Comparison of the contribution of smart charging, V2G and energy demand reduction to the energy autonomy of a Belgian city depot

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ABSTRACT

Combining electric vehicles and renewable energy production offers opportunities for grid optimization in many ways. Within the European SEEV4-City project, an increase of *energy autonomy*, *ultra-low emission kilometres* and a reduction of the *peak of the grid exchange* are the main goals of the Kortrijk pilot. The impact of demand reduction, the introduction of a smartly (dis)charged electric vehicle and an energy storage system on the self-sufficiency, peak demand and ultra-low emission kilometres has been assessed. It shows that in rolling out a smart grid, the first step should always be optimizing energy savings, followed by coordinated or bidirectional charging.

KEY WORDS: smart grid, electric vehicle, self-sufficiency, peak demand, self-supplied green kilometres

1. INTRODUCTION

Both the sales of electric vehicles and the capacity of renewable energy production are rising in Europe, offering a great base for a transition towards a sustainable society. Unfortunately, there is a major hurdle: the injection of renewable energy rarely follows the extra energy demand from electric vehicles. This emphasises the need for the introduction of smart grids and the development of ecologically and economically interesting types of energy storage. The European Interreg project SEEV4-City [1] aims to demonstrate the opportunities of the local combination of electric energy from renewable sources, electric vehicles and smart ICT systems. The opportunities to be demonstrated are an increase of *energy autonomy*, an increase of *ultra-low emission kilometres* and avoiding extra investments to make the existing electrical grids compatible with a boost in e-mobility and local energy production. The project contains 6 operational, long term pilots in 5 European cities.

One pilot is located in the Belgian city of Kortrijk, and consists of a city services technical depot and an adjacent indoor/outdoor sports centre operated by the city, shown in Fig.1. The rooftop PV capacity amounts to 78.75 kWp with a yearly yield of about 75 MWh. This paper explains how the project goals can be achieved on this particular pilot by introducing an electric vehicle and carrying out a relighting project. The simulations in this paper are based on historical data (on a 15 minute time base) of PV production and of energy exchange with the electrical grid for the years 2015 and 2016. From February 2018 on, the local smart grid is operational, resulting in realistic EV user data.

Fig.1 The Belgian pilot: city depot and sports centre.

2. BASELINE

2.1. Metrics

2.1.1 Assessing energy autonomy

One of the goals of the local smart grid in the Belgian pilot is to maximize the use of locally produced renewable energy and thus the so-called energy autonomy. Different metrics can be formulated to measure load matching. For this project, two parameters were considered to assess this: *self-sufficiency* and the *self-consumption ratio*. Self-sufficiency is the extent to which an entity can provide for its own energy needs, it is calculated as:

$$\text{Self}-\text{sufficiency} = \frac{\text{self-consumption}}{\text{total energy consumption}}, \qquad (1)$$

with self-consumption defined as the self-consumed part of the total local energy production *(area C in* Fig. 2*)* [2]. The higher the self-sufficiency, the lower the amount of energy exchanged with the grid and the better the load matches with the local energy production. Energy savings in the base load or an expansion of the PV installation will generally result in an increase in self-sufficiency. Note that the need for self-sufficiency is not a general need, but it is a goal that might be interesting depending on the technical regulations as well as the pricing system of the local grid operator.

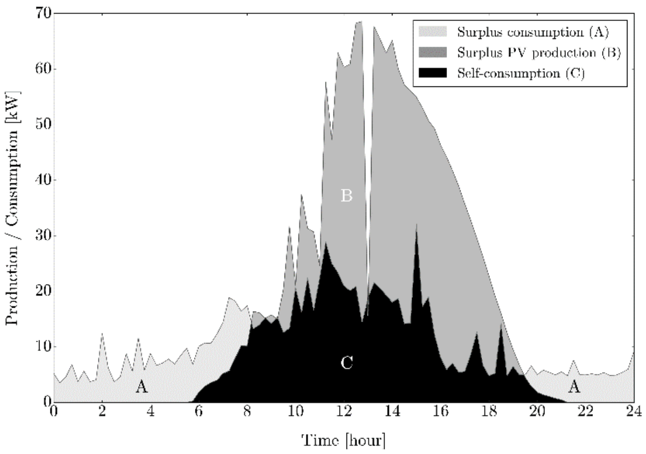

Fig. 2 Electrical load at Kortrijk pilot on June 25th 2018;

self-sufficiency = $\frac{C}{A+C}$, *self-consumption ratio* = $\frac{C}{B+C}$

The self-consumption ratio is the ratio of the absolute self-consumption relative to the total local energy production [2]:

$$\text{self}-\text{consumption ratio} = \frac{\text{self}-\text{consumption}}{\text{total local energy production}}. \qquad (2)$$

