

## **Is Vehicle-to-Home or Vehicle-to-Grid suitable for the electric vehicle user? Discussion from a one year intensive experience**

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### **Summary**

Vehicle-to-Home, Vehicle-to-Grid, and more generally Vehicle-to-X (or V2X) refer to the use of electric storage from plug-in electric vehicles (PEVs) for other purposes than powering the vehicles.

Before proposing detailed business offers around V2X, the consequences for the car must be properly quantified, since it will directly impact the user acceptance.

During more than one year, intensive charging and discharging cycles of an electric car were performed. Realistic V2X needs were also evaluated from simulations, for different real houses in a maximum energy autonomy scenario.

An ageing comparison is made with similar cars and no V2X, and with laboratory results at cell level. The efficiency of V2X cycles is evaluated, and impact on economical benefits is discussed.

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## **1. INTRODUCTION**

Vehicle-to-X (or V2X) refers to the use of electric storage from plug-in electric vehicles (PEVs) for other purposes than powering the vehicles [1].

The concept is not new [2], but is gaining interest with the increasing deployment of EVs worldwide.

Two specific configurations are particularly discussed in literature and implemented to some extent:

- Vehicle-to-Home (V2H): Use of the PEV as a residential backup power supply during periods of power outage or for increasing self-consumption of energy produced on-site;
- Vehicle-to-Grid (V2G): concept in which an electric utility may be willing to purchase energy from customers during periods of peak demand, and/or use the EV battery capacity for providing ancillary services, like grid balancing and grid frequency control [3].

Moreover, the motivation and the implication differs between the countries:

- In Japan, commercial V2H solutions are available since 2012, as back-up solutions in case of electricity black-out [4,5];
- In the US, pre-commercial solutions exist, as a support to the grid in locations with weak electrical infrastructure [6];
- In Europe, several pilot projects are on the run, like in the Netherlands (Amsterdam), Spain (Malaga), Denmark and Germany. In Europe, other motivations are present, like local energy management, including smart charging [7,8,9,10].

Some car manufacturers (especially Japanese) see in V2X an additional argument to promote the EV. In Europe, the motivation for using V2X can be related to a lower dependence on the electricity grid, or to demand-response with variable tariffs, as already implemented in some EU countries. In theory, this can lead to a reduced energy bill, if the car charges when the electricity tariff is lower and if (part of) this energy is then used locally when the electricity tariff is higher.

Other car manufacturers do not see enough added value of V2X today for their EV business, and are therefore not pushing.

As of today, only a limited number of car manufacturers (e.g. Nissan, Mitsubishi, Toyota, BYD) are actively involved in V2X initiatives. Moreover, only limited (dis-)charging infrastructure is commercially available today.

A quantitative evaluation of the potential and limits are important prerequisites, before proposing detailed business offers around V2X. The impact for the car must be properly quantified, as well as the round trip efficiency of the V2X process, since they will directly impact the user acceptance.

In this paper, the focus is made on the impacts of bidirectional EV charging for the EV user.

## 2. SIMULATIONS

Given the current regulatory and market conditions, we expect that a maximum autonomy scenario has more chance at short term in Europe. Therefore, in the simulations, the focus is made on this scenario. The V2H needs were evaluated for different houses showing different consumption characteristics (big/small consumers, day/night consumers) in a scenario of maximum autonomy including smart, bi-directional EV energy transfers. Simulations were based on real consumption data and real EV data from Belgian users (car availability, charging needs, flexibility window based on the next planned departure time).

An example of results is shown in Fig.1 below.

