Independent, not-for-profit,
low carbon technology experts

EFES - V2G Data Analysis

Summary Report

Prepared for:

Public Domain

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1.0	Initial Release	08/03/2019
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Contents

Abbreviations

Abbreviation	Definition
BEMS	Building Energy Management System
CSV	Comma Separated Variables
DSR	Demand Side Response
EFES	‘Ebbs & Flows of the Energy System’ Project
EV	Electric Vehicle
GUI	Graphical User Interface
PV	Photovoltaic Solar
V2G	Vehicle-to-grid
VPP	Virtual Power Plans

1 Introductions

1.1 Cenex

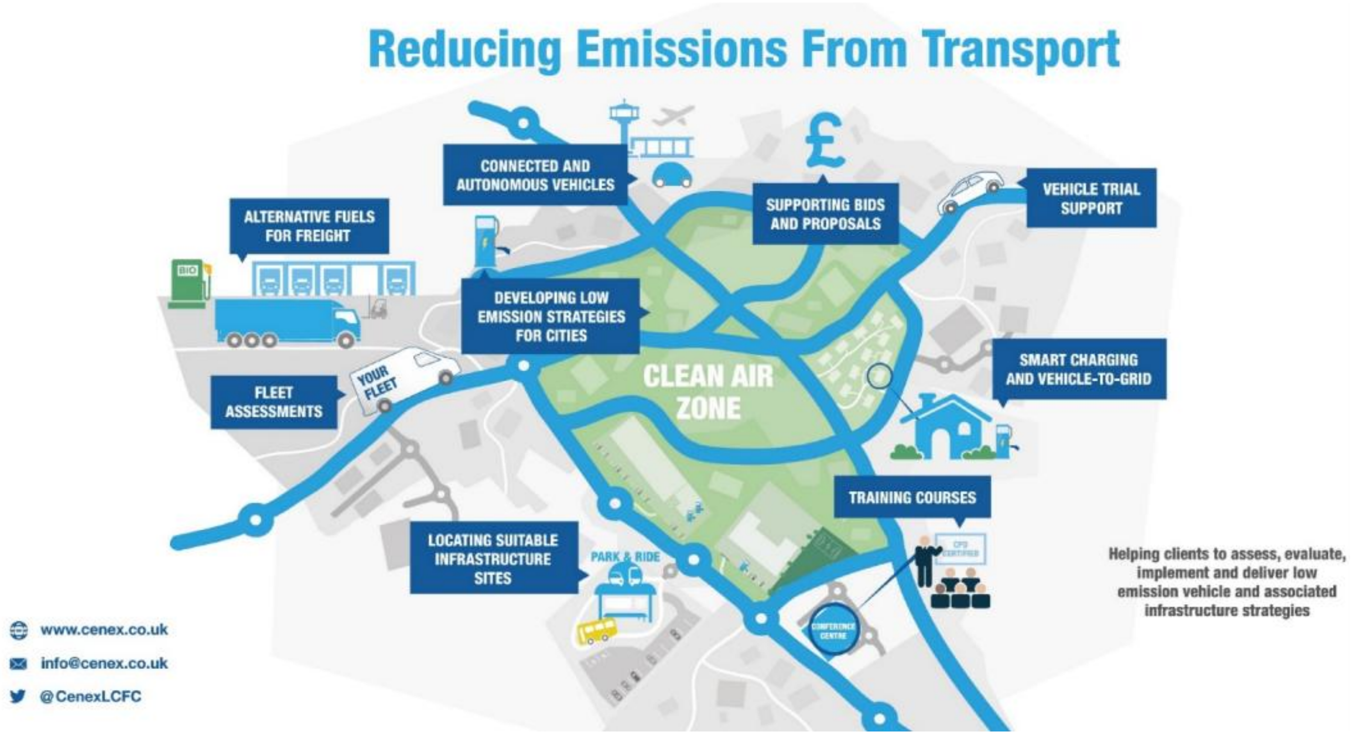

Figure 1: Cenex Core Activities Map

Cenex was established in 2005 as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies.

Today, Cenex operates as an independent, not-for-profit consultancy specialising in the delivery of projects, supporting innovation and market development, focused on low carbon vehicles and associated energy infrastructure.

