International Transport Forum

Electric Vehicles Revisited – Costs, Subsidies and Prospects

03

Discussion Paper 2012 • 03

Philippe Crist
International Transport Forum
at the OECD, Paris

OECD

This document was produced as a Background Paper for the 2012 Summit of the International Transport Forum, on *Seamless Transport: Making Connections,* held from 2-4 May 2012 in Leipzig, Germany. The views expressed in this document do not necessarily reflect those of the member countries of the International Transport Forum.

Further information about the International Transport Forum is available at **www.internationaltransportforum.org**

ELECTRIC VEHICLES REVISITED:
COSTS, SUBSIDIES AND PROSPECTS

Discussion Paper No. 2012-03

Philippe CRIST

International Transport Forum
Paris
France

April 2012

INTERNATIONAL TRANSPORT FORUM

The International Transport Forum at the OECD is an intergovernmental organisation with 53 member countries. It acts as a strategic think tank with the objective of helping shape the transport policy agenda on a global level and ensuring that it contributes to economic growth, environmental protection, social inclusion and the preservation of human life and well-being. The International Transport Forum organizes an annual summit of Ministers along with leading representatives from industry, civil society and academia.

The International Transport Forum was created under a Declaration issued by the Council of Ministers of the ECMT (European Conference of Ministers of Transport) at its Ministerial Session in May 2006 under the legal authority of the Protocol of the ECMT, signed in Brussels on 17 October 1953, and legal instruments of the OECD.

The members of the Forum are: Albania, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, China, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, FYROM, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Japan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom and the United States.

The International Transport Forum's Research Centre gathers statistics and conducts co-operative research programmes addressing all modes of transport. Its findings are widely disseminated and support policymaking in member countries as well as contributing to the annual Summit.

DISCUSSION PAPERS

The International Transport Forum's Discussion Paper Series makes economic research, commissioned or carried out at its Research Centre, available to researchers and practitioners. The aim is to contribute to the understanding of the transport sector and to provide inputs to transport policy design. The Discussion Papers are not edited by the International Transport Forum and they reflect the author's opinions alone.

The Discussion Papers can be downloaded from:

www.internationaltransportforum.org/jtrc/DiscussionPapers/jtrcpapers.html

The International Transport Forum's website is at: www.internationaltransportforum.org or for further information on the Discussion Papers, please email: itf.contact@oecd.org

TABLE OF CONTENTS

Boxes

ELECTRIC VEHICLES REVISITED – COSTS, SUBSIDIES AND PROSPECTS

AN ILLUSTRATION WITH MODELS MARKETED IN FRANCE

SUMMARY

This paper compares the lifetime costs of like internal combustion and battery electric vehicle pairs on the market in France and finds that relative costs of electric vehicles remain elevated for consumers and even more so for society under current conditions and typical use scenarios. It also suggests that in those cases where electric vehicles do already compare favourably to internal combustion engine powered cars, subsidies may be superfluous. In the future, a number of simultaneous changes in battery electric vehicles (BEV) and ICE technology, fiscal regimes and prevailing energy prices might reduce and even eradicate the consumer cost differential in favour of ICEs. Reducing the social cost differential between BEVs and ICEs seems more challenging under most scenarios and, when successful, raises the question of how much should society seek to subsidise BEVs in instances where there begins to be a business case for them.

Electric cars are often presented as zero-emission vehicles and are central to many long-term decarbonisation scenarios for the transport sector but battery electric vehicles face considerable cost and environmental hurdles before they can realise their potential. This study looks at a set of comparable battery electric and internal combustion engine cars for which commercial pricing data is available, in order to assess cost differences from first-order consumer and societal perspectives. We find that the cost of these BEVs (excluding the battery) is still higher than equivalent internal combustion vehicles, though it is conceivable that this gap may narrow as production volumes increase. Batteries still present a challenge as the costs for batteries providing a "useable" range (approximately 150 kms per charge) are still high. These costs may decline in years to come as the scale of production increases but ICEs will still provide superior range at lower costs under many scenarios. This study does not account for indirect impacts of BEC uptake (e.g. reduced oil dependence, resulting productivity benefits and employment effects). These may be important but may also result from improved ICE efficiency at a lower cost.

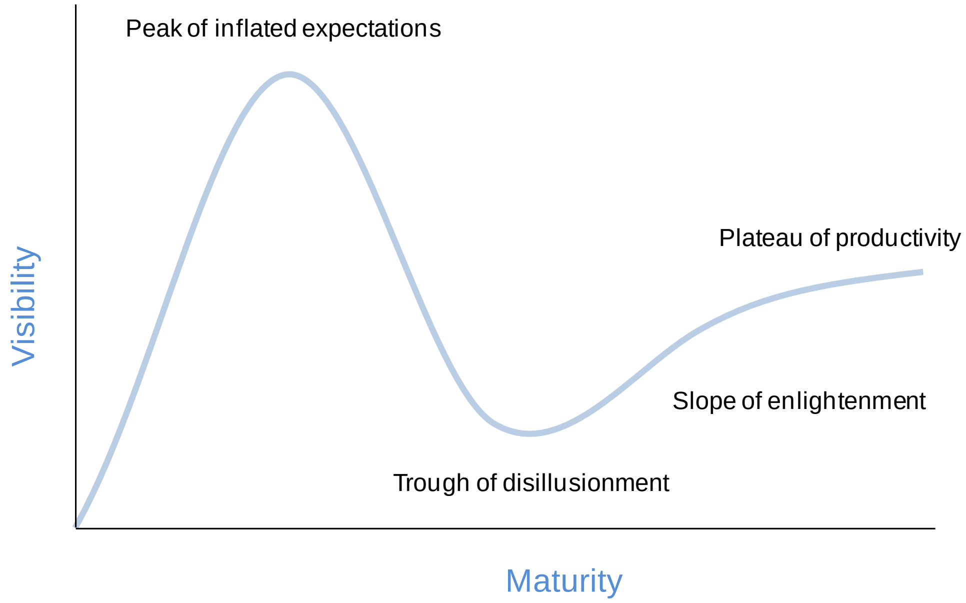
It is also important to note that electric cars are "displaced emission" rather than zero emission vehicles since electricity production may generate both CO_2 and conventional pollution. In almost all cases, BECs will generate fewer lifecycle CO_2 emissions than comparable ICE counterparts. Exactly how much less depends on the carbon intensity of marginal electricity production used to charge electric vehicles, the full lifecycle emissions (including production) of comparable electric and fossil-fuel powered vehicles (and their fuels) and the relative energy efficiencies of those vehicles. In most scenarios studied here, the marginal CO_2 abatement costs of replacing fossil fuel powered cars with electric vehicles remain elevated – the exception being for high vehicle travel scenarios.

1. BACKGROUND

Electric vehicles have gathered renewed interest in recent years as concerns about the future availability and price of fossil fuels, increasing greenhouse gas (GHG) emissions and air pollution[1] have motivated governments and manufacturers to consider alternative transport energy pathways. Recent estimates put the global electric vehicle fleet at over 120 million in 2010 with sales in 2011 topping 27 million. These are surprisingly high numbers but the overwhelming majority of these vehicles are electric bicycles and scooters and most of these are sold in China. Electric car sales, in contrast, are multiple orders of magnitude smaller with the most popular models representing the lion's share of the 2011 electric car market (Nissan Leaf and Mitsubishi iMiev) tallying global sales at approximately 44 000 units. These numbers are likely to pick up as more car models become commercially available but real questions remain regarding consumers' ultimate uptake of battery electric cars.

As with discussions of other technological innovations that purport to solve the dual challenge of energy security and climate change (e.g. biofuels and hydrogen fuel cells), the return of the electric car can be characterised by what can be colloquially termed a "hype cycle"(Fenn & Time, 2008) (see Figure 1).

Figure 1: Gartner "Hype Cycle" for technology innovation



Source: (Bakker, 2009) adapted from Gartner.

1 We do not address air pollution impacts of EVs here but we note that where electricity generation is relatively polluting, evidence suggests that the air quality-related health impacts of BEVs are greater than gasoline ICEs and lower than diesel ICEs. An increase in BEV uptake would also lead to a shift in exposure to air pollution away from urban areas and towards rural populations in the downstream vicinity of power plants (Ji, et al. 2012)

That a new technology generates interest and excitement is a good thing as these are often grounded on very real and desirable attributes -- but the "hype" can go too far. New technologies are often greeted by over-enthusiasm, boundless optimism and inflated expectations. If these technologies fail to meet expectations, they risk falling into a "trough of disillusionment" where consumers and others (e.g. the press), quickly move on. The failure of a technology to meet over-inflated expectations does not mean that it is devoid of potential and some companies (and governments) will continue to develop and support these technologies in the hope that a good business or societal case will eventually emerge. Sometimes it does and subsequent iterations of the technology, if it survives, may find a stable market niche or even a foothold towards dominance given the right conditions.

The battery electric vehicle (BEV)[2] is somewhere on such a "hype curve" but it is difficult to say where exactly. If one considers the visibility of BEVs in the press and in government discourse, it seems that despite the perennial re-apparition of BEVs, we appear to be (once again) near the top of the initial slope of a new "hype curve". Enthusiasm is high, expectations are far-ranging and critical analysis of where BEVs will fit in the future mobility landscape is limited.

BEVs are not a new technology per se even though the current generation of BEVs certainly represents a significant improvement over previous ones. It is a technology that has gone through several previous "hype cycles" (e.g. most recently in the mid-1990's with 3 commercially available models from Peugeot, Citroen and Renault and in the United States with General Motors EV-1). In each case, the BEV has fallen into a "trough of disillusionment" and away from public and government interest. Work on BEVs has nonetheless continued intermittently as battery and vehicle technology have improved and by 2011-2012 manufacturers are again offering several advanced market-ready commercial models. Those manufacturers that have brought BEVs to market again may consider that the technology has matured and that their offer incorporates the lessons learned from previous cycles.

Despite the state of technical advancement of current generations of BEVs, most manufacturers still underscore the need for government intervention for wide-spread uptake. In response, and in line with strategic decarbonisation goals, governments have provided upstream assistance for research and development and direct and sometimes substantial purchase subsidies in many jurisdictions. One justification for doing so is the belief that the shift to a low-carbon transport sector is inevitable but that an early (and assisted) shift to electro-mobility will reduce the overall burden on society that may otherwise result from a late shift.

The "early-shift" storyline stresses that not only is government intervention in BEVs required (on a sometimes large scale) but that society ultimately benefits due to a reduction of the oil import bill (with beneficial productivity impacts throughout the economy) and an increase in domestic manufacturing and jobs[3]. An alternate storyline may highlight the elevated upfront opportunity costs of reducing energy dependency and greenhouse gas emissions via BEVs as opposed to advanced internal combustion engine

---

2 For the purposes of this paper, we define a battery electric vehicle as a light-duty car, van or sports utility vehicle propelled solely by a battery-powered electric motor (e.g. not hybrid vehicles)

3 See (Cassen, et al. 2009) for an exploration of this storyline.

vehicles and hybrids[4]. Such a storyline may also underscore the potential for domestic manufacturing to suffer losses to lower cost foreign battery and BEV manufacturers.