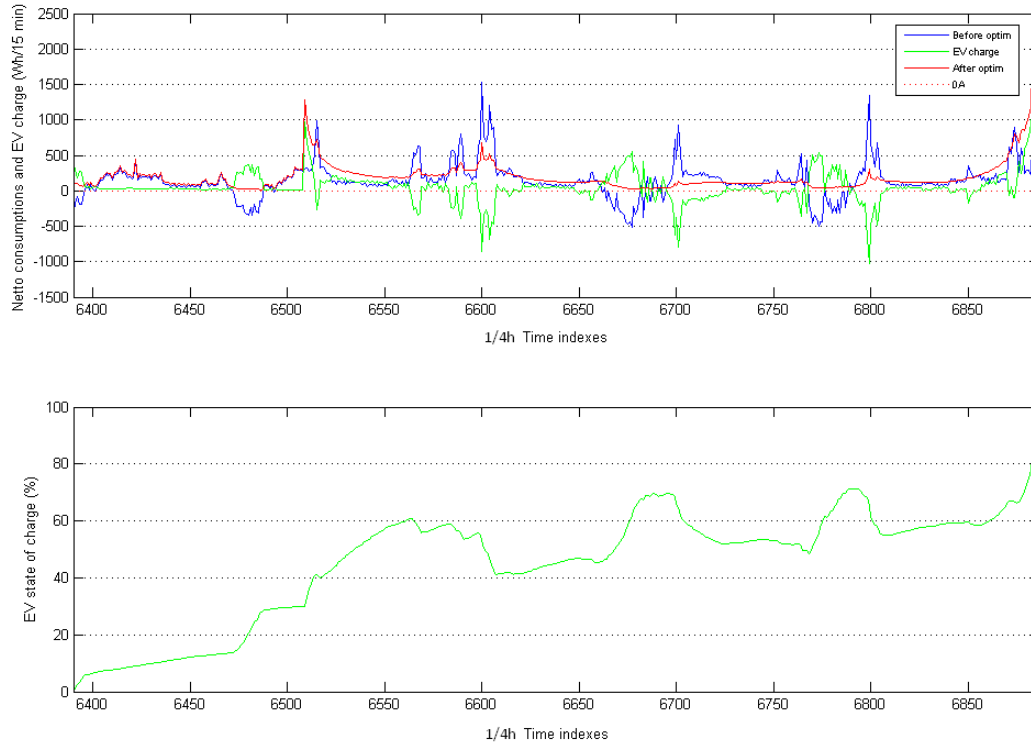


Figure 1: Example of a V2H implementation; upper part: netto consumption (Wh/15min) without (blue) and with (red) V2H, and energy charged and discharged from the car (green); positive (resp. negative) values are energy consumption (resp. production); one value is given per 1/4h; lower part: evolution of the battery state-of-charge (%); a zoom is made on the 6400<sup>th</sup> to 6850<sup>th</sup> first 1/4h periods of the year (i.e. between March 8<sup>th</sup> and March 17<sup>th</sup>)

As can be seen in the upper part of Fig.1, V2H allows a clear reduction of the energy peaks and energy transfers between the house and the grid. In the lower part of Fig.1, the resulting state-of-charge evolution is shown when V2H is applied. Several small discharges are observed in the state-of-charge evolution in the lower part of Fig.1.

When the process is applied to a full year, it leads to statistics on frequency, power and duration indications for the V2H cycles, in order to limit the energy flows between the house and the distribution grid. A selection of 12 different consumption profiles is considered, representing big versus small electricity consumers and day versus night consumers. For each house, a 4kWp PV installation and Belgian solar conditions are considered.

It appears from the simulations that the average needs of V2H are 4 times 1hour discharge per week at 500W. On average, about 8% of the total charged energy on year basis is also used in a discharging cycle.

The total energy flows between the house and the distribution grid, observed with normal charging during the period when the car is connected to the charging station, can be reduced by about 9.5% when using the flexibility offered by the V2H solution.

### 3. LABORATORY RESULTS

#### 3.1 Test setup

A test bench was mounted in March 2015 with a commercially available car (Nissan Leaf of the first generation, with a 24kWh battery) and a V2X station developed for the Japanese market (Nichicon Leaf-to-Home system) (Fig.2). Repeated charging and discharging cycles of an electric car were performed, in order to evaluate the impact of V2X on the EV battery ageing, as seen from the user side. Electrical radiators are used as tunable loads (up to 5.7kW). Their (AC) power consumption is measured. The (DC) battery charging and

discharging power and state-of-charge are measured in the car from CANbus data, and the (AC) grid charging power is also logged.

