Final report – Loughborough Operational Pilot

Loughborough V2H Operational Pilot Final report with extension of Burton-upon-Trent with V2G application

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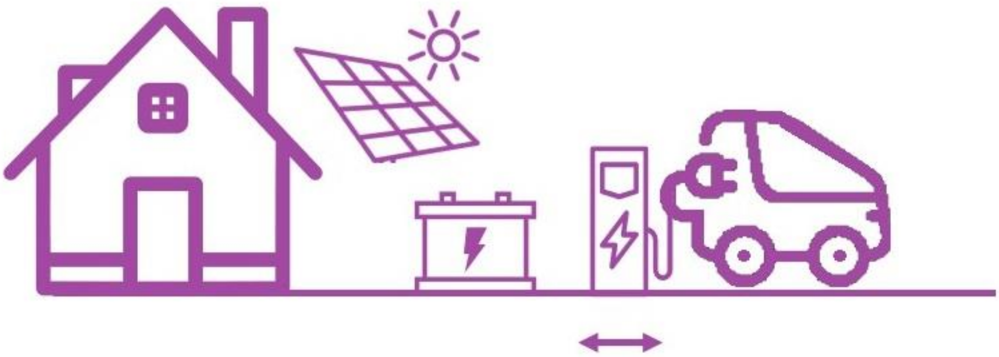

Subtitle: Loughborough V2H Operational Pilot Final report with extension of Burton-upon-Trent with V2G application

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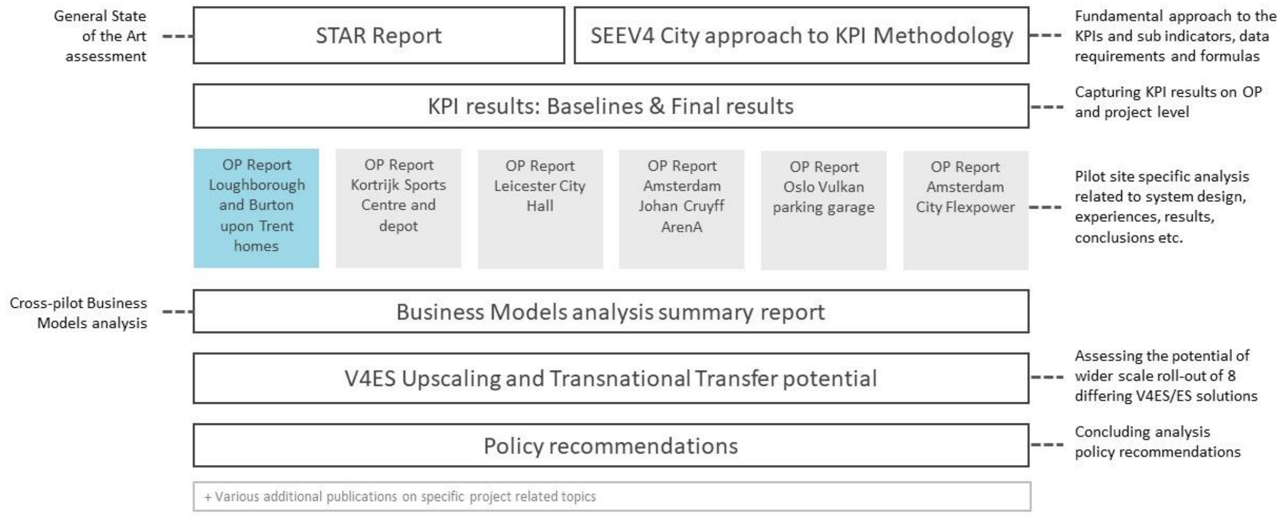
Executive summary

This is the final report of the SEEV4-City Operational Pilot (OP) in Loughborough and its second phase in Burton-upon-Trent, UK. It is part of a collection of reports published by the Smart, clean Energy and Electric Vehicles for the City (SEEV4-City) Project. This report is dedicated to the analysis of the pilot itself and the figure, below, indicates where this report fits into the wider final project reporting.



This OP was deployed in two phases, focusing on Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G). Its first phase took place at a private residence in Loughborough and ran from March 2017 up to December 2017. This phase 1 is also referred to as the 'Loughborough pilot'. The second phase took place from February 2020 until present at a comparable residence in Burton-upon-Trent, thereafter, referred to as the 'Burton pilot' or 'phase 2'. Both pilots included bi-directional chargers, Electric Vehicles (EV), Battery Static Storage (BSS) and rooftop solar PhotoVoltaic panels (PV).
The main goals of this pilot were to demonstrate the added value of V2H and V2G of using additional energy storage and PV in households.

Challenges encountered in the project include interoperability issues, particularly in phase 1, and the unforeseen development of the homeowner selling his house, meaning a new location needed to be found. However, this challenge ultimately provided an excellent opportunity to implement lessons for interoperability and to act upon the recommendations from the intermediate analysis of the Loughborough pilot. This report is mainly focussed on phase 1 (Loughborough), and additional analysis for Burton-upon-Trent (phase 2) can be found in the appendix.

The KPI results for phase 1 are summarised in the table below. These reflect the fact that the system design of both locations was specifically selected to allow the two to be comparable and merge the results as combined KPI results. The results show that the Loughborough Pilot was able to reduce 1.02 tonnes of CO_2 emissions (KPI A) and improved its energy autonomy (KPI B) by 5.1% point. KPI C was never able to be directly calculated; see the KPI Methodology Report for a discussion of the challenges of this KPI.

Loughborough Operational Pilot – KPIs			
KPI		***Target***	***Phase 1 Results***
A	CO_2 Reduction	2 – 5 tonnes annually	1.02 ton
B	Energy Autonomy increase	From 37 to 72% → Δ +35	5.1% point increase
C	Grid Investment deferral	No target set	2 – 12% improvement

An initial Net Present Value (NPV) analysis of the first phase at a discount rate of 2% indicates that the deployment of similar systems could generate a positive NPV if smart charging was used to manage energy flows at the site. From an economic perspective, smart charging or V2H balances differential tariffs or costs within a dwelling to reduce the overall cost of energy consumption. Managing charging in this way also increases energy autonomy, reduces CO_2 emissions and may also have benefits in deferring grid investment – all of which are borne out in the positive KPI results, above.

By extending to bi-directional charging and managing chargers to deliver Fast Frequency Response (FFR) services, the NPV increases further and may be profitable even when aggregator and other value-chain costs are subtracted.

This pilot has therefore demonstrated the environmental, energy and economic benefits of such a system.

These benefits are further evaluated and compared to results from the other SEEV4-city pilot sites in the Upscaling and Transnational Transfer Report, as summarised in Section 6. This pilot also generated a number of policy recommendations, which are included in the Policy Recommendations report, including observations on subsidies, market stimulation, data sharing, dissemination, standardisation and user acceptability. One specific recommendation on the impact of the UK's benefit-in-kind taxation on technology pilots such as this one is highlighted.

Furthermore, the results from phase 1 supported Cenex to work with the UK Government's Innovate department to establish a wider investigation into Vehicle-to-Grid (V2G) technology, which now has eight demonstrations running in a variety of settings, making it one of the biggest V2G programmes in the world.

Phase 2 allowed the lessons learnt from phase 1 to be implemented, including on the preparation and initiation of demonstrations, procurement of equipment, implementation and installation, and operation of the site. Given a commissioning date of February 2020, only initial analysis was possible at the time of writing. However, a CO_2 saving of 3.5 tonnes per year is predicted, which is a significant improvement over phase 1. Analysis of the Energy Autonomy over the first three months of 2020 indicated that this is highly seasonal, so results from winter and early spring are likely to be lower than for the whole year. Nonetheless, autonomy appears to have risen from under 10% in January (after PV installation) to 20-30% (after V2G installation), suggesting at least a 10 – 20% point improvement. Grid investment deferral was not analysed.

As such, it is concluded that despite technical and logistical difficulties this was a very successful two-phase pilot to the degree that it generated data, analysis, results, recommendations and follow-on work. The team are grateful to the Interreg North Sea Region for their sponsorship of this exciting and interesting project.

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Glossary

Term	Abbreviation
Battery electric vehicle	BEV
Combined cycle gas turbine	CCGT
Combined charging system	CCS
Battery charging/discharging rate relative to its maximum capacity	C-Rate
Energy storage system	ESS
Electric vehicle	EV
Firm frequency regulation	FFR
Feed-in tariff	FIT
Internal combustion engine	ICE
Information and communication technology	ICT
Key performance indicator	KPI
Levelized cost of energy	LCOE
Low voltage	LV
Net present value	NPV
Open cycle gas turbine	OCGT
Open Charge Point Protocol	OCPP
Original equipment manufacturer	OEM
Office of Low Emission Vehicles	OLEV
Open Smart Charging Protocol	OSCP
Photovoltaic	PV
State of charge	SoC
US dollar	USD
Vehicle to grid	V2G
Vehicle to home	V2H
Vehicle for energy services	V4ES

1 About the Loughborough pilot

1.1 Local context and Energy Profile

Loughborough is a town in the Charnwood Borough of Leicestershire, England, with a population of about 60,000. The Loughborough pilot involved a single household equipped with a Photovoltaic (PV) panel, a Nissan Leaf EV and stationary battery storage.

This pilot is the smallest operational pilot (household level) in the EU Interreg North Sea Region funded SEEV4-City project. It aimed to demonstrate the benefit of smart (controlled) charging and Vehicle-to-Grid (V2G) to better integrate renewable energy generation, reduce carbon footprint, alleviate power system stress and achieve an economically feasible solution to electrical transportation and renewable energy integration.

The initial installation was as follows:

- 4 kWp PV array;
- 2 kWh stationary battery with 400W fixed input / output capacity;
- Prototype control system designed by Moixa;
- 2012 24kWh Nissan LEAF; and
- V2G unit from a previous project EFES which never satisfactorily functioned.

This system was the first-ever domestic V2G unit installed in the UK, using very early technology which often suffered from reliability problems in its operation from 2016 to 2018. This report includes mainly the Loughborough OP (phase 1) analysis. A second stage development of the original Loughborough pilot was set up in the nearby town of Burton-on-Trent (referred-to as phase 2).
Note that additional analyses of Phase 2 can be found in the appendices.

1.2 Local partners

The first stage Loughborough Pilot was planned by Cenex themselves and implemented using equipment including a prototype control system partly by Moixa and a V2G unit from a previous project ('EFES'). The house was owned and occupied by a Cenex employee who assisted in the running of the system.

The project sought to achieve the following:

- demonstrate that V2G technology works at a residential level;
- prove the business case for residential customers participating and benefiting from V2G service provision; and
- demonstrate the value of V2G to vehicle manufacturers.

The project brought together a unique consortium, highly skilled in their respective sectors, to deliver a first-of-a-kind large-scale demonstration of a truly innovative V2G proposition, with national and global exploitation potential.

The partners intended to develop and build technologies in the UK, establish a UK supply chain and secure the position of the UK in this rapidly growing market. The market for aggregated V2G chargers providing flexibility services is currently immature, but evolution is rapid, and demand is strong; therefore, a highly competitive market is expected to develop.

1.3 *Objectives and SEEV4-City KPI targets*

The different aspects mentioned in this report constitute the key elements of a successful business model, which is essential for wide implementation of this concept in real-life applications. This report explores these different dimensions of the business model by making use of stationary energy storage, EV smart charging and V2G, including ancillary network services, which are collectively referred to as Vehicle for Energy Services (V4ES).

The SEEV4-City project uses three key performance indicators (KPIs), namely energy autonomy, CO2 emission savings, and grid investment deferral, to measure the environmental and economic benefits achieved by providing V4ES.

The objectives for the system design therefore focused on using V4ES solutions:

1. To increase the level of Energy Autonomy as defined by the concept of energy self-sufficiency discussed hereafter.
2. To create CO2 emission savings by substituting ICE vehicle miles by EV use, and to a degree using PV to charge the EV rather than the fossil fuel rich energy mix provide when power is drawn from the Grid.
3. To postpone the need for grid reinforcement by minimising the peak system demand.

Pilot's SEEV4-City KPIs targets:

KPI	**Target for the OP**
CO_2 Reduction	2 – 5 tonnes yearly
Sub-KPI: ZE km increase factor	Increase factor: 2.4
Energy Autonomy Increase	From 37 to 72% → Δ +35 %

Although Grid Investment deferral was not set as a formal target for this pilot, the deferral due to V4ES was nonetheless evaluated as a percentage value in terms of the improvement in voltage profile and substation/main feeder loading, to give a rough indication of how the solutions deployed could benefit the distribution grid.

1.4 *Pilot V4ES solution(s) building blocks*

Both the Loughborough and Burton pilots combined a number of components for the V4ES solutions:

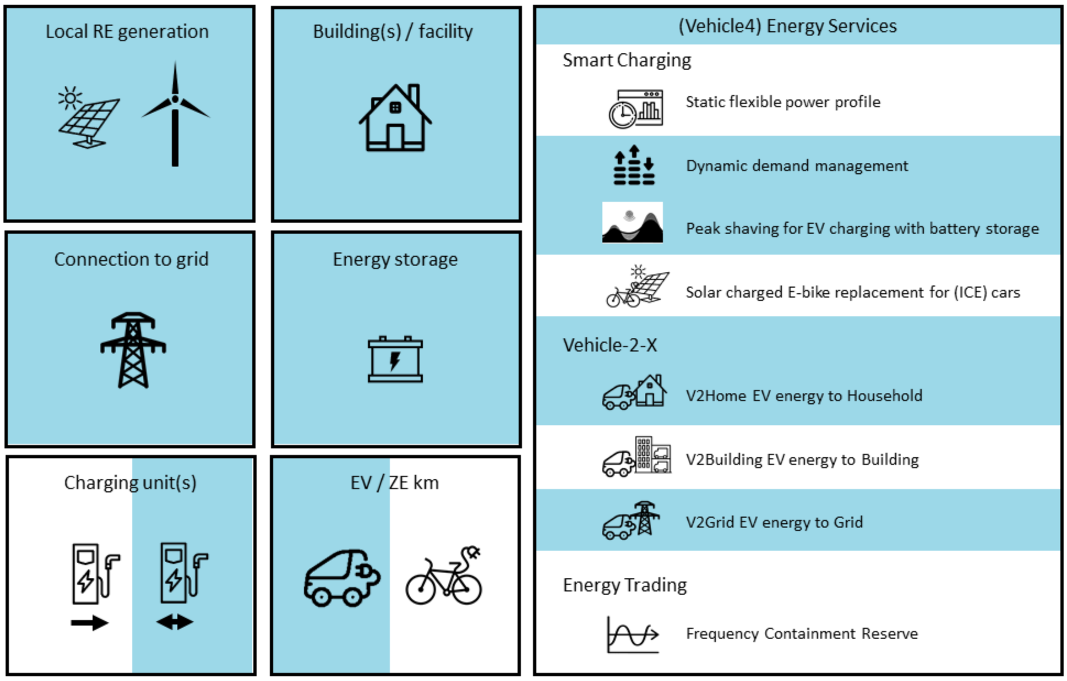

Figure 1 Pilot sites overview - design components

Figure 2 is adapted from the Moixa website to depict the power flow within the pilot. The numbersare described in Table 1, with their database name, plain-English explanation and the data source (recorded or deduced).

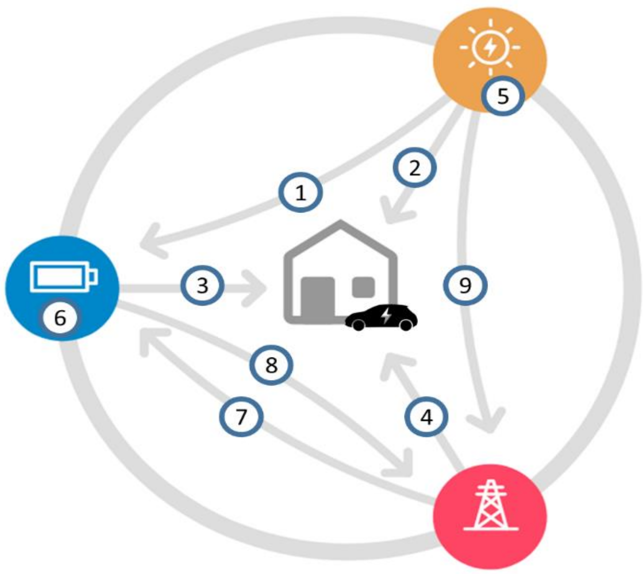

Figure 2 Household energy flow structure at Loughborough site

The PV generation profile and the household baseload profile (exclusive of EV charging/discharging profile) were obtained from the Moixa database. The former is recorded in the database (#5), whereas the latter is not directly measured. Therefore, the household baseload was calculated by adding the power import from the grid (#4), PV (#2) and the stationary battery (#3) together with the EV exchange profile.

