for this particular segment of the demand only. It means that the electric car is, and should be presently considered as, a *niche market*, not as an alternative to the fuel car in general.

Five simultaneous changes - All of the above changes have been considered parameter by parameter. We can also conduct the sensitivity analysis for sets of changes. We discussed an earlier draft of this paper with Renault officials. While they endorse the methodology, they

---

9 If the electricity used were, beginning in 2011, entirely photovoltaic electricity sold at cost – an unrealistic hypothesis indeed − the electricity cost of the electric car would be above 11 200 €, much greater than the fuel cost of the fuel car, and the economic surcost would jump above 23 000.

10 See ENTD (enquête nationale sur les transports et déplacements), at www.statistiques.developpement-durable.gouv.fr

suggested that the *simultaneous* introduction of five changes (relative to our baseline case) would, in their view, better reflect reality: (a) a 100% higher fuel tax, (b) a 30% greater electricity efficiency; (c) a 30% higher mileage; (d) a slightly lower sales price for the electric car (19 500 € instead of 20 000 €); and (e) a significantly higher price of the fuel car (15 000 € instead of 12 000).

The three first changes have already been examined individually. What happens when these five changes are jointly introduced? The surcost for the consumer is reduced to 2 600 €. A 5 000 € subsidy would be more than enough to compensate and create a market. The socio-economic surcost, however, remains high, at 9 200 €, and the electric car remains a bad deal for society.

Considered one-by-one, none of the changes simulated leads to drastic changes. In practically all cases, the present value of the cost of the electric car is 10 000-12 000 € higher than that of the fuel car for the consumer (before subsidy). In socio-economic terms, the surcost is in the 12 000-14 000 € range. It is very difficult to justify this surcost by the CO2 gain generated by the electric car. This CO2 is highly dependent upon the CO2 content of the electricity used to recharge the batteries. It vanishes with a CO2 content as high as the average one that presently prevails in Germany, the United Kingdom, the Netherlands and Denmark. In the best of cases (in Sweden and France), assuming recharging takes place at night, the gain over the 15 years period amounts to some 17 tons of CO2.

The simultaneous introduction of several changes obviously improves the outcome. The consumer surcost can be reduced to a subsidizable level. But even in that case, the socio-economic surcost remain high (above 9 000 €).

Longer Term Sensitivity Analyses

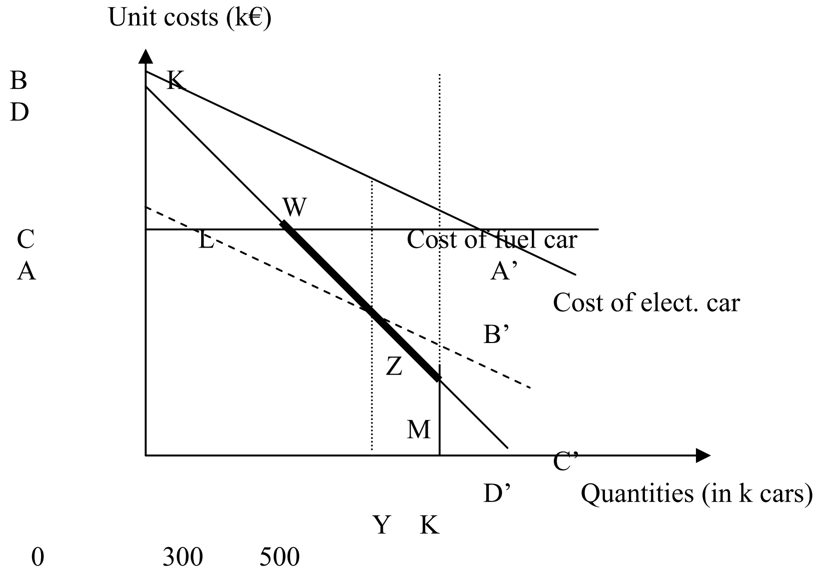
The preceding sensitivity analyses apply to the present batch of cars. Things might be different in the future, for two obvious reasons: economies of scale, and technological improvements. Economies of scale are particularly important in the automobile industry. The production cost of a car, or of parts of a car, can be cut by as much as 50% when production volumes increase from 10-20 000 units a year to 500 000 units a year. Such volumes are current for the standard fuel cars. Production costs of electric cars and of batteries presently given probably assume volumes sufficiently high to reap part of the potential scale economies. But it can be hypothesized that more remains to be reaped, and that increased volumes would mean lower costs. Technological improvement might be even more important as cost drivers for a relatively novel technology like that of electric cars. Over the course of time, the curve representing production costs as a function of volume will go down.