Government intervention in emerging and volatile markets is fraught with potential downsides. The recent experience of some countries with guaranteed feed-in tariffs for large-scale solar facilities highlights the risk of intervention which can have unexpected outcomes and significantly disrupt the long-term functioning of the very markets it seeks to help[5]. In a number of countries the cost of support for solar power grew more rapidly than expected due to the combined effect of dropping photovoltaic panel costs and the strength of the stimulus (feed-in tariffs) provided. This and the economic crisis prompted governments to scale back support which disrupted investor's plans and contributed to the closure of several photovoltaic cell manufacturing plants already under pressure from inexpensive imports. The danger also exists for the BEV market and understanding some of the dynamics at play will help policymakers gauge the need and, eventually, the scope for intervention.

Our analysis does not test the validity of either storyline outlined above. Rather than reviewing the progress and potential positioning of BEVs in the current economic and regulatory landscape, we approach the questions above by drawing lessons from a micro-analysis of commercially available BEV models in France and by looking at what can be revealed from estimating their lifetime consumer and first-order societal costs.

This paper builds on analysis by Professor Rémy Prud'homme in "Electric Vehicles: A Tentative Economic and Environmental Evaluation" presented for the International Transport Forum – Korea Transport Institute joint seminar "Green Growth in Transport" (Prudhomme, 2010). That analysis found that current electric car models are not only more expensive for consumers than a comparable internal combustion engine-based vehicle (ICE) but that they were very much more expensive for society under a wide range of assumptions. It also highlighted that while electric cars may have the potential to reduce CO_2 emissions compared to ICEs, this came at a relatively high cost per tonne of CO_2 reduced.

The analysis in (Prudhomme, 2010) was based on early and incomplete reports relating to the commercial roll-out of electric car models in France. In this paper, we use Prud'homme's framework and supplement it with up-to-date information relating to market prices and vehicle performance characteristics for three electric vehicles offered for sale in France by Renault. We select these models because each has an almost identical (from the perspective of vehicle body, chassis and comfort level) ICE counterpart facilitating like-for-like comparisons. All of the data used in the calculations is based on publicly available information from Renault or from other public industry, government or academic sources.

Because of the small set of vehicle pairs and the fact that they represent only one manufacturer, we caution the reader that the results of our analysis should be taken as an indicative snapshot of the relative costs of BEVs vs. ICEs at this point in time (e.g. at the first stages of what is hoped to mass commercialisation). Furthermore, while the commercial model adopted by Renault (battery leasing vs. purchase) is not necessarily

4 See (Michalek, et al. 2011) for an example of this storyline.

5 See, for example, (Frondel, et al. 2009) and (Voosen 2009) for a discussion of the outcome of intervention in solar PV markets in Germany and Spain

shared by other BEV manufacturers, we find no compelling evidence that would indicate that our findings would not a priori apply to other BEV business models.

2. METHODOLOGY

We compare battery electric vehicles with internal combustion engine vehicles displaying similar characteristics so as to provide an indication of how a typical BEV might compare to its ICE equivalent. Since the total BEV cost for the selected models is typically higher than the ICE equivalent, we express this difference as the additional cost of the BEV over the ICE—i.e. where the BEV is less costly than the ICE, the difference is expressed as a negative.

Renault has announced sales prices and marketing plans in France for several BEV models. The tables below compare the technical characteristics and announced sales prices for each BEV with its ICE counterpart. Where data was not provided by the manufacturer, we include our estimates that are explained under each relevant section of this paper.

Renault's BEV models will be sold in France with a monthly battery lease option. This contrasts with many other commercially available BEVs which are priced inclusive of the battery. This is a significant difference since battery costs are still quite high. The International Energy Agency recently estimated (IEA, 2011) that near-term (before 2020) high-volume production costs for lithium-ion automotive battery packs for electric vehicles could be as low as US$500/kWh. At this cost, the upfront costs for the battery packs for these models would be approximately US$11000 (€7700). Renault battery lease options range upwards in price for shorter car lease periods and greater yearly travel distances. We have matched battery lease prices to the yearly travel distances selected for each vehicle assuming a 36 month lease.

Table 1. Vehicle Characteristics: 4-Door sedan


	Diesel Fluence Expression dCi 90	Battery Electric Fluence Z.E.
Length	4618	4748 mm
Width	1809 mm	1813 mm
Max. engine power	66 kW	70 kW
Max. Torque	220 Nm	226 Nm
Top speed	180 km/hr	135 km/hr
Seats	5	5
Doors	4	4
Weight	1280 kg	1543 kg
Trunk volume	530 l	317 l
Transmission	Manual	Automatic
Range (NEDC)	1364 km	185km*
Fuel Tank	60 l	
Battery		22 kWh Li-ion
Fuel consumption	4.5 l/100km (22.2km/l)	
Electricity consumption		13 kWh/100km (7.7 km/kWh)*
TTW CO2 emissions (WTW)	115 g CO2/km (142 g CO2/km)	variable depending on electricity source
Sales price, no subsidy (+19.6% sales tax)	€20 300	€26 300
Battery Rental		€82/month (36 months, up to 15000 km/yr)

Table 2. Vehicle Characteristics: 5-door compact


Selected Model	Diesel Clio Authentique 5P dCi 75 eco2	Battery Electric Zoe Z.E.
Length	4027 mm	4086 mm
Width	1720 mm	1540 mm
Max. engine power	55 kW	60 kW
Max. Torque	n/c	222 Nm
Top speed	165 km/hr	135 km/hr
Seats	5	5
Doors	5	5
Weight	1175 kg	1392 kg
Trunk volume	288 l	n/c
Transmission	Manual	n/c
Range (NEDC)	1375 km	200 km*
Fuel Tank	55 l	
Battery		22kWh
Fuel consumption	4 l/100 km (25km/l)	
Electricity consumption		n/c (estimate:11 kWh/100km or 9 km/kWh)*
TTW CO2 emissions (WTW)	106 g /km (126 gCO2/km)	variable depending on electricity source
Sales price, no subsidy (+19.6% sales tax)	€16 000	€20 700
Battery Rental		€79/month (36 months, up to 15 000km/yr)

Table 3. Vehicle Characteristics: 2-seat light commercial vehicle

	Diesel Kangoo Gd Volume Confort - dCi 85	Battery Electric Kangoo Maxi Z.E.
Length	4597 mm	4597 mm
Width	2133 mm	2133 mm
Max. engine power	63 kW	44 kW
Max. Torque	200 kW	226 Nm
Top speed	158 km/hr	130 km/hr
Seats	2	2
Carrying capacity (weight)	800 kg	650 kg
Carrying capacity (volume)	4.6 m^3	4.0-4.6 m^3
Transmission	Manual	Automatic
Range (NEDC)	1132 km	170 km
Fuel Tank	60 l	
Battery		22 kWh Li-ion
Fuel consumption	5.3 l/100 km (18.9 km/l)	
Electricity consumption		16.5 kWh/100km (6.1 km/kWh)*
TTW CO2 emissions (WTW)	140 g/km (167 gCO2/km)	variable depending on electricity source
Sales price, no subsidy (+19.6% sales tax)	€16 400	€21 200
Battery Rental		€89/month (36 months, from 20 000 to 25 000 km/yr)

* Range and electricity consumption estimates are for NEDC test cycle, actual range may deviate according to driving style and auxiliary electricity consumption.

Assuming typical usage levels for each model type, we calculate the extra cost of the BEV compared to the ICE from both consumer and societal perspectives. For consumers, we also provide an estimate of the added cost of a BEV over the first three years of ownership, arguably in line with consumer calculations when purchasing a new vehicle. All future costs are expressed as their net current value using a social discount rate of 4%. Consumer costs represent the total cost of ownership including purchase and operational costs[6], taxes and subsidies and exclude CO_2 and local pollution costs.

We define societal costs to cover ownership and operation costs exclusive of taxes (which from this point of view are simply a transfer), and include the subsidy, CO_2 and local pollution costs. For BEVs, we do not include costs for public charging infrastructure which may be substantial as discussed further on. Our definition of societal costs is limited in that it only looks at the first-order societal costs deriving from a decision to purchase and operate a BEV instead of an ICE. This provides an incomplete picture of the total cost or benefit to society resulting from the BEV purchase decision. A full accounting of social costs and benefits would include energy security impacts. As noted earlier, one putative impact from BEV uptake is the reduction of fossil energy import bills and the knock-on effects this may have on productivity and exposure to oil price volatility. We do not address this impact here[7] though we note there is uncertainty on both the amplitude

6 Excluding insurance since this should normally cost the same for BEVs and ICEs (though in practice, some insurers in France offer promotional differentiated rates – discussed further on).

7 See (Cassen, et al. 2009) for a more complete discussion.

and the sign of the impact if renewable energy remains more expensive and nuclear energy becomes scarcer in response to public concerns.

High rates of BEV uptake also impact government revenue streams and this may have an incidence on societal cost of BEVs insofar as some revenue streams cost more to collect than others (see Box 1).

Our baseline calculations do not assign a cost to CO_2 emissions as there is no common agreed cost for these in France or Europe (outside of the European Trading System which, in the present case, only covers emissions from electricity production in Europe and not emissions from ICEs). However, we do determine the per-vehicle impact on lifetime CO_2 emissions including upstream emissions associated with electricity generation and fossil fuel extraction and processing. These can then be used to test the sensitivity of our findings to different CO_2 price scenarios. We also use these to derive an indicative societal cost and government cost per tonne of CO_2 reduced by the BEV.

2.1. Ownership costs

We use the advertised ex-subsidy prices for all vehicles (as of April 2012). Advertised prices do not represent manufacturer costs but we assume that they are close enough to serve as a reasonable proxy given the competitive nature of the auto industry. However, it may very well be that manufacturers choose to endure losses on a new technology in order to gain a longer-term competitive foothold in the market. We do not exclude that may be the case here which would mean that our cost figures may underestimate current BEV costs. BEV prices include a 19.6% sales tax (VAT) which is also levied on the equivalent ICE models. As such, our findings would overestimate BEV ownership costs where jurisdictions exempt BEVs from VAT.

We further assume that Renault's business model completely separates battery costs from vehicle costs. In other words, the BEV price includes no cross-subsidy covering a portion of the battery cost. This is a contestable assumption given the high costs for batteries, but we have no evidence that this is the not case for the vehicles in our analysis. We note that if the battery lease represents the full present value of the battery pack, then the electric vehicles examined here have slightly higher battery costs than the IEA near-term costs (US$500 kWh) cited above. The net present value of 15 years of battery lease payments is €10 940 and €10 540, respectively, for the sedan and compact models. These models have 22kWh batteries and thus the per kilowatt hour battery cost for the BEV sedan and compact models are around €480-€495/kWh (US$ 630-650/kWh).

Box 1: Impacts of BEVs on public coffers: evidence from input-output modelling in France

High rates of BEV uptake are likely to have an impact on government revenue streams. (Leurent & Windisch, 2012) undertake an economy-wide input-output analysis for the French case (high fuel and employment taxes) for a simplified compact car BEV model. Their model accounts for government revenue from VAT, social security taxes and other taxes paid on intermediate outputs and extends to upstream vehicle and fuel-related sectors of the economy.

Table 4 summarises their results. They find that government revenue impacts are significant -- government revenue over the lifetime of the vehicle are 2.5 times and 1.5 times, respectively, the purchase price of an ICE and BEV vehicle excluding purchase subsidies. This revenue stream is dominated, in the French case, by social security taxes (accounting for 71% and 79% of total government revenue for the ICE and BEV, respectively). On balance, they find that BEVs and ICEs generate roughly equivalent amounts of government revenue over their lifetime with a slight advantage for the BEV, excluding the €5 000 purchase subsidy offered in France. Accounting for the purchase subsidy significantly erodes the government revenue advantage of the BEV (-16%).