Table 1 Household energy flow variable list for Figure 1

	Name in the database	Interpretation	Data source
1	Core/power/dc/all-solar-store-to-battery	PV supply to stationary battery	Recorded
2	Core/power/ac/cons-from-solar	PV supply to home	Recorded
3	Core/power/ac/cons-from-battery	Stationary battery supply to home	Recorded
4	Core/power/ac/cons-from-grid	Home import from grid	Recorded
5	Core/power/ac/solar-production	PV generation	Recorded
6	Core/power/dc/battery	Stationary battery power exchange	Recorded
7	Core/power/dc/grid-store-to-battery	Stationary battery import from grid	Recorded
8	---	Stationary battery export to grid	Derived
9	---	PV export to grid	Derived

2 Data collection and processing

2.1 Assumptions and research questions

2.1.1 Assumptions

In conducting the evaluation of the Loughborough pilot business model, as defined in SEEV4-City project specification, the following key ***assumptions*** were made:

- Home charging is regarded here as the only charging method. Charging events that took place elsewhere are not considered as part of V4ES, although these have been taken into account in the baseline evaluation (see section 2).
- Energy autonomy for this pilot is defined as self-sufficiency (see section 3.1.2).
- CO_2 emissions savings are predominantly from the substitution of an EV for an Internal Combustion Engine (ICE) vehicle, where the different lifecycle emissions of ICE and EV have been considered, as well as those achieved via energy autonomy (see section 3.2).
- A typical UK low voltage distribution network has been simulated for the evaluation of grid investment deferral, in terms of substation transformer/main feeder loading and voltage profiles. These are then translated into percentage values of improvement for the associated component savings (see section 3.1).
- The battery degradation cost used in this report is based on the empirical model that is derived from laboratory tests at Northumbria University on commercial EV cells. Currently this model is solely dependent on C-rate, and future work will extend this to include other degradation factors, such as temperature and average State of Charge (SoC) for a more comprehensive model (see section 4.2).
- V4ES proposed in this analysis covers smart charging and V2G in terms of FFR. V2H is not included in the scope of the proposed business model due to the flat electricity tariff in the Loughborough pilot, which prevents the possibility of profitable price arbitrage. Although V2G is not implementable yet for the Loughborough pilot, its potential benefit is evaluated in the proposed business model (i.e. V4ES).
- The period of 11:00 pm - 07:00 am was considered for FFR provision and the EV was assumed to be available during this time. If the EV was not available, the pilot would be ineligible to provide FFR according to the current National Grid's qualifying rules for participation in FFR.
- The EV needs to be part of an aggregator's asset set in order to comply with the minimum FFR capacity requirement. Consequently, a share from the resulting net profit would be passed to the aggregator. This was not considered in the cost-benefit analysis (see section 4.6).
- A lifetime of 10 years is assumed for the V2G charger and ESS, and 20 years for the PV system (section 4.6).
- As per industry standards, a 2% discount rate has been used for the NPV calculation (section 4.6).

2.1.2 Research Questions

Cenex proposed a demonstration project to evaluate the technical requirements and commercial benefits of V2G technology and to develop their cost benefit analysis with City Authorities in Leicester, Grid and Energy Companies, large building owners, EV fleet operators & EV owners. A domestic property in Loughborough with on-site renewable energy generation and electric vehicles would be used to to provide the baseline data for a City-scale Virtual Power plant. Appropriate management strategies for EV charging and discharging are imperative to ensuring that system overload does not occur, whilst guaranteeing that every EV user can undertake their required journeys. Therefore, managed charging and discharging through vehicle-to-grid technology (V2G) can provide an ideal solution, delivering peak demand support when required and enabling managed off-peak charging of electric vehicles.

2.2 Data Processing

2.2.1 Household energy data

The available data from the Loughborough pilot was provided in two parts: household energy data by Moixa[1], and EV usage data by Viriciti[2]. These two data sets were used to derive the four parameters used in the cost-benefit analyses for smart charging and V2G (described in section 4). The four parameters are PV generation, household base load, EV driving energy consumption and EV availability for charging and provision of non-driving services (energy and network support) at the home in Loughborough.

The data processing with associated assumptions is presented as follows:

Figure 3 presents a time series of the main variables for the 7th November 2017. A few observations can be made from this figure. First, PV generation (the red dashed line) is used to supply home demand and there is no energy import from grid to home (blue solid line) when excess PV generation is observed, roughly between 11.00 am and 1.00 pm. This implies that the measured household consumption, as represented by 'grid to home', has taken into account the contribution from PV generation (black line). Similarly, the contribution from stationary battery (green line) to household consumption has also been considered.

Another observation is that the stationary storage has been used to increase household energy autonomy on top of self-sufficiency from PV generation, as indicated by the light blue line.

Finally, it can been seen by comparing the blue line in Figure 6 and Figure 3 that the EV discharging and charging profiles correspond to the measurement of consumption from grid, during the period of 00:00-02:00 am, and 02:00 am - 05:00 am, respectively. Given that there was no PV generation or ESS supply during this time, the household consumption can be attributed to the EV energy exchange.

1 Available from: https://gridshare.moixa-data.com/
2 Available from: https://portal.viriciti.com/signin

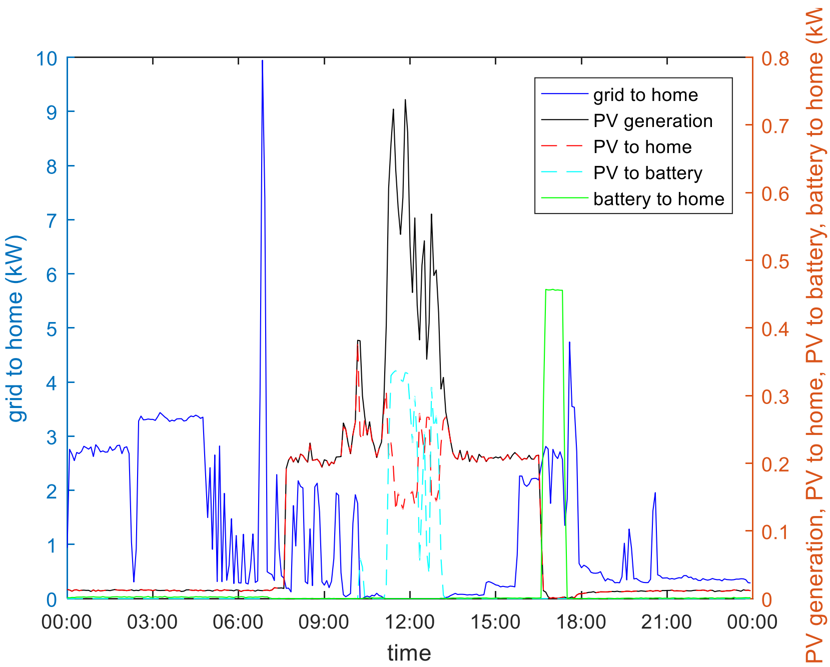

Figure 3 Household energy data – winter example

The actual household baseload consumption can be derived by excluding the contribution of 'PV to home' and 'battery to home' as well as the EV exchange profile from the 'grid to home' profile,. The result is illustrated in Figure 4 where the presented data is in 5-minute averaged format.

It is worth pointing out that the data sampling rate is irregular in the EV usage data and it is essential to synchronise the time appropriately. Here the timestamps for different variables were aligned using EV drive mode as a reference, i.e. it was done by aligning to the nearest available timestamps in the EV drive mode data. A similar approach was applied when aligning the EV data to the household energy data, which was in 5-minute averaged format.

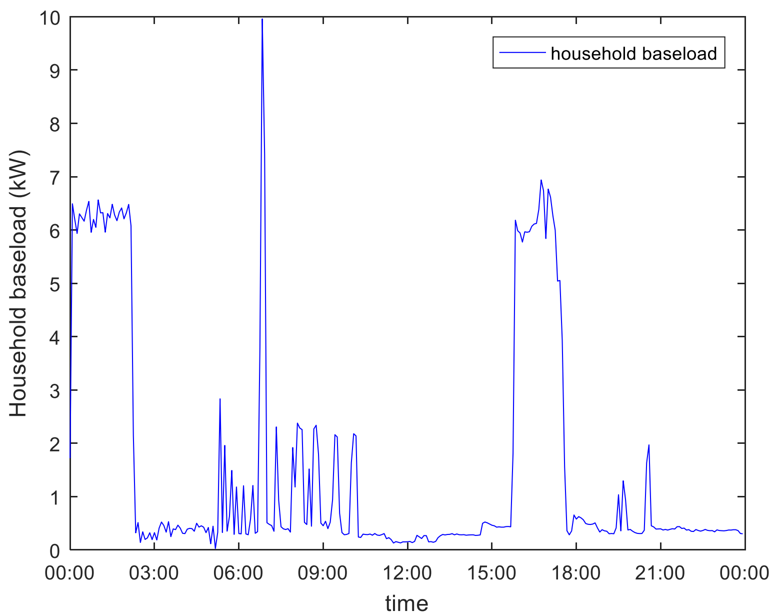

Figure 4 Household baseload – winter example

2.2.2 EV usage data

From the EV usage data, drive mode, GPS position and SoC of the EV battery were all used to determine EV driving energy consumption and EV availability for V4ES. The EV in this pilot was used by the employee's partner, and home charging was the only charging method. Charging events that took place when the EV was away from home (public charging, long trips and holidays) were not considered in this report. Therefore, the EV has been assumed to be available when it is parked at home (with status value of 1) and unavailable otherwise (with status value of 0). EV availability is determined by checking the vehicle GPS when it arrives at home, which can be interpreted by reading the EV drive mode. There are 5 drive modes available (0 = Park; 1 = Reverse; 2 = Neutral; 3 = Drive; 4 = Brake), so arrivals are indicated by transitions from non-zero mode to zero mode. Home location is GPS-bounded in the vicinity of the pilot house. As such, the drive mode can be converted to EV availability, both of which are shown in Figure 5 for a typical weekday (07/11/2017), with green stem and red line, respectively.

Figure 5 shows that the EV's SoC (blue dotted line) reduced due to driving occurring between at around 9.00 am and 3.00 pm, which was captured by the driving mode (green stems). This can be used to calculate the EV's driving energy consumption such as charging energy requirement for each home arrival, which depends on the householder routine and driving habits. The gaps in parameter logging for EV driving mode and SoC between 9.00 am and 3.00 pm as well as 6.00 pm to midnight are due to the event-based parameter logging manner in the Viriciti database. In other words, gaps in the data logging are expected when the monitored parameters stay unchanged.

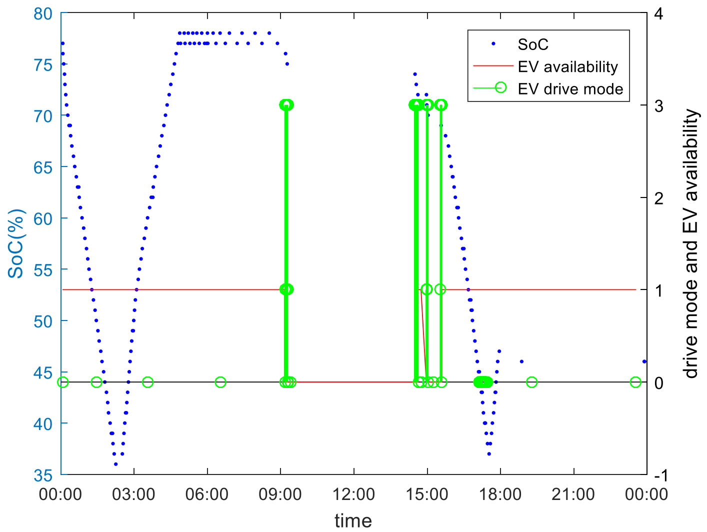

Figure 5 EV usage data processing example

From Figure 5, variation in SoC could be observed during home parking, e.g. between midnight and 9.00 am as well as between 3.00 pm and 6.00 pm. By comparing this with the household energy consumption data (the blue line given later in Figure 3), this change in SoC can be attributed to the energy exchange with the household, i.e. EV charging or discharging. The associated charging/discharging rate can be calculated as the rate of change of SoC for each available timestamp when the EV is available, which can be further converted into kW from a percentage value. As such the EV power exchange profile is obtained, as given in Figure 6. This figure shows the profile calculated from the raw data (the green solid line) together with the processed data[3] after filtering and cleansing (the blue dashed line), where the spikes

3 This is the EV exchange profile measured for the pilot. Note that for the EV smart charging scheduling in Section 4.3 and 4.4, the parameter 'driving consumption' was taken from the Viriciti database as the EV charging requirement, which was checked with the net EV exchange profile and the difference was found to be negligible.

due to measurement errors were successfully removed. The relatively constant level of the bi-directional EV exchange rate is due to the fixed charger rate of ±3 kW. As mentioned in Section 1.1, only vehicle to home (V2H) is technically available for this pilot [1].

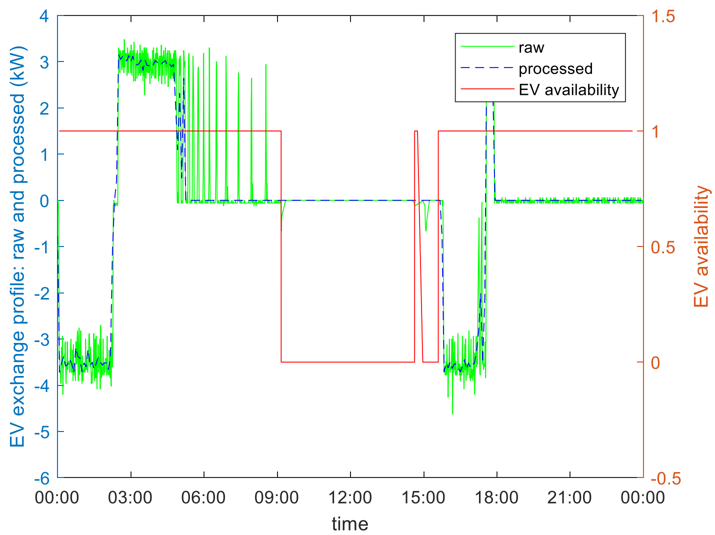

Figure 6 EV power exchange profile: raw and processed (kW)

2.2.3 Yearly data selection

The aforementioned parameters, PV generation, household base load, EV driving consumption, and EV availability, were used in the cost-benefit analyses of V4ES (smart charging and V2G) presented in section 4.

Calendar Year 2017 was initially selected to carry out the yearly analysis. However, the period between May 2017 – May 2018 was subsequently selected due to the fact that V2H was only fully functional from early May 2017. Further observation of the pilot data showed minimal EV activities since January 2018, due to a garage renovation at the pilot location. Therefore, the evaluation was carried out for the period from May 2017 to Dec 2017 and to allow comparison the associated results (from May to Dec 2017) were extrapolated to achieve the annual figures. For each of the three evaluation periods, the data processing described in Sections 2.1 and 2.2 was applied and the associated KPIs were evaluated, as presented in Section 4.4.

One additional observation to note is that the database for vehicle usage (Viriciti) changes time in line with the British summer time, whereas the database for household energy (Moixa) does not update the clock. An example of this asynchronous effect is illustrated in Figure 7 for the summer week commencing from 24/07/2017. This mismatch in time has been calibrated by shifting the household energy record by 1 hour ahead and the Thursday in this summer week has been used as an example to demonstrate this. Figure 8 depicts various household energy records from Moixa, and Figure 9 shows the derivation of base load from household energy data (black curve) and the EV exchange profile (green curve). By comparing these two curves with those in Figure 7, it can be noted that the mismatch in time has been eliminated after time calibration.

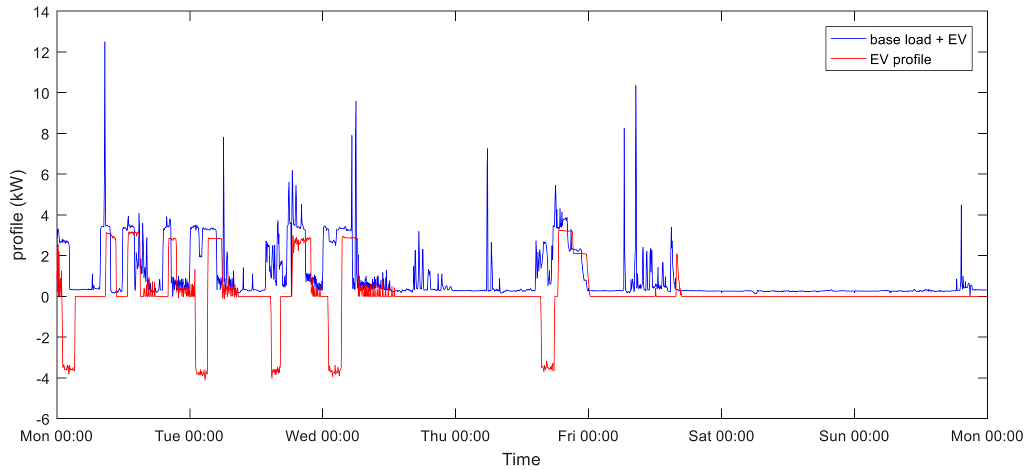

Figure 7 Example of asynchronous data between Viriciti and Moixa database for w/c 24/07/2017

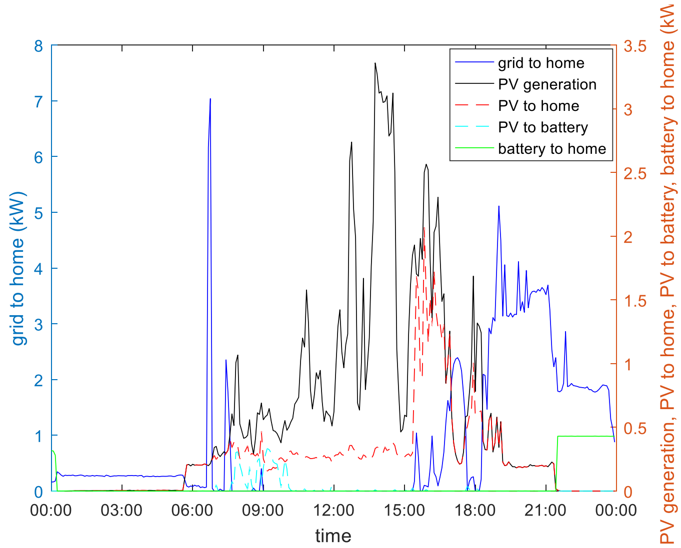

Figure 8 Household energy data – summer example

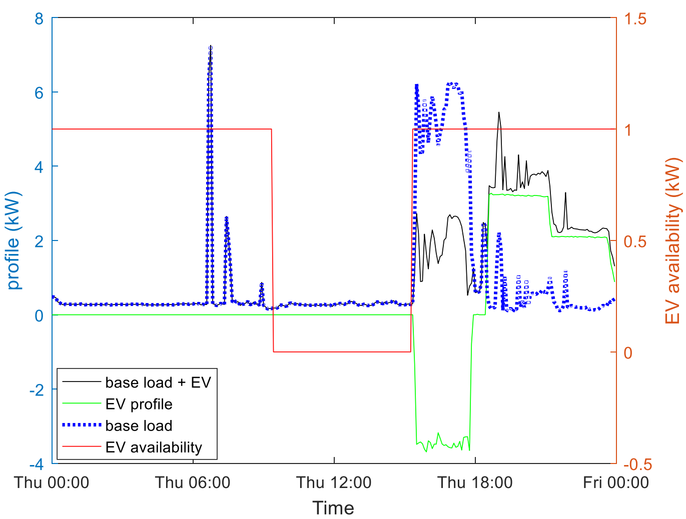

Figure 9 Data processing – summer example

3 SEEV4-City Results – Key Performance Indicators (KPIs)

3.1 *Methodology (summary)*

Each of the SEEV4-City pilots adopted different system components and took their own approach within their relevant system boundaries. They do not all use the same combination of components but instead, these are applied in different combinations. The SEEV4-City project recognised the potential value in identifying the benefits of individual energy system components (such as PV, BSS and EV battery as storage) for design decisions for a specific location in relation to the project's main KPIs, for CO_2 and Energy Autonomy in particular.