Figure 2 illustrates the possible future of the electric car. AA' is the production cost curve for a fuel car. It is flat, because economies of scale have already been obtained. BB' is the present production cost curve for an electric car. We do not know exactly where we are presently on this curve. DD' is the potential demand curve for an electric car, low for a high price, high for a low price. The effective demand curve, however, is doubly bounded. First, it only begins in L, because of the existence of a fuel car substitute at a lower price (prices are assumed to be equal to production costs). Second, it is limited by the number of car owners that drive sufficiently (for instance at least 13 000 km/year) in the form of short trips (for instance less than 150 km/day). This limit is figured by line KK'. M is the intersection of DD' and KK'. The demand for electric cars is therefore figured by the segment LM.

As appears on Figure 2, the present production cost curve of an electric car (BB') does not intersect the demand curve (LM), and there is no market for electric cars. For a market to be created, a subsidy that will lower BB’ to, for instance, CC’ is necessary. An equilibrium will be reached in Z, with Y cars sold – at a cost to public finance equal to BWZC.

For this to be sustainable, the subsidy must be replaced, over the course of time, by a reduction of the electric car cost at least equal to the subsidy. Can such a cost reduction be expected?

Figure 2 – Costs as a Function of Volumes



A reduction of the usage cost of electric vehicles could come from three improvements: a reduction of the construction cost (or sales price before subsidy) of the car, a reduction in the cost of batteries, and an increase in the electric efficiency of the car. We simulated the impact of such changes individually, then jointly, on the electric car surcosts. For construction costs, we consider a 30% reduction, from 20 000 € to 14 000 €. For batteries cost, we also consider a 30% reduction, from 900 €/year to 630 €/yr. For electric efficiency, we consider a 100% improvement, from 5 to 10 km/kWh (from 20 to 10 kWh/100 km). Each of these improvements would be a significant industrial achievement. Results are presented in Table 8.

Taken individually, the impacts of these changes are not impressive. Surcosts are reduced, but remain substantial: in the 6,000-11,000 € range for the consumer surcost, in the 8 000-13 000 € range for the socio-economic surcost.

If they were to happen simultaneously – which would represent a remarkable industrial achievement – they would reduce the electric car surcosts to much lower levels : 1 800 € for the consumer, and 4 100 € for society. They would not suffice to create a non-subsidized market for the electric car, and electric cars would continue to be operated at a high social cost. In order to eliminate the consumer surcost, one has to add to these three technological changes a rather high (12%/year) increase in oil prices, that would bring the price of oil to 370 $ per barrel. Even in this extreme case, the electric car would be operated at a cost (a socio-economic surcost) to society.

These simulations assume no improvement in the fuel car technology, and a constant price (i.e. cost) of electricity. A more realistic scenario would probably abandon such assumptions, which would increase surcosts. They have also ignored the cost of battery recharging stations, which would (or will) be supported by public finance.

Table 8 – Outcomes Generated by Improved Electric Vehicles

	Consumer surcost (€)	Economic surcost (€)	CO2 gain (t)	Cost CO2 gain (€/t)
Present Vehicles (baseline case)	12 100	14 400	16.8	856
Future vehicles :				
(A) Initial cost : -30%	6 100	8 400	16.8	498
(B) Battery cost : -30%	9 000	11 400	16,8	677
(C) Electricity efficiency : +50%	10 800	13 200	18,2	723
(D) (A)+(B)+(C) together	1 800	4 100	18,2	226
(E) (D) + Oil prices : =12%/year	-200	2 141	18,2	118

Notes : Numbers have been rounded to the nearest 100 to facilitate reading. In the baseline case, the initial cost is 20 000 €, the battery cost is 900€/year, the electric efficiency is 5 km/kWh (20 kWh/100 km), and the oil price is 75 \$/barrel. A 12% per year increase in the oil price means 367 \$/barrel in year 15.

The CO2 gains generated by the electric car are not much affected by these technological changes. The numbers in Table 8 have been calculated using the French average CO2 content of electricity. In most other countries, they would be lower − even much lower. And they assume no progress in CO2 emissions of fuel cars, another unrealistic hypothesis.

Conclusion

The conclusions of this analysis are not encouraging for the electric car. On the basis of the available information on costs and performances, it appears that the present electric car fares much less well than a standard classical fuel car. Over the lifetime of a car, it will cost some 12 000 euros more to the consumer, and 14 000 euros more to society. These numbers take into account the difference in maintenance costs, and the cost of local pollution by fuel cars.

