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Plug-to-wheel energy balance - Results of a two years experience behind the wheel of electric vehicles

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Abstract

In this paper, a plug-to-wheel energy balance is made of battery electrical vehicles. The study is based on real data from a two years continuous monitoring of five Peugeot iOn cars, that was performed in Belgium since June 2011, with the financing and support of Electrabel. Different driving styles, trip profiles, type and intensity of use were observed, leading to different energy patterns. The AC/DC vehicle (slow) charge efficiency and brake energy recovering are considered, as well as battery efficiency and auxiliary consumption. In particular, seasonal impacts on battery efficiency and auxiliary consumption are taken into account. This gives valuable information that cannot be obtained from theoretical, e.g. NEDC measuring conditions.

A broad range of values is obtained for the average plug-to-wheel efficiency. The resulting well-to-wheel efficiency is slightly better than the one of classical cars, but can still be significantly improved. The consumption of the auxiliaries is of particular importance in the total balance. Because of a higher impact of the auxiliary consumption, cars with a higher urban use show a globally lower plug-to-wheel efficiency. This is an important result when considering the urban trips as the primary segment for EV, and should encourage the EV manufacturers to focus on the reduction of auxiliary consumption. On a yearly basis, regenerative braking can be sufficient to compensate, and even over-compensate the plug-to-battery losses. The average battery losses are limited, even if they can be significant during the cold days.

Keywords: demonstration, efficiency, energy consumption, regenerative braking, vehicle performance

1 Introduction

The first new generation electric cars [1] were introduced in Belgium by the end of 2010. Laborelec and Electrabel have implemented an in-depth monitoring in the first available Peugeot iOn cars, with support from the Vrije Universiteit Brussel.

A dedicated monitoring system was developed, in conformity with the prescriptions of Peugeot regarding connection and consumption. Battery current, voltage and state-of-charge are monitored, as well as odometer data, instant speed, GPS coordinates and ambient temperature.
The tests were started in June 2011 and are still continuously running two years later. This initiative is the first of its kind in Belgium.

In this paper, the averaged energy balance Sankey diagram of the cars is built, based on the two first years of test.

2 Test conditions

Five Peugeot iOn cars are used continuously as personal leasing cars and/or as service or business pool cars. Some of the cars are used in the same context/by the same person since the beginning of the tests, while other cars have known a change in their attribution during the 2 years. This is detailed in Fig. 1 below.
The cars show very different consumption profiles, depending on their use [2]. Some key figures are given in Table 1 below.

Table 1: Key data of the cars

	Total distance (km)	Urban distance (%)	Extra-urban distance (%)	Highway distance (%)	Avg. consumption (kWh_{AC}/100km)
EV1	6189	72.2	25.7	2.1	18.0
EV2	23968	40.3	43.5	16.2	20.9
EV3	22174	41.5	48.2	10.3	15.5
EV4	12408	24.3	40.4	35.3	18.1
EV5	4373	55.1	34.9	10.0	18.6

3 Results

3.1 Brake energy recovering

The regenerative braking is defined here as the ratio between the in- and outgoing DC energy during the trips [3]. The values are given in Table 2 below for the 5 cars after two years of measurements.

Table 2: Regenerative braking energy of the cars

	Regenerative braking
EV1	16.9%
EV2	16.9%
EV3	16.8%
EV4	13.1%
EV5	19.3%

3.2 Auxiliary consumption

The auxiliary consumption is seen as the measured power at zero speed during the trips, related to heating/cooling, battery management system, lights,... A distribution of the auxiliary power is shown in Fig. 2 below, in function of the driving time, for each car.

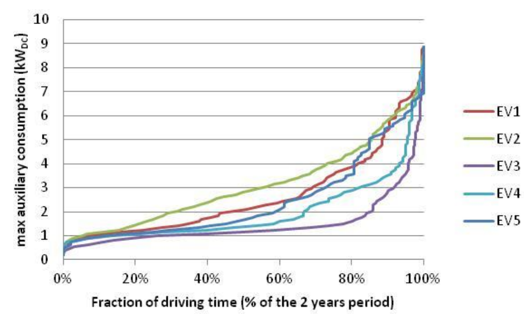

Figure 2: Auxiliary consumption in function of total driving time

Significant differences are encountered between the cars. A car parked outside (e.g. EV2) has a higher heating demand than a car parked inside (e.g. EV3). On a yearly basis, the fraction of energy that is used by the auxiliaries can be very important [4], as

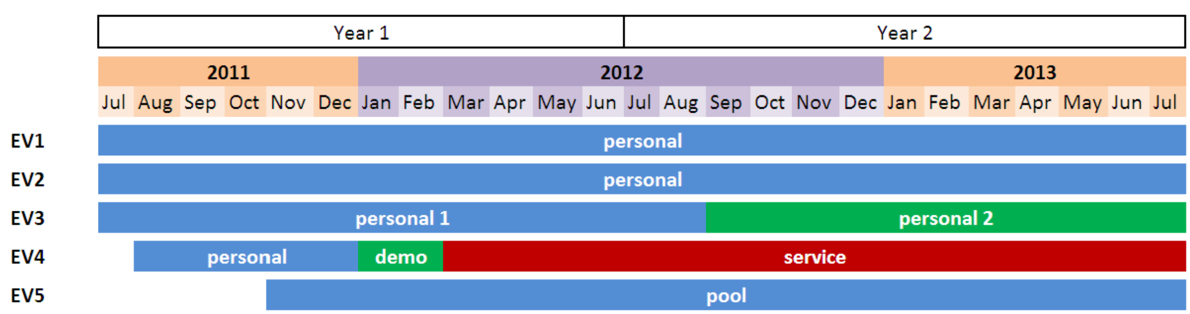

Figure 1: Attribution of the cars during the two-years test period

shown in Table 3 below for the two years. This is namely related to the trip profile: trips at globally lower speed (e.g. urban conditions) show a relatively higher auxiliary consumption than trips at higher speed.