They also find qualitative differences in the government revenue streams amongst BEVs and ICEs. Fuel taxes account for 9% of lifetime government revenue from an ICE while electricity taxes only account for 1% of revenue for a BEV. This is compensated by a higher share of social security tax revenue for the BEV -- 73% versus 65% for the ICE. Insofar as fuel taxes are among the least expensive to collect, a shift away from these to more expensive taxes will impose greater costs on society, holding government revenue constant.

Table 4: **Lifetime Fiscal and Social Revenues for a "B" Class French ICE and BEV (€ per vehicle)**

	ICE		BEV	
	Manufacture	Use	Manufacture	Use
Consumer expenditure	*14600*	*17650*	*24400*	*10814*
Government revenue				
VAT	2862	4121	4782	2119
Fuel/Electricity Tax		3375		420
Production-related taxes	1002	1031	1648	618
Social security taxes	10594	12837	18505	7798
Total Revenue (no subsidy)	14457	21364	24936	10956
(combined)	***35821***		***35892***	
Total Revenue (ex subsidy)	14457	21364	18956	10956
(combined)	***35821***		***29912***	

Assumptions: French tax rates, fuel and electricity prices, ICE fuel consumption 5l/100km, BEV electricity consumption 18 kWh/100km, 15 000 km/yr both vehicles (for other assumptions, see source)
Source: (Leurent & Windisch, 2012)

From a political economy perspective, it is interesting to note that the slight government revenue advantage modeled in the ex-subsidy scenario disappears if a significant share of vehicle, battery or electricity production shifts outside of France. This helps explain the strong push to develop domestic BEV production capacity as a way of gaining early leadership position in what are hoped to be strong domestic and export markets.

Renault's battery lease is bundled with a series of other services that include guaranteed battery exchange should the battery lose 25% of its original capacity, assistance with setting up a home charging point, programmed maintenance, preferential rental rates for ICEs (for longer distance trips), on-call assistance and towing and customised on-board data connection and GPS-based services. Providing these services has a cost and so it is likely that our estimate of battery-only costs overestimates BEV versus ICE ownership costs in the case that such services are not provided to ICE owners.

We assume that the yearly maintenance costs for BEVs will be less than their ICE counterparts given the simplicity of the electric motor and its small number of moving parts relative to a combustion engine. Finally, some insurers in France have offered differentiated promotional insurance rates in favour of BEVs. It is not clear that there is an economic justification for insurance rate differentiation and so we do not assign a difference in insurance costs between BEV and ICE models.

France has a feebate system in place ("bonus-malus") that rewards low CO_2 emitting cars and punishes higher-emitting cars. None of the ICE cars examined here qualify for a reward payment under the system's 2012 rates and the BEV subsidy payment of €5 000 covers the feebate payment for the BEVs.

2.2. Fuel use

We use fuel consumption data[8] provided by Renault for the ICE vehicles in this analysis. These are expressed in terms of litres of (diesel) fuel consumed per 100 kilometres according to the combined NEDC (New European Drive Cycle) test cycle. In reality, it is plausible that the ICE vehicles under consideration, especially if they are to be replaced by their BEV counterpart, will be driven in essentially urban conditions. As urban fuel consumption is higher (due to repeated accelerations and partial engine-load driving), using the combined NEDC fuel consumption figures will likely underestimate on-road ICE fuel consumption (and thus decrease the cost differential with BEVs). Indeed, NEDC test results do not represent "real" driving conditions and there is a gap between actual fuel use and test cycle results (with test cycles underestimating "real" fuel use by approximately 15%-25% and more in the case of hybrids) (Patterson et al, 2011), (Zachariadis, 2006). Thus, even if BEVs may display a gap in terms of "real" versus "test" electricity use per kilometre (discussed below), because the unit costs of fuel are higher, we believe that accounting for "real" driving patterns would further reduce the cost differential between BEVs and their ICE counterparts. On the other hand, increased uptake of stop-and-start technology on ICE vehicles, which can significantly reduce ICE fuel consumption in urban traffic, will increase the cost differential by disproportionately reducing ICE running costs.

2.3. Electricity use

We use NEDC test-cycle energy consumption (kWh/100km) and its corollary, energy efficiency (km/kWh) for the BEVs in question as communicated by Renault or, in the case of the ZOE[9] calculated by dividing the claimed NEDC battery range of 200km by the battery capacity of 22 kWh[10]. We do not account for electricity losses during charging (estimated to be around 10% to 15%) in calculating electricity use as we have no specific information on charging losses for the vehicles considered here and, in any case, given

8 In our actual calculations, we convert fuel consumption data to fuel efficiency data (e.g. kilometres per unit of fuel or energy) to better reflect the work accomplished (km) by each economic input (litre of fuel or kWh).

9 Renault had not at the time of this paper's release communicated homulgated energy consumption figures for the ZOE.

10 An imperfect measure of electricity consumption that doesn't account for the BEVs' regenerative braking, auxiliary electricity consumption and ~10-15% losses during recharging.

the low relative cost of electricity, the added cost is likely to be marginal. Other estimates of BEV electricity consumption indicate somewhat higher figures in the 20-25 kWh/100 km range (NEDC) for similarly-sized vehicles – discussed below. It may be that such estimates reflect typical on-road rates of electricity consumption for the current generation of battery electric vehicles.

As with ICEs, on-road BEV electricity consumption can vary, sometimes significantly, from test cycle figures[11]. While the "Tank to Wheel" efficiency of ICEs is sensitive to driving style and speed profiles, this is much less the case with BEVs whose "Battery to Wheel" efficiency is relatively constant. BEV's, however, are much more susceptible to power draws from auxiliary devices such as heating and cooling systems and other embarked powered devices (entertainment systems, on-board computers and small electric motors such as those used for windshield wipers and power windows) which are not included in test-cycle runs.

Figure 2 shows different modelled estimates of electricity consumption, including auxiliary equipment in terms of kWh per 100 kilometres for an average compact car (e.g. Volkswagen Golf) based on various published reports and sources (Helms et al., 2010). These estimates are based on second-by-second speed profiles weighted according to average German traffic levels in urban and extra-urban areas as well as on motorways. The propulsion-only energy consumption figures are higher than the NEDC cycle figures given for the BEVs examined in this paper. There are two plausible reasons for this. The first is that the results in Helms et al. are based on a composite vehicle model that necessarily simplifies (and possibly overestimates) BEV electricity consumption. The Renault vehicles, on the other hand, are purpose-built BEVs and can be considered to have been optimised for low electricity consumption. The second is that the driving profiles used in Helms, et al, are more reflective of "on-road" driving conditions and are thus not equivalent to NEDC tested figures[12,13].

Electricity consumption of auxiliary devices is a function of time, not of distance and thus driving profiles in slower traffic (e.g. urban and "stop-and-go" versus motorway speeds) display higher rates of electricity use by these devices. (Helms et al., 2010) find that modelled runs in average German traffic conditions generally consume more electricity than the modelled NEDC profile – the "real-world"-test-cycle energy consumption gap seems to exist for BEVs as well. This concurs with other reviews of on-road BEV performance[14].

---

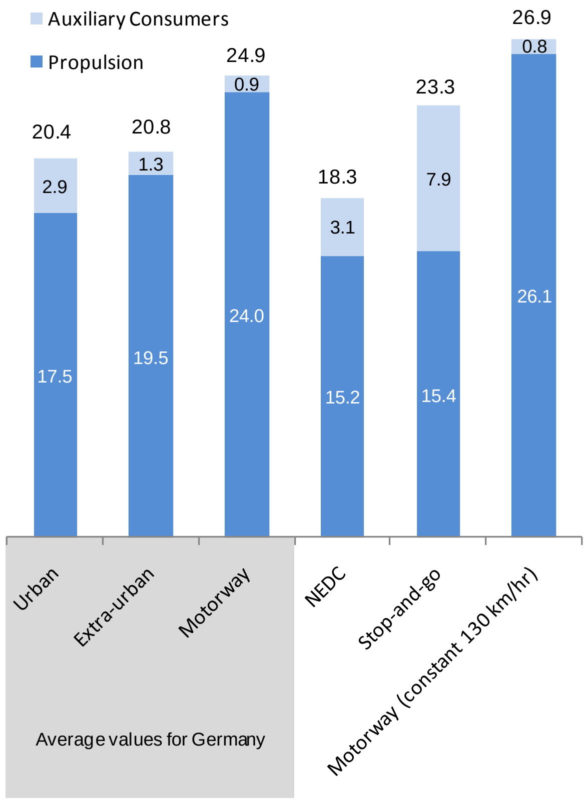
11 It is important to note that electric motors are much more efficient than combustion engines (upwards of 90% of the input energy is converted into useful work for electric motors compared to about 40% for the best diesel car engines) (Delorme, Pagerit, Sharer, & Rousseau, 2009). The cumulative efficiency of the electric motor, charging system and drivetrain for the BEV is less than that of the motor alone at around 70%.

12 The NEDC result cited by Helms *et al.* is higher than the NEDC energy consumption figures given for two of the three Renault models – but this might be explained by a sub-optimal BEV configuration used by Helms, et al as discussed above.

13 Though the relative importance of auxiliaries draw in real-life energy consumption is supported by many studies – see for example (Beeker, *et al.* 2011) for a detailed discussion.

14 See, for instance, (Beeker, et al. 2011).

Figure 2: Modelled BEV Electricity Consumption for a Compact Car in Germany (kWh/100 km)



Source: (Helms, Pehnt, Lambrecht, & Liebach, 2010).

That this gap exists is not disputed by manufacturers and some expressly caution future owners about the impacts of different factors on electricity consumption and range (though current BEV ranges seem largely sufficient for most, but not all trips – see Box 2). Among these, speed, acceleration, heating and cooling are all significant and can potentially halve the test-cycle range of vehicles as noted by Nissan (Table 5).

Table 5: Estimates of impact of auxiliary power consumption and driving conditions on BEV range (Nissan Leaf, New battery)

Use Scenario	Average speed	External temperature	Heating/cooling on?	Range
EPA LA4 test cycle	31 km/hr	20°C to 30°C	off	161 km
"Ideal" conditions (flat terrain, steady speed)	61 km/hr	20	off	222 km
Suburban driving, temperate climate	39 km/hr	22	off	169 km
Highway driving, summer	89 km/hr	35	on	113 km
Cross-town commute, hot day	79 km/hr	43	on	109 km
Urban congested stop-and-go traffic, winter	24 km/hr	-10	on	100 km

Source: Nissan - http://www.nissanusa.com/leaf-electric-car/index#/leaf-electric-car/range-disclaimer/index

Box 2: Range Perception, Performance, Requirements and Costs for Battery Electric Vehicles

Driving range is not a direct component in our calculation of BEV versus ICE costs. “Range Anxiety”, however, has been consistently cited as a barrier to BEV uptake even though current BEV ranges are generally greater than most people’s daily car travel needs (Depoorter & Assimon, 2011). Tables 1-3 show that for the vehicles we consider, ICEs significantly outperform BEVs in terms of range[15]. However, BEV costs scale upwards with range so that BEVs offering greater ranges will necessarily have higher battery costs.