It is hard to justify such enormous surcosts by the CO2 gains that will be produced. Over the lifetime of a car, these gains will range from zero in a country like Poland, to a maximum of 19 tons in a country like Sweden or France, provided batteries are recharged at night when the CO2 content of electricity is close to zero. Assuming the average European Union CO2 content of electricity, the CO2 gain of an electric car operating 10 000 km during 15 years will be about 8 tons. The implied cost of saving one ton of CO2 ranges from about 900 euros to infinity (in extreme cases, the electric car would increase CO2 emissions), with an average of 2 500 euros.

There are serious uncertainties about several of the parameter values used, for the present, and even more so for the future. We conducted sensibility analyses to evaluate the impact of alternative values of these parameters upon our conclusions. We considered different rates of discount, important increases in fuel taxes, in crude oil prices, in electricity efficiency (of electric cars), in mileage driven, in the carbon content of the electricity utilized, and important decreases in the cost of electric cars and of batteries.

All of these changes do impact the surcosts and the CO2 gains. But not much. Taken individually, they typically reduce surcosts by 1 000 or 2 000 euros. In that sense, the model used turns out to be quite robust. It is only when several of these changes are introduced jointly that surcosts are reduced significantly. A 30% decline in electric car cost and in battery cost, plus a 100% increase in electric efficiency, plus a 12% per year increase in the price of oil eliminates the consumer surcost but not the socio-economic cost. The probability that all these changes would occur together is not zero, but it is not very high.

CO2 gains remain always low: they are increased by a few tons over the lifetime of the car by a better, or much better, electricity efficiency, and decreased by an increase in the carbon content of the electricity used.

One parameter deserves a particular attention: mileage. The more km per year an electric car is driven, the more economic (or, more precisely, the least uneconomic) it is. But mileage is constrained by the limited range (150 km) of electric cars. This means that the electric car market can, if anything, only target the cars driven many km per year in the form of small trips. This is only a fraction (about 10%according to industry estimates) of the automobile market. The idea that the electric car could be a general substitute to the fuel car is not acceptable. It can only, at best, be a niche market.

The electric car appears to be a gamble on the part of producers and governments. Until massive cost and efficiency improvements are achieved, it will require massive subsidies. If they are achieved, and achieved rapidly, this gamble might pay. If not, a lot of resources will have been wasted. In this case, a fraction of these resources would have made it possible to reduce CO2 by much larger amounts.

Annex A – Spreadsheet used for calculations

	(For reference)				
Value of parameters:					
Number of years (n)	15	15	1	2	3
Social rate of discount	4%	4%			
Car usage (k/yr)	10 000	10 000			
Fuel car:					
Purchase cost (If) in €	12 000	12 000			
Fuel efficiency (xf) in lm/litre	20	20			
Oil price (po- in $/barrel)	75	75			
Change in oil price (%)	6%	6%	75	80	84
Fuel taxes (t) in €/lit	0,512	0,512			
Change in fuel tax rate (%)	0%	0%	0,512	0,512	0,512
Other fuel costs (z) in €/lit	0,193	0,193			
Change in local emission costs (%/yr)	-4%	-4%			
Local pollution costs (€/km)	0,006	0,006	0,006	0,0058	0,0055
CO2 emissions (gf), in kg/lit	2,6	2,6			
Electric car:					
Purchase cost (Ie), in €	20 000	20 000			
Battery renting (B) in €/yr	900	900			
Electricity efficiency (xe) in km/kWh	5	5			
Electricity price (pe), in€/kWh	0,11	0,11			
Change in elect price	0%	0%	0,11	0,11	0,11
CO2 content of electricity (c) in g/kWh	90	90			
Usage cost of fuel car (in €):					
Purchase cost		12 000			
Oil cost of fuel		3 704	224	237	252
Fuel taxes		2 846	256	256	256
Other fuel costs		1 073	96,5	96,5	96,5
(Subtotal: fuel costs)		7 623			
Surcost of repairs		778	70	70	70
Total		20 402			
Local pollution costs		524	60	57,6	55
Usage cost of electric car, in €:					
Purchase cost		20000			
Battery cost		10 007	900	900	900
Electicity cost		2 446	220	220	220
Total usage cost		32 453€			
Results:					
Surcost (consumer), in €		12 051			
Surcost (economy), in €		14 373			
CO2 gain, in tons		16,8			
Cost/ton of CO2, in€/t		856			