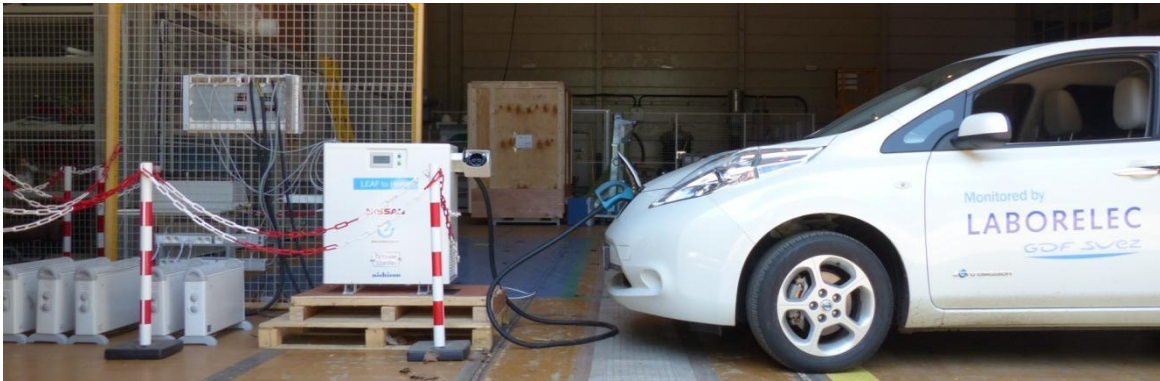


Figure 2: V2X laboratory setup

### 3.2 Test conditions

Fourthty-six charging and discharging cycles were performed between April 2015 and April 2016 (Fig.3). The minimum state-of-charge level while discharging is by default limited to 30%, and can go down to 10%. In the tests, both limits were used, so that state-of-charge variations of 70 up to 90% were applied for each charging and discharging cycle.

The charging power is controlled by the car and cannot be adjusted by an external intervention. The discharging power is function of the connected load. In the performed tests, the nominal power of the discharging system is used, i.e. about  $6\text{kW}_{\text{DC}}$ .