The cost of batteries providing ICE-like range has traditionally been cited as one of the major barriers to the widespread uptake of BEVs. Manufacturers historically have been hesitant to produce BEVs that perform less well (in terms of range and performance) than like ICE vehicles stating that consumers would not accept lower driving ranges … at least not in sufficient numbers to justify the investment costs for the development and deployment of electric-only models. Recently however, some manufacturers have decided to bring battery electric vehicles to market in 2011-2012 under the expectation that at least some significant market segments will be receptive to these vehicles despite (or perhaps, because of) their characteristics.

(Axsen, Kurani, & Burke, 2010) suggest that official performance objectives for BEV design range may be more than what consumers expect or require in order to purchase electric vehicles -- and that the “battery problem” may indeed be largely *virtual*. They find that current official vehicle battery design objectives are overly ambitious when compared to the vehicles consumers themselves spontaneously “designed” in experiments. Though development of battery technology will of course decrease BEV costs or increase range, policymakers and manufacturers may be underestimating consumers’ willingness to buy these vehicles even before battery technology performance goals are met.

Many studies point out that most urban travel is well within the capacity of current BEV designs. However, in 2011 most consumers have no actual experience with the on-road range of BEVs which may be highly variable according to *total* electricity use during travel (not just the power used for propulsion). Consumers are not only anxious about the “official” driving range of BEVs but perhaps even more so about the “on-road” driving range which may be well below official rated estimates – especially in urban driving where travel takes longer or when on-board accessories such as cooling or heating systems are in use. Ensuring that official driving range estimates match those experienced by consumers in the early stages of BEV commercialization will go a long way towards getting consumers to accept less than ICE-like performance in terms of vehicle range and autonomy.

Given that our estimates of electricity consumption for Renault’s vehicles are for NEDC test cycle conditions, we might reasonably assume that they underestimate the real-world energy use of the BEVs in our analysis (and thus only slightly underestimate BEV ownership costs due to the relatively low cost of electricity compared to fossil fuel).

2.4. Vehicle life

We estimate that both the ICE and BEV will be operated for 15 years. We make no estimate, nor account for, the residual value of the vehicle in the second-hand market though it has been suggested that this might be higher for BEVs since electric motors are likely to wear less than internal combustion engines. High residual values might especially be the case for BEVs sold under battery swap arrangements since frequent battery renewal would mean that these vehicles would have consistently high performing battery packs.

[15] Though our assumptions regarding ICE range based on fuel tank capacity and NEDC mixed urban/motorway fuel consumption likely overestimate the real range of the ICEs considered given the gap between test cycle and “on road” fuel consumption.

2.5. Annual vehicle use

Daily and annual vehicle use is a critical component in our cost calculation since the more a BEV travels, the greater are the cumulative avoided fossil fuel costs. We assume different baseline use profiles for this analysis. Our baseline daily travel assumption for the 4-door sedan and the 5-door compact pairs are 35 and 30 kilometres a day (365 days per year) respectively (~13 000 km/yr and ~11 000 km/yr, respectively). This is roughly in line with average annual vehicle travel statistics for France (~13 000 km/yr). We assume the 5-door compact will be driven slightly less since most travel will be in urban settings. Our baseline daily travel assumption for the light commercial van is higher – 90 km/day (assuming non-weekend days only or 260 days a year) or 23 400 km/yr – in line with statistics on van use in France (Delort, 2008). For all vehicles, we assume a 1% decrease in annual travel per year.

2.6. Fuel costs

Our baseline assumption for fuel costs is based on an oil price of $90 Bbl. Is this a reasonable assumption? London Brent oil prices had traded consistently above $120 Bbl at the time of publishing this paper (April 2012) and had not dipped below $90 Bbl since December 2010. Oil price variability has been a steady feature of international energy markets in recent years and there is no evidence that this is likely to change much in the future, especially as the slow and sometimes erratic nature of the post-2008 crisis recovery continues. Nonetheless, despite variability, it is generally assumed that oil prices will increase over the next 15 years (IEA, 2010). For the purposes of our calculation, we assume that prices will increase 6% per year -- consistent with the assumption in (Prudhomme, 2010). This means that oil prices will reach $203/Bbl at the end of the life of the vehicles examined in this paper. We assume a constant Dollar/Euro parity over the lifetime of the car for convenience – this has not been the case in the past and may not be the case in the future. A weakening of the Dollar vis-à-vis the Euro would decrease lifetime fuel costs in France and would therefore increase the cost differential between the BEV and ICE, the opposite would be true in case of a strengthening of the dollar versus the Euro.

In line with (Prudhomme, 2010), citing estimates from the *Union Française de l'Industrie Pétrolière*, we assume a supplementary cost of €0.193 per litre (remaining constant over the lifetime of the vehicle) reflecting refining and distribution costs.

2.7. Fuel taxes

As of January 2011, the TICPE (taxe intérieure de consommation sur les produits énergétiques) is the principal excise tax on liquid fossil fuels in France. It is calculated per litre, not on the non-tax price of fuel. For diesel fuel the TICPE is currently set at €0.4284/litre. In addition, Regional governments in France can assess an additional tax on liquid fossil fuels up to €0.025/litre, and many do though some of the most populous regions (Ile de France, Provence-Alpes-Cote d'Azur, Rhone-Alpes) have levied a lower rate (€0.0115/litre). For our calculations, we take the lower rate. Thus our base rate for the TICPE and the Regional sur-tax is €0.4399 (for diesel fuel).

France also levies a sales tax on the post-TICPE (including the Regional component) price of fuel. This rate is currently set at 19.6%.

It is important to note that the under current fiscal structures, the replacement of an ICE by a BEV entails a loss of fuel tax revenue to the state (see Box 1). High rates of BEV penetration in vehicle fleets, all else held equal, will entail losses of government revenue that are not only important in terms of their size, but also because replacement revenue streams will likely entail higher collection costs (Van Dender & Crist, 2010).

2.8. Electricity costs

France produces relatively low-cost electricity due to a long standing energy policy in favour of nuclear power generation. Households have several choices of electricity contracts from a small set of providers dominated by Electricité de France (EDF). All of these providers offer variable rate contracts and it is thought that many households will take advantage of lower off-peak rates, especially at night, to slow-charge electric vehicles. While early results from small-scale BEV trials support the hypothesis of off-peak charging, it is not certain that this will remain the norm as BEVs are purchased by greater numbers of consumers. One reason might be that technical progress in fast-charging systems will allow BEV owners to more-or-less replicate refuelling patterns of ICEs (e.g. around 3-5 minutes at all times of day). The second reason is that BEV users may compare peak electricity prices not to off-peak prices but rather to fossil fuel prices. If this were the case, consumers might remain insensitive to peak/off-peak electricity price differences as long as these remain substantially below equivalent fossil fuel prices.

Given uncertainty on how consumers will recharge their BEVs and the applicable electricity rates, we take an average ex-tax price for electricity paid by households in France in Q1 2011 weighted by the current distribution of rates as calculated in (IEA, 2011). The ex-tax electricity price we use in our calculations is €0.088 per kWh. We further assume that this price increases 1% per year due to an expected increase in the renewable share of electricity production.

2.9. Electricity taxes

There are a number of taxes levied upon electricity use in France including VAT. These are levied on each kWh consumed or on different shares of electricity consumption depending on the tax. We do not seek to create an "average" household electricity use (including BEV charging) profile in order to calculate the relevant tax rates. Instead, we use the Q1 2011 weighted average excise and VAT tax calculated in (IEA, 2011) -- €0.0349/kWh. We assume that this tax remains constant for the lifetime of the BEV.

2.10. Cost of charging infrastructure

BEVs can be charged directly from most household electricity circuits in France and it is assumed that this will be the principal recharging mode (93% of charging points) used by BEV owners through 2020 (though we discuss in the previous section how this might not be the case if fast-recharging technology becomes widespread). Renault recommends that BEV owners install a home charging point (e.g. EVlink Wall box from Schneider Electronics at a cost of approximately €800) and that they equip themselves with a dedicated recharge cable (EVSE -- Electric Vehicle Supply Equipment cable -- €400 available from Renault). We include these in our calculations though in certain instances the home recharging point may be subsidised.

According to (Depoorter & Assimon, 2011), these home charging points are assumed to account for the majority of charging locations. The remaining 7% of charging points are projected to be public fast-charging (23 kVA) and ultra fast (43 kVA) charging points with total costs ranging from €7 000 to €55 000 per charging point. The costs for these points will be shared amongst a number of actors including local authorities, electricity companies, parking garage owners and private workplaces. On average, (Depoorter & Assimon, 2011) estimate the total cost for charging facilities to be on the order of €3 000 per BEV in 2010 declining to €2 000 per BEV in 2020.

Given uncertainties on the final cost allocation amongst the different actors involved (and whether or not value-added services linked to recharging may recoup some of these costs), we assign no cost to non-domestic BEV recharging facilities in our analysis. This likely underestimates the societal cost of the BEV and thus underestimates the gap between BEV and ICE societal costs.

2.11. Well-to-tank and tank-to-wheel CO_2 emissions for fuel cars

ICE vehicles emit CO_2 during use as opposed to BEVs (see section below). However, just as BEVs, fossil-fuel powered ICEs also have "well-to-tank" (or, more precisely "power-plant to battery") upstream emissions that should be accounted for in a like-to-like lifecycle comparison of BEVs and ICEs. The ICE models examined here are all diesel vehicles – Concawe, EUCAR and JRC-IES (Edwards et al, 2008) estimate that the extraction, production and transport of diesel fuel for use in Europe produces approximately 14.2g CO_2/MJ. Diesel fuel contains approximately 34 MJ/litre and so the corresponding upstream "well-to-tank" CO_2 emissions are approximately 482 g CO_2/litre. Diesel ICE tank-to-wheel CO_2 emissions are approximately 2600 g CO_2 per litre. These figures are reflected in the "well-to-tank" emission estimates for the 3 ICEs in Tables 1-3.

2.12. Carbon content of electricity

From a lifecycle CO_2 and pollutant perspective, BEVs are not zero-emission vehicles but rather "displaced-emission" vehicles since in most instances electricity generation entails both greenhouse gas and pollutant emissions. In France, the carbon content of average electricity production is relatively low due to the high share of nuclear power and renewables.

A key factor to consider, however, when looking at the CO_2 impacts of upstream electricity production for BEVs is the carbon intensity of marginal electricity generation, not necessarily the average or the base load generation profile. Depending on the number of BEVs in the fleet, the time of day, season of the year and the geographic location, sufficient base load electric generation capacity may or may not be available to handle additional BEV-related demand. In these cases, marginal capacity will be brought on line to handle excess demand and this can have a significant impact on overall CO_2 emissions. ADEME notes that even in France, the difference between base load carbon intensity and marginal generation can be quite high – around 80g per kWh for the former to more than 600g kWh for the latter – due mainly to reliance on oil and coal plants for marginal electricity generation(ADEME, 2009).

For electric vehicles to truly deliver lower well-to-wheel emissions, electric power generation will have to be less carbon intensive – especially where coal and oil are used to generate electricity. Put more starkly, in regions where electricity generation is coal-based (absent carbon capture and storage) and BEVs less efficient than those examined here (see for example Chinese manufacturer BYD's rating of 20.75 kWh/60 miles (approximately 100 km) – non-specified driving cycle test – for its E6 BEV), BEVs may deliver no CO_2 savings over conventional ICEs and in some cases, may even emit more CO_2 on a well-to-wheel basis (Ji, Cherry, Bechle, Wu, & Marshall, 2012) (Horst et al, 2009) (Hacker et al, 2009) (Early, Kang, An, & Green-Weiskel, 2011). Even in regions where base-load electricity generation is relatively low-carbon, high rates of peak-hour BEV and PHEV charging will come from marginal electricity generation which may very well be much more carbon intensive than the base load mix (e.g. from gas or coal rather than from nuclear). The timing of recharging will have a not insignificant impact on overall GHG emissions for BEV (and plug-in hybrid) use.