Also for the self-consumption ratio applies that a higher value implies a better load matching. For this parameter, both energy savings in the base load and an expansion of the renewable energy production capacity will decrease the value for the self-consumption ratio.

Since base load energy savings are considered beneficial and the PV capacity at the pilot site will not change during the project, there has been chosen for self-sufficiency as the most suitable metric to assess energy autonomy.

2.1.2. Assessing the peak of grid exchange

Because of the pricing system for this pilot, the goal of 'avoiding extra investments in the existing electrical grids' is evaluated by assessing the peak of the energy exchange with the electrical grid. In literature, many metrics used for assessing this peak exchange, are related to a power limit that should be exceeded as little as possible [3] [4]. At the Kortrijk pilot, the technical maximum power supply would be 250 kVA (the rating of the transformer). Since the maximum measured power peak in the two years of data was only 152 kW, there is chosen to use a parameter referring to the reduction of the absolute peak value: the *Peak Load Reduction (PLR)* [4]. The lower this absolute peak, the less fixed costs will be charged by the DSO.

The absolute power peak from the grid is the *Peak Demand* (*PD)* [kW], as shown in Fig. 3. The peak load reduction shows the effect of the developed algorithm on this peak demand and is calculated as:

$$\text{Peak Load Reduction} = \frac{\text{PD}_{\text{before}} - \text{PD}_{\text{after}}}{\text{PD}_{\text{before}}}. \qquad (3)$$

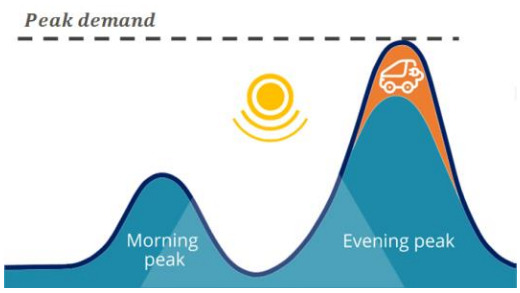

Fig. 3 Peak demand [1]

2.1.3. Assessing 'ultra-low emission kilometres'

A third major project goal is increasing the amount of kilometres covered with locally produced renewable energy, the so-called 'ultra-low emission kilometres'. In order to calculate this, the *Self-Supplied Green Energy Ratio (SSGER)* [5] is introduced.

The *SSGER* is calculated whenever the electric vehicle is charging using formula (4):

$$\mathrm{SSGER}(t) = \frac{P_{\text{self-consumption}}(t)}{P_{\text{total consumption}}(t)}. \quad (4)$$

Thus the *SSGER(t)* is the instantaneous self-sufficiency at the time of charging. The *Ultra-Low Emission Kilometres (ULEK)* gained when charging are calculated from the SSGER according to formula (5):

$$\mathrm{ULEK}_{\text{gained}} = \frac{\int \mathrm{SSGER}(t) \cdot P_{\text{EV,charge}}(t) \cdot dt}{E_{\text{consumption EV}}}, \quad (5)$$

with $P_{EV,charge}(t)$ the charging power of the electric vehicle and $E_{consumption\ EV}$ its energy use per kilometre. In the bidirectional charging scenario, the ultra-low emission kilometres stored in the battery are not necessarily used for driving, but can also be fed back into the local grid. The ULEK lost due to the discharging of the electric vehicle in the V2G scenario is calculated according to formula (6):

$$\mathrm{ULEK}_{\text{lost}} = \frac{\int \alpha \cdot P_{\text{EV,discharge}}(t) \cdot dt}{E_{\text{consumption EV}}}, \quad (6)$$

with $P_{EV,discharge}(t)$ the discharging power of the electric vehicle and α the ratio of locally produced green energy stored in the EV battery to the total energy stored in the EV battery, calculated according to formula (7). The ratio α is calculated at the start of each discharging process and is assumed constant during.

