An electric taxi fleet charged by second use batteries: not just economic profit

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Abstract

Purpose – The road transport sector is the second biggest CO2 emissions contributor after energy generation. In urban environments, its impact is increased due to the worse combustion engine driving efficiency. It is thought that electric mobility might bring some relief to big cities' polluted air. At the same time, car manufacturers are searching for second battery applications in order to reduce its manufacture cost and make electric cars achievable for most people. This paper seeks to address these issues.

Design/methodology/approach – This study presents an economic and environmental approach of an electric taxi fleet charged with second use electric car batteries. The environment impact comes from the possible CO2 emissions reduction due to the use of electricity instead of fuel and from reusing the old electric car batteries instead of brand new ones. On the economic side, apart from the financial and consumption costs and profits, the Kyoto protocol trades permit an economic evaluation of the benefits achieved.

Findings – The results show that improvements come together with the type of electric generation technology, but it is clear that if both sectors (road transport and energy generation) are treated together, the emissions might substantially drop.

Originality/value – The originality of this article comes from taking into account two environmental issues in the project: the reuse of "old batteries" from electric cars to enlarge their useful life and the gas emissions analysis.

Keywords Electric vehicle, Battery, Li-ion, Second use, Road transport, Energy generation, Electric cells, Electric motors, Electricity

Paper type Research paper

Introduction

The automotive industrial world is slowly appreciating a change toward the electric car: the not so far to come European euro-6 emissions regulation expect such a low limit that it seems hard to achieve using the actual or even improved internal combustion motors (European Commission Regulation, 2009). The electric or hybrid vehicle is presented as an interesting alternative. But still, the two main problems for selling these vehicles are the high price (mostly due to the battery costs) and the not so long displacement range (about 200 km max) (Broussely, 2007).

In order to solve the first one, the automotive industry is searching for second uses for the already used batteries trying to have some extra revenue and decrease the initial selling price (Kley, 2011; Vilayanur and Kintner-Meyer, 2011). For the displacement range, fast 15-30 minutes charging stations are considered (Botsford and Szczepanek, 2009; Muñoa, 2012) to be the first steps to permit longer drive trips. With this mentioned time, the batteries can be charged up to an 80 percent of state of

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charge, which is, by the way, the average available charge for second use batteries (Kley, 2011).

According to the European Environment Agency (2013) road transportation is the second most important source of CO_2 emissions, just after the energy generation. Both sectors are discussed in this paper. This same agency reported that Spain has still some work to do in order to achieve the Kyoto protocol goals (European Environment Agency, 2012).

It has been thought that, an electric taxi fleet charged with second hand batteries might bring an opportunity to minimize the environmental impact of road transportation and, at the same time, give an economical return to the car manufacturers.

Methodology

It is estimated that a taxi in the city of Barcelona drives over 42,000 km per year (Carles Amat i Bertran, 2010; Zamora *et al.*, 2012). That is about 185 km per day (230 working days). Not many passenger electric cars are capable to achieve this autonomy range and less in urban driving conditions (Larminie and Lowry, 2012). Therefore, in this study it is supposed an average of 130 km autonomy before going to charge. Then, a fast charge during working hours would be needed and the following charge will be done "at home" with a slow charge mode.

The idea of a charging system for an electric taxi fleet using recovered "old" batteries comes from unifying two propositions in one project:

P1. The use of second life batteries might report some money income to the car manufacturer, which is a must considering the high prices from today (Broussely, 2007).

P2. Be able to do a fast charge with a slow charging grid installation. The 15-30 minutes charge per taxi would permit the taxis to cover the whole day work medium range of a Barcelona Taxi service with just one charge during working hours.

A taxi fast battery charge with a normal installation is achievable with a 26 second use battery system per station. Normally, a battery needs about 6 h to be charged with a 220 V charging equipment (Botsford and Szczepanek, 2009) and all second use batteries are going to be charged this way. Once a second use battery is charged it is ready to transfer all its contained energy to the taxi's battery. It gets disconnected from the grid and switches to a higher voltage (fast) discharge mode. Just two batteries are able to be transferring their energy into taxis at a time. The other 24-second use batteries are either getting slowly charged or waiting to transfer.

The calculations and optimization of the number of batteries and configuration was done with the Rockwell ARENA simulation software. There are some aspects that should be presented in order to fully understand the charging station idea:

(1) Every station has at least two charging spots.

(2) 30 minutes average is considered to be the needed time for a vehicle charge. Even if in most cases the system might do it with less than that (Botsford and Szczepanek, 2009), some spare more minutes are taken thinking on the time the

driver might spend to disconnect, enter the car and leave the station ready for next user.