Under the EU Emissions Trading Scheme, upstream CO_2 emissions from electricity generation are capped. This means that under no scenario (e.g. high carbon electricity, low efficiency EVs) will uptake of BEVs lead to an increase in CO_2 emissions in the French case (except perhaps from non-EU battery and component manufacturing – see below). However, should BEV use of high-carbon electricity significantly increase, there could be a knock-on effect on carbon prices which would potentially entail an increase in electricity prices. This is an improbable scenario in Europe in the near to medium term given the current economic-crisis-induced oversupply of carbon emission permits and the general move to lower carbon electricity . Under all but the most extreme scenarios, it is unlikely that BEV charging would lead to significant new electricity demand by 2020-2030.

One point to keep in mind is that marginal built capacity will not necessarily be the same as marginal used capacity. Under an optimistic scenario where BEV uptake is elevated, utilities may choose to install new capacity to handle added BEV-related demand. However, the last plant built will not necessarily be the last plant brought on-line to handle time-specific BEV electricity demand. This is an important consideration when much new built capacity may be renewable (e.g. solar and wind) but the most responsive plant at a given cost may be fossil-powered (e.g. gas).

For the purposes of our analysis, we assume an average carbon content of 90 grams of CO_2 per kWh (adapting the French average carbon profile of 82g CO2/kWh upwards slightly to account for a greater share of higher CO_2 marginal power generation). For comparison, Table 6 displays different regional CO_2 intensities for electricity production by source.

Table 6: 2008 Carbon intensity of electricity production for selected country/region by source (g CO_2/kWh)

	OECD Europe	Non-OECD Europe	France	Germany	UK	Japan	USA	China
Coal/peat	826.3	953.7	856.6	826.9	919.4	910.7	901.4	899.9
Oil	534.0	576.8	547.2	588.5	457.8	573.6	651.8	574.0
Gas	329.2	289.3	267.3	278.5	379.7	438.8	390.0	434.3
Total	335.2	509.2	82.7	441.2	486.9	436.5	535.0	745.0

Source: 2008 IEA CO2 Emissions from Fuel Combustion Statistics.

2.13. Production and disposal CO_2 emissions for BEVs and ICEs

In this analysis, we do not account for vehicle and component production-related CO_2 emissions nor for those emissions related to the disposal of vehicles. A full lifecycle assessment should take these into account, especially as evidence is emerging that they can be significant and differ according to vehicle technology. Recent analysis by Ricardo and the UK Low Carbon Vehicle Partnership (Patterson et al, 2011) looking at projected vehicle technologies in 2015 highlights these points. They find that CO_2 emissions linked to vehicle disposal are minimal in all cases (1-3% of total lifecycle emissions). They also estimate that a 2015 BEV will be roughly half as carbon intensive as a mid-sized ICE over their respective lifetimes excluding CO_2 emissions linked to production. Accounting for production-related CO_2 emissions changes the picture however. They estimate production-related emissions for a mid-sized gasoline car to represent slightly less than a quarter of overall emissions (23%) and slightly more than a quarter for a mid-sized diesel (26%) though overall lifecycle emissions for these vehicles are projected to be essentially the same in 2015. For a mid-sized BEV, however, they estimate that production-related CO_2 emissions will represent nearly half (46%) of total lifecycle CO_2 emissions in 2015[16]. This suggests that ignoring production-related CO_2, emissions (as we do in our analysis) may significantly underestimate total BEV emissions – in the present case by about a quarter when integrating production-related CO2 emissions for both ICEs and BEVs[17].

16. Assuming an electricity carbon content of 500 gCO_2/kWh

17 Additionally, since a major share of CO2 emissions related to BEV production are related to battery production, replacing the battery during the vehicle lifetime will further increase BEV lifecycle intensity and erode the BEV CO_2 advantage over like ICEs.

Box 3. Seasonal Variability of Electricity Carbon Content

Yearly average figures for France show that at night from 02:00 to 08:00, approximately 4 GW in base load generation are available – largely enough to partly recharge ~ 1 million BEVs to a 40-50 km range. However, yearly averages do not serve as a good guide for specific available baseload capacity as this varies by season and is largely determined by heating needs in winter and air-conditioning needs during the summer. In France, due to a high reliance on electric heating, ADEME finds that there are only one or two hours per day during the winter where base load capacity is sufficient to meet current electricity demand (in 2007) (ADEME, 2009). This means most of the demand for vehicle re-charging outside of those time slots would draw on more carbon-intensive marginal capacity should no new baseload capacity be made available. In another example, the figure below shows how the CO_2 intensity of marginal electricity production varies by time of day and month of year if 1% of California vehicle traffic were composed of BEVs recharging during off-peak hours. More continental locations (e.g. with hotter summers and colder winters) might show different intensities even if the marginal mix were the same.

Marginal electricity CO_2 emissions by time of day and month of year in California (Scenario with BEVs representing 1% of total California VMT, Off-peak recharging, compare to well-to-tank CO2 intensity of gasoline of 346 gCO2 kWh-1 in California[18])

HR	Avg. recharging demand (Off-peak)	Average hourly marginal generation GHG emissons rate (gCO_2eq/KWh^{-1})												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
00	307	630	548	612	531	494	564	638	646	608	634	586	641	595
01	307	634	544	589	517	502	548	570	633	583	623	547	630	577
02	276	619	535	586	507	515	530	546	614	571	595	549	630	567
03	184	623	539	588	512	509	543	541	618	576	589	552	629	569
04	123	639	562	609	535	510	546	569	618	596	622	573	639	585
05	61	646	615	632	592	509	543	610	644	630	636	625	653	611
06	31	654	633	640	600	566	600	614	652	639	638	612	640	624
07	15	657	638	644	639	615	616	650	673	654	656	640	641	644
08	15	665	642	661	644	631	651	667	684	672	654	654	652	657
09	46	665	648	653	650	657	667	682	679	679	655	659	660	663
10	77	654	648	661	661	677	681	684	692	673	674	666	662	670
11	77	658	649	665	670	676	681	707	715	694	667	659	664	676
12	77	658	651	658	667	678	687	714	721	710	658	659	663	677
13	77	658	654	658	667	675	685	721	743	699	672	656	652	679
14	77	655	643	660	661	685	688	745	742	691	675	656	658	680
15	31	648	645	669	658	676	690	750	721	712	681	659	654	680
16	15	657	646	653	652	678	683	732	736	699	671	663	658	678
17	15	687	680	656	658	673	679	710	774	704	669	669	671	686
18	61	687	680	666	660	665	668	696	725	699	680	669	685	682
19	123	678	667	670	671	686	679	693	704	705	675	664	672	681
20	184	673	662	660	662	681	687	675	695	683	670	656	666	673
21	276	660	660	662	659	670	681	687	693	680	656	647	664	668
22	307	654	629	636	627	600	695	660	666	663	654	634	661	648
23	307	647	576	625	555	510	590	658	659	645	632	632	648	615
Demand-weighted avg.		647	601	629	590	580	617	639	665	640	640	613	650	626

Source*:* (McCarthy & Yang, 2009).

2.14. CO_2 price

Human-induced climate change impacts will likely be costly but their scope and scale is uncertain as are specific climate change cost projections. This makes assigning a specific social cost to anthropogenic CO_2 emissions challenging. The cost of credits in the EU ETS can serve as a proxy though an imperfect one at that since the cap is set in accordance with a political target (-20% by 2020) and carbon prices in the market relate

18 Though marginal off-peak electricity generation is more carbon-intensive than gasoline in California, the much higher efficiency of electric drivetrains vs. ICEs more than makes up for the difference in fuel carbon intensity and BEVs under this scenario still emit less CO2 than their ICE and hybrid equivalents.

more to bounded scarcity rather than damage costs. In France, semi-official CO_2 social cost estimates have been made in two reports (the "Boiteux" report and the "Quinet" report) (Depoorter & Assimon, 2011). They both assign a cost of 32€/tonne in 2010. The Quinet report estimates this cost to rise by 5.8% per year through 2030 slowing to 4% per year thereafter.

In our baseline case, we do not assign a price to CO_2 emissions, preferring, as in (Prudhomme, 2010) to calculate the absolute change in CO_2 emissions resulting from BEV over ICE use. However, the CO_2 cost estimates described above can be used for sensitivity testing.

2.15. Local pollution costs

We assume local pollution costs to be €0.01 per kilometre, as does (Prudhomme, 2010), declining by about 4.5% per year to account for technical progress in reducing tailpipe emissions. This figure, adapted from an official French government commission report (the Boiteux commission) is for private cars in non-dense urban areas. It also is an average estimate of the external costs of air pollution – for both petrol and diesel cars. We expect that much BEV driving will take place in urban areas and especially in some of the larger, denser urban areas. We also expect that the specific external costs related to pollution from diesel cars (linked to NOx and particulate matter emissions) will be slightly higher than average French figures (which include both petrol and diesel cars) and that real-world emissions of these substances will also be higher than those predicted by test-cycle runs. For these reasons, our figures for the external pollution costs of ICEs might underestimate actual costs and thus lead to an higher cost differential between BEVs and ICEs than might actually exist.

Table 7 summarises the values of the parameters used in our baseline case.

Table 7: Value of parameters used in baseline case

	4-Door Sedan	5-Door Compact	2-Seat Light Commercial Vehicle
Both Vehicles			
Vehicle life in years	15	15	15
Discount rate	4%	4%	4%
Car travel (km per workday)	35	30	90
Days use per year	365	365	260
Car travel (km/yr)	12775	10950	23400
Yearly decline in car travel in percent per year	1%	1%	1%
Internal Combustion Engine Vehicle (ICE)			
Purchase cost in €	20500	15800	16400
Fuel efficiency in km/litre (litre/100km)	22.22 (4.5)	25.0 (4.0)	18.9 (5.3)
Oil price in $/barrel	90	90	90
Oil price change in %/year)	6%	6%	6%
Fuel excise tax in €/lit	0.4399	0.4399	0.4399
Change in fuel tax (%/year)	0%	0%	0%
VAT on fuel	19.6%	19.6%	19.6%
Other fuel costs in €/lit	0.193	0.193	0.193
Change in local pollution costs (%/yr)	-4%	-4%	-4%
Local pollution costs in €/km	0.006	0.006	0.006
Lifecycle CO_2 emissions for diesel fuel in kg/lit	3.1	3.1	3.1
WTW* grams CO_2 per km	142	126	167
Battery Electric Vehicle (BEV)			
Purchase cost in € (w/out subsidy)	26300	20700	21200
Battery rental in €/yr	984	948	1068
BEV subsidy in €	5000	5000	5000
BEV domestic wall charger in €	800	800	800
BEV recharge cable in €	400	400	400
Electricity efficiency in km/kWh (kWh/100km)	7.7 (13)	9 (11)	6.1 (16.5)
Electricity price in €/kWh	0.088	0.088	0.088
Change in electricity price	1%	1%	1%
Electricity Tax (€ per kWh)	0.03	0.03	0.03
CO_2 content of electricity in g/kWh	90	90	90
WTW* BEV grams CO_2 per km	12	10	15

* "Well-to-wheel"

3. Results:

As can be seen in Table 8, under our baseline assumptions including low carbon electricity typical of France, the BEV configurations examined here emit approximately 18 to 50 tonnes less CO_2 than their ICE counterparts over their lifetime. However, they cost society €7 000 to €12 000 more than their ICE equivalent. For the sedan and compact models, this amounts to a marginal abatement cost of approximately €500 to €700 per tonne of CO_2, which is at the high end of the range of costs of measures to reduce CO_2 emissions in the transport sector. The compact van, largely because of higher travel volumes (and thus avoided fuel costs), represents a better deal all round and displays much lower marginal abatement costs.