The project has therefore chosen to define several sub-indicators for KPIs A and B for the purpose of capturing potential additional insights in relation to CO_2 and Energy Autonomy objectives, and the role these different components may play. The methodology for calculating their contributions is described in more detail in the project's KPI Methodology and Methodology Report. The identified sub-indicators within the methodology are:

KPI A – CO_2 reduction

- CO_2 related to baseline demand
- CO_2 related to use of battery: EV
- CO_2 related to use of battery: BSS
- CO_2 savings by PV production
- Zero Emission kilometres increase

KPI B – Energy Autonomy

- Self-consumption
- PV to Baseline Demand
- PV to EV
- PV to BSS
- PV to Grid

For **KPI C – Grid Investment Deferral**, the methodology is not specific to the specific pilot site only, but instead seeks to evaluate the impact potential of the chosen V4ES solution within the regional grid context.

Relevant results are highlighted in section 4.4 of this final report as part of the Cost-Benefit Analysis.

3.1.1 Approach to CO_2 emissions reduction

The CO_2 emission savings for the Loughborough pilot were calculated from the following two parts:

- Savings due to substitution of an EV instead of an ICE vehicle; and
- Savings due to smart energy management.

The first part considers the difference between the CO_2 emissions in the lifecycles of ICEs and EVs, covering all stages of manufacturing, operation, maintenance and decommissioning. During each of these stages, a certain amount of CO_2 is emitted. To allow a fair comparison, the whole lifecycle for both types of vehicles must be taken into account. It is worth noting that within the scope of SEEV4City, the operation of the vehicle is the only controllable part; the other three parts are driven by technology advancement and penetration level of the technology. Consequently, in this project, the savings in CO_2 emission due to the operation of the electric vehicle must at least compensate for the inherent CO_2 emission penalty due to manufacturing, maintenance and decommissioning, the sum of which for ICE vehicles are significantly less than those for EVs according to Figure 10 [2].

Based on 2010 data shown in Figure 10 [2], CO_2 emissions due to the manufacturing, maintenance and decommissioning phases for EVs (totalling 65.28 g/km) are almost double those for ICE vehicles (34.45 g/km). This is due to the considerable CO_2 emission in the manufacturing of the EV battery. It is worth pointing out that with the continuous advancement in battery technology and the utilization of automotive batteries in second life applications, these figures will significantly improve in favour of EVs [2] [3]. In fact, predictions suggest a CO_2 emission value of 15.53 g/km for EVs in 2050, excluding the operation of the vehicles [2]. In the case of second life battery usage, the overall CO_2 emitted from the aforementioned three phases is distributed over a longer period and therefore the emission per km (or kWh) can be reduced further.

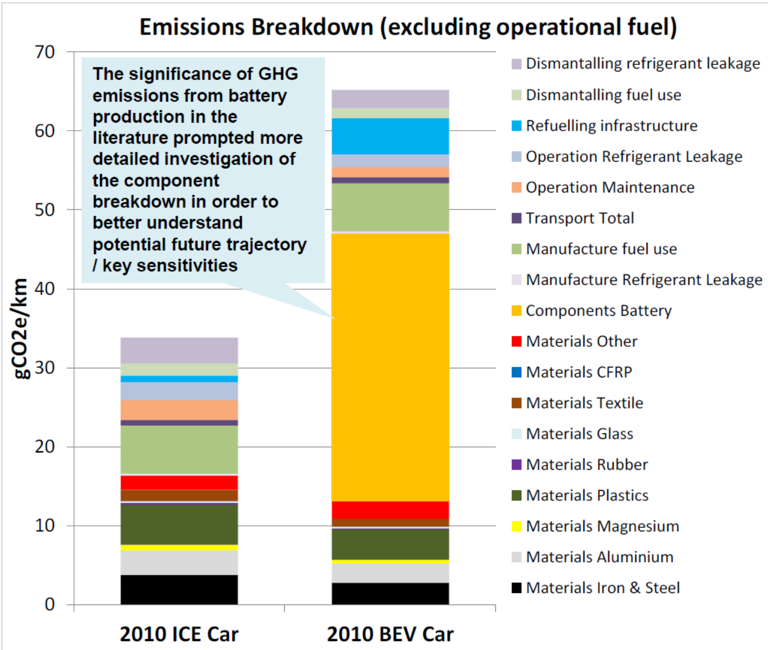

Figure 10 CO2 emission for ICE and EV for manufacturing, maintenance and decommissioning [3]

The CO_2 emission caused by ICE operation is due to the well-to-wheel and tailpipe emissions, and the average value for European ICEs of 210 gCO_2/km, as shown in Figure 11, is taken from [3].

The CO_2 emission due to EV operation depends on the marginal gCO_2/kWh characteristics of the energy mix that is used to charge the battery (kWh) for driving purpose. As can be seen from Figure 11 [3], the average European EV operational emission is much higher than that of France (mainly powered by nuclear) and Norway (mainly powered by hydro). On the other hand, CO_2 intensive national energy mixes, such as in Germany, lead to a lower margin of environmental benefits by EVs when compared to ICEs. For the UK, the electricity energy mix is better than the EU average, Germany and the Netherlands, but worse than that of France and Norway.

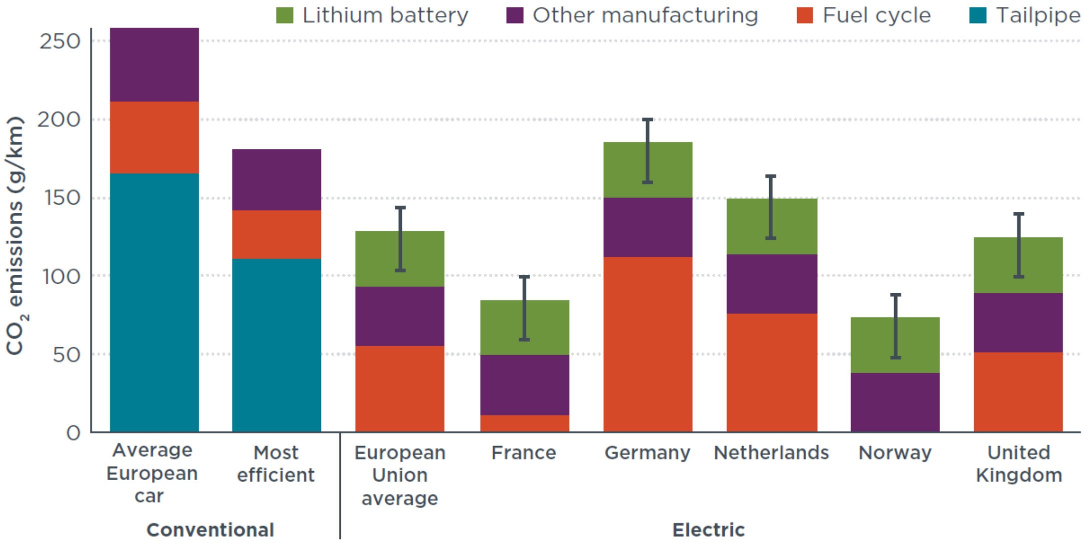

Figure 11 CO_2 emission due to the operation of ICE and EV in Europe [3]

The energy mix used for EV charging changes during the day, week and the season, and hence the CO_2 emissions will change over time. Therefore, there are periods of low marginal gCO2/kWh, which usually happen during off-peak periods (when low-carbon power plants are operated), and then periods with high marginal gCO2/kWh, which usually happen during peak times (when CO_2 intensive power plants are deployed). An example of this is given in Figure 12, which shows the daily CO_2 emissions per kWh based on the UK national energy mix for 9th November 2017.

The energy mix based on the CO_2 emission figures are obtained from the lifetime CO_2 emission values for the various generation types listed in Table 2. This demonstrates that the equivalent CO_2 emission per kWh imported from the grid varies significantly, depending on the generation mix at any specific time. Therefore, CO_2 emissions from EV driving can be reduced by implementing smart energy management and smart charging of EVs. Scheduling EV charging to occur during off-peak periods with low-carbon generation and local PV generation will reduce overall CO_2 emissions and at the same time smooth the overall grid demand profile.

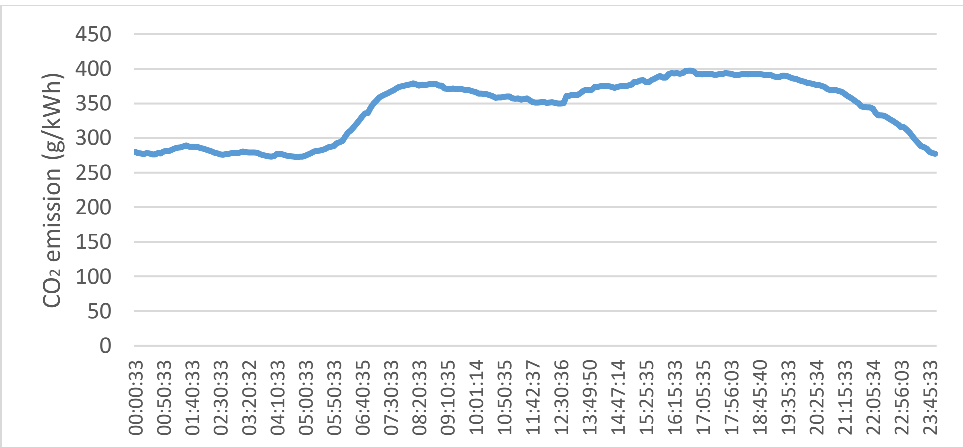

Figure 12 Energy mix based CO_2 emission for the UK on 09/11/2017 [4]

Table 2 Lifetime CO2 emission for different generation types [4]

Generation type	Lifetime CO_2 emission [g/kWh]
Wind	11
Nuclear	16
Hydro	20
PV	40
CCGT	487
OCGT	487
Oil	650
Coal	870

3.1.2 Approach to Energy Autonomy increase

Within the scope of the SEEV4-City project, energy autonomy is defined in line with established literature as energy self-sufficiency, as expressed by equation (1) [5] and illustrated in Figure 13. In the case where PV is the only local production source, the energy storage (whether stationary or in an EV) is used to store excess generation from the PV and supply this during the peak demand later in the day (see **ES+** and **ES-** in Figure 13). The difference between an EV and a static battery (apart from the potential size difference) lies mainly with the fact that an EV (essentially used as a transportation vehicle) presents availability constraints and requires a specific SoC before journeys.

$$Self-sufficiency = \frac{Amount\ of\ local\ PV\ production\ consumed}{Total\ energy\ consumed} = \frac{C + ES^{+}}{A + C} \qquad (1)$$

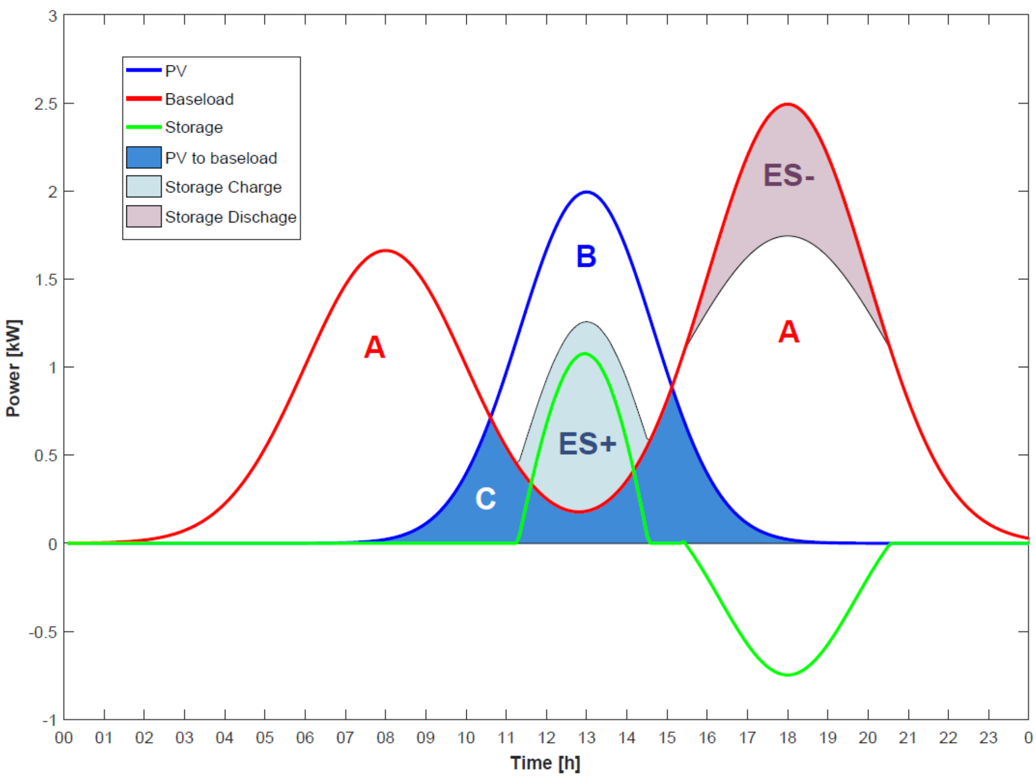

Figure 13 Illustration of energy autonomy

3.1.3 Approach to Grid Investment Deferral

Due to the small scale of the Loughborough pilot , its impact on the grid operation was assessed within the low voltage (LV) distribution network (where the highest impact will occur). To this end, a radial distribution network was used to evaluate the impact of EV charging on grid operations and the benefits of V4ES (see Figure 14).
The main technical specifications of the LV distribution network used in this pilot are listed in Table 3. In the analysis presented in section 4, the grid investment deferral due to V4ES was evaluated as a percentage value in terms of the improvement in voltage profile and substation/main feeder loading.