Independent. Not-for-Profit. Consultants.

We highly value our independence as it allows us to provide impartial advice and helps us build trust with our customers.

Being a not-for-profit, Cenex isn't driven by doing the work which pays the most or builds our order book, but by what is right for our customers and for the industry. This is reflected in everything we do, from the work we do and the advice we give, even to the prices we charge.

Finally, as consultants our aim is to be trusted advisors with expert knowledge – the go-to source of help and support for public and private sector organisations. We want to be people you can trust to help where and when it is most needed as our customers progress along their journey to a zero-carbon future.

To find out more about us and the work that we do, visit our website:

www.cenex.co.uk

1.2 Ebbs and Flows of the Energy System (EFES)

The EFES project started as a feasibility study in 2013, funded by Innovate UK as part of the ‘Buildings better connected’ call. Following a successful feasibility, a proposal for a demonstration project was funded by Innovate UK as part of the ‘Localised energy systems’ call.

The aim was to practically demonstrate whether vehicle-to-grid (V2G) technology could work using electric vehicles (EVs) and prove the viability of using ‘virtual power plants’ or aggregators to manage their operation to provide the maximum benefit to the network.

The project involved the development of four prototype V2G units for use across both domestic and commercial applications.

Figure 2: EFES V2G units during development

The project ran between January 2015 – December 2017 and was delivered by a consortium consisting of the following:

2 Project Set Up

2.1 Core Technologies

The project was set up with four key technologies:

- **Virtual Power Plant (VPP)** – Rather than a single physical power generation asset, a virtual power plant aggregates and controls a combination of distributed generation, electricity storage and demand assets such as static batteries or vehicle-to-grid, allowing them to be managed and operated as one unit in order to provide third-party energy services such as frequency response.
- **Vehicle-to-Grid (V2G) Unit** – A bi-directional EV charger.
- **V2G Gateway** – Alternatively known as the Building Energy Management System (BEMS). This is a control unit for the V2G system and other linked devices including energy storage, enabling the unit to communicate with both the building and the VPP to determine the most appropriate charging or discharging option.