(3) Then, as there are two spots per station, every 30 minutes there should be at least two ready to use charged batteries.

(4) There is a conceptual difference between the time spent waiting for a charging spot to be freed and the time waiting for a battery to be charged in a charging spot. The first one refers to the time spent by a driver while waiting for other drivers to leave a charging spot in a station and be able to plug-in, it is the queue waiting time. In the simulation it was limited to no more than 1 h and the average waiting time resulted of about ten minutes. The waiting time for a battery to be charged is the time that a taxi should wait if, when it has already entered into a free spot and plugs-in to charge, there is no second use battery ready and has to wait for it. The system is dimensioned so no time should be spent on waiting for a second use battery to be charged. There will always be a battery ready to use. That is why there are 26 and not 24 batteries per station.

(5) About 44 taxis are treated every day per charging spot. That is 88 per station.

(6) 6 h with ten minutes standard deviation is taken as the time needed for a second use battery to be charged.

(7) Taxis enter the simulation every 1 h, with a five minutes standard deviation. And after 5 h working a half of an hour deviation (due to the different driving abilities) is added before going to the closest charging station.

When the taxi driver is getting out of energy he would have to drive to the nearest and/or sooner to be freed charging station plug. The simulation was done with four stations (two of them with two charging spots (or plugs) and the other two had four charging spots because a higher trip frequency is expected). This distribution is appreciable in Table I. As Barcelona's longest distance is no more than 24 km, the four stations can be distributed so there's always the possibility to arrive to one of them when the out of energy sensor (supposed at about 15 percent of charge) is activated.

The best way to eliminate important car queues at the charging stations is to establish their entry to work at least every 1 h. Unfortunately, Barcelona's taxi shifts timetable should change again in order to permit 9 h work (pauses included) in a row no matter the incorporation hour (El Consell Metropolità, 2013).

Results

The simulation showed that each second use battery charged about 3.4 taxis per day. This means that, at the end of the year, every second use battery does more than 1,100 cycles. That is nearly its total capacity on a second use application (Neubauer *et al.*, 2012).

Table I. Station, plugs per station and second use batteries per station

Stations	No. batteries per station	Charging spots
Airport	52	4
Catalunya	26	2
Sants	52	4
Nord	26	2
Total	156	12

Therefore, all second use batteries should be removed and changed for "new" second use batteries yearly.

The cost of these second use batteries is expected to decrease along time due to its own devaluation by use degradation and because of the new battery cost reduction (Neubauer *et al.*, 2012); Cready *et al.*, 2003). For this study the different price reductions are shown in Figure 1. The second use selling and buying price is supposed from the ten year expected 0.3 ratio between new and second use batteries (Neubauer *et al.*, 2012) ($132/$440) and a 75 percent from sell/buy second use ratio ($100/$132). The monetary change is fixed at $1,294 per euros. The initial actual new battery cost is 773 per kWh (Price *et al.*, 2012).

The installation costs are considered as follows: €3,000 per simple second battery charge allocation (with a 1.5 security margin for special configuration) and €10,000 per fast charge plug (Becker, 2009).

Considering the infrastructure investments and the every year whole second use batteries replacement, the final eight year amount rises up to €4,526,491. The ideated system allows a maximum of 528 cars per day. As these drivers will work only 230 days per year, the rest of days may be filled with other owners. Therefore the total number of cars forming the taxi fleet would be 723. Dividing the more than 4.5M by the 723 taxi drivers, the repartition falls down to €7,074 per driver, so an average of €884 per year.

Continuing with the calculations, let us see how much can be saved by driving an electric vehicle instead of a diesel and if it worth the effort. The following assumptions were taken:

(1) Electricity cost: €0.1509 per kWh, 1.822443 kW per month (Gas Natural/Union fenosa & Endesa, 2013) (fixed power cost in Equation (2)).

(2) Fuel (gasoil) cost: €1.36 per l.

(3) Consumptions: 0.07 l per km for a common diesel car and 0.15 kWh/km for the EV.

(4) 75 percent driving taxes discount for the EV (Ordenança fiscal Núm. 1.2, 2013).

(5) 20 kWh battery packs for the taxi fleet and second use batteries.

(6) €6,000 government incentive for EV selling (Real decreto, 2011).

(7) €16,000 for a diesel car and €28,000 for an electric car (without subventions).