Table 8: Results of baseline case for three BEV-ICE pairs

4-door Sedan											
Km/day, 365 days	**35**										
Km/yr (new)	**12775**										
Fluence ZE (electric) 12g CO2/km	Purchase cost (€) w/ subsidy	Battery cost (€82/month)	Electricity cost (€)	Electricity taxes (€)	Electric vehicle subsidy (€)	CO_2 intensity Electricity (g/kWh)	**Total lifetime useage cost (€)**	**Additional consumer cost (veh. life)**	***Additional consumer cost (3 yrs)****	**Additional societal cost (veh. life)**	**CO_2 reduction (Tonnes)**
	21300	10940	1622	605	5000	90	**35668**	**4388**	***2889***	**12240**	**23.4**
Fluence dCi 90 (diesel) 141.57g CO2/km	Purchase cost (€)	Oil cost of fuel (€)	Other fuel costs (€)	Fuel taxes (€)	Additional repair cost (€)	Local pollution costs (€)					**Cost per Tonne CO_2 reduced (€/t)**
	20500	4751	1159	4091	778	634	**31280**				**524**
5-door Compact											
Km/day, 365 days	**30**										
Km/yr (new)	**10950**										
Zoe ZE (electric) 10g CO2/km	Purchase cost (€) w/ subsidy	Battery cost (€79/month)	Electricity cost (€)	Electricity taxes (€)	Electric vehicle subsidy (€)	CO_2 intensity Electricity (g/kWh)	**Total lifetime useage cost (€)**	**Additional consumer cost (veh. life)**	***Additional consumer cost (3 yrs)****	**Additional societal cost (veh. life)**	**CO_2 reduction (Tonnes)**
	15700	10540	1190	444	5000	90	**29074**	**4875**	***2265***	**12005**	**17.9**
Clio dCi 75 eco2 (diesel) 125.84g CO2/km	Purchase cost (€)	Oil cost of fuel (€)	Other fuel costs (€)	Fuel taxes (€)	Additional repair cost (€)	Local pollution costs (€)					**Cost per Tonne CO_2 reduced (€/t)**
	15800	3620	883	3117	778	543	**24199**				**673**
2-seat Compact Van											
Km/day, 260 days	**90**										
Km/yr (new)	**23400**										
Kangoo Maxi Z.E. 15g CO2/km	Purchase cost (€) w/ subsidy	Battery cost (€75/month)	Electricity cost (€)	Electricity taxes (€)	Electric vehicle subsidy (€)	CO_2 intensity Electricity (g/kWh)	**Total lifetime useage cost (€)**	**Additional consumer cost (veh. life)**	***Additional consumer cost (3 yrs)****	**Additional societal cost (veh. life)**	**CO_2 reduction (Tonnes)**
	16200	11874	3807	1420	5000	90	**34501**	**-4254**	***322***	**6992**	**50.0**
Kangoo Maxi - dCi 85 (diesel) 166.738g CO2/km	Purchase cost (€)	Oil cost of fuel (€)	Other fuel costs (€)	Fuel taxes (€)	Additional repair cost (€)	Local pollution costs (€)					**Cost per Tonne CO_2 reduced (€/t)**
	16400	10249	2501	8827	778	1161	**38755**				**140**

Source: ITF analysis based on data from Renault, ITF, IEA.

Results are more nuanced for consumers. A consumer will pay between €4000 and €5000 more for a BEV over the vehicles' lifetimes in the case of a sedan or a compact car. But a BEV van in our base case scenario will cost the user approximately €4000 less than an equivalent ICE over the lifetime of the vehicle, or nearly the same as an ICE equivalent over the three-year consumer payback period (for the reasons mentioned above). Under these conditions, one might expect that a market already exists for BEV vans if potential buyers have confidence in the advertised driving ranges and dealer support for these vehicles. Even without the €5000 subsidy, a BEV light van user in our base case would only pay €750 more over the lifetime of the vehicle – calling into question the need to subsidise BEVs where a good business case already exists.

A niche market also likely exists for "early adopters" of green technology who are willing to pay more for a BEV sedan or compact car with less potential range than a comparable ICE. This may be especially the case for those who value the dynamic driving style of the vehicles examined here. However, it seems that the additional cost of BEVs will remain an important barrier to general market penetration in the passenger car market. This may be especially true if consumers' interest in BEVs declines as ICE fuel efficiency increases as recent survey evidence suggests (Giffi, Vitale, Drew, Kuboshima, & Sase, 2011).

We have made many, sometimes contestable, assumptions regarding certain variables in our baseline analysis. In Table 9, we test the sensitivity of our baseline results to changes in those variables. These findings suggest that costs for BEVs remain high for consumers and even more so for society under most typical use scenarios.

Table 9: Sensitivity tests of various parameter changes (compact 5-door BEV)

	Excess lifetime consumer cost of BEV, €	Excess lifetime societal cost of BEV, €	Lifetime CO_2 reduced, tonnes	Cost per tonne CO_2 reduced €/tonne
5-door compact BEV				
Baseline	4 880	12 000	18	673
Private discount rate 8%	4 100	10 710	18	600
ICE purchase price +20% (a)	1 720	8 850	18	470
BEV purchase price -20% (b)	740	7 870	18	440
Both of above (a+b)	-2 430	4 710	18	260
Battery cost -30% (c)	1 710	8 840	18	500
All of above (a+b+c)	-5 590	1 540	18	86
ICE maintenance costs €300 more than BEV	2 320	9 450	18	530
Oil price $120 Bbl	3 430	10 800	18	600
Oil price $70 Bbl	5 840	12 810	18	720
Oil price + 12%/yr	2 600	10 100	18	570
Fuel taxes + 5%/yr	3 970	12 000	18	670
Electricity price + 5%/yr	5 220	12 360	18	690
"Revenue neutral" electricity taxation	7 540	12 000	18	670
BEV efficiency +30%	4 500	11 730	18	650
ICE efficiency +50%	7 410	13 500	11	1 180
Both of above	7 030	13 230	12	1 120
CO2 content of electricity = EU Gas	4 880	12 000	14	860
CO2 content of electricity = EU Coal	7 880	12 000	6	1 960
120 km/day, 260 days/yr	-6 200	4 870	50	100
4-door sedan				
Baseline (35 km/day)	4 390	12 240	23	524
BEV "Taxi" profile (150km/day, 312 days/yr)	-16 320	-870	86	-10

We also find our results to be robust to most variable changes though we find that different assumptions regarding certain key variables will either strongly attenuate the consumer cost of BEVs or even make them more competitive than ICEs. This is much less the case when looking at social costs. We also highlight the impact of some variables on CO_2 emissions and on CO_2 abatement costs.

Changing the discount rate from the social rate in our baseline case to one more in line with private decision making has little impact on our final results. Changing the ex-battery vehicle costs much more so, especially if we assume a strong reduction in BEV costs. Should BEV production volumes deliver significant economies of scale, BEVs could become much more cost competitive with like ICEs. Several recent studies underscore the potential for BEVs to close the cost of ownership gap with like ICEs over time.

France (Matheu, 2009)	2010: BEVs €0.16/km more costly than ICE	2020: BEVs €0.06/km more costly than ICE
France (Beeker, Bryden, Buba, Le Moign, von Pechmann, & Hossié, 2011)	2010: BEV total cost of ownership €12 000 than ICE	2020: BEV total cost of ownership €1 000 than ICE
EU (CE Delft, 2011)	2010: BEV total cost of ownership 60% more than ICE	2030: BEV total cost of ownership 20% more than ICE

One conceivable scenario is that ICE costs increase (due to costly fuel-saving technology) while BEV costs decrease (due to mass production). In that scenario, holding all else equal, consumers would already benefit more from a BEV than an ICE under our other baseline assumptions. If battery costs were also to reduce by 30% at the same time, then the BEV's lifetime cost to society would drop to about €1 700 – still a cost – but a relatively small one compared to our baseline assumptions. Under the latter scenario (decreasing BEV and battery costs, increasing ICE costs), a consumer would save approximately €5500 over the lifetime of the BEV and the marginal CO_2 abatement costs drop to nearly €100 per tonne. Removing the €5 000 subsidy under this scenario would still result in savings for BEV owners.

Evidence from the European car fleet indicates that, contrary to what had been predicted, decreasing ICE CO_2 emission levels have been accompanied by decreasing, rather than increasing ICE vehicle costs in real terms (European Federation for Transport and the Environment, 2011). While technology costs linked to regulatory compliance are but one element contributing to the total cost of a vehicle, the fact that significant decreases in CO_2 emissions have not caused car prices to increase may mean that the cost gap between ICEs and BEVs will not close as much as many have thought by 2020 and beyond.

We assume that an ICE vehicle costs €70 more a year to maintain than a BEV in line with (Prudhomme, 2010). Others studies assume much higher ICE to BEV maintenance cost differentials in the order of €300-€400 in favour of BEVs (Beeker, Bryden, Buba, Le Moign, von Pechmann, & Hossié, 2011)(Leurent & Windisch, 2012). An increase in the ICE to BEV yearly maintenance cost differential from €70 to €300 more than halves the lifetime excess consumer cost of a BEV over a like ICE.

Plausible changes in oil prices (e.g. from $90/Bbl to $120/Bbl) have a relatively small impact on base case findings holding all else equal. One point to keep in mind is that the impact of oil prices on comparative costs will evolve as relative efficiencies improve. (Douglas & Stewart, 2011) investigate the evolution of the total cost of ownership for a range of ICE, hybrids and BEV vehicles from 2010 to 2030. They find that as fuel efficiency increases for ICEs (and for hybrid and plug-in hybrid combustion engines), the impact of changes in oil price diminishes since fuel contributes less to the total cost of ownership of these vehicles over time. Another point to keep in mind is that in regions with low fossil fuel taxes, the lifetime consumer cost differential between like ICE and BEV cars will be more than we have calculated here in favour of the ICE car.

As noted earlier, ICE replacement by BEVs will entail a loss in government revenue, including fuel tax revenue, that can be significant should BEVs penetrate the car fleet in sufficiently high numbers (Van Dender & Crist, 2010). For illustration, (Prudhomme, 2010) estimates that if BEVs represented 10% of 2011 car sales in France this would imply a tax loss of €0.7 billion. This drop in revenue, at least in France, could conceivably be counterbalanced by an increase in other taxes related to BEV and electricity production (if production remains in France) but if those revenue streams are hypothecated (as they are for social security taxes), one might expect a drop in “flexible” forms of revenue (Leurent & Windisch, 2012). If we adjust electricity taxes upwards to make up for the loss of fuel tax revenue in the case of BEVs replacing ICEs (the “revenue-neutral” electricity tax case in Table 7 resulting in a ~600% increase to a tax rate of €0.24/kWh), the BEV becomes much less desirable to consumers than in our base case.