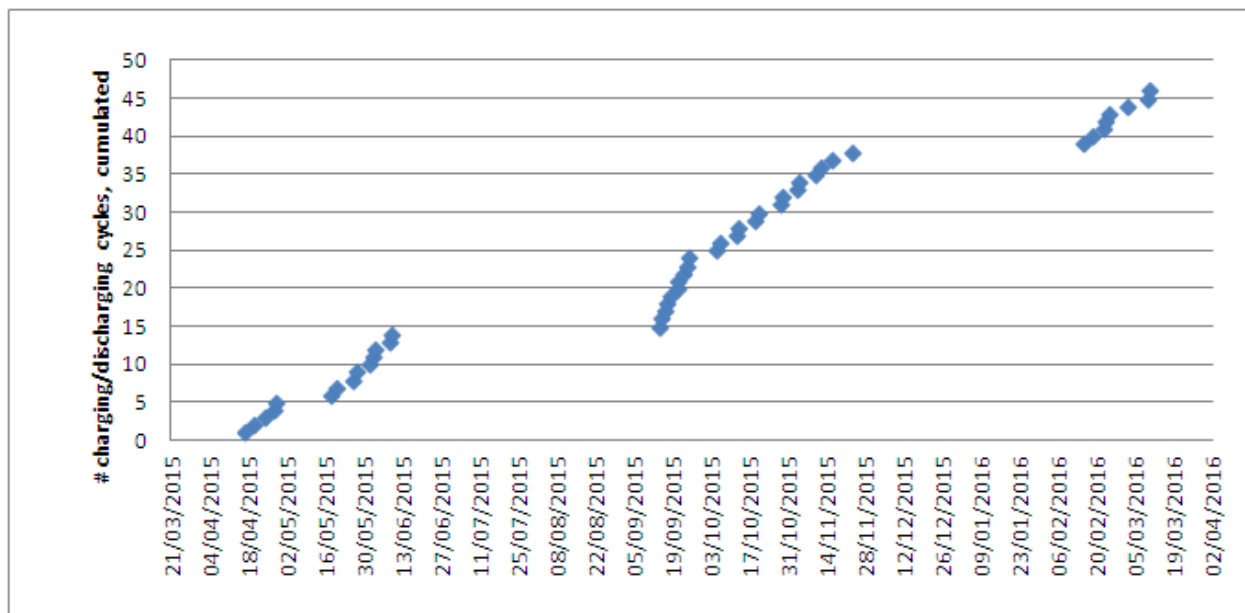


Figure 3: Distribution of the charging/discharging occurrences during the one-year tests period

Three periods of intensive V2H use were observed (Table 1).

Table 1: Details of the V2H periods

| From      | To        | Weekly avg #<br>charging & discharging cycles |
|-----------|-----------|-----------------------------------------------|
| 17/4/2015 | 9/6/2015  | 1.8                                           |
| 14/9/2015 | 4/11/2015 | 2.6                                           |
| 15/2/2016 | 15/3/2016 | 2.3                                           |

Between the periods mentioned in Table 1, the car was used for driving purposes only.

### 3.3 Test results

A focus was made on system efficiency and car ageing evaluation.

#### 3.3.1 System efficiency

Different sources of losses are present in the charging/discharging sequence. About 10% AC/DC conversion losses are observed between the AC grid and the DC energy charged in the battery; among which a significant part is the energy used by the car auxiliaries [11]. About 4% battery losses are observed. Finally, about 15% DC/AC conversion losses are measured between the DC energy discharged from the battery and the AC load; here again, a significant part of the losses is the energy used by the car auxiliaries.

The global efficiency is synthesized in Fig.4 below.

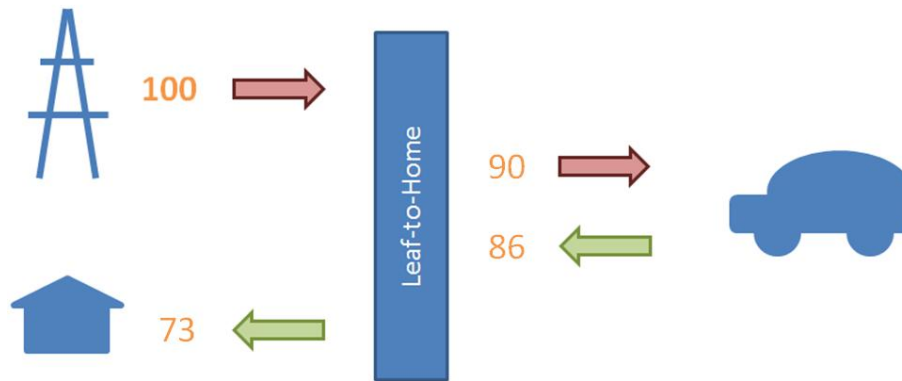


Figure 4: Synthesis of the round-trip energy efficiency (charging and discharging cycles)

Fig.4 shows that when using 100 energy units from the AC grid to charge the car and discharge it later for a house consumption, about 73 is really available, meaning about 1/4 losses.

A first requirement for the end-user is, at least, to compensate those energy losses by sufficiently high gain on his energy bill (e.g. 73 units consumed by the house when the energy price is high, at least equivalent to the price of the 100 units at the charging time). In order to be economically interesting for the end-user on an energy price basis, the time-of-use energy tariffs should be proposed with price at the low tariff periods at least 25..30% lower than the price of the high tariff periods. This is more than what is proposed today for the day and night tariffs in many European countries, as shown in Table 2 below. Better time-of-use tariff schemes are needed to further motivate Vehicle-to-Home, possibly combined with profitable ancillary services to the distribution network operator, like in the US [12].