$$\alpha = \frac{\mathrm{ULEK}_{\text{in\_car\_at\_start\_discharge}} \cdot E_{\text{consumption EV}}}{E_{\text{EV\_battery\_at\_start\_discharge}}}. \quad (7)$$

2.2 Smart Energy System

The 'Smart Energy System' *(SES)* of the Kortrijk pilot is schematized in Fig. 4. This smart ICT system is measuring and managing the energy flows at the local pilot. The database of the SES contains the measurements of all energy meters, supplemented with the Belgian energy pricing forecast [6]. In the future, a weather forecast could also be added. The database is updated on a one minute base. The electric car, a Nissan e-NV200, is charged using the *KEBA KEContact P30* wallbox, allowing the electric vehicle to be smart charged, single phase, with a power up to 6.6 kW. Other EVs that are present at the Kortrijk site are: The electric forklift, charged using a domestic 230V socket, and e-bikes that are charged using the universal e-bike charger from Bike Energy. Currently the charging of the electric forklift and the e-bikes cannot be controlled.

Fig. 4 Schematic of energy flows in Kortrijk pilot

2.3 Baseline

The baseline of the pilot was determined at the beginning of the project. At the time, the PV installation was already operational, but there was no electric vehicle nor Smart Energy System. The baseline values for self-sufficiency, grid exchange and ultra-low emission kilometres are shown in Table 1. They are calculated from the historical data from the years 2015 and 2016 for this site.

Table 1 Baseline metrics

	Self-sufficiency [%]	Peak demand *[kW]*	Peak load reduction *[%]*	ULEK *[km/year]*
Baseline	**24.8**	**152**	***na***	**0**

Analysing the baseline, remarkable power peaks were noticed in the evening hours during the winter months, as can be observed in Fig. 5, depicting the total energy consumption for a 'typical day' of each month of the year. Discussions with the responsible for the sports centre revealed that these power peaks are due to the lighting of the outside sporting fields.

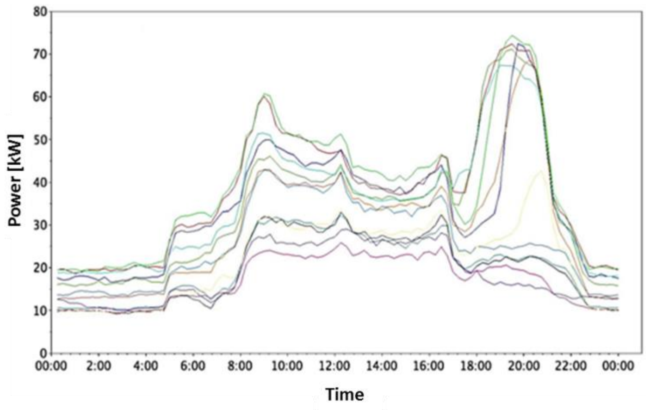

Fig. 5 The pilot's power usage of a "typical day" for each month

3. SIMULATIONS

The Nissan e-NV200 that is introduced at the pilot, is mainly used by the city mailman and is replacing the previous ICE (diesel) van. The EV is almost exclusively charged at the technical depot and will only be used on weekdays from 7h45 to 15h00 to cover a yearly distance of about 9,500 km. In this section, the impact of three different charging strategies (uncoordinated, coordinated and bidirectional charging) on the metrics discussed in Section 2 will be compared. The simulations are based on the data used in the baseline calculations, combined with the measured charging profile of the Nissan e-NV200, depicted in Fig. 6.