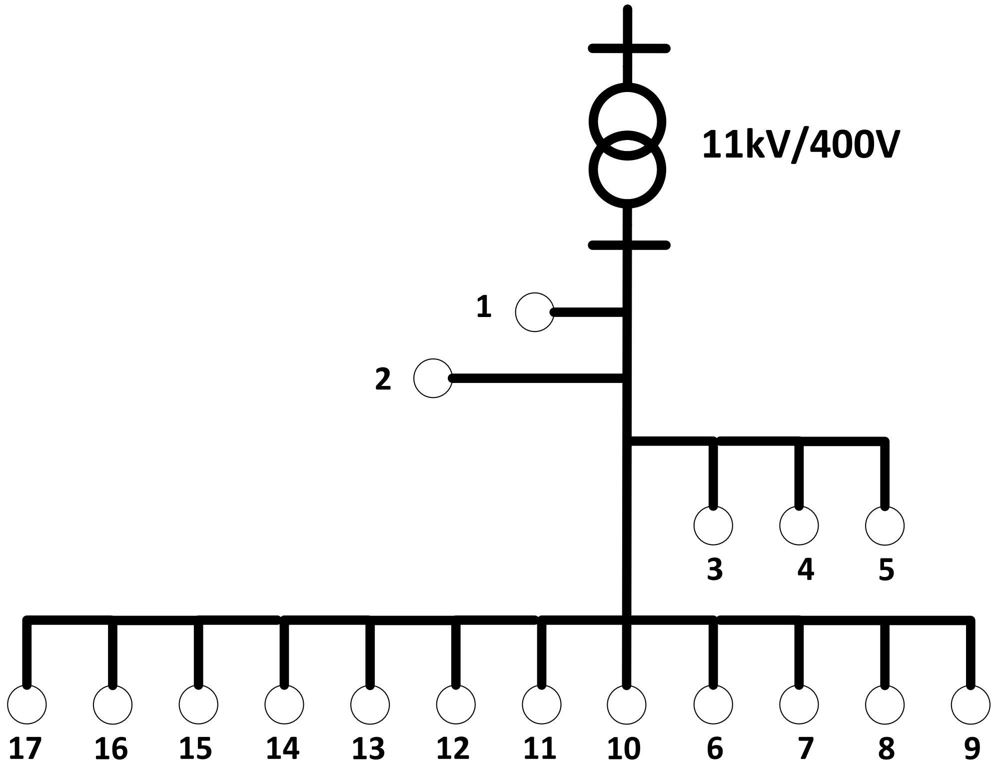

Figure 14 Single line diagram of the LV distribution network

Table 3 Technical specifications of the main components of the LV network

	Technical specifications
Substation transformer rating	300 kVA
Main feeder thermal limit	Maximum current of 393 A
Voltage operation range	0.94 – 1.1 per unit of rated voltage of 230 V

3.2 Baseline and Final measurements

The table, below, presents the baseline and final measurements for each of the KPIs and sub-indicators, where it was possible to calculate them:

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
A. CO_2 Reduction				
A.1	Pilot CO_2 footprint	2.04 tonnes	1.00 tonnes	-1.04 tonnes
A.1.1	CO_2 related to baseline demand	1.63 tonnes	1.51 tonnes	-0.12 tonnes
A.1.2	CO_2 related to use of battery: EV	0	0.22	0.22 tonnes
A.1.3	CO_2 related to use of battery: ESS	0	0	0
A.1.4	CO_2 savings by PV production	-0.85	-0.85	0
A.1.5	CO2 savings by ICE to EV replacement	1.26 tonnes	0.12 tonnes	-1.14 tonnes
A1.6	ZE km increase EV	0	3478 km	3478 km
A.2	Grid Services	N/A	N/A	N/A
A.2.1	FCR – Frequency Containment Reserve	N/A	N/A	N/A
A.2.2	Battery as back-up services (replacement of diesel generators)	N/A	N/A	N/A

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
B. Energy Autonomy Increase				
B.1	Self Sufficiency	25.0%	30.1%	5.1% point increase
B.2	Self Consumption	48%	65%	17%
B.3	PV to Baseline Demand	1.6	1.5	-0.1
B.4	PV to EV	0.0	0.4	0.4
B.5	PV to ESS	0.0	0.2	0.2
B.6	PV to Grid	1.8	1.1	-0.6

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
C. Grid Investment Deferral				
C.1	Peak Demand Value	N/A	2.6% to 12.3%	Improvement of 2 to 12%

4 Cost-Benefit Analysis

Cost benefit analysis is the core of any business model and in the context of the SEEV4-City project, this must be conducted for each V4ES service to evaluate the profitability of the required investment. The structure of a generic business model for V4ES is presented in Figure 15. According to the business model adopted (baseline or the proposed one), there will be different stakeholders involved and different costs or benefits for each stakeholder.

The user (house/EV) entities consist of the base load, PV, stationary energy storage, EV charger and EV. All of these are linked to the power grid (distribution and transmission) and the direction of energy flow is as indicated in Figure 15 (black coloured arrows). Currently, the contract is signed between the user and energy retailer, which then links with the energy market. In the future, more stakeholders will be involved in V4ES and these are coloured in red in Figure 15, where the blocks indicate a commercial entity and the red dashed arrows show the associated ICT connections. The aggregator shown in Figure 15 is the contractor/coordinator of EV energy, although this role is currently not present in the actual Loughborough pilot, as the V2G function was technically unavailable due to the limitation in the hardware. The energy retailer in this case is responsible for settling the transactions for base load with the user. The mobility retailer and the infrastructure provider are included in the structure and the OEM of EV is also included in the value chain. Finally, policies for energy, transportation and environment can have direct or indirect impact on the EV energy scheduling scenarios; thus, these were also considered in the business model. It should be noted that the services provided by different stakeholders could be fully or partially combined to achieve certain objectives for the stakeholders.

V4ES and the associated business model can be tailored to favour different targets, following the reasoning illustrated in the 4 pillars shown in Figure 16. Currently, the priority objective of the Loughborough pilot is the maximization of energy autonomy (Pillar 2) and as such, the stakeholders involved in the baseline case include the EV, the EV charger and the retailer that is responsible for the billing of the energy consumption. V2G operation was not currently implemented in phase 1 of this OP. However, the economic viability of V2G in terms of frequency regulation has been analysed in this work (section 4.5), which would involve extra stakeholders such as the aggregator and system operator.

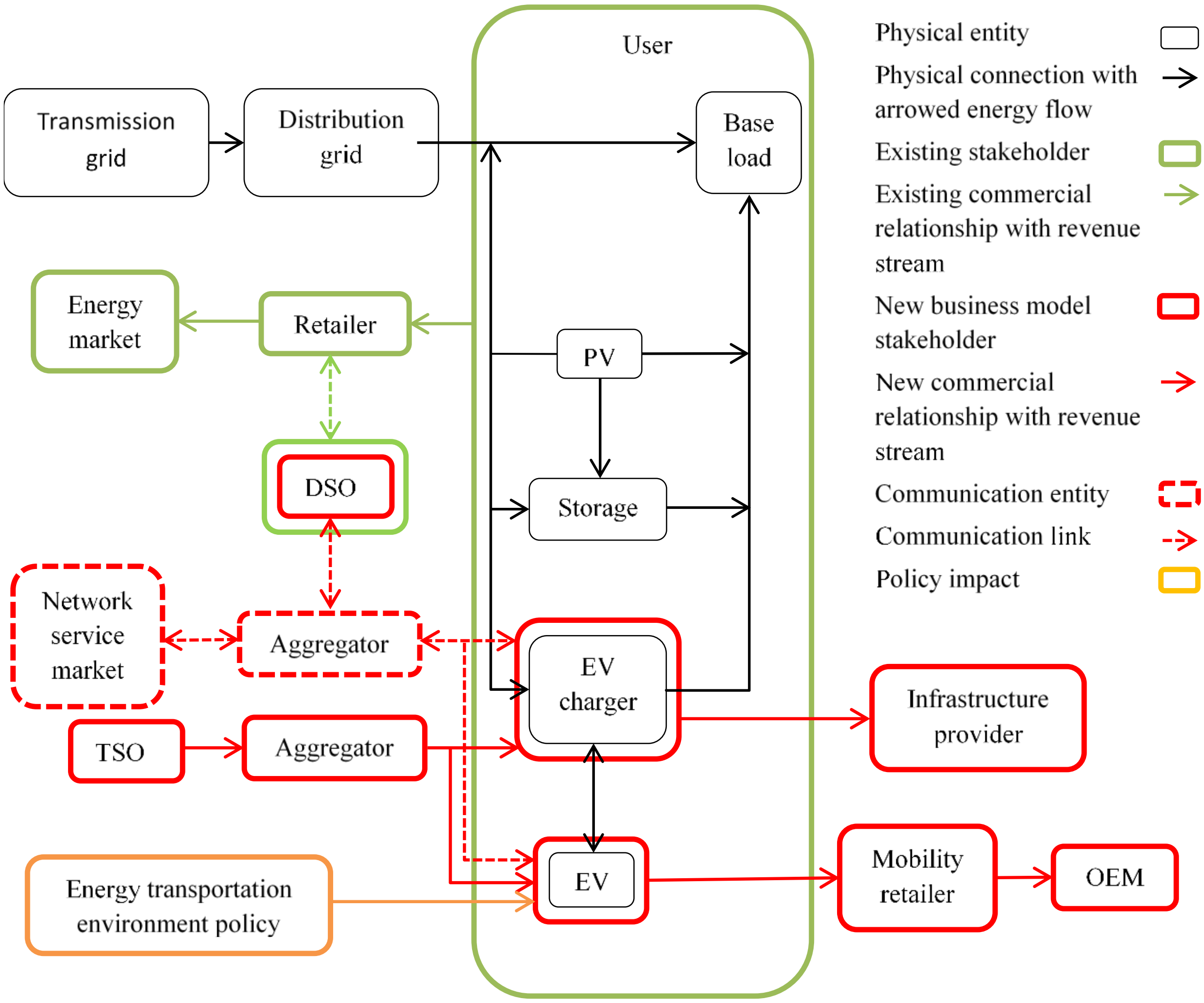

Figure 15 Generic business model structure for V4ES

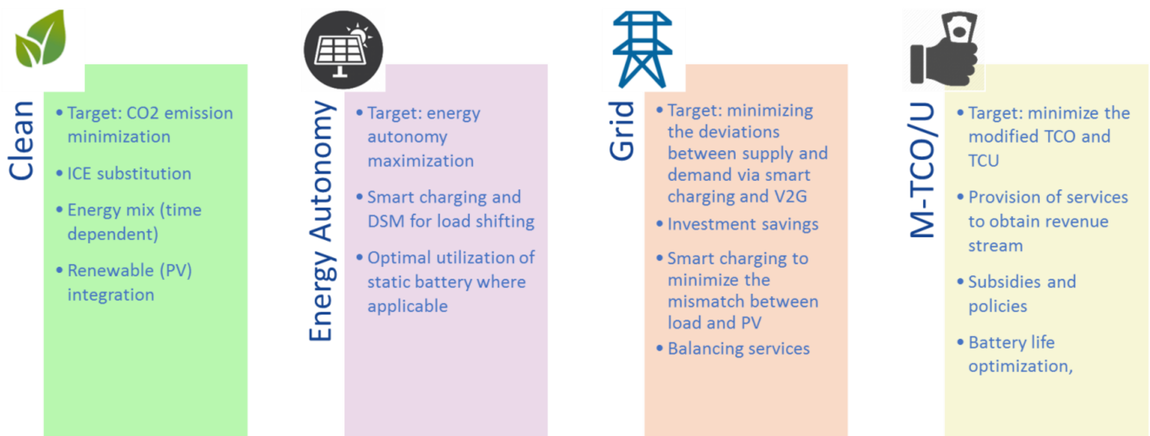

Figure 16 Business model pillars

4.1 Loughborough pilot setting

The economic feasibility of the proposed business model (with associated V4ES) was compared with a baseline case which reflects the current status of the operational pilot. The baseline case was derived from the records in the databases, as explained in Section 2, where smart charging and V2H have been implemented. The analysis demonstrates the improvements the proposed business model for V4ES can bring into the baseline case in terms of the KPIs, i.e. improved energy autonomy, reduced CO_2 emissions, deferred grid investment, and improved overall economics.

The setting of the baseline case is defined in Table 4, where the battery degradation cost of 6.8p/kWh of energy throughput was assumed (for an EV with bi-directional rating of 3 kW).

Table 4 Baseline setting for Loughborough pilot

Variable	Value	Unit
PV system	4	kWp
Vehicle battery capacity	24	kWh
Charging/V2G unit converter size	3	kW (fixed)
Static battery size	2	kWh
Static battery charging rate	Max 350 W charging Max 430 W discharging	W W
Electricity standing charge	30.1	p/day
Electricity tariff price	15.1	p/kWh (fixed)
PV generation tariff	13.74	p/kWh
PV export tariff	4.5	p/kWh
Battery degradation cost @ 3kW	6.8	p/kWh of throughput

In terms of the renewable supporting scheme, the Loughborough pilot benefitted from the UK's Feed in Tariff (FIT) (given in Table 4) which consisted of:

- a generation tariff, for each kWh generated
- an export tariff for each kWh exported to the grid, but since there is no dedicated meter for PV export measurement, it is assumed that half of the generation is exported. This assumption is accepted and commonly used in FIT calculations for residential PV systems in the UK.

4.2 EV battery degradation cost

Batteries are expensive assets and therefore need to be utilized in the most efficient way to preserve their state of health. Previous work suggested that extra degradation can be caused by providing V2G [6]. As such, battery degradation is investigated in this section and included in the V4ES business model.

Battery reduction in capacity (fading) always occurs both when the battery is inactive (calendar loss) or used (cycle loss) [7]. Calendar degradation occurs even when a battery is not used and is understood to be a function of the time of storage, the average SoC and the temperature during storage. For instance, storage at a low temperature in the absence of energy exchange is favourable, as is storage at a low SoC, since both these factors reduce electrical and thermal stress factors which otherwise promote degradation [8].

When the battery is used to provide energy services, energy is stored (charging) in the battery or supplied (discharging) and the battery is cycled at a certain charge/discharge rate. Performing a cycle at a high charge/discharge rate has a more adverse impact than performing a cycle at a low charge rate [8]. Both calendar and cycle degradation affect the available capacity of the battery. The charge rate is usually normalised with respect to the battery's full capacity, which is known as the C-rate. For example, a nC rate means the battery can be fully charged or discharged in 1/n hours at this current level. Thus, 1C represents the current to charge the battery from zero to full in 1 hour. This normalisation helps to present the charging speed directly without considering the specific battery capacity.

In the automotive industry, one of the conditions that determines that a battery has reached the end of its useful life is when its maximum capacity falls below 80% of its nominal capacity when the battery was new. In this case, the battery needs to be replaced, and may perhaps be used to provide stationary storage (as a 'second life' application).

The research work carried out at Northumbria University has evaluated the effects of different factors that contribute to battery degradation. Commercial battery cells are stored and cycled under different conditions and their lifetime is measured in terms of number of cycles before reaching end of life (20% capacity degradation). In the context of the SEEV4-City project, the charge rate, one of the factors which determines the energy throughput, has been selected as the main stress factor for the following analysis of V2G. This assumption is reasonable since the effects of other degradation factors may be kept relatively low by keeping the temperature and average SoC reasonably constant.

For SEEV4-City analysis, cells were tested using the experimental setting given in Table 5, where 2016 Nissan Leaf 32.5 Ah $LiNiMnCoO_2$ EV pouch cells were cycled at 0.3C and 1C. It is known that, for Li-ion cells of a given type, the degree of battery degradation per cycle is proportional to the C rate up to 1C [9] [10]. The experimental results enabled the production of a graph of cycling degradation vs charging rate. For these tests, a full cycle means a discharge at a certain depth of discharge (DoD), followed by a charge at the same DoD, so the average SoC remains constant.

Table 5 Experimental setting for battery testing

C-rate	Temperature (°C)	DoD(%)	Battery type
0.3 C	25	80	EV pouch 33Ah chemistry $LiNiMnCoO_2$
1 C			

The test results are illustrated in Figure 17, where the capacity degradation is plotted against the number of cycles under different C-rates.

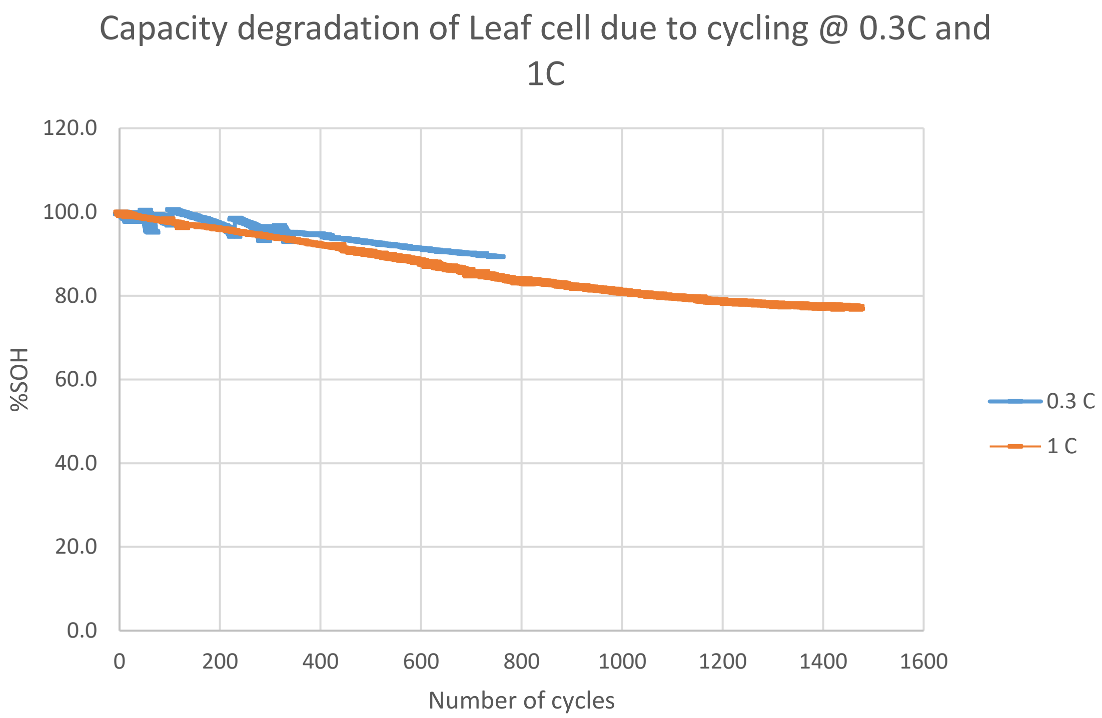

Figure 17 Capacity degradation at different charging rates

The different slopes of the curves in Figure 17 indicate different degradation rates at the corresponding C-rate, i.e. 0.3C and 1C. These two degradation rates are illustrated in Figure 18 against the C-rate they were tested under, and a linear fitting, as expressed in Equation (2), is assumed according to [11].

$$degradation\ per\ cycle\ (\%) = 0.0067 \times C + 0.0122 \qquad (2)$$

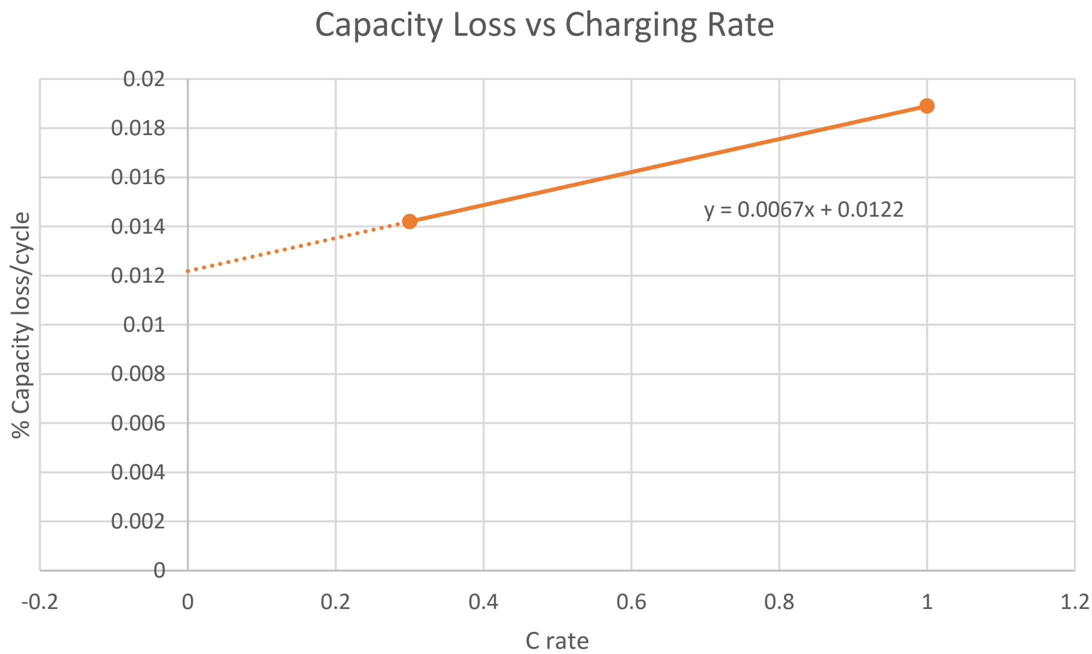

Figure 18 Extrapolation of the capacity loss against the charging rate from actual results

A tentative value for EV battery degradation per cycle can be determined from Figure 18 , which could then be used to calculate the number of cycles (as well as the lifetime energy throughput) before the estimated end of life. As such, a cost of degradation can be established by dividing the cost of battery by the lifetime energy throughput, $E_{life@C\text{-}rate}$, as expressed in Equation (3).

$$c_{\deg\_C} = \frac{c_b}{E_{life@C-rate}} \ [£/kWh] \qquad (3)$$

where c_{deg_C} is the degradation cost due to a specific charging rate and c_b is the cost of the battery.