Table 2: Electricity cost reduction in off-peak vs peak, 1MWh base (source: Eurelectric 2015 [13], ENGIE Electrabel 2015)

|         | € Diff, peak vs Off-peak in % of Peak |
|---------|---------------------------------------|
| Belgium | 23%                                   |
| France  | 21%                                   |
| Germany | 22%                                   |
| Spain   | 29%                                   |

### 3.3.2 EV ageing

The charging cycles show a typical shape, that is controlled by the battery management system of the car. In the beginning, the nominal power is used, with limited variations. After 30 minutes, a power in the range of the nominal value is still used, but regular short interruptions are observed, typically with a 45 seconds duration every three minutes (Fig.5); this is controlled by the battery management of the car, probably for reasons related to the battery temperature evolution. Finally, the power rapidly decreases during the last 30 minutes, to allow the battery to equilibrate the charge of the different cells.

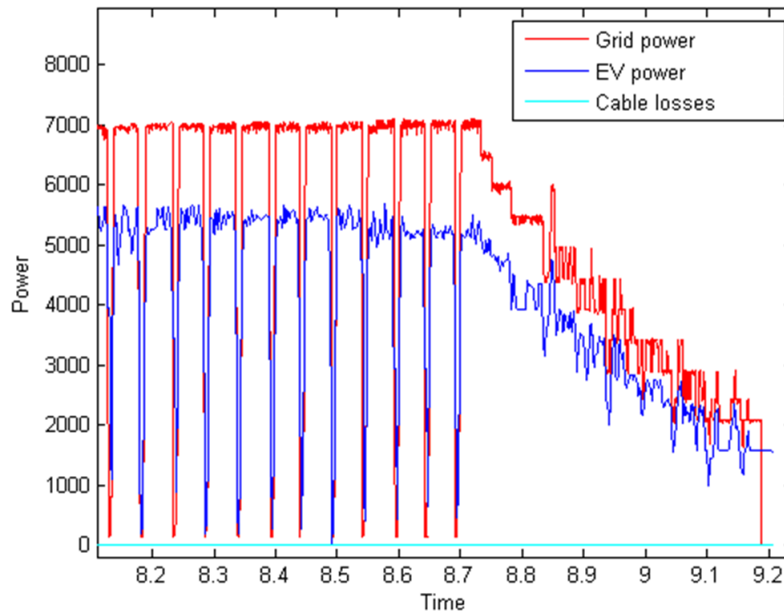


Figure 5: Zoom on the regular short interruptions in the charging cycle (power in Watts, time in hours)

Contrary to the charging cycles, the discharging cycles are not controlled by the battery management system of the car. The system goes in error mode if the power asked by the load is higher than the nominal power of the system, but no dynamic control is made by the battery management system. The load is exclusively connected to the discharging system, meaning that the grid cannot compensate a power demand that the EV battery could not provide. In the extreme case, as implemented in the laboratory tests, the load will be constant and the power delivered by the battery will be the nominal power during the whole discharging cycle (no interruptions and no decrease) (see period between 2.5h and 5h in Fig.6).

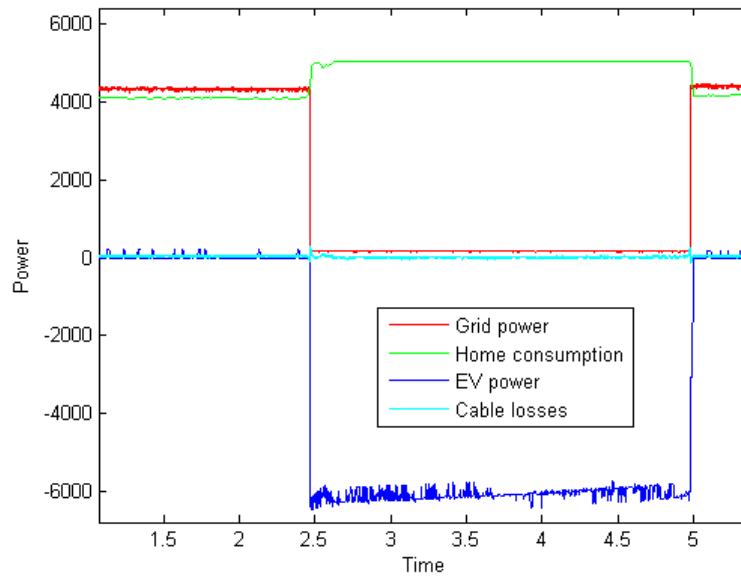


Figure 6: Extreme discharging case: constant nominal load down to the minimum acceptable battery state-of-charge (power in Watts, time in hours)

The use of the battery for driving involves much more dynamic energy flows than V2X discharging, up to five times higher average power values and up to ten times higher peak values (Fig.7); however, in the case of driving, the battery management system has the control of the power output. As a consequence, is V2X more impacting than driving on battery ageing ?