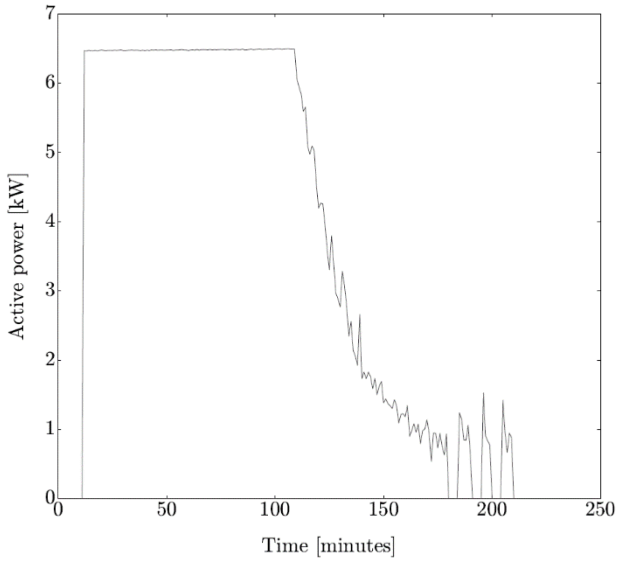

Fig. 6 Measured charging profile of the Nissan e-NV200

3.1 Uncoordinated charging

The scenario of uncoordinated charging assumes that the electric van will start charging as soon as it is plugged in. The effect of this charging strategy on the parameters considered, is shown in Table 2. Uncoordinated charging will result in a slight increase in self-sufficiency, but the peak grid exchange parameters remain unchanged. This is due to the start of the charging at 15h00, charging the EV with solar energy, that would otherwise be injected into the grid, but avoiding the winter evening power peaks. The simulation also shows, that when the EV would be uncoordinatedly charged, 4844 kilometres would be covered using locally produced PV energy.

Table 2 Uncoordinated charging metrics

	Baseline	Uncoordinated
Self-sufficiency *[%]*	**24.8**	**24.9**
Peak load reduction *[%]*	***na***	**0**
ULEK *[km/year]*	**0**	**4844**

3.2 Coordinated charging

In the case of coordinated charging, the charging does not start automatically when the car is plugged in, but it may be deferred to later moments, depending on the charging strategy used. The exact charging strategy is depending on the parameters to be optimized. This can be observed in Fig. 7 and Fig. 8. Fig. 7 shows the algorithm optimized for self-sufficiency (and thus ‘energy autonomy’). The algorithm optimizing the amount of ultra-low emission kilometres is shown in Fig. 8. In the case of coordinated charging, there is no optimization for the peak of the grid exchange possible, since the introduction of the EV did not influence Peak Demand. Hence it is not possible to lower this peak by shifting the car’s energy demand.