In the Loughborough pilot, the rating of the EV charger was fixed at 3 kW, which translates to 0.125C for the Nissan Leaf 24 kWh battery. This gives a degradation of 0.013% per cycle according to Equation (2), which leads to a capability of 1538 cycles and an energy throughput of 53,160 kWh before the estimated end of automotive life. The cost of commercial Lithium ion cells is currently in the range of £150/kWh - $200/kWh [12] [13]. As such the battery degradation cost per kWh at 0.125C for a Nissan Leaf battery can be estimated using Equation (3) as 6.8 pence/kWh.

4.3 Smart Charging for Energy Autonomy and CO_2 emissions reduction

As introduced in Section 1, V4ES considered in this report cover smart charging and V2G. Due to the flat electricity tariff in the Loughborough pilot, which prevents price arbitrage, V2H is not included in the scope for the proposed business model. In contrast, V2G in the form of frequency regulation receives an extra payment for the service provision and it is therefore evaluated in Section 4.5 as possible route to consider.

The smart charging methodology presented in this section is designed to maximize energy autonomy, which also reduces the CO_2 emission by utilizing local renewable generation, and at the same time smoothes the demand profiles exchanged with the grid. To this end, a smart charging methodology as shown in Figure 19 was adopted, where the energy consumed due to driving is recharged from arrival at home (12pm-3pm) in the ascending order (i.e. 1, 2, 3, 4) of net exchange (yellow curve), which is the difference between the baseload (red curve) and the PV generation (blue curve). On top of this, the stationary ESS is also scheduled to increase the household energy self-sufficiency by charging at times of excess PV generation and releasing this energy later on to supply the local demand.

Due to the limitation of the pilot configuration as presented in Section 4.1, the EV charging rate was fixed at 3 kW, and the ESS was set to charge during excess PV generation up to a limit of 350 W; a demand threshold of 430W was used to trigger the ESS discharging.

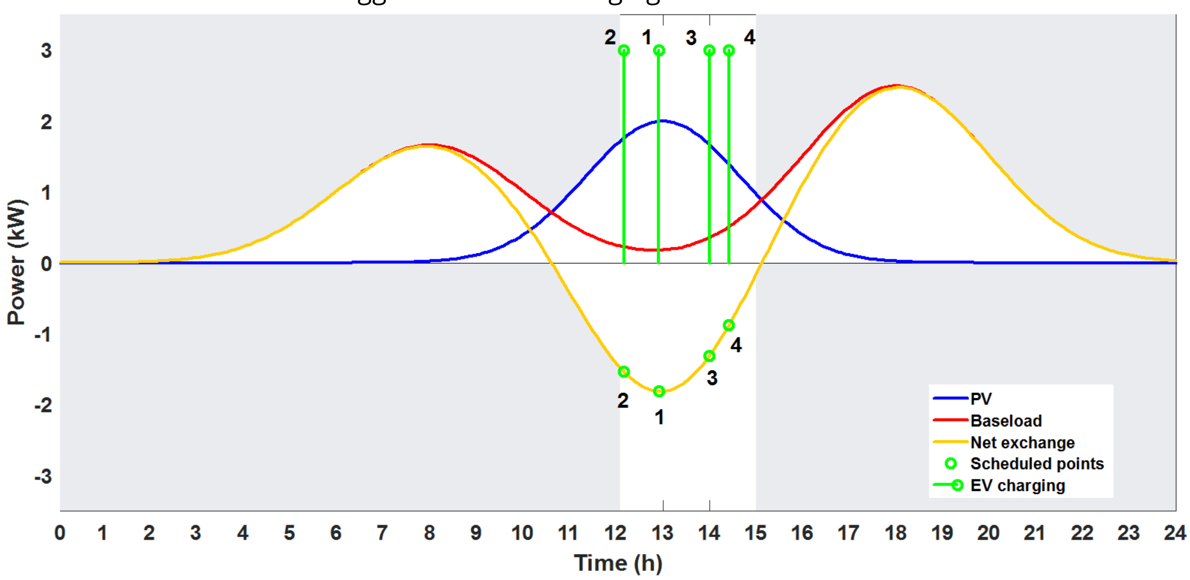

Figure 19 Smart charging methodology

4.4 Annual evaluation results

Following the discussion of the yearly data selection in Section 2.3 and the smart charging methodology explained in the previous section, the improvement by smart charging compared to the baseline case is presented here

An example of five consecutive days from the midnight of Thursday 9th November to midnight on Tuesday 14th November 2017 is shown in Figure 20 to illustrate the scheduling results from the smart charging methodology. The EV availability, as illustrated by the red lines in this figure, presents 5 full arrival–departure cycles during the period, and the profiles for EV smart charging and ESS scheduling are represented by the magenta and black curves, respectively, alongside the household base load (represented by the blue line) and the PV generation (represented by the green line).

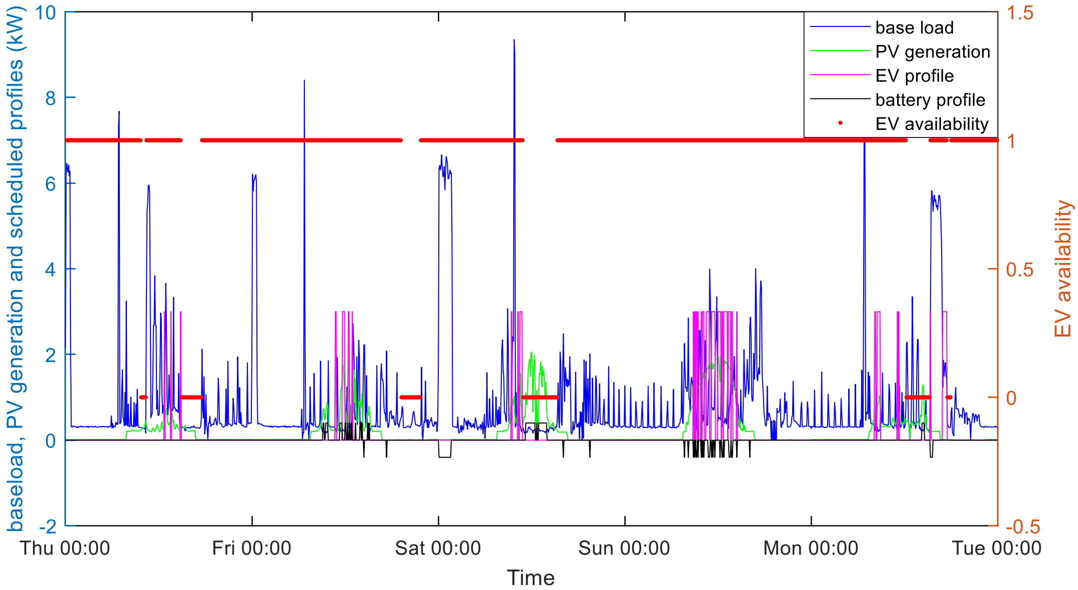

Figure 20 Charging scheduling of EV ESS for energy autonomy maximization

The annual evaluation of energy autonomy and CO_2 emission savings that are calculated in line with the KPIs defined in Section 3 are presented in Table 6 with the associated operational cost. For the three selected evaluation periods as mentioned in Section 2.3, smart charging has shown, on average, an increase of 5.1% point in energy self-sufficiency, a CO_2 emission reduction of 771kg, and a reduction of £188 in the operational cost, compared to the baseline case. The operational cost is further broken down in Table 7 where the benefit from FIT is represented as a revenue stream, while energy consumption and battery degradation are represented as a cost.

Table 6 Comparison between the Baseline and Smart charging as part of V4ES for the selected periods of analysis

		Annual evaluation (projected from)		
		Jan 2017 – Dec 2017	May 2017 – Dec 2017	May 2017 – May 2018
Energy autonomy (%)	Baseline	29.77	26.86	24.96
	Smart charging	35.48	32.24	30.08
	Improvement	5.71	5.38	5.12
CO_2 saving (kg)	ICE replacement	631	646	665
CO_2 emission (kg)	Baseline	1403	1669	1633
	Smart charging	1301	1522	1512
Total CO_2 saving (kg)	ICE + Baseline - Smart charging	734	793	787
Operational cost (£)	Baseline	350	531	569
	Smart charging	190	292	403
	Savings	160	239	166

Table 7 Operational cost breakdown

		Breakdown of projected annual cost (for period of)		
		Jan 2017 – Dec 2017	May 2017 – Dec 2017	May 2017 – May 2018
Home base demand (kWh)		5694	7040	6288
EV driving consumption (kWh)		762	818	831
PV generation (kWh)		3598	4036	3275
Baseline	Energy cost (£)	796	944	917
	FIT (£)	-589	-620	-506
	Battery degradation cost (£)	143	206	157
Smart charging	Energy cost (£)	725	858	853
	FIT (£)	-589	-620	-506
	Battery degradation cost (£)	53	54	56

With regards to the grid impact analysis in the smart charging and baseline cases, a random day in the evaluated period was selected for each of the 17 buses (representing 17 different houses) in the network simulation to emulate the pilot behaviour, as illustrated in Figure 14. The simulated results, are shown in Figure 21 and Figure 22 for substation transformer/main feeder loading and voltage profile (at the furthest end from the substation transformer, i.e. bus 17), respectively.

Smart charging (the red curve) shows higher consumption during the day (implying higher energy autonomy) compared to the baseline (blue curve), where the latter shows reverse power flow (from 10am to roughly 1pm in Figure 21), indicating insufficient use of PV generation. An improvement of 12.3% and 2.16% has been achieved in substation transformer/main feeder loading (in Figure 21) and voltage profile at bus 17 (in Figure 22) respectively, during the morning demand spike between 6:00 am and 7:00 am.

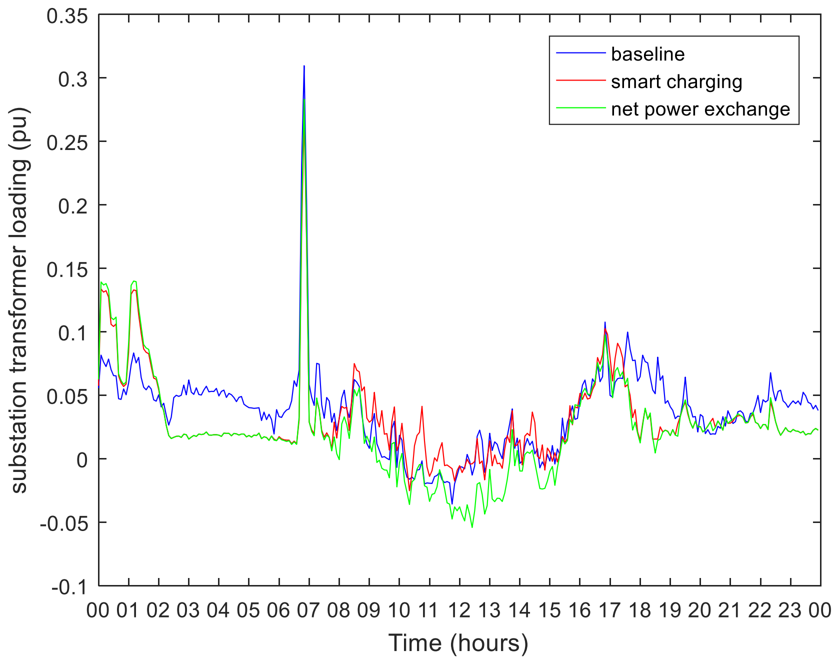

Figure 21 Substation transformer/main feeder loading in p.u. value

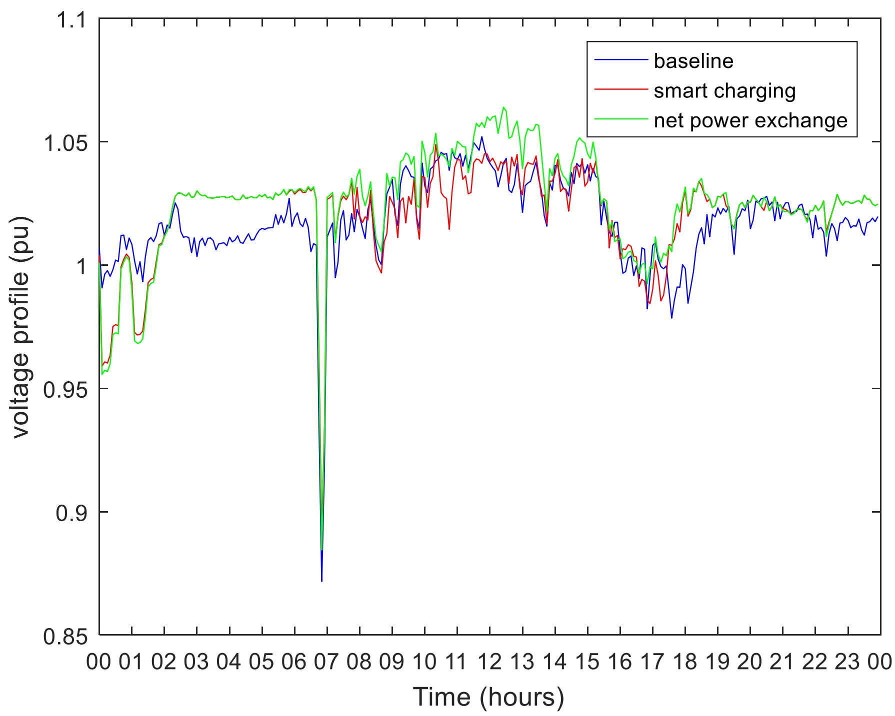

Figure 22 Voltage profile of bus 17 in p.u. value

4.5 V2G – frequency regulation provision

The SEEV4-City state-of-the-art review (2018) has identified frequency regulation as the most profitable ancillary service in the UK. Frequency regulation requires shallower battery cycling compared to other V2G services such as peak shaving and therefore is likely to be less harmful for the battery's state of health. In addition to smart charging as presented in the previous section, frequency regulation service provision is investigated in this section as a V2G service, in terms of its associated technical requirements and economic feasibility.

Firm Frequency Response (FFR) was selected out of the three frequency response options in the UK, due to its tender based procurement process and low entry capacity requirement. FFR is procured via monthly tenders and the successful providers are rewarded with an availability fee (a payment being made based on power committed and the period for which the commitment is offered) and a regulation energy fee (a payment based on the actual energy provided). Table 8 summarises the tender details for the FFR provision modelled in this report, where the primary dynamic frequency response with a response range of 0.2Hz was selected.

The asset must respond within 2s from the provision request and provide all of the power requested within 10s followed by continuous provision for a further 30s, which has been shown to be possible from EV fleets [14] [15]. The FFR commitment period from 11:00 pm - 07:00 am was chosen due to the compatibility with the user requirement for transportation in the Loughborough pilot (judged based on the historical EV GPS data and Viriciti driving mode). In addition, overnight primary FFR provision between 11pm-7am is currently deemed the most valuable by the UK National Grid [16].

Table 8 FFR provision tender details

		Value
Contracted type		Primary dynamic frequency response
Contracted period		11:00 pm - 07:00 am
Contracted amount		3 kW/h
Availability payment		23.03 £MW/h
Energy payment (£/MWh)	Regulation up	$p_e = E_r * 1.25 * PXP$ [17] [18]
	Regulation down	$p_e = E_r * 0.75 * PXP$

The contracted amount of power was set at the maximum EV charging rate of the V2G unit of 3 kW and it was assumed that this EV was part of the aggregated balancing units in order to meet the entry capacity requirement of 1 MW. Note that aggregation costs were not considered. The availability payment was obtained from a post-tender report in November 2017 [16]. Energy payment symbolised by p_e is calculated differently for regulation up and regulation down as can be seen from Table 8, and E_r is the energy absorbed from or injected into the grid during FFR provision. PXP is the wholesale market index price.