Changes in the energy efficiency of either BEVs or ICEs do not significantly change the outcome of our base case findings. We also model a case where ICE efficiency improvements outstrip those of BEVs. This is a plausible scenario since technology trajectories would likely benefit ICEs over BEVs in terms of energy efficiency gains (excluding upstream efficiency gains). In other words, it is likely that ICEs will experience stronger improvements in fuel efficiency than BEVs will experience in electric efficiency (albeit from an already high level). These combined efficiency trajectories increase the extra lifetime costs of A BEV over an ICE from our base case.

Most regions do not have as much low-carbon base load or marginal electricity generation capacity as France. Taking a value of 330g CO_2/kWh, more consistent with OECD-EU natural gas plants, and a more extreme value of 825 g CO_2/kWh (typical of an OECD-EU coal plant) we find that higher carbon electricity considerably diminishes the CO_2 reduction impact of replacing a ICE with a BEV (without necessarily switching the balance such that a BEV produces more lifecycle CO_2 than an ICE[19]). Under the assumption that all other costs remain the same, the use of higher carbon electricity significantly increases BEV marginal CO2 abatement costs – in the case of coal-generated electricity, by a factor of three over our baseline scenario.

In many regions considering the deployment of BEVs coal-based electricity generation is the norm. The rationale for subsidising or otherwise promoting EVs in these instances cannot be principally for direct CO_2 mitigation but rather for developing a market for electric vehicles in anticipation of the development of low carbon electricity production. As noted earlier, however, in Europe, where there is a CO_2 emissions permit trading system, any excess emissions from generating electricity for cars will be offset by reductions in emissions from other plants subject to emissions trading.

Different levels of vehicle taxation could also have an impact on our findings. Denmark, for instance, taxes vehicles at much higher rates than France and this has

---

19 These findings reflect the purpose-built efficient BEVs under consideration in this analysis. Less efficient BEVs (starting at 20% less efficient – 6.16 km/kWh or 16.2 kWh/100km – emit more CO_2 than their ICE counterparts when powered by electricity from OECD-EU coal plants. In the latter and other analogous cases (e.g. lower BEV efficiency or more carbon intensive electricity), society would actually pay more for additional CO_2 emissions (absent CO2 emission trading).

been one reason the country has attracted interest as an electric car test-bed since electric cars have been granted a temporary exemption from registration and annual environmental taxes (currently through 2015). Using the Danish vehicle tax base, assuming that the pre-tax costs for both ICE and BEV 5-door compact cars are the same as in France (in fact, they are likely to be higher), a battery rental cost of €94[20] per month, and adjusting other parameters to reflect the Danish case (see Table 10), we find that a Danish BEV owner would save €3 380 over the lifetime of the vehicle compared to a like ICE. In Denmark, the BEV is a much more attractive prospect for consumers as compared to France.

However, backing out taxes (fuel, electricity, VAT and car registration taxes) and adding external pollution costs, we find that the cost to society of the BEV (€15 200) is still greater than a like ICE (and higher than the French case, largely due to more expensive electricity).

In the Danish case, BEV owners will be offered the option to subscribe to "Project Better Place"s network of quick-swap battery stations (though only for the 4-door sedan model at present, not the smaller compact car we discuss here). Quick-swap stations are expensive to build but will allow consumers to exchange batteries in essentially the same amount of time as filling an ICE car's petrol tank. "Project Better Place" has announced various price levels for battery quick-change subscriptions depending on the number of kilometres travelled per year. For a vehicle travelling 10 000 kilometres per year, the "Better Place" battery subscription is set at Kr 1 495 (€201) per month[21] to which a one-time cost for a home-charging point should be added (Kr 9 995, or € 1 344)[22]. This battery cost is 2.5 times the advertised battery leasing cost in France and has a substantial impact on the lifetime cost comparison between the BEV and ICE rendering the BEV much more expensive to the owner than the like ICE and very much more expensive for society under our assumptions[23].

---

20 Advertised battery rental rates for the 5-door compact are 699 Kr/month for a 36 month, 12 500 km per year package.

21 For a Renault Fluence -- better Place Denmark currently does not include the Renault ZOE. The price of a quick-drop subscription for the smaller 5-Door compact ICE might be marginally less as is the case for the price difference between the Zoe and Fluence monthly battery leases announced for the French market. For our cost calculations of the "Better Place" case, we assume that home charging represents one quarter of the BEV electricity needs, the remainder is included in the quick-swap subscription.

22 Both inclusive of 25% sales tax

23 For the Danish case we have outlined here, holding all else equal, a monthly battery leasing cost of about €110 would just about eliminate any lifetime cost difference between the BEV and ICE alternatives from the consumer's perspective.

Table 10: "High Vehicle Taxation" case – Denmark (compact 5-door BEV)

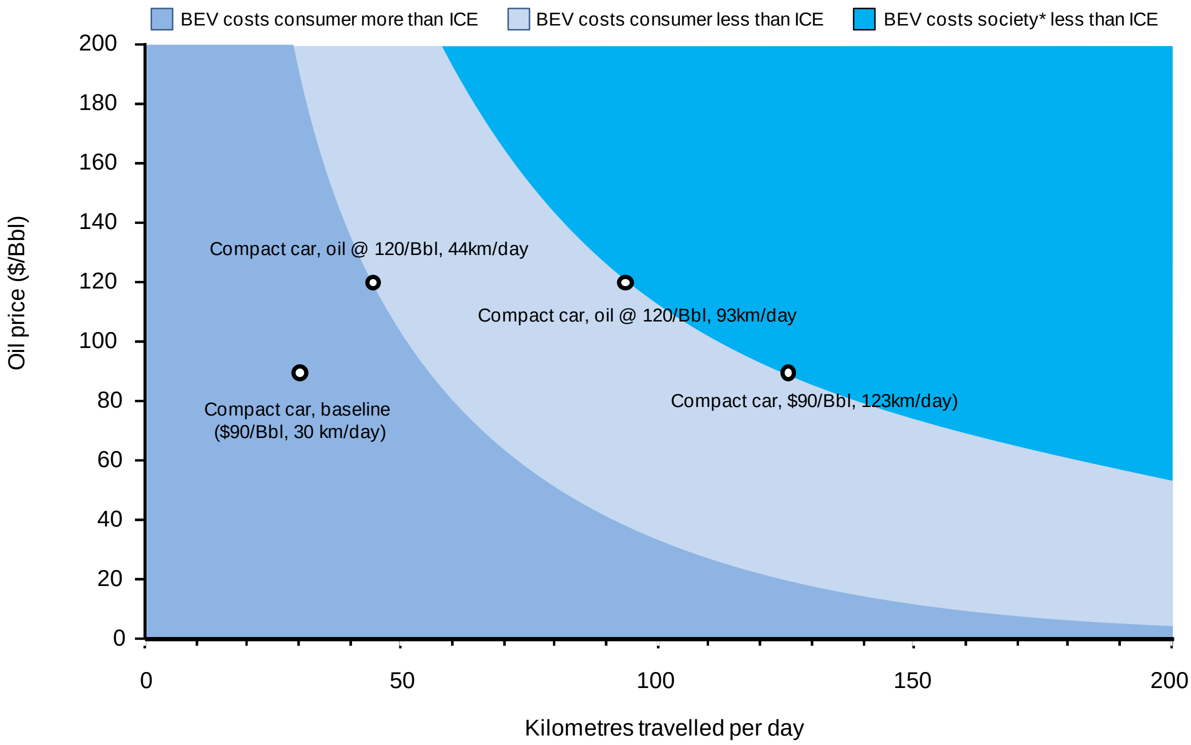
Danish "High-taxation case" 5-Door Compact car (30 km/day, 10 950 km/yr)	ICE	BEV
Danish variables		
Vehicle price with registration taxes[24] and VAT	€31 200	€21 653
VAT	25%	25%
Fuel excise tax (€/lt)	€0.5933	n/a
Annual car tax "(€)	€178	n/a
Electricity price (€/kWh)	n/a	€0.1183
Electricity tax (€/kWh)	n/a	€0.1439
Battery lease (€/month)	n/a	€94
Home charging point, (€, incl. VAT)		€1 344
"Better Place" Quick Change battery subscription, 10k km/yr (€/month, incl. VAT))		€201
CO_2 content of electricity in g/kWh		302
Findings		
WTW CO_2 reduction BEV over ICE (tons)		15
Additional consumer cost of BEV over ICE, vehicle lifetime of 15 years (€94/month battery cost)		- €3 380
Additional societal cost of BEV over ICE, vehicle lifetime of 15 years (€94/month battery cost)		€15 200
Cost per Ton CO_2 reduced BEV over ICE (€94/month battery cost)		€1 050
Additional consumer cost of BEV over ICE, vehicle lifetime of 15 years ("Better Life" subscription)		€8 320
Additional societal cost of BEV over ICE, vehicle lifetime of 15 years ("Better Life" subscription)		€28 280
Cost per Ton CO_2 reduced BEV over ICE ("Better Life" subscription)(€)		€1 950

The amount of annual travel per vehicle plays a key role in determining the comparative cost balance between BEVs and ICEs in France (and elsewhere). As seen in the case of the BEV van in Table 6, increasing annual vehicle use has a significant effect on overall costs. Similarly, increasing daily travel for the 5-door compact car reduces the cost of ownership gap significantly (see Figure 3). Holding all our baseline assumptions equal, a compact car travelling slightly more than 120 kms/day results in societal (and consumer cost savings). At an oil price of $120 Bbl, a compact car travelling 44 km/day already is an attractive option for consumers and at 90 km/day, society benefits as well[25].

24 Registration tax is 105% of the first 79k Kr of the car's taxable value and 180% of the remaining taxable value. Taxable value is equal to the ex-tax price of the car plus the 25% VAT, adjusted downwards for the presence of specific safety equipment (e.g. ABS, EPS, additional airbags) and exhaust treatment. Final tax inclusive price is further adjusted to account for low fuel consumption and seat belt alarms. (see http://www.skm.dk/tal_statistik/satser_og_beloeb/228.html)

25 In the Danish cases outlined earlier, increasing daily travel to approximately 170 km for the €94 battery lease case and 200 km for the "Better Place" case eliminates the excess societal costs of operating a BEV in place of an ICE (at 60 km per day, the excess consumer cost is eliminated in the Danish "Better Place" case).

Figure 3: Consumer and Societal Break-even Curves: Compact Diesel Car, 365 days/yr



*See Methodology section for definition of societal costs

In the bottom of Table 7, we simulate using the BEV 4-door Sedan as a taxi, travelling 150 kilometres a day (consistent with daily travel for taxis within Paris), 6 days a week. For current batteries this would require a battery switching service or access to numerous (and expensive) ultra-fast charging points, the cost of which has not been accounted for here. Ignoring the cost of charging infrastructure, the additional lifetime costs of the BEV from consumer and societal perspectives are -€16 320 and -€870, respectively – i.e. the BEV saves money in comparison to the ICE[26] for both the owner society overall. At these levels of travel, replacing an ICE with a BEV also leads to net negative marginal CO_2 abatement costs – i.e. each ton of CO_2 reduced produces net societal benefits, not costs. As in the other high-travel scenarios we examine, removing the €5000 subsidy does not nullify the consumer case for BEV use.

The sensitivity to daily travel distance underscores a clear tension in BEV roll-out. The greater a BEV travels per day, the more attractively it compares to an ICE. Yet most BEVs are currently constrained by their daily travel range – sometimes significantly so in adverse climatic and traffic conditions. Increasing range requires increasing battery capacity (or swapping the battery) which increases costs and thus erodes the attractiveness of BEVs over ICE counterparts.