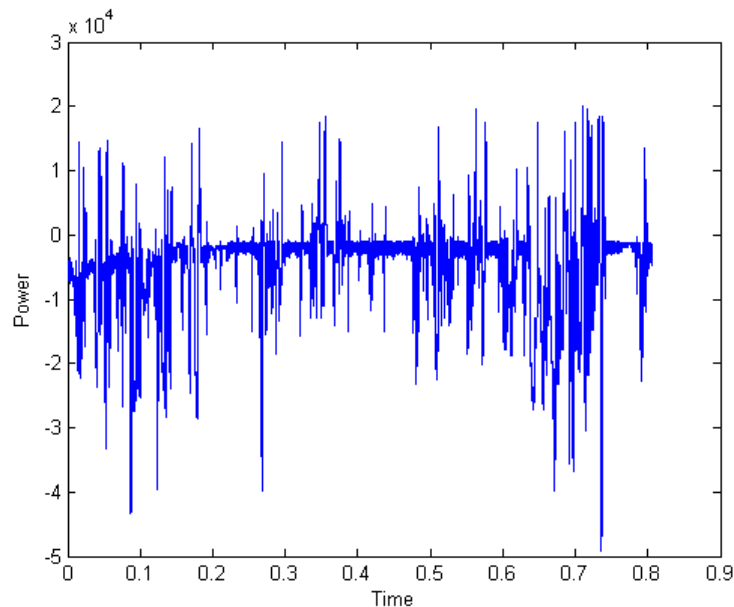


Figure 7: Power evolution during a typical trip (power in Watts, time in hours); negative values represent the driving power; positive values represent the regenerated braking power

To bring an answer to this question, the battery capacity is calculated, based on the relation between state-of-charge and energy. In Fig.8 below, one value is given for each discharging cycle.

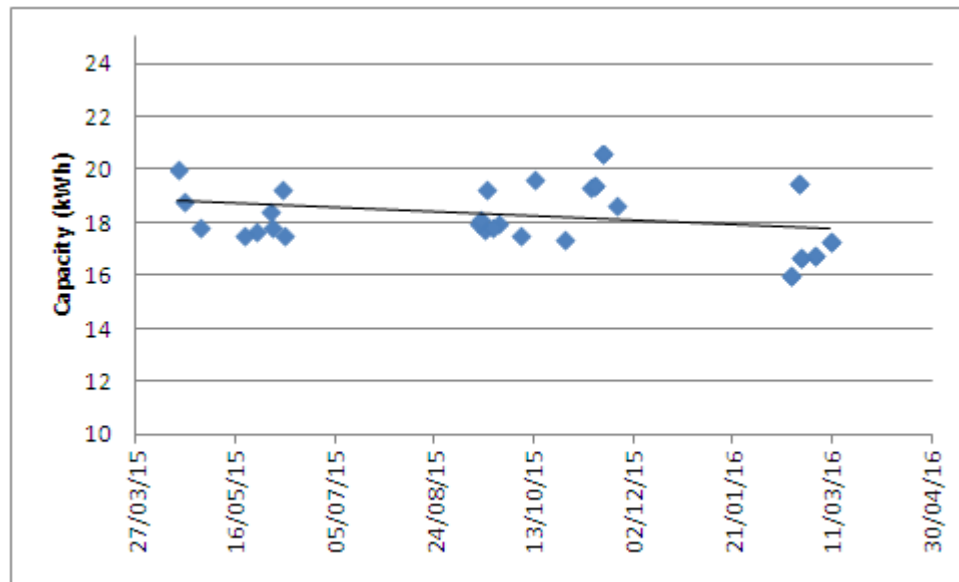


Figure 8: Calculated battery capacity and evolution during the testing period; calculation for discharging cycles (= useful DC energy capacity)