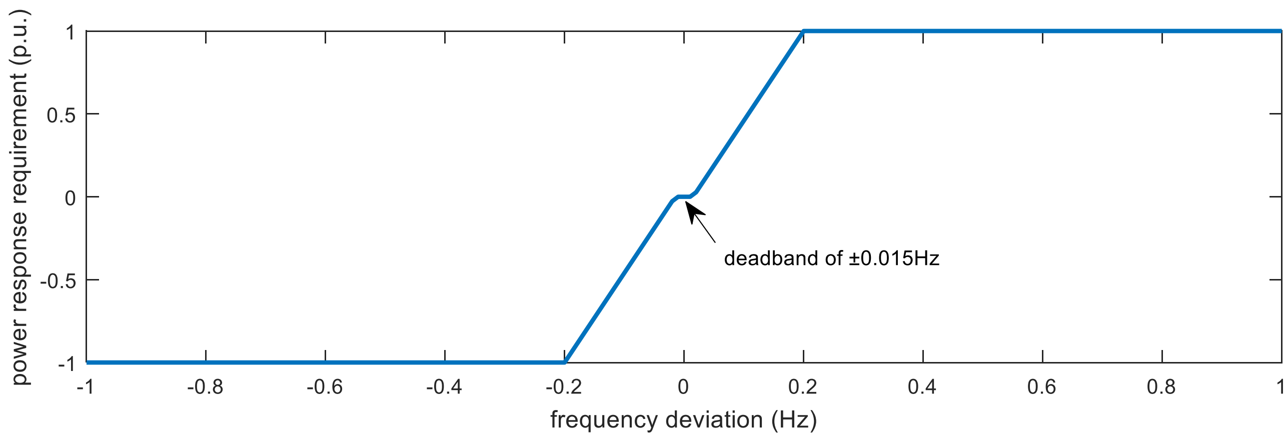

Figure 23 Droop frequency control characteristic

The frequency control requirements are illustrated in Figure 23, where the power requirement responds linearly to the frequency deviation within 50±0.2Hz, with a dead band of ±0.015Hz. This would require a variable rate EV charger, or variable numbers of EVs committed, and the technical feasibility of the former operation is supported by the current standard IEC 61851 [19]. As such, the annual economic evaluation for the period from May 2017 to May 2018 is shown in Table 9 with detailed cost and profit terms. FFR in this case is demonstrated to be profitable, ignoring capital costs, even when battery degradation cost is considered as presented in Section 4.2.

Table 9 Cost and benefit of FFR provision

		Value
Availability payment (£)		204
Energy payment (£)		41
	Regulation down	– 26
Battery degradation cost (£)		-108
Total cost benefit (£)		111

4.6 Investment/return analysis

This section presents a cost and benefit analysis using the net present value (NPV), for both the baseline case and the proposed smart charging and V2G FFR business model. Table 10 lists the investment cost on the infrastructure used in the pilot, i.e. PV system, static energy storage system and the EV smart/V2G charger along with the assumed lifetime of these components as per industry standards.

Table 10 Investment figures for additional infrastructure [1] [20]

Infrastructure	Investment cost (£)	Lifetime (year)
PV system (4 kWp)	$1.83\frac{£}{Wp} * 4000\ Wp = £7320$	20
Static energy storage system (2 kWh)	£2000	10
EV smart/V2G charger	£500	10

NPV was used in this report to analyse the profitability of the Loughborough pilot, being an international industry standard method for conducting such an assessment. NPV provides the current monetary value of a potential investment project by converting the yearly cash flow throughout its lifetime to the present value using a discount rate. An investment with a positive NPV will be considered profitable, prior to the non-accounted aggregation costs, whereas an investment with a negative NPV is result in a net loss compared to a 'do-nothing' scenario [21].

NPV is defined by Equation (4):

$$NPV = \sum_{i=1}^{N} \frac{Yearly\ cash\ flow}{(1+r)^i} - Investment \qquad (4)$$

where the *yearly cash flow* during the investment lifetime of *N* years, is converted to the present value using a discount rate, *r*, of 2%, [22]. In this case, *N*=10, based on minimum component lifetime. The investment and return terms are detailed in Table 11 for three cases, namely the baseline, smart charging, and V4ES which includes additional FFR provision in addition to smart charging. The investment cost is the same for the three cases investigated, and the yearly cash flow was calculated based on the annual evaluation projected from the period between May 2017 - December 2017, as presented in the previous sections. Equation (4) is then used to obtain the NPV for a lifetime of 10 years, which covers only half of the assumed PV lifetime. An effective NPV is therefore calculated by taking into account the residual PV value after 10 years.

Table 11 Cost and benefit breakdown

	Baseline	Smart charging	V4ES = smart charging + FFR
Investment (£)	-9820	-9820	-9820
Yearly cash flow (£)	633	872	983
NPV (£)	-4134	-1987	-990
Residual PV value after 10 years (£)	3660*	3660*	3660*
NPV in effect (£)	-474	1673	2670

* : 7320/2 = 3660

It can be seen from Table 11 that the baseline case is the least profitable scenario, which fails to recover the initial investment over the specified time period of 10 years. Smart charging on the other hand achieves an effective NPV of around £1.7k in 10 years, which shows an increase in NPV of £2.1k when compared to the baseline. FFR provision, if enabled and was undertaken, would bring in £1k more profits to the investor than using smart charging alone. However, it is worth pointing out that these NPV figures do not include the share that needs to be deducted to defray the aggregation cost. In addition, the cost benefit analysis is also very sensitive to the discount rate. In this case a discount rate of 2% is used, which is an optimistic but realistic choice. This concludes that a combination of profitable services would make the most economically feasible solution in the V4ES business model.

5 Lessons from the different pilot phases

5.1 Preparation and initiation

Cenex created a customized system for the Loughborough pilot, where the system was installed in a Cenex employee's house, by combining hardware and software from a number of suppliers. The 2 kWh battery (400W fixed input/output) and 4 kWp solar panels were provided and operated by Moixa. The bi-directional charger was provided by Potenza (very early technology which suffered from reliability problems) to charge and discharge the 24 kWh Nissan Leaf (2012).

5.2 Procurement

Contrary to other pilots the Loughborough pilot had no procurement process as the complete energy system was inherited from a previous energy project called the Ebbs and Flows of Energy Systems (EFES).

5.3 Implementation and installation

Apart from initial commissioning issues, the system performed as expected. Commissioning of the system appeared to be sensitive to delays for the Loughborough pilot (or rather the EFES forerunner). The delay took about a month until the issues were solved (the exact details are unknown). Due to the immaturity of the DSO grid regulations at the time, the bi-directional charger was installed behind-the-meter and could only discharge the EV battery to the house (V2H).

5.4 Operation

After being operational for almost a year, the system was shut down due to construction works on the home, but issues arose when reconnecting the system. Both the V2G unit and battery systems did not work. In the case of the former, it became clear that the unit had outlived its expected lifetime and some components had broken. In the case of the battery system, the relocation appeared to clash with a server migration, leading to a communications malfunction.

In addition, during the period where analysis of the root-causes and potential solutions were taking place, the homeowner made the decision to move house. The decision was therefore made to transfer the pilot to another comparable home situation, which resulted in the second phase of the project (see the appendix).

6 Upscaling and Transnational transfer potential of this V4ES

With a growing number of EVs on the roads as well as the rise in RES (PV) adoption on household roofs both in the UK and outside its borders, it is interesting to explore what the potential for wider roll-out and adoption of this V4ES is, either as V2H or as V2G. To explore this potential, we have identified a number of factors that are expected to be of significant influence. Below some of these aspects relevant to the Loughborough and Burton-upon-Trent pilots are discussed.

N.B: *A more extensive background and evaluation of the upscaling and transnational transfer potential across all four countries of this and other solutions, please read the SEEV4-City 'V4ES Evaluation for Upscaling and Transnational potential' report, which can be found on the SEEV4-City website.*

The extent to which this solution can be adopted elsewhere and used at scale depends mostly on the following influencing factors:

a) Market size, particularly
   a. RES and EV growth, incl. penetration of bi-directional capable EVs; and
   b. Maturity of the automotive and energy markets.
b) Legislation and standardisation, particularly
   a. regulatory controls; and
   b. technology standardisation.
c) Commercial / prosumer factors, particularly
   a. incentives for vehicle2home services and optimisation of self-consumption;
   b. applicability of relevant technologies to the types of dwellings in the market; and
   c. perception and understanding of EV charging and discharging technology (based services).

6.1 Within the country of the OP

Figure 24 shows the number of electric cars registered in the UK – at the end of August 2020 there were almost 340,000 plug-in vehicles with 142,273 BEVs and 196,800 PHEVs registered, nearly 1% of the total vehicle parc. Last year saw the most significant annual increase in number of registrations, with more than 72,000 EVs registered showing a growth of 22% on 2018. Despite the coronavirus impact, this year promises to mirror or even surpass this growth rate. [23]

Most bi-directional charging units available on the market at the time of writing are Direct Current models requirig a bi-directional charging compatible EV such as Nissan Leaf or Mitsubishi Outlander, which use the CHAdeMo connector. However, Nissan announced using CCS for its new Ariya model in Europe, giving the impression that it intends to move away from CHAdeMo in Europe despite maintaining it in Japan [24]. Therefore, CCS seems set to become the standard for Europe and the winner in the battle between the two protocols. However, bi-directional functionality for CCS is yet in development and the roadmap states that level 3 bi-directional charging for V2H will be rolled out between 2020 and 2025 [25]. Level 4 is on the horizon for rollout around 2025, which will include V2G capabilities. Currently, bi-directional charging is only available in demonstration pilots [26].

All in all, it looks like the industry is moving to CCS as a standard. Still, bi-directional functionality is yet under development, and there are limited compatible EVs available on the market today. Fortunately, the first bi-directional chargers carrying both the CHAdeMo and the CCS connector have entered the public domain [27]. But the market availability in general for bi-directional chargers remains very limited and are very costly compared to regular chargers. The prices are expected to drop by a factor six over the next ten years [28].

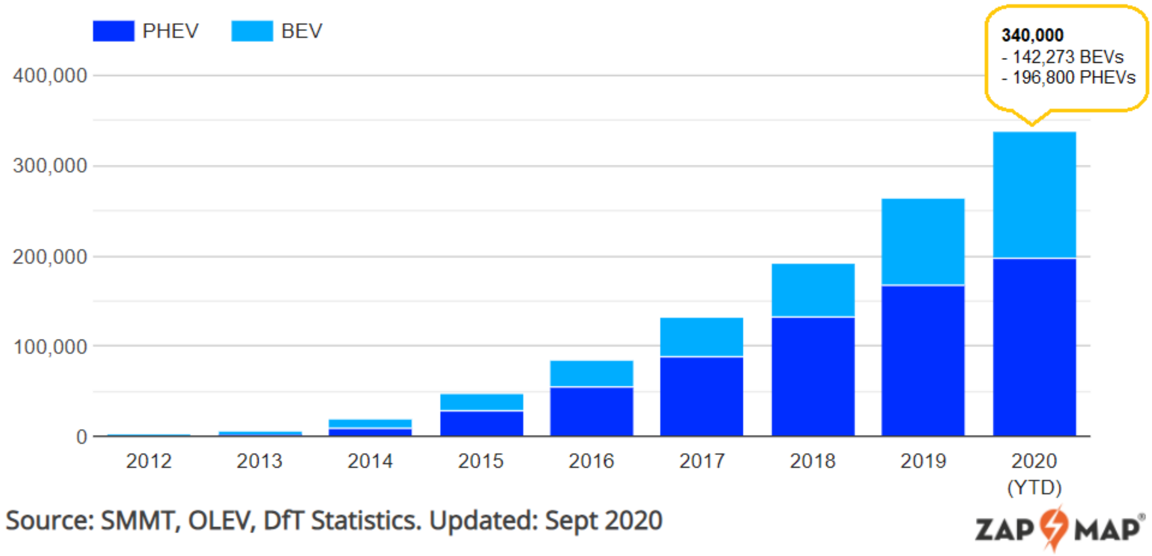

Figure 24: Cumulative number of plug-in vehicles registered in the UK (2012 to date)

V2H can also benefit households in non-financial aspects. Looking at the KPIs from this project, use of the vehicle battery as a storage facility can increase energy autonomy (being less grid-dependent) and reduce the overall carbon intensity of the household. Additionally, grid investments can potentially be avoided through more comprehensive scale implementation within the local grid area. A business model for a V4ES around V2H should include the use of time of (grid) use tariff schemes with Feed-in-Tariff rates. The non-financial observations from this project have been fed into a recent report by Cenex entitled 'V2G: a fresh perspective'.

In 2019 there were some 24.4 million homes in the UK [29]. The great majority of these were in England. The UK housing stock is dominated by houses, with over half (52%) of homes being semi-detached or terraced and just under one fifth (18%) being detached. Just over a fifth (21%) of UK dwellings are flats. 78% of UK homeowners indicated [30] they have access to off-street parking, this combined with available (shared) roof space for PV in most (suburban or outer city) residential neighbourhoods translates into a sizeable amount of locations for this type of technology . A recent Smart Energy GB study indicated customers find lower electricity bills mostly appealing when it comes to time-of-use tariffs, but not far behind are the possibility of 'helping the environment and relieving grid stress'.

The high initial investment costs for and limited market availability compared to 'normal' (unidirectional) charging units are significant inhibiting factors for wider roll-out and adoption. A parallel factor is the limited number of compatible EV models available. There are several (regulatory) controls over vehicle-discharging technologies that may restrict the technology choice for the customer: a small and immature market (both vehicles and chargers), battery warranties, G-99 type-testing, suitability to use in a domestic environment (likely single-phase 7 kW charger), possible power rating restrictions/upgrade costs for a charger by the DNO.

Awareness around smart charging amongst customers appears higher than it is for V2G, but in general customers are interested and energy suppliers are offering more additional services that can support a variety of smart charging approaches, including V2G and V2H, with or without additional static battery storage.

In short, the limited market-choice availability with high purchase prices for bi-directional chargers as well as static energy storage and grid/tariff-related policies currently result in an unattractive return-on-investment for the customer. Combined with the undervalued benefits of energy autonomy and the potential to alleviate grid congestions (or otherwise necessary grid investments) significantly suppress the potential upscaling under current conditions. However, if these barriers (largely) disappear growth potential increases significantly.

Summary conclusion
Potential for the Loughborough pilot solution across UK:

As is (short term)	Potential beyond niche application, but strongly limited by market and regulatory influencing factors
5 – 10 years (barriers removed)	Potential towards useful mid-stream application but is not likely to achieve mainstream adoption as some of the current bottlenecks may not be fully addressed yet and remains reliant on site characteristics.

The main enabler is the relatively high amount of available dwelling types that are particularly suitable for V2H and V2G in the UK, allowing for PV and allocated parking coupled with relatively high EV growth-rate. The main barrier is the market availability and high investment costs as well as regulatory barriers. Availability is expected to increase, and costs expected to decrease further. Regulatory barriers may or may not be fully addressed in 5 – 10 years to achieve mainstream adoption in line with optimal upscaling potential.

6.2 Transfer to other countries

Belgium
The uptake of EVs in Belgium is expected to grow significantly from its low base of approximately 15,000-20,000 BEVs (i.e. battery electric vehicles, thus excluding hybrid vehicles) in 2019 [31], to more than 700,000 [32] by 2030.

Nuclear energy has traditionally had an essential position in the Belgian energy mix. Still, post-coal (phase-out in 2016 and incumbent nuclear phase-out in 2025), Belgium is facing a base-load capacity vacuum. Growth in renewable energy is not likely to fill this in time and would still require solutions for its intermittent nature. Therefore, gas is expected to fulfil base-load capacity from 2025. Smart Charging solutions, including for V2H and V2G are expected to be part of the solution for Belgium's future electricity grid.

In Belgium, nearly 38% of dwellings are detached and almost 40% semi-detached or townhouses [33] which are suitable for V2H application. For apartment buildings, a Vehicle2Building type service is the more exciting marketing segment. The roll-out of smart meters is ongoing in Belgium. There are currently no time-of-use tariffs or other dynamic pricing schemes available for end-users in Belgium, except for:

- fixed or variable contracts (prices based on monthly or quarterly average market).
- the peak/off-peak tariff scheme (different day/night/weekend rates)

A study performed by Powerdale about the profile of the Belgian EV-driver provides some interesting insights, such as that currently 84% of the EVs are company owned (but 46% of them would buy the same car if they were purchasing a privately-owned car), that 50% of EV-drivers own photovoltaic solar panels and 70% of e-drivers are interested in a car with V2G technology. [34]

As is the case for the other countries, the limited availability and higher purchase cost of V2G chargers compared to unidirectional chargers, as well as the uncertain developments in the prevailing technology in coming years, complicates the business case and therefore the likelihood of deployment in the short term. Ultimately, the EV-uptake growth in Belgium may end up being well timed as the market for bi-directional chargers becomes more diverse and the questions surrounding the prevailing technology resolved. Changes to billing structures are expected to kick in from 2022 at the earliest [35]. Absent subsidy support schemes or strong market development which reduces purchase costs, similar to what has been done in Germany for home energy storage systems, make the short-term potential for behind-the-meter batteries lower than EVs with V2G.