It is likely that several of the parameters we have examined in this section would change concurrently – what then would be the outcome of multiple simultaneous changes along the lines of those outlined above?

---

26 Largely due to significant fuel cost savings.

If we assume that ICE vehicle costs increase 20%, BEV vehicle costs decrease 20%, battery costs decrease 30%, oil prices grow 6% per year from $120 Bbl, Fuel taxes increase by 2% year as do electricity prices, and that ICE efficiency increases 50% and BEV efficiency 30%, we find that a consumer would save about €4 520 over the lifetime of a BEV (compared to its ICE counterpart) and that society would still face an additional cost of approximately €2 030 (assuming a €5 000 purchase subsidy). The BEV would emit 12 tonnes less of CO_2 over its lifetime than its ICE counterpart at a social cost of about €174 per tonne.

How likely is this scenario? We cannot say. It would seem that some of the elements of the scenario might come about and that others are much more contestable. This uncertainty is a key element surrounding business and policy decision-making regarding electric vehicles. Making a decision with an uncertain outcome can be characterised as a gamble – one that some BEV manufacturers seem confident enough to make at present. On the other hand, overcoming uncertainty about electric car markets is a rationale for government intervention.

If manufacturers are correct in believing that they have incorporated lessons from the past and are offering a relatively mature technology to a targeted and potentially receptive market then the current generation of electric cars may surpass the limited market success of previous electric car generations. The analysis of a few limited cases that we have undertaken in this paper, however, would seem to indicate that the cost barriers for consumers are still important and that uptake of the EVs we have examined will largely, but not exclusively, be conditioned by the availability of government subsidies.

Electric vehicles already promise financial savings for certain operators without subsidies. These include fleet vehicles that have predictable daily travel patterns and can be charged on-site at night, shared car systems where charging takes place several times a day and daily vehicle travel levels are elevated, urban delivery vehicles and taxis (if range allows). In France, the government purchasing authority has coordinated the largest single commercial order of electric vehicles (18 700 units) for several State-affiliated and commercial vehicle fleets (e.g. post office, national rail operator, general government services and several large private companies including Electricité de France and various telecom operators). The rationale for subsidizing these purchases is not clear since these fleets are generally operated in conditions favourable to the use of electric vehicles and their operators have the financing capacity to make the upfront capital investments needed without assistance.

Crucially, however, we have assumed in this paper that consumers will compare BEVs to like ICEs when making purchasing decisions. This model may not hold for developing country markets (where most future vehicle sales will take place) or for many urban households (50% of the population in 2010 growing to 70% in 2050). The BEV that is bought instead of an ICE may be a two-wheeler or other small, purpose-built, low range, agile, easy-to-park and congestion-beating urban electric vehicle[27].

[27] Renault offers a small 2-passenger urban-specific electric vehicle as part of its BEV range – the "Twizzy". It has a 6.1 kWh battery, an advertised range of 100 km to 120 km (ECE-15 test cycle) and an advertised price of €6 999 (max. speed 45km/hr) to €7 690, excluding the battery (for comparison, Renault's small 4-seat car, the "Twingo", retails for €7 999). The battery lease is advertised at €50/month for a 36 month lease and 7 500 kms/yr.

How confident then are governments that the technology has progressed beyond the “hype” and that subsidies are warranted to help car-like BEVs gain traction in an evolving market? Certainly, given the wide range of subsidies, many believe this may be the case but our analysis points out that the societal costs of BEVs (limited to first-order effects) are still significant. Some commentators argue that the costs of intervention will be more than compensated by future savings (on reduced oil imports and avoided environmental costs). Others suggest that high levels of government support for electric cars diverts attention from other, possibly more cost-effective investments. Are direct purchase subsidies for electric cars a “good bet” for society? Our analysis does not conclusively answer that question but cautions that in those cases where electric cars already compare favourably to fossil-fuelled vehicles, subsidies may be superfluous and that where they do not compare favourably, the onus is on demonstrating that subsidies represent value for money.

BIBLIOGRAPHY

ADEME. (2009, August). Enjeux consommations électriques, émissions CO2 des transports électriques à l'horizon 2020-2030. Agence de l'Environnement et de la Maitrise de l'Energie.

Axsen, J., Kurani, K., & Burke, A. (2010). Are batteries ready for plug-in buyers? *Transport Policy, 10*.

Bakker, S. (2009). The car industry and the blow-out of the hydrogen hype. (U. o. Utrecht, Ed.) Utrecht, Netherlands: Innovation Studies Utrecht (ISU) Working Paper Series.

Beeker, Étienne, Alan Bryden, Johanne Buba, Caroline Le Moign, Felix von Pechmann, and Gaëlle Hossié. "La voiture de demain: carburants et électricité." Paris: Centre d'Analyse Stratégique, 2011.

Cassen, C., Hourcade, J.-C., Sassi, O., & Vogt-Schlib, A. (2009, Octobre). Electric vehicles: What economic viability and climate benefits in contrasting futures? Nogent-sur-Marne, France: Centre International de Recherche sur L'Environnement et le Développement (CIRED).

CE Delft. "Impacts of Electric Vehicles -- D4: Economic Analysis and Business Models." Delft, April 2011.

Delorme, A., Pagerit, S., Sharer, P., & Rousseau, R. (2009). Cost Benefit Analysis of Advanced Powertrains from 2010 to 2045. *EVS24 Proceedings.* Stavanger, Norway: EVS.

Delort, A. (2008, April). Les véhicules utilitaires légers en 2006. *SESP Infos Rapides #349* . France: Ministère de l'Écologie, de l'Énergie, du Développement durable, et de l'Aménagement du territoire.

Depoorter, S., & Assimon, P.-M. (2011, May). Les véhicules électriques en perspective: Analyse couts-avantages et demande potentielle. (F. Maurel, Ed.) Commissariat Général au Développement Durable.

Douglas, C., & Stewart, A. (2011, July). Influences on the Low Carbon Car Market 2020–2030. Cambridge, United Kingdom: Element Energy for the UK Low Carbon Vehicle Partnership.

Early, R., Kang, L., An, F., & Green-Weiskel, L. (2011, May). Electric Vehicles in the Context of Sustainable Development in China. The Innovation Center for Energy and Transportation (iCET), Background Paper No.9 (CSD19/2011/BP9) for the United Nations Department of Economic and Social Affairs Commission on Sustainable Development, New York, United States:

Edwards, R., Larivé, J.-F., Mahieu, V., & Rouveirolles, P. (2008). Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context, V.3. Bruxelles: CONCAWE, EUCAR, JRC-IES.

Elgowainy, A., Burnham, A., Wang, M., Molburg, J., & Rousseau, A. (2009, February). Well-to-Wheels Energy Use and Greenhouse Gas Emissions Analysis of Plug-in Hybrid Vehicles. *ANL/ESD/09-2* . Argonne, Illinois, United States of America: Argonne National Laboratory.

European Federation for Transport and the Environment. (2011, September). How Clean are Europe's Cars? An analysis of carmaker progress towards EU CO2 targets in 2010 . Brussels, Belgium.

Fenn, J., & Time, M. (2008, June). Understanding Gartner's Hype Cycles. Cambridge, MA, United States: Harvard Business Press.

Frondel, M., Ritter, N., Schmidt, C., & Vance, C. (2009, November). Economic Impacts from the Promotion of Renewable Energy Technologies – The German Experience. Bochum, Germany: Ruhr-Universität Bochum (RUB), Department of Economics.

Giffi, C., Vitale, J., Drew, M., Kuboshima, Y., & Sase, M. (2011, October). Unplugged: Electric vehicle realities versus consumer expectations. Deloitte Survey . Deloitte Touche Tohmatsu Limited.

Graus, W. (2007, August). International Comparison of Fossil Fuel Efficiency. Utrecht, Netherlands: Ecofys.

Hacker, F., Harthan, R., Matthes, F., & Zimmer, W. (2009, June). Environmental Impacts and Impact on the Electricity Market of a Large Scale Introduction of Electric Cars in Europe. *ETC/ACC Technical Paper* . Copenhagen: European Topic Centre on Air and Climate Change.

Helms, H., Pehnt, M., Lambrecht, U., & Liebach, A. (2010). Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions. *18th International Symposium Transport and Air Pollution* (pp. 113-274). Dübendorf, Switzerland: ETH-Zurich.

Horst, J., Frey, G., & Leprich, U. (2009, March). Auswirkungen von Elektroautos auf den Kraftwerkspark und die CO2-Emissionen in Deutschland. Frankfurt , Germany: WWF Deutschland.

IEA. (2009). Energy Balances of Non-OECD Member Countries - Extended Balances . Paris, France: International Energy Agency.

IEA. (2009). Energy Balances of OECD Countries - Extended Balances. Paris, France: International Energy Agency.

IEA. (2011). Energy Prices and Taxes. *Quarterly Statistics: First Quarter 2011* . Paris: International Energy Agency.

IEA. (2010, December). World Energy Outlook 2010. Paris: International Energy Agency.

Ji, S., Cherry, C. R., Bechle, M. J., Wu, Y., & Marshall, J. D. (2012). Electric Vehicles in China: Emissions and Health Impacts. *Environmental Science and Technology* , 46.

Leurent, Fabien, and Elisabeth Windisch. "Avantages et coûts du véhicule élictrique pour les finances publiques: modèle d'évaluation inégrée et application au territoire français." Congrès ATEC 2012.

Matheu, Michel. "Quelles Perspectives pour les Infrastructures de Charge?" Presentation made to the "Ecomobility" workshop organised by the Sustainable Development Chair of Ecole Polytechnique-EDF. Paris, 29 September 2009.

McCarthy, R., & Yang, C. (2009, April 2). Determining marginal electricity for near-term plug-in and fuel cell vehicle demands in California: Impacts on vehicle greenhouse gas emissions. *Journal of Power Sources* .

Michalek, J., Chester, M., Jaramillo, P., Samaras, C., Shiau, C.-S. N., & Lave, L. (2011). Valuation of plug-in vehicle life-cycle air emissions and oil displacement benefits. Proceedings of the National Academy of Sciences of the United States of America , vol. 108 (no. 40).

Patterson, J., Alexander, M., & Gurr, A. (2011, May). Preparing for a Life Cycle CO2 Measure. *RD.11/124801.4* . Ricardo, Low Carbon Vehicle Partnership.

Prudhomme, R. (2010, November). Electric Vehicles: A Tentative Economic and Environmental Evaluation. *Discussion Paper 2010-22* . Paris: France International Transport Forum - OECD Publishing.

Van Dender, K., & Crist, P. (2010, November). What does improved fuel economy cost consumers and taxpayers? Some illustrations. *2010 ITF-KOTI Joint Seminar on Green Growth in Transport* . Paris: OECD Publishing.

Voosen, P. (2009, August 18). Spain's Solar Market Crash Offers a Cautionary Tale About Feed-In Tariffs . Retrieved September 14, 2011, from New York Times online: http://nyti.ms/bmKp4C

Werber, M., Fischer, M., & Schwartz, P. (2009). Batteries: Lower cost than gasoline? *Energy Policy , 7*.

Zachariadis, T. (2006). On the baseline evolution of automobile fuel economy in Europe. *Energy Policy , 34* (14).

International Transport Forum
2 rue André Pascal
75775 Paris Cedex 16
itf.contact@oecd.org
www.internationaltransportforum.org