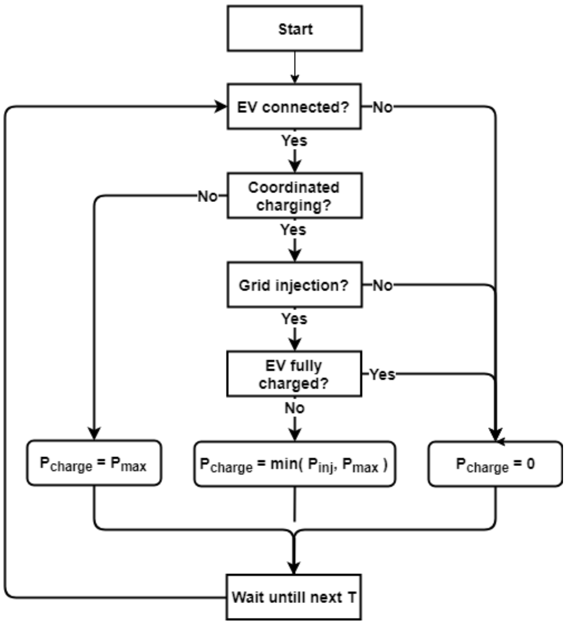

Fig. 7 Flowchart for coordinated charging – *Self-sufficiency*

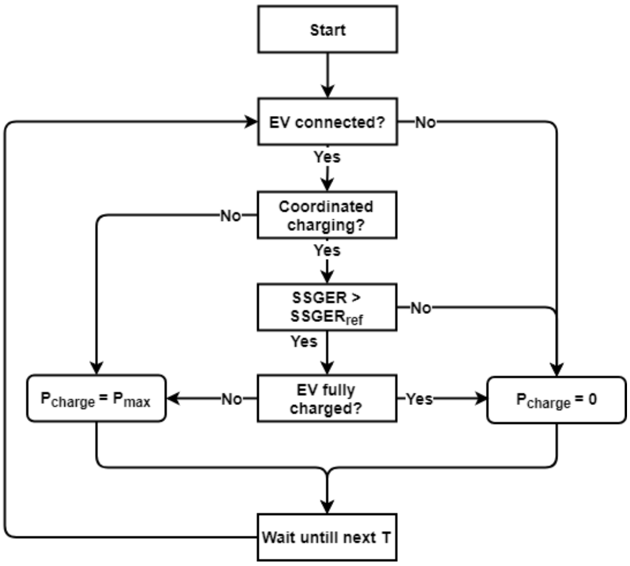

Fig. 8 Flowchart for coordinated charging – *ULEK*

The effect of the two coordinated charging algorithms on the metrics considered is shown in Table 3. It can be observed that the algorithm for self-sufficiency only increases the self-sufficiency with 0.1% compared to the uncoordinated charging strategy, but decreases the amount of ultra-low emission kilometres with 242 km/year *(-5%)*. The algorithm optimising the ULEK, indeed increases the amount of ultra-low emission kilometres with 189 *(+3.9%)*, but results in the same self-sufficiency as for uncoordinated charging. Hence it is possible to optimize the chosen metrics using coordinated charging, but it should be noted that optimizing the algorithm for one parameter may be at the expense of the other parameters.

Introducing up to four extra, coordinately charged, electric mail vans would further increase the self-sufficiency of the pilot to a maximum of 25.3%. From five extra electric vans on, the self-sufficiency would start decreasing again, due to the extra energy demand exceeding the increase in self-consumption.

Table 3 Coordinated charging metrics

	Baseline	Coordinated *Self-Sufficiency*	Coordinated *ULEK*
Self-sufficiency *[%]*	**24.8**	**25**	**24.9**
Peak load reduction *[%]*	***na***	**0**	**0**
ULEK *[km/year]*	**0**	**4602**	**5033**

3.3 Bidirectional charging (V2G)

In the scenario of bidirectional charging, the van is charged as per coordinated charging, but can also be discharged to further optimise grid exchange and the amount of low emission kilometres. Bidirectional charging may also achieve peak load reduction, discharging the EV at peak demand, using the algorithm shown in Fig. 9. The effect of these algorithms on the metrics considered are shown in Table 4. Also in this case, it holds that optimizing the charging algorithm for a certain metric is effective for the metric considered, but may negatively affect the other parameters.

Table 4 Bidirectional charging metrics

	Baseline	V2G *Self-Sufficiency*	V2G *PLR*
Self-sufficiency *[%]*	**24.8**	**25.6**	**24.9**
Peak load reduction *[%]*	***na***	**0**	**4**
ULEK *[km/year]*	**0**	**2963**	**3647**

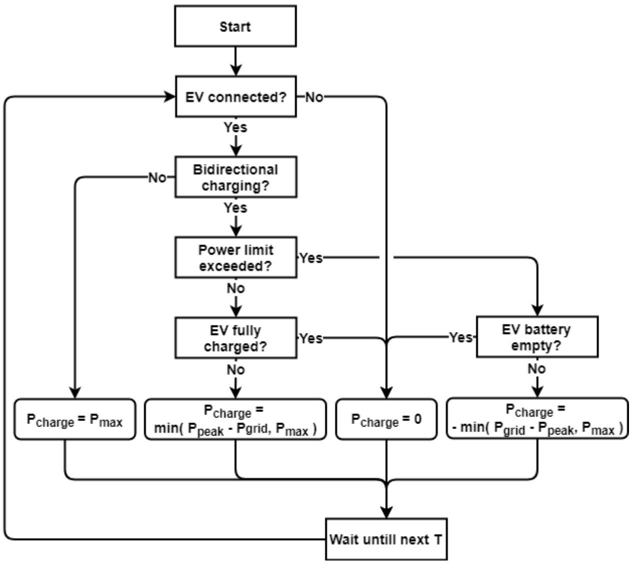

Fig. 9 Flowchart for bidirectional charging – *PLR*

4. RELIGHTING

In the baseline analysis, a remarkable power peak due to the lighting of the outside sports centre, depicted in Fig. 5, was observed. Because the current HID lighting is energy-consuming, a relighting study [7] was carried out to replace this HID lighting by LED-fixtures, that can be dimmed during training activities. Since the energy flow to the lighting is only monitored from January 2018 on, the relighting study was not integrated in the previous simulations. But as the lighting peak rarely coincides with PV injection and peak demand is due to this lighting, a reliable estimate can be made.