Summary conclusion

Potential for the Loughborough pilot solution transfer to Belgium:

As is (short term)	Potential beyond niche application, but strongly limited by influencing factors
5 – 10 years (barriers removed)	Potential towards mid-mainstream application, but still limited by some influencing factors

The main enabler is the available dwelling types most suitable for Vehicle2Home (and Vehicle2Grid) in Belgium, allowing for PV and allocated parking. Main bottleneck is the compatible market availability and high investment costs as well as the relatively low EV growth-rate.

Norway

The Norwegian Parliament has decided that all new cars sold by 2025 should be zero-emission (i.e. either electric or hydrogen). To date, mid 2020, there are around 290k BEVs and 130k PHEVs on the road in Norway. The limited availability and higher purchase cost of V2G chargers compared to unidirectional chargers, as well as the uncertain developments in the prevailing technology in coming years, complicates the business case and therefore reduces the likelihood of deployment in the short term.

The energy mix of the electricity grid is different from that of other countries. The amount of PV installed in Norway is logically comparatively low to other countries due to 98 percent of the electricity production coming from renewable energy sources, primarily hydropower [36]. Norway did add 51 MW of new solar capacity last year, of which 35% was made up by residential systems. There are 2.6m dwellings in Norway, 49% of which are detached houses [37]. These dwelling types are most suited for V2H application. Although in urbanised areas, a high ratio of residents live in apartment buildings or townhouses, for example 61% of Oslo residents are currently living in multiple-family buildings (apartments or townhouses).

Electricity prices in Norway are relatively low. The wide-scale smart meter roll-out is advanced. This, combined with factors such as the high percentage of local hydro generated electricity, favoured the introduction and broad acceptance of Real-Time Pricing. Currently, around 71% of households and 88% of SME und small industries chose RTP tariffs. Around 27% of the households chose dynamic Time of use tariff and only 2% fixed price tariffs. [38]

V2G has regulatory barriers since the energy regulator's control of the design of the electricity markets does not yet allow aggregated services to bid in the electricity markets. Currently, Norway lacks a specific policy framework for V2G which would be treated in the same way as solar feed-in to the grid.

Summary conclusion

Potential for the Loughborough V2H Single Household solution transfer to Norway:

As is (short term)	Potential beyond niche application, but strongly limited by influencing factors
5 – 10 years (barriers removed)	Potential towards mid-mainstream application, but still limited by some influencing factors

The leading enabler is the available dwelling types most suitable for V2H and V2G in Norway, particularly outside (or outskirts of) major cities, allowing for PV and allocated parking. The main barrier is the market availability and high investment costs as well as the relatively low PV growth-rate. Therefore, incentives to address regulatory barriers may or may not be fully addressed in 5 – 10 years to achieve its upscaling potential.

The Netherlands

The Netherlands is seen internationally as a significant player in the field of electric mobility. When it comes to charging infrastructure, it was ranked the country with the highest density of charge points globally [39]. The total amount of BEVs in the Netherlands has reached 131k as of August 2020, with an additional 102k PHEVs. There are 60k (semi)public charge points and 1,463 fast chargers. The number of private charge points is a bit less clear, but the last estimate indicates around 100k [40]. OCPP, initiated in the Netherlands and currently de facto protocol standard for charging infrastructure, has bi-directional power flow (V2G/X) is on the agenda in coming years [41]. As with other countries, however, the difference in purchase costs for bi-directional charging units as well as battery storage devices (for further optimisation of supply and demand) compared to unidirectional chargers are still considerable. These are substantial inhibiting factors for smart(er) charging solutions such as V2H or V2G, as implemented in various SEEV4-City pilots.

Historically for the Netherlands, the share of coal and (in particular) natural gas has been high. A policy change [42] will likely require the Netherlands to import gas at least initially. Still, it has already resulted in a significant growth-spurt for renewable energy, increasing production to account for 18 percent of electricity consumption in the Netherlands in 2019, compared to 15 percent in 2018 [43]. Outages on the grid, although relatively limited, are increasing [44] and capacity on the grid is reaching its limits in more and more (local) areas due to steep demand increases.

On 1 January 2020, the Netherlands possessed nearly 8 million dwellings. Data from 2015 shows that of homeowners around 42.6% live in (semi) detached (19.6% semi and 23% detached); 42.5% in townhouses or end-of-terrace and 15% in flats/apartments [45]. The latter is expected to have increased somewhat in recent years.

In terms of commuting, data indicates that 33% of Dutch employees and students commute between cities (compared to 27% in 1995). It also shows that in recent decades the commute-distances have increased to an average of 19 kilometres. However, it is worth to note that about 50% of Dutch employees work within same municipality as their residence. Almost 75% of commuting kilometres are travelled by car, 12 % by train and 25% by bicycle, often for short distances, which amounts to a total of 7 percent of total commute kilometres. [46]

In 2019, 56% of Dutch people was considering purchasing an EV in the long term, a significant increase over the figure of 37% recorded in 2018 [47]. The report from 2018 provides some additional information, indicating those interested (compared to those not interested) are often more informed about EVs and electric driving, are younger in age and have received higher education. They also are more likely to already have PV installed. [48]

The report 'Dutch EV drivers' acceptance of vehicle-to-grid (V2G) at long-term parking' also indicated familiarity with the technology increase willingness to participate for V2G. Their motivations range from being compensated to knowing they are contributing to solutions for societal challenges (environmental and relieving grid stress). Requirements ranged from accurate and transparent communication and relatively smooth integration with their 'normal' (EV) use patterns [43] [49]. The number of commercially available services entering the Dutch markets appear higher than for the other three NSR countries within SEEV4-City.

From a regulatory perspective, however, Vehicle2Grid is likely to suffer from double taxation. The current 'salderingsregeling' scheme is scheduled to be scaled down, starting in 2023 and ending altogether in 2031. Although, bottom line, this means the prosumer receives less for each kWh it delivers back to the grid, it does have the potential to make self-consumption (and V2H/G) more attractive.

Summary conclusion

Potential for the Loughborough pilot solution transfer to the Netherlands:

As is (short term)	Potential beyond niche application, but strongly limited by influencing factors
5 – 10 years (barriers removed)	Potential beyond niche application, but still limited by some influencing factors

The main enabler is the high EV growth-rate in the Netherlands and relative high rate of interest in V2H and V2G from market and consumer. The main barrier is the compatible market availability and high investment costs as well as risk of double taxation and the limited number of highly suitable dwellings with both allocated PV and parking space. Regulatory barriers may or may not be fully addressed in 5 – 10 years to achieve mainstream adoption in line with optimal upscaling potential.

7 Conclusions and recommendations

7.1 Conclusions

The Loughborough Pilot was able to reduce 1.02 tonnes of CO_2 emissions(KPI A) and to improve its energy autonomy (KPI B) by 5.1% points. Grid investment deferral may be possible from this solution by a factor of 2% to 12%

An initial Net Present Value (NPV) analysis of the first phase at a discount rate of 2% indicates that the deployment of similar systems could generate a positive NPV of £1,500 if smart charging are used to manage energy flows at the site. When Fast Frequency Response (FFR) revenues were included, the NPV increased further to £2,700, although aggregator and other value chain costs would need to be subtracted from this in any deployment.

This pilot took equipment from a first-of-its kind bi-directional charger demonstration and combined it into a sophisticated home energy management system, delivering CO_2 reductions, an increase in energy autonomy and potential grid benefits, and contributing to the overall successful delivery of the SEEV4-city project KPIs.

7.2 Policy recommendations

The following ***policy recommendations*** are provided to enable a smoother transition into smart and clean electrification of transportation. More policy recommendations can be found in the SEEV4-city Policy Recommendations report and the main ones are summarised in Points B and following, below.

A. Benefit-in-kind implications for employee trialists

Many companies choose to test their innovative or emerging products and services on their employees. This has a number of benefits in the Research and Development (R&D) process. Firstly, the employees are usually committed to the product or service by virtue of their employment and involvement in its development. Selected staff may also have open enquiry / learner attitudes to systems and services. This makes for a very understanding test user population that perseveres in spite of many issues. Staff users may also have a contextual knowledge that is on-par or similar with Early Adopters, and may be technology or environmentally conscious and open/motivated.

Secondly, by testing the product or service themselves, the developers can place themselves in users' shoes and have first-hand experience of the benefits and flaws of the technology and how the service evolves. Lastly, in-house testing protects the organisation's brand by allowing managers to judge when the development is sufficiently mature to be released on the general public.

Benefit-in-Kind (BiK) rules exist in the taxation system to avoid companies flouting national tax rules by rewarding their employees with items or services, rather than money (which would reduce their tax burden). These rules, though often complex, are good to ensure that everyone plays fairly, and vital national services are appropriate supported by a tax basis.

However, the SEEV4-city project has observed that the BiK system works as a barrier to the kind of employee testing described above. Unlike employers, who can benefit from the Corporation tax relief for R&D, employees who want to participate in the research and development are subject to increased income taxation. This pilot experienced this first-hand.

To the project's knowledge, no equivalent for employees exists for the Corporation Tax Relief for R&D, which can be applied to a proportion of an organisation's R&D expenditure. This presents a barrier to innovation. The project therefore recommends that there be a zero-BiK-rate for the small number of employees receiving benefits from innovative products and services which advance the overall knowledge or capability in a field of science, technology or social /environmental service, or projects that help resolve scientific, technological or basic usability uncertainties.

This should be limited to a small number of staff to prevent abuse of the system and should be subject to employees volunteering to test the product, service or offering, and the item being tested remaining the property of the company.

This small change to BiK rules has the potential to accelerate early testing without undermining the taxation system and help to avoid that smaller less-mature companies fall foul of the current rules.
It would also bring about a balance between the benefit available to companies and the benefit available to their employees.

B. Subsidies/incentives

Given the high battery investment cost for ESS, additional subsidies on ESS could be beneficial to encourage the utilization of ESS and to achieve higher energy autonomy, lower CO_2 emission and better grid stress alleviation. Similar considerations could still apply for bi-directional charging hardware. However, prices of current bi-directional charging hardware have already dropped in recent years and there is some uncertainty which direction technology developments in the market may take (AC/DC based and ChADEMO vs CSS). Alternatively, a dedicated V2G Feed-in Tariff could be established, and progressively reduced as EV battery costs decline as projected, somewhat like the UK's historic Solar PV feed-in tariff.

C. Policy stimulation for 'EV-drive inclusive' service offerings

Regulatory and policy considerations that allow and/or help stimulate the market to develop service offerings that entice EV-drivers' participation through compensation by removing current bottlenecks. These should create additional financial triggers, making the ROI of potential high purchase cost equipment more interesting and, in turn, increase the potential for wider adoption.

D. Data availability and transparency for better integration of electric transportation at all levels.

To enable and stimulate an uptake of electric vehicles beyond the early adopters (which are also often the participants of experimental and organisational set-ups of pre-commercial trials) there will need to be a greater need to make data recordings and readings more transparent. This will also lead to fewer assumptions needing to be made for cost-benefit analyses. In this way, automatic recording, and accurate processing (with clear data definition) of historic data on EV transport energy are required, to calculate the charging energy requirement. This recorded data will then be coupled with energy price data to construct a smart energy management model. This could be further optimised by automated intelligent route planning for EVs.

E. Rewards for carbon savings to encourage EV uptake and usage

There are increasingly advanced tools that allow the analysis of CO_2 (carbon) intensity of electricity at regional levels within the UK (as well as the other three countries in the scope of SEEV4-City). The National Grid, for instance, has led the development of a Regional Carbon Intensity forecast for the GB electricity system which can be accessed from http://carbonintensity.org.uk/. This should be given greater prominence in framing the messages to encourage motorists to use EVs for their transportation needs.

F. Dissemination of the benefits of smart charging and V2G to relevant stakeholders.

It is important to organise communication efforts to frame and explain the relative merits of smart charging and V2G to a broad spectrum of stakeholders. This could be combined with the carbon savings mentioned above and presented in a Dashboard similar to that of a smart meter, or like the MyGridGB smart home's Dashboard [50] which provides a quick overview of the live electricity mix, carbon emissions and the amount of low carbon electricity generated in the UK. The MyGridGB dashboard and site both displays live electricity data for the UK (including with a Twitter feed) by generation source of low carbon electricity as well as carbon intensity by generation type, but also trends in electricity supply and demand over time (both annual and monthly: http://www.mygridgb.co.uk/last-12-months/).

G. Standardization and communication protocols to allow interoperable smart charging and V2G

International level agreements should be reached to allow more standards such as CCS to be compatible with V2G in addition to the current standard CHAdeMO [51]. Open standards should be further encouraged through the adoption of the Open Charge Point Protocol (OCPP) [52], and the Open Smart Charging Protocol (OSCP) [53], in their updated versions.

H. Successful business model development to benefit relevant stakeholders

As part of any stimulation of V2G uptake, it is essential to develop business models with built in distributional dimensions – that is shared (including monetarised) benefits for stakeholders built in which encourage and incentivise the respective stakeholders – including the EV owners – at domestic scale to contribute to an aggregated V4ES future.

I. Users' acceptability towards various V4ES services

Consumer behaviour and receptiveness should be measured much more extensively to provide insights into EV owners' attitudes and their response to V2X products and services.

J. Development of an energy market or a platform for V2G services

In the UK some of these dimensions are to be explored in the latest funded V2G projects by Innovate UK, with the support of the Office of Low Emission Vehicles (OLEV) [54]. Policy makers are advised to closely follow the outcomes of these projects over the next 2 years. To understand the current UK V2G context, it is recommended to refer to the findings from the Innovate UK funded V2G market study conducted by Cenex [53].

7.3 Key messages

Based on the results achieved from the Loughborough pilot, the following ***key messages*** can be drawn:

1. **Vehicle2Home benefits:** Currently, the most common purpose is to reduce electricity bills through self-consumption or by (additional) balancing differential tariffs or costs within the dwelling. A business model for a V4ES around V2H should include the use of time of (grid) use tariff schemes with Feed-in-Tariff rates but depends on the commercial availability of both ToU and FIT schemes.

2. **Smart charging demonstrates an improvement in the KPIs** set in the SEEV4-City project, namely, energy autonomy, CO_2 emission reduction, grid investment deferral, and lower operational cost compared to the baseline.

3. **Impact on battery**: Smart charging causes less damage to the EV battery's state of health compared to the V2H implemented in the baseline case.

4. **Result variations in time:** The achievable energy autonomy and the associated CO_2 emission savings depend on the season and weather conditions, and therefore show variations accordingly.

5. **FFR is shown to be profitable** even when the battery degradation was taken into account. However, the commitment for this service provision, i.e. the EV being available for the contracted period of 11:00 pm - 07:00 am may conflict with user's requirements, such as overnight journeys etc.

6. **Smart charging was demonstrated to be profitable** for this pilot and can bring the investor a NPV of around £1.7k over a 10-year life. Compared to the baseline, which proved to be economically unviable, smart charging would bring an extra £2.1k. FFR provision, if applicable and enabled, would increase the NPV by an additional £1k when used in addition to smart charging. This indicates that a combination of profitable services would make the most economically rewarding solution to the V4ES business model.

7. **Return on Investment:** High market prices for bi-directional chargers and battery storage make the financial business case less attractive in the short term. Once more suppliers enter the market and market prices drop further the potential for V2H/V2G services increase significantly. If the added value (return) of increasing energy autonomy and reducing CO_2 emissions is considered as part of the RoI, the investment may be sufficiently attractive in the current market.

8. **EV-driver (Technology) awareness and motivations:** Awareness about Vehicle2Home or Vehicle2Grid amongst the general public seems limited but increasing. On average, the EV-driver seems to have greater awareness. They are more likely to already have PV installed and are more inclined to gain knowledge about relevant technology. However, a better understanding and clear and transparent communication/interaction is considered key for wider uptake by EV-drivers. On average approximately 60-70% are interested in the V2G technology mainly for: environmental reasons, ability to support the (national) electricity grid and the receiving compensation for a quicker return for the investments.

9. **Housing stock:** A relatively large proportion of homes (72%) are dwelling types with space for dedicated (PV). Around 78% of UK homeowners have access to off-street parking [55]. It is fair to conclude that a significant proportion of housing stock would have access to both and be most suitable for V2H or V2G. In the other three countries the percentage is estimated to be lower, either due to higher percentage of urbanisation (with higher percentage of flats and apartments) or lack of private/dedicated parking.

10. **Customer commercial offering options:** Across all four countries the commercial offerings regarding bi-directional (incl. storage) hardware are limited and require high investments. Also, double-taxation for bi-directional energy exchange is likely to occur. And the commercial availability of dynamic (time of) use tariffs schemes are still limited (or uptake is lacking, possibly due to limited awareness amongst the public).

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Appendices

I Burton-upon-Trent

In Burton-upon-Trent, phase 2 of the pilot started in February 2020 and built on Phase 1, which was unable to continue.

As with phase 1, the pilot is a private household with:

- 3.86 kWp PV array;
- 3 kWh stationary battery capable of 760 W variable input / output power;
- commercial control system by Moixa;
- 2018 40 kWh Nissan LEAF; and a
- A commercial V2G unit from energy supplier Ovo Energy as part of Sciurus project.

This latter hardware is market-ready, backed by commercial service-level agreements, guarantees and warranties, so better reliability is anticipated. The DNO (Western Power Distribution) G99 Agreement limited export power to 3.68 kW.

This second phase is again running with the assistance of a Cenex employee who lives in and owns the house concerned. Phase 2 of this household pilot formed a part of the Sciurus project which aims to deploy 1,000 V2G chargers with participants who own/lease a Nissan Leaf EV. It also includes the development of a grid balancing platform to provide electrical support to grid operators during peak energy demand times. Furthermore, it explores and test commercial propositions to identify a viable long-term business model. Finally, consumer behaviour and receptiveness will be measured to provide insights into EV owners' attitudes and their response to V2G products and services. The results of the Burton on Trent trial using an OVO V2G charger are being made available to the SEEV-4 City project by Cenex UK.