A degradation of 5%/year is observed. Note that in Fig.8, the calculated capacity values show a significant dispersion. This is due to a  $\pm 4\%$  typical uncertainty (or a  $\pm 1.3\text{kWh}$  maximum uncertainty), resulting from the combined uncertainties on the energy and state-of-charge.

No clear evolution of the battery specifications can be found after one year of intensive charging/discharging. Seven other cars of the same type were monitored during a 9 months period. The driven distances of those cars were between 4000 and 12000km/year, with consumption between 20 and 29kWh/100km on average, and a yearly energy consumption between 1000 and 2500kWh. The resulting battery ageing, based on the battery capacity decrease, was evaluated (Fig.9).

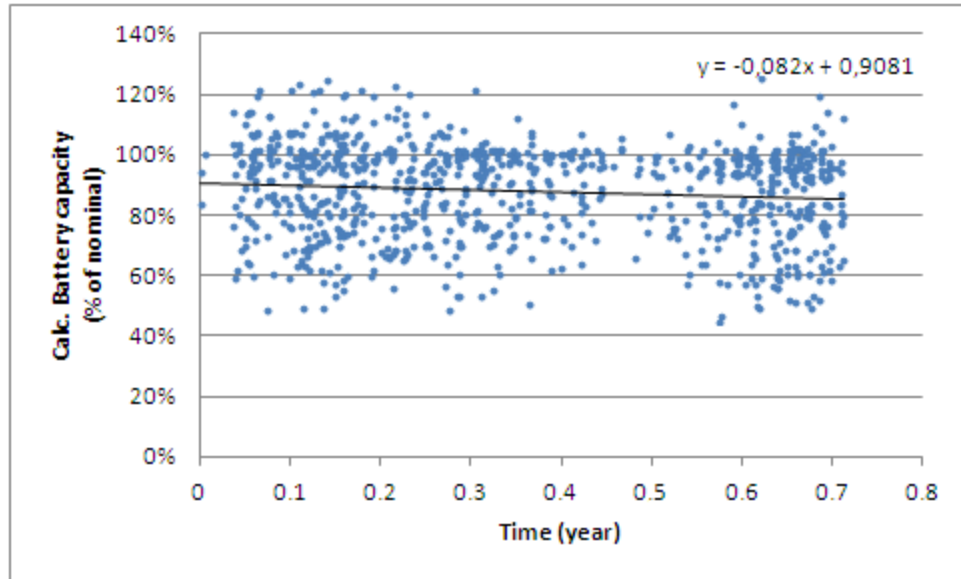


Figure 9: Average battery capacity decrease of 7 Nissan Leaf with no V2H

The comparison between cars with and without V2H is synthesized in Table 3 below.

Table 3: Comparison of Nissan car with V2H and 7 reference Nissan Leaf cars with no V2H

|                                | V2H car   | Reference cars     |
|--------------------------------|-----------|--------------------|
| Driven distance                | 1000km/y  | 4000 .. 12000 km/y |
| On-road discharged energy      | 245 kWh/y | 1000 .. 2500 kWh/y |
| Stationary discharged energy   | 730 kWh/y | 0kWh/y             |
| Total discharged energy        | 975 kWh/y | 1000 .. 2500 kWh/y |
| Avg. battery capacity decrease | 5%/y      | 8%/y               |

Based on this comparison, there is no evidence of an increased battery degradation with V2H. Battery tests at cell level can help clarify this.

It is generally known that there are several impact factors that are affecting the battery ageing in EVs. These factors can be classified under cycling (depth of discharge (DoD), current rate, temperature) and calendaring. Regarding cycling the proposed aging parameters can be linear or non-linear depending of the used battery chemistry and design [14-19]. In Fig.10 one can observe that the evolution of cycle life is polynomial as function of DoD.