Table 3: Auxiliary and global consumption

	Mean auxiliaries (kW_{DC})	Auxiliaries vs global consumption (%)
EV1	2.6	42
EV2	3.1	38
EV3	1.5	23
EV4	2.0	24
EV5	2.4	38

3.3 Battery efficiency

In first instance, the battery efficiency is directly related to the battery serial resistance and the average square of the battery current. The average resistance value is given in Fig. 3, for each trip of each car, in function of the outside temperature. Two-years average values for battery efficiency are given in Table 4 below.

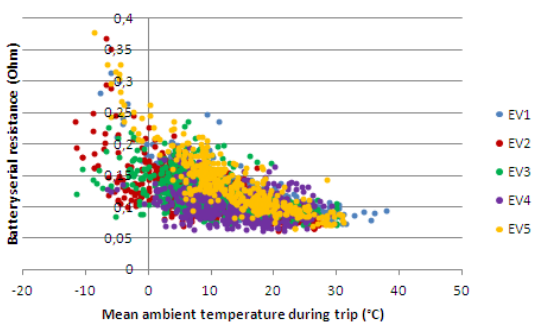

Figure 3: Battery serial resistance in function of the ambient temperature

Table 4: Detailed battery efficiency

	Avg. battery resistance (Ohm)	Avg. charging losses (%)	Avg. discharging losses (%)	Avg. battery efficiency (%)
EV1	0.122	0.2	2.6	97.2
EV2	0.127	0.2	3.5	96.3
EV3	0.124	0.2	2.0	97.8
EV4	0.115	0.2	2.4	97.4
EV5	0.130	0.2	3.4	96.4

3.4 Other efficiencies

An 82% AC/DC vehicle (slow) charge efficiency was measured in laboratory for complete charging cycles, and observed in the field test for the real (partial) cycles. A significant part of the not converted energy is used by the battery management system during the charging cycle (typically 0.5kW).
A yearly 85% efficiency is estimated for the drive train, based on chassis dynamometer tests in different torque and speed conditions.
Note: some EV models experience a standby energy consumption when not connected. Some others have a pre-heating option when charging. The Peugeot iOn cars that are considered here don't experience those additional consumptions.

3.5 Plug-to-wheel yearly efficiency

The 2 years average plug-to-wheel efficiency is synthesized in Fig. 4 and Table 5 below.
A broad range of values is obtained for the 2 years

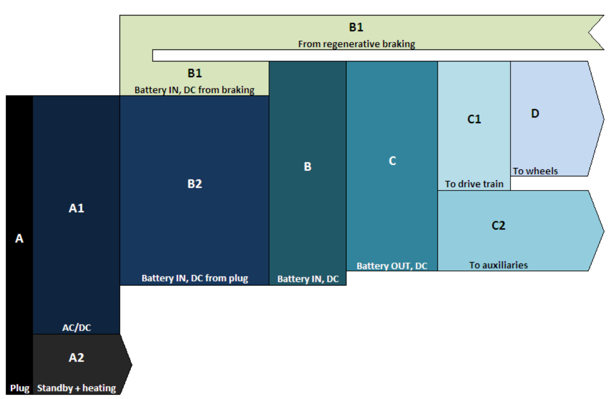

Figure 4: Schematic Sankey diagram of the plug-to-wheel efficiency – scale of the components is arbitrary

Table 5: Two-years plug-to-wheel efficiency of the cars

		EV1	EV2	EV3	EV4	EV5
Total energy from plug, AC	**A**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Plug to car, AC	*A1*	100.0	100.0	100.0	100.0	100.0
Standby and pre-heating, AC	*A2*	0.0	0.0	0.0	0.0	0.0
Battery IN, DC	**B**	**98.1**	**97.9**	**98.1**	**94.0**	**100.7**
Battery IN,DC from braking	*B1*	16.1	9.9	12.5	9.1	11.7
Battery IN,DC from plug	*B2*	82.0	82.0	82.0	82.0	82.0
Battery OUT, DC	**C**	**95.4**	**94.3**	**96.0**	**91.5**	**97.1**
Battery OUT, DC to drive train	*C1*	55.3	58.5	74.4	69.6	60.7
Battery OUT, DC to auxiliaries	*C2*	40.1	35.8	21.6	22.0	36.4
Energy to wheels	**D**	**47.0**	**49.7**	**63.2**	**59.1**	**51.6**

average plug-to-wheel efficiency, which is the ratio between lines A and D in Table 5.
The relative consumption of the auxiliaries is of significant importance in the total energy balance.
On average, regenerative braking can be sufficient to compensate the AC energy which is not converted to DC for the battery, as can be seen by comparing the values in lines A1 and B of Table 5.

4 Conclusions

Because of the higher relative importance of the auxiliaries at lower speed, cars with a higher urban use (EV1, EV5) show a globally lower plug-to-wheel efficiency. This is an important result when considering the urban trips as the primary segment for EVs, and should encourage the EV manufacturers to focus on the reduction of auxiliary consumption.
Taking into account an average well-to-plug efficiency of 45.6%, as defined for Europe [5], a well-to-wheel efficiency between 21 and 29% is obtained. This is slightly better than the values for a conventional car (between 14 and 26% annual efficiency according to [6]), but can still be significantly improved, namely by improving the auxiliary consumption.

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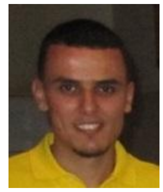

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