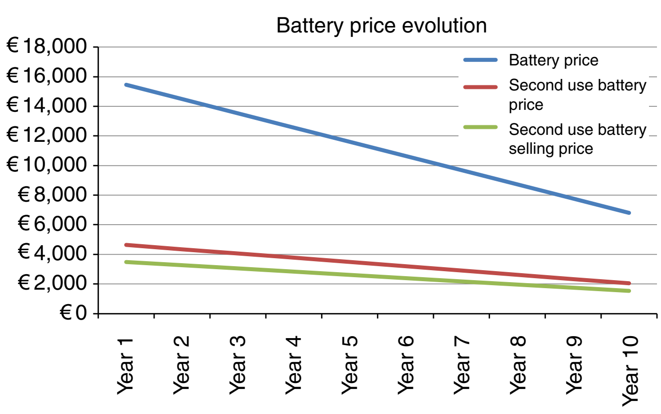

Figure 1.
New (blue), second use buying (red) and selling (green) battery prices along time

It is important not to forget the mileage warranty. In fact, the EV batteries are supposed to endure 2,000 cycles or 160,000 km (Cready *et al.*, 2003). These two limits are rapidly achieved by the taxis just after four years. Then, the driver might choose to buy a new battery or a whole new car. Meanwhile, the diesel cars are known to last for over 300,000 km without many problems, that is: twice the electric taxi. That is why, in the business calculation (Figure 2) there is an 11,609 expense from a new battery acquisition after four years, and there are two "old batteries" sold out incomes: after four and eight years providing €2,612 and €1,747, respectively.

Using the yearly consumption cost Equations (1) and (2), it is possible to know the economical differences between the two traction power possibilities:

$$\text{Diesel cost} = \text{consumption} \times \text{fuel cost}(\text{km per year}) \quad (1)$$

$$\text{Electric cost} = \text{consumption} \times \text{electricity cost}\,(\text{km per year}) + \text{fixed power cost} \times 12 \quad (2)$$

This solution gives a positive balance of €3,030 per car to the electric vehicle. Note that this calculation does not take into account the fuel and electricity price fluctuations.

To these €3,030 it has to be subtracted the annual investment amortization and there are still the d, e, f, g, and warranty issues from the calculation assumptions list to take into account which are summarized in Table II.

Three possible end-of-project results are presented (Table II and Figure 2). A 4,737 (all included) positive balance per vehicle, a too tight €378 equilibrated cost/benefit situation from not considering the selling batteries and a €−1,263 loss if no incentive is received from the Spanish government. In fact Spanish environmental and social programs are being severely reduced year after year and maybe it is better not to have many economic expectations from this side.

In the most optimistic situation, each driver gains €4,737. Considering the €43,258 coming from installation costs, car bought and new battery, it is just an 11 percent profit exercise after eight years, which means a too low 1.5 percent annual revenue. As it is, no huge investor is going to try this project out. In global, it is a €31,275,622 investment project with just a €3,424,654 profit after eight years.

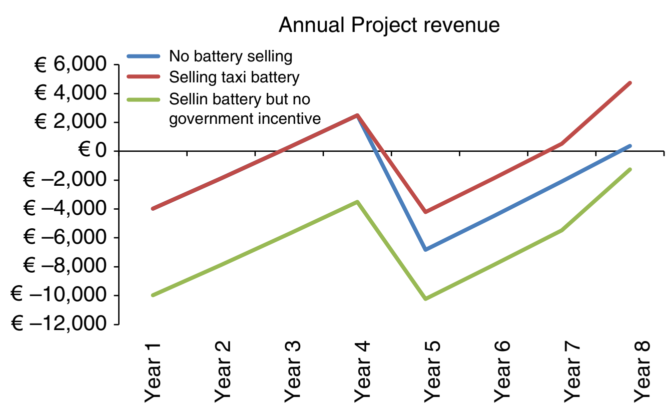

Figure 2.
Economic expectations along time

ID	Description	Year 5 (€)	Year 6 (€)	Year 7 (€)	Year 8 (€)
1	Consumption annual income	3,030	3,030	3,030	3,030
2	Plus the 75% driving taxes discount (d)	3,133	3,133	3,133	3,133
3	Minus the annual investment amortization	2,280	2,342	2,404	2,466
4	Yearly accumulated plus government incentive (ulated3 + 6,000) (f)	16,775	19,117	21,521	23,987
5	Yearly accumulated (4) minus the 12,000 initial car difference price (g)	4,775	7,117	9,521	11,987
6	Yearly accumulated (5) minus replace the 4year old car battery for a new one	−6,834	−4,492	−2,088	378
7	Yearly accumulated (6) plus selling the 4 and 8 year old car battery for 2nd use	−4,222	−1,880	524	4,737
8	Yearly accumulated (7) minus the un-assured 6,000 government incentive	−10,222	−7,880	−5,476	−1,263

Note: Points 6, 7 and 8 are the three presented results

Table II.
Final four-year economical project description

It might seem a risky business, but then, there are the environmental and health aspects that are important to look at. It should not all be just economics, which is, by the way, the best path to crush the planet.