In Table 5, the estimated effect of the relighting on the three metrics is shown. The relighting study indicates a yearly energy saving of 20 MWh (8% of the total yearly energy consumption), increasing the self-sufficiency of the pilot with 2.2%, compared to the baseline. It shows a peak load reduction of 18%. This shows that when aiming for higher self-sufficiency or peak load reduction, the first step should always be optimizing energy savings.

Table 5 Estimate of relighting metrics

	Baseline	Relighting
Self-sufficiency *[%]*	**24.8**	**27**
Peak load reduction *[%]*	***na***	**18**
ULEK *[km/year]*	**0**	**0**

5. NEXT STEPS

The calculations above show reasonable improvements on the project metrics, but a considerable PV grid injection remains. Therefore further improvements are achievable. Currently, an 11 kWh stationary battery buffer is being assembled, shown in Fig. 10. This energy buffer will be installed at the pilot in the near future. Similar control algorithms as for V2G will be used, differing in the continuous availability of the stationary battery buffer. A second improvement is the further promotion of the use of e-bikes. The distances covered will be logged and included in the calculations for the ultra-low emission kilometres. Since the measured energy consumption of the e-bikes to be used *(speed pedelecs)* is with 10 to 20 Wh/km [8] only 5 to 10% of that of the Nissan e-NV200 [9], a considerable increase in ULEK is expected. Thirdly, a multi-objective algorithm should be developed, optimising the combination of the three aforementioned metrics. Therefor the concerns of the city of Kortrijk will be taken into account. Finally, simulations will be made for this new set-up and compared with the measured results of the pilot after one year.

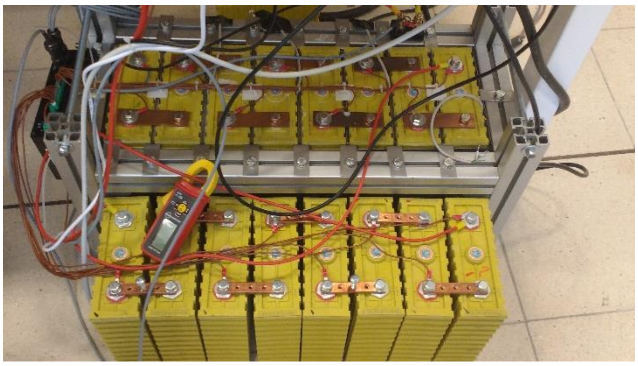

Fig. 10 Construction of 11 kWh stationary battery storage

6. CONCLUSION

The goal at the Belgian pilot of the SEEV4-City project is to investigate the potential increase of ‘energy autonomy’, increase of ‘ultra-low emission kilometres’ and reduction of grid investments by installing a local smart grid at a city depot and the adjacent sports centre. The parameters chosen to evaluate the progress are *self-sufficiency*, the amount of *ultra-low emission kilometres* and *peak load reduction.* To achieve this, a smart energy system has been installed, measuring and managing all energy flows at the pilot and the ICE van of the city mailman is replaced by a Nissan e-NV200 EV. To optimise the local smart grid, three different charging strategies (uncoordinated,

coordinated and bidirectional charging) were compared. Without applying any smart grid technologies *(uncoordinated charging)*, the test location in the Belgian city of Kortrijk has a self-sufficiency of 24.9%, 4844 ultra-low emission kilometres and 0% peak load reduction. These values can be increased by coordinated or, achieving the best results, bidirectional charging. It should be noted that using algorithms optimized for a certain metric may negatively influence the others. Analysing the baseline, a remarkable power peak was observed at winter evenings, due to the lighting of the outdoor sports fields. A relighting study shows that the effect of the relighting on self-sufficiency and peak load reduction would exceed the results obtained by the tested V2G algorithms. To further increase the self-sufficiency, an additional energy buffer of 11 kWh will be installed. To increase the ultra-low emission kilometres, the use of e-bikes will be promoted and they will be included in the calculations for this parameter.

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