I.I Phase 2 V2G initial results

To understand the degree to which the EV charging and discharging patterns were designed to minimise CO2 emissions and minimise grid impact, data were examined over the 55 hour period from 1-3 April 2020.

Firstly, the household consumption was established for the period after removing the effects of EV charging and V2G (see Figure 25). There was seen to be a peak in consumption at approximately hours 40 and 42.

Figure 26 shows EV charging over the period. It can be seen that charging times appeared to avoid times of peak domestic demand, tending to take place when domestic demand was low, for instance between hours 0-7 and 25-30. This charging control would minimise the impact of charging on the grid , but Figure 26 demonstrates that this is economically-driven rather than environmental as there is no correlation between charging powers and CO_2 intensity (see hours 30-40).

Therefore, the V2G control was satisfactory from the point of view of minimising the grid impact of household consumption, battery discharge took place between hours 40-42 when household maximum demand occurred, so that grid impact was kept to a low level (Figure 27). Again, however there does not seem to be any intention in the control regime to minimise CO_2 emissions by discharging the EV battery when CO_2 intensity was at a peak.

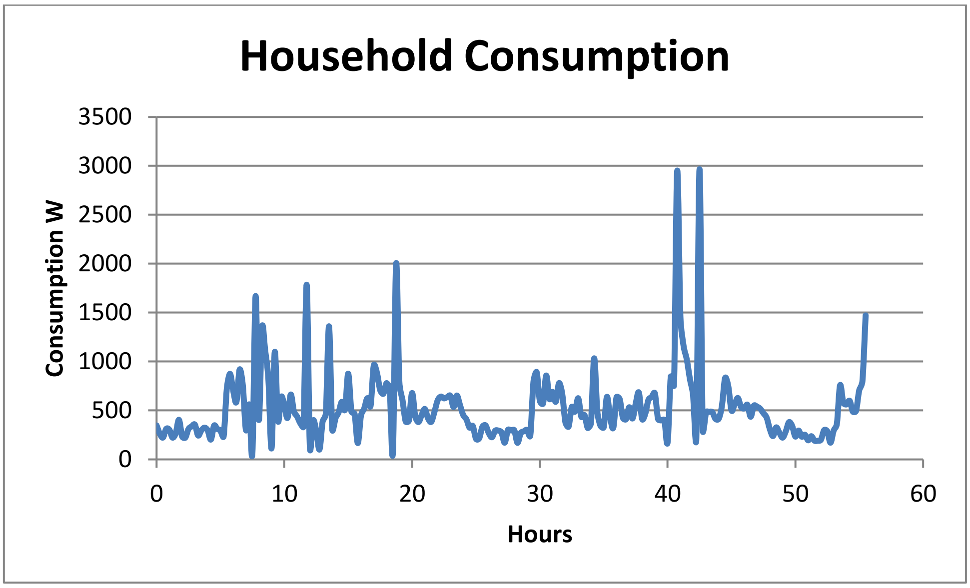

Figure 25 Household consumption for period 1-3 April 2020 after removing effects of EV charging and V2G

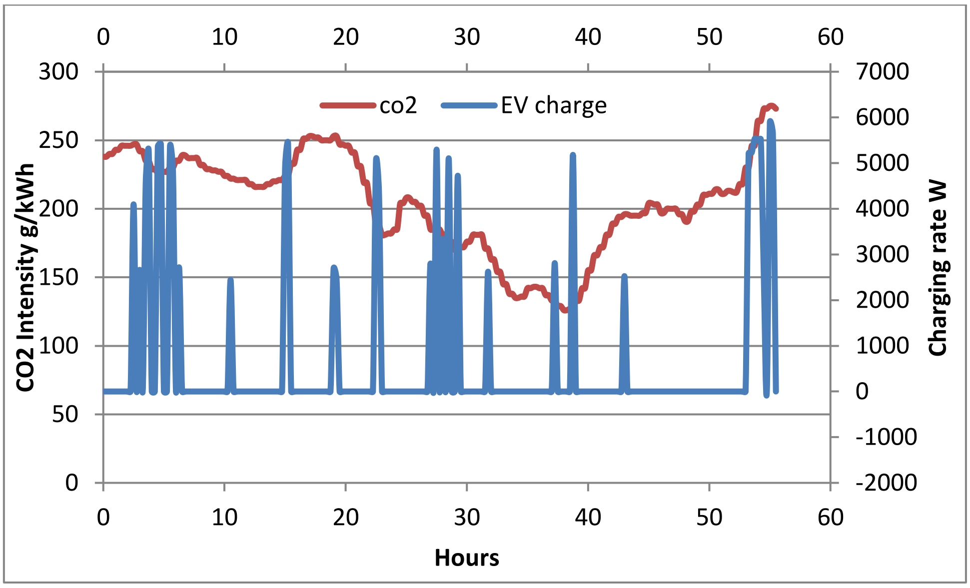

Figure 26 EV charging pattern 1st-3rd April 2020. Charging pattern does not seem to be designed to minimise CO_2 emissions by charging when CO_2 intensity low.

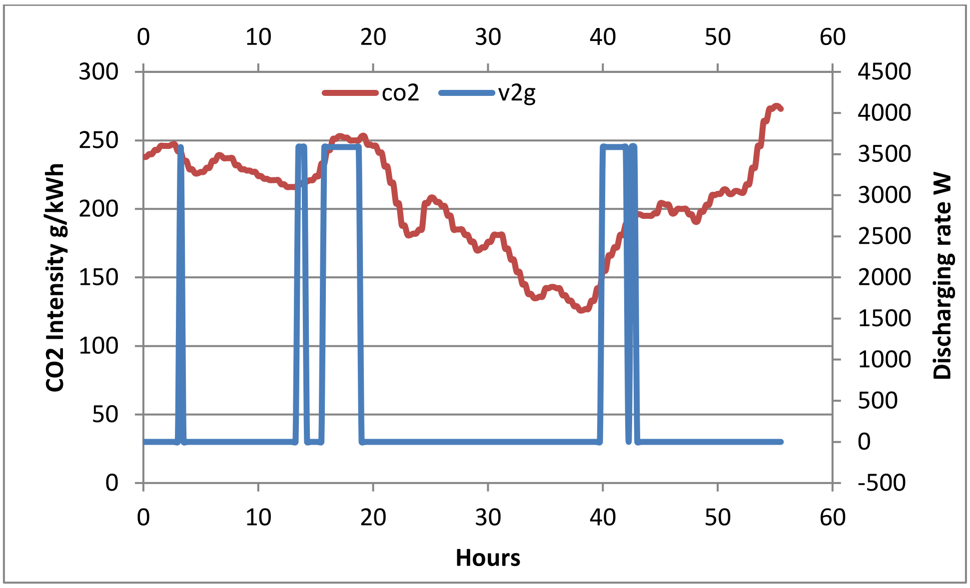

Figure 27 EV V2G discharging pattern 1st-3rd April 2020. Discharging pattern does not seem to be designed to minimise CO_2 emissions by discharging only when CO_2 intensity high, but a reasonable proportion does occur when CO_2 emissions can be saved, eg at 17 h.

I.II Burton on Trent V2G profitability

The following calculation outlines the potential profitability of the phase 2 business case.
Between 1st and 3rd of April, 42.535 kWh was imported and 25.692 exported. The EV battery lost 31% state of charge (56 to 25%) which represents 10.44% losses (42.535 – 25.692 – 12.4 = 4.44 kWh loss in a 40 kWh battery).

25.692 kWh was exported to the grid, which would require 28.37 kWh output from the EV battery. At 12.12p per kWh, this would have cost £4.57.

Battery degradation costs are 5.3p per kWh for 28.37 kWh which is £1.50.

Revenue from OVO at 26p per kWh for 25.692 kWh is £6.68.

Therefore, the net profit over this 55 hour period is £6.68 - £1.50 - £4.57 = £0.61.
Pro-rated to a whole year, this is equivalent to **£96 profit** annually.

This figure is ignoring depreciation costs on hardware since funded by OVO as part of the Sciurus project. No additional aggregators costs are to be deducted here, as OVO Energy has taken on the role of the aggregator and is assumed to have priced this into the export payments (the 26p/kWh from OVO energy referred to above payable to the household & EV triallists is part of the terms and conditions of the Sciurus project funded by Innovate UK).

It should also be noted that this period was in the middle of the UK's lockdown, when the vehicle was not used, and therefore represents an unrealistic scenario. The conclusions should be treated as an upper-bound estimate.

I.III Energy Autonomy

Below Figure 28 shows the household energy consumption, measured in kWh per week, for the period 2nd January to 2nd April 2020 for the Burton on Trent house. As may be seen the household consumption is considerably enhanced when EV charging occurs, making the result more uneven than would otherwise be the case. Also shown is a plot representing PV generation, again measured in kWh per week. The rising trend in PV output as solar irradiation seasonally increases may be seen.

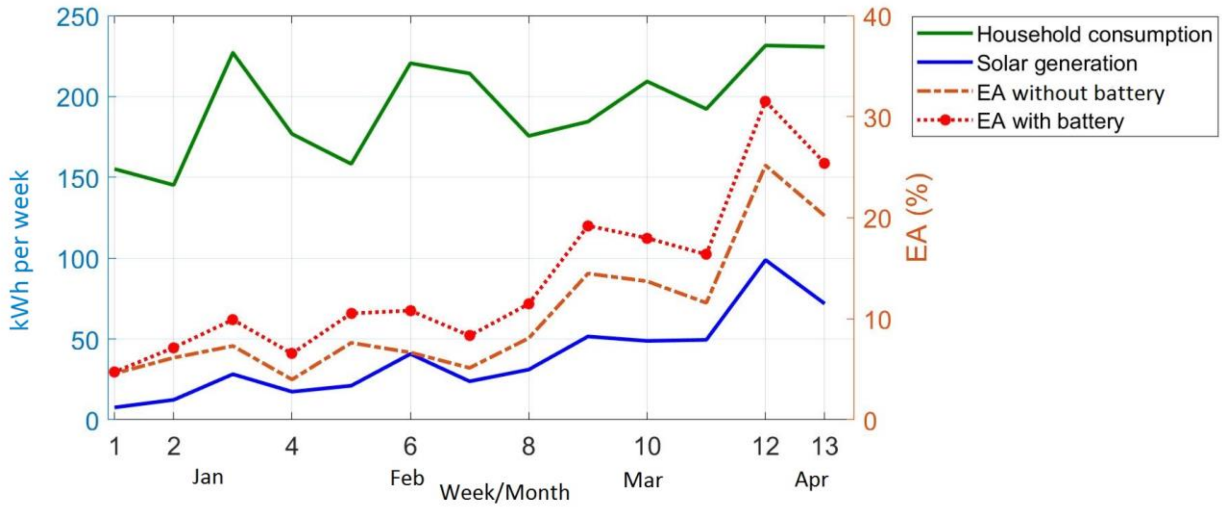

Figure 28 Burton on Trent Energy Autonomy January to April 2020

Not all of the available PV output is absorbed by the house – where PV generation exceeds domestic demand the surplus energy is first stored in the stationary battery, with any surplus being exported to the grid. As a result the above figure shows a plot of % Energy Autonomy (EA) without use of the stationary battery, being measured in terms of the direct absorption of PV energy by the household. EA is the % of domestic electricity consumption supplied directly by PV. As the PV output increases, with the seasonal increase in solar irradiation level from January to April, the available PV generation increases. Thus, the degree to which PV generation can supply domestic energy demands increases from January to April, as the PV output rises at a greater rate than does domestic energy consumption. EA measured as % of household consumption rises from Winter in early January to Spring, early in April.

The stationary battery is seen from the plot in the figure to augment the degree of EA achieved. Interestingly, as the amount of available PV energy rises as one moves into Spring, the EA augmentation produced from battery storage also increases, as may be seen from the increasing divergence of the plots for EA without use of the storage battery and EA with such assistance. Average EA over the period was 10.4% without the storage battery, increasing to 13.8% with use of the battery. This represents an improvement of 33%.

I.IV Burton on Trent EV substitution calculation

Methodology

In this analysis, Diesel car total emissions are assumed to be 244 g CO_2/km and BEV energy use is 0.161 kWh/km[4]. Average UK CO_2 annual value is 0.281715 kgCO_2/kWh[5]. From these values, the BEV driving emission rate per km can be calculated and combined with the manufacturing CO_2 emission/km to find

[4] A. Hoekstra, "The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions," Joule, vol. 3, no. 6, pp. 1412-1414, 2019.

[5] https://gridwatch.templar.co.uk/download.php

the total BEV emissions/km. Then we can subtract to find the difference in emissions/km between EV and ICE, and then multiply by the annual mileage.

Calculation
Based on actual recorded mileage October 19-March 20:

Advised mileage 9,017km Oct 19 – March 20, so annual mileage = 19,707 km

Diesel car total is 244 g CO_2/km. BEV energy use is 0.161 kWh/km

Average 2019 UK CO_2 annual value is 0.256 kg CO_2/kWh. BEV driving CO_2 emission = 0.256*0.161*1000 g/km = 41.2 g/km

BEV manufacturing CO_2 emission = 24 g/km

Total BEV emissions = 41.2+24 = 65.2 g/km

Savings by ICE substitution = 244 - 65.2 = 178.8 g/km

Over 19,707 km annual mileage savings = 178.8*19,707 = 3.52 tonnes/year

I.V Lessons learnt

Preparation and initiation
Moving the household scale pilot to another Cenex employee's household in 2019, issues around taxation had to be overcome first, as staff cannot be unfairly advantaged in the UK tax system. The Burton-upon-Trent set-up is similar to the Loughborough set-up, using a 3 kWh battery and 3.86 kWp solar panels provided and operated by Moixa, a market ready OVO bi-directional charging unit (7.3 kW charge / 7.3kW discharge) and a 40 kWh Nissan Leaf (2018).

Procurement
By the time phase 2 at Burton-upon-Trent was initiated, (although still limited in terms of the number of providers) improved hardware and software were available on the market. Lessons from the experiences in the Loughborough pilot, such as attention to interoperability and compatibility contributed to an improved knowledge about the necessary requirements for equipment purchase and support services, especially if hardware and software are to be provided by different suppliers. The bi-directional charge unit is supplied by OVO, originating from the Sciurus V2G project in the United-Kingdom (2018-2020), manufactured by Indra. The PV panels and stationary battery are supplied on commercial terms by Moixa.

Implementation and installation
Compared to the Loughborough set-up, the newer generation BSS charges and discharges at a variable rate, whereas in the Loughborough it could only charge/discharge on a fixed rate. The grid connection rules have been updated and can more readily accommodate feeding energy back to the network, driven in particular by the high penetration of PV (i.e. solar energy) into the UK's Low Voltage Network. Therefore, the OVO bi-directional charger has true V2G capabilities. The bi-directional charger plays well together with the Moixa battery and solar system to balance the household energy system. Both control systems have different control strategies. Moixa: PV + battery + energy manager tracks household energy balance and OVO: V2G + backend tracks grid services.

Operation

Compliant V2G units from single suppliers are now readily available for households or businesses, steered from cloud systems rather than on the units themselves. Battery technology has come on leaps and bounds so that the Moixa battery proposed for the new is more efficient and more effective than the old one by for instance being able to offer variable charging and discharging. Although the networks are supporting V2G increasingly better, the site export rate is limited to half its potential due to network constraints. The roundtrip efficiency observed is 78%. Overall, the mean import increased by 9% when V4ES was switched on (see Figure 29). Moreover, the export credits are only valued ¼ the value of the import price. For this pilot, these factors would add up to ~£20 extra a year. On scale, this could represent a significant additional cost. As the system comprises of two separate systems (the Moixa operated solar+battery system and the OVO V2G system), they have two different control strategies. This has not resulted in any conflicts; however, taken from a holistic view, the best V4ES will include a holistic view of all energy flows and coordinate all assets.

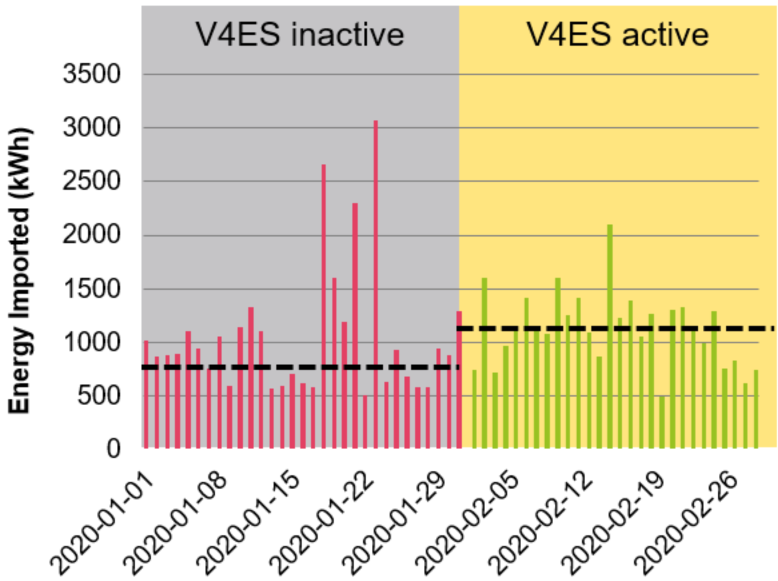

Figure 29 Mean import increase when activating V4ES in Burton-upon-Trent OP)