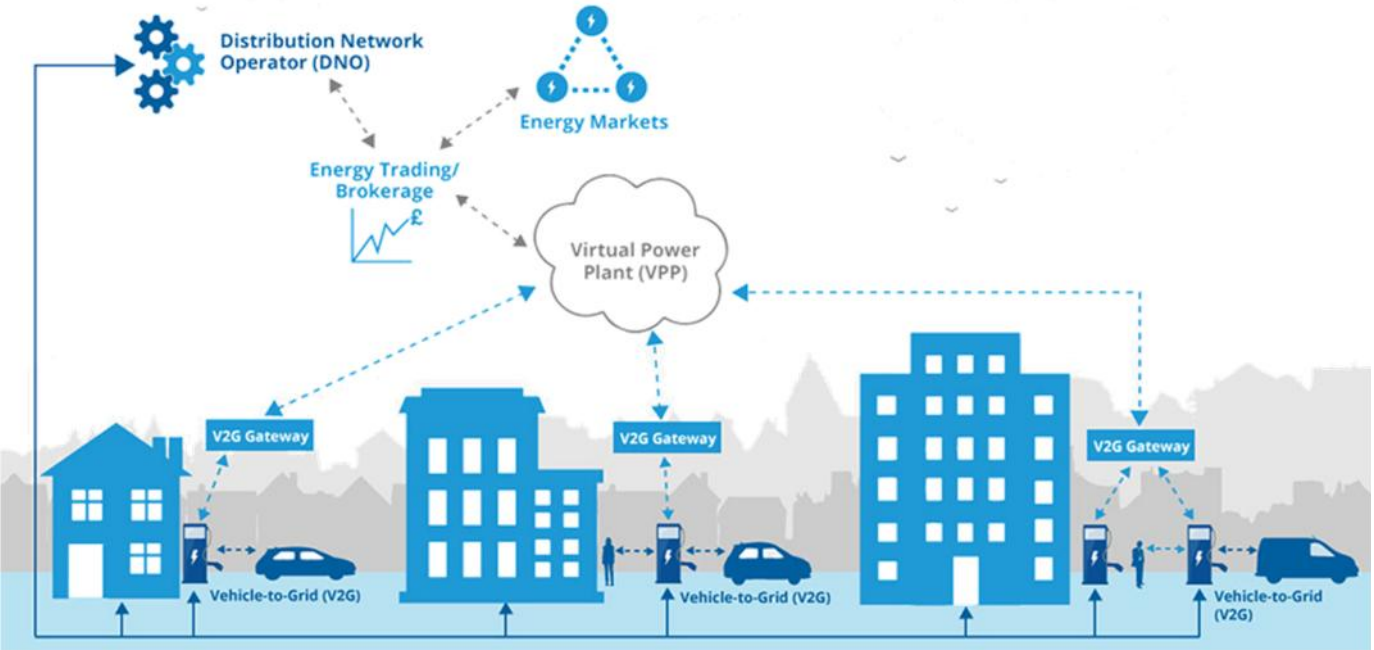

Figure 3: EFES Project Overview

2.2 Detailed Set Up

A VPP algorithm and GUI control was developed by Cardiff University. The VPP took advantage of half hourly prices to control EV charging and V2G for optimum demand management.

The interface and 'Maslow' energy storage units were provided by Moixa. The prototype V2G chargers were developed by Potenza Technologies. The trial sites used in the project incorporated a combination of technologies including V2G, solar PV and stationary batteries.

The detailed architecture used during the project can be seen in Figure 4.

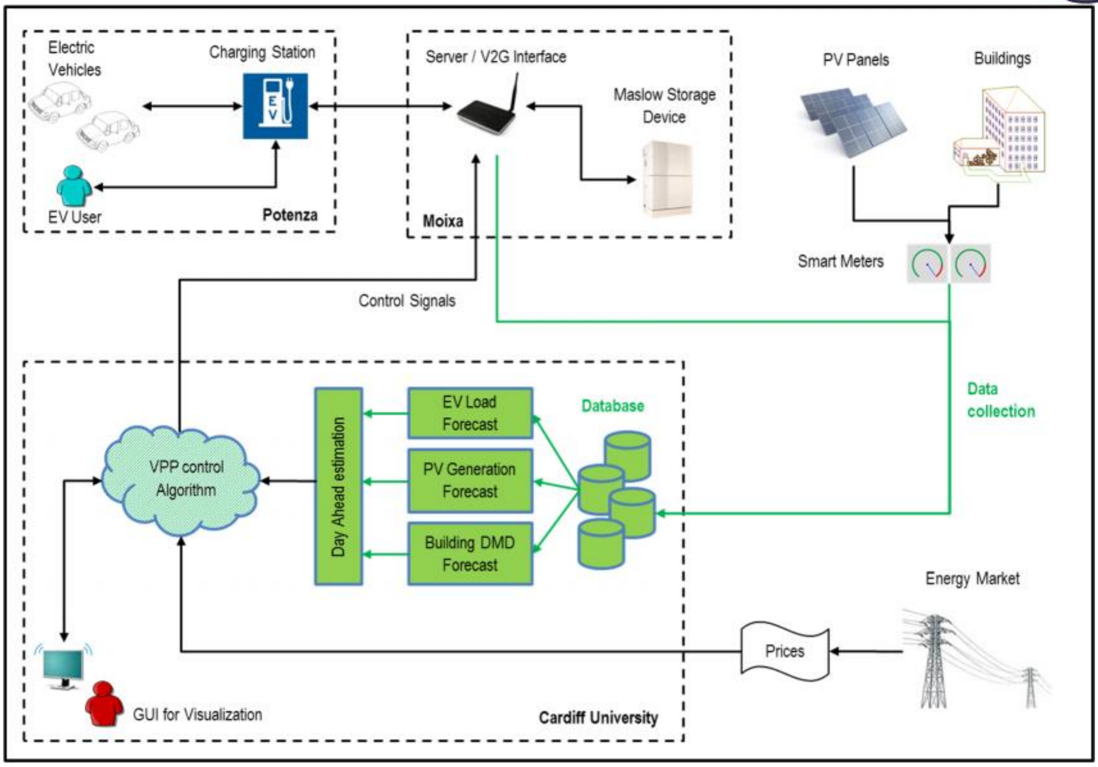

Figure 4: EFES System Architecture

2.3 Smart Charging Methodology