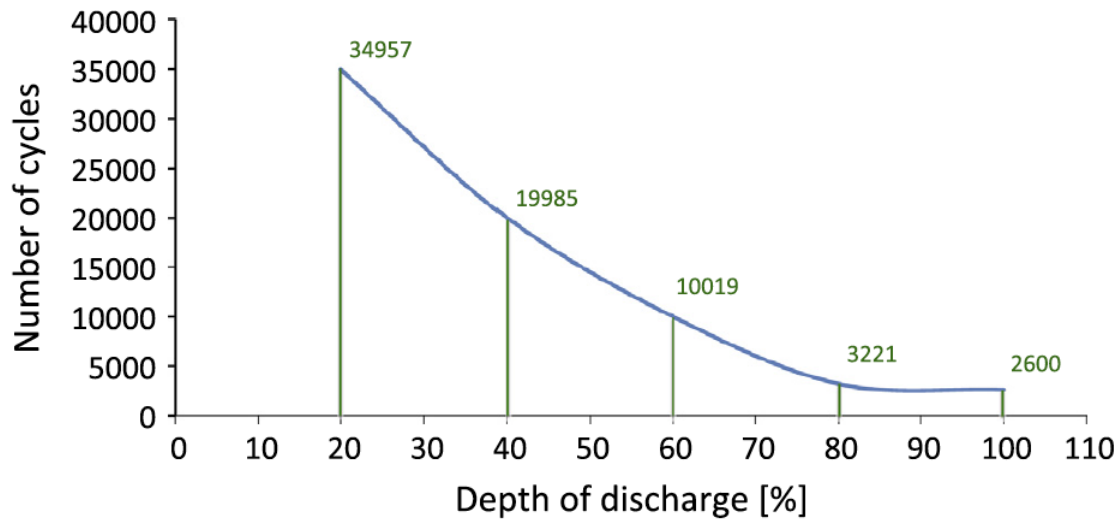


Figure 10. Evolution of number of cycles as a function of DoD for a LFP 2,3Ah cell [17]

On average, the 1hour discharges at 500W, as tested in our simulations, happen around 35% DoD. In these conditions, the impact of V2H on the total number of cycles, based on the data of Fig.10, would be a reduction of 6.3% on the number of charging cycles, compared to the same situation with no discharge. In other words and in first approximation, the battery capacity with V2H would show a 6.3% higher yearly degradation than the same battery with no V2H. For the car used in the laboratory tests, instead of the 5% degradation observed with V2X, the same car with no V2X would show a degradation of  $5\% / (1 + 6.3\%) = 4.7\%$ . Given the dispersion observed on the measurements, this difference is practically not observable. However, the strategy of V2X should be designed in such way that the battery lifetime should be kept as high as possible.

## 4. CONCLUSIONS

No negative impact for the battery was observed after one year of intensive use of V2X in laboratory tests, compared to the same car type with no V2X. Since the real V2X needs are by far lower than the ones implemented in the laboratory conditions, it is not expected that V2X will have a negative impact on the battery ageing, when used in a maximum autonomy scenario at house level.

According to the authors, the maximum autonomy scenario for the house is the one with the most potential in Europe at short term. It was shown that energy flows between the house and the distribution grid could be reduced by 9.5% during the period when the EV was plugged in, compared to normal charging, with on average 4 times 1hour discharge per week at 500W. However, the round-trip efficiency was shown to be too low for most of the European countries, when considering the peak versus off-peak electricity tariffs today, leading to limited economical benefits of Vehicle-to-Home for the end-user. Political willingness in Europe is needed (and starting), on one hand to increase energy self-production and self-consumption, by enlarging the spread between intra-day peak and off-peak energy tariffs, on the other hand to support the distribution grid by financially encouraging the end-users to provide ancillary services. In these conditions, V2H could find an increased interest in the coming years.

In the next steps, other scenarios will be evaluated; technical and economical comparisons will be made with smart charging, impact of other battery sizes will be considered, and the ageing tests will be continued.

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