Even if Spain has done some important investments in renewable energies and was one of the leader countries in this sector, it is still far away from achieving the Kyoto protocol goals (European Commission for Climate Actions, 2013; European Union Derivative, 2013; United Nations, 2013) and has to jump into the greenhouse gas emissions trading market to soften its evaluation results.

The prices of these gas trades change constantly and they have visibly dropped during these last years. Anyhow the Climate Brief 13 report (Valentin *et al.*, 2012) expects a soft recuperation and estimates an average buying price of €8.5/t of CO_2 equivalent gas.

The calculations of the CO_2 gas emissions were done for different cases (Figure 3): Diesel car, emissions from a common HEV hybrid car, and for a full EV (Oficina catalana del canvi climàtic, 2012). As the electric energy should come from somewhere, four scenarios were studied taking the data offered by the Spanish government (SECRETARÍA GENERAL; RED ELECTRICA DE ESPAÑA):

- the 2011 mixed composition;
- whole carbon;

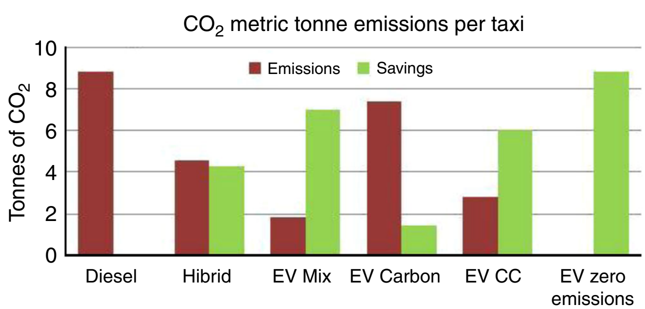

Figure 3.
Total of CO_2 ton eq. emissions and saving per taxi per year

- whole combined cycle; and
- from a zero emission generation (wind, hydraulic, solar, etc.).

A complete urban driving condition has been taken for these calculations.

Now that gas emissions and price are obtained, a simple multiplication has to be done to evaluate the direct savings the government might have from this project because of the greenhouse gas trades. The results from Table III present the eight-year use savings per car and energy source in the third column and the total project savings (including all the cars involved).

In the best condition, taking the zero emissions energy source, every car provides €580 saving to the government. That might seem not enough to ensure the business, but it still brings an idea of the intangible profits that this project might come with. Indeed this air market air approach represents a 153 percent of profits in the no battery selling assumption (six) or a 46 percent of loss reduction in the no government incentive case (eight).

Indeed, just by the fact of re-using the "old car batteries" for any project, a 25 percent reduction on the environmental impact is estimated (Cicconi *et al.*, 2012). And what about the incomes that might come for breathing a less polluted air? There are still uncountable advantages to foresee.

Discussions

The economical issues show that, for the moment, this project might not be economically self-sustained, but there are other aspect to take into account when analyzing the results. It has been proved that the environmental analysis, even if it is not a proper way to look at it, might bring some economic benefits. And in this direction, there are many other aspects; such as less air pollution, less noise in the city, etc., that will bring other unexpected benefits.

It has been also proved that the electric vehicle might be interesting going hand to hand with renewable energies, but it is much less attractive if the electric energy is taken from any other polluting source.

And even more, looking ten years forward, the lithium-based batteries are expected to cost less than half the price they do now (Cready *et al.*, 2003). That means that, all of a sudden, the project would be really profitable. The tendencies show some good future perspectives: fuel prices are rising since the last decades (US Energy Information Administration) and the difference between diesel and electricity prices might continue increasing. If the project is started now, maybe some money will be lost during the first years, but, almost everything points out that it will possibly worth a try.

If the governments are to look after its citizens, maybe this would be a good project to invest in.

Table III. Economic savings for not buying the CO_2 eq. emissions permit

Car type	Energy source	Economic saving per car (8 year) (€)	Economic savings for the project (€)
ICE	Diesel	0	0
HEV	Hybrid/gasoline	280	197,642
EV	Mix	460	325,507
Carbon	€93	65,862	
CC	€397	280,393	
Zero emissions	€580	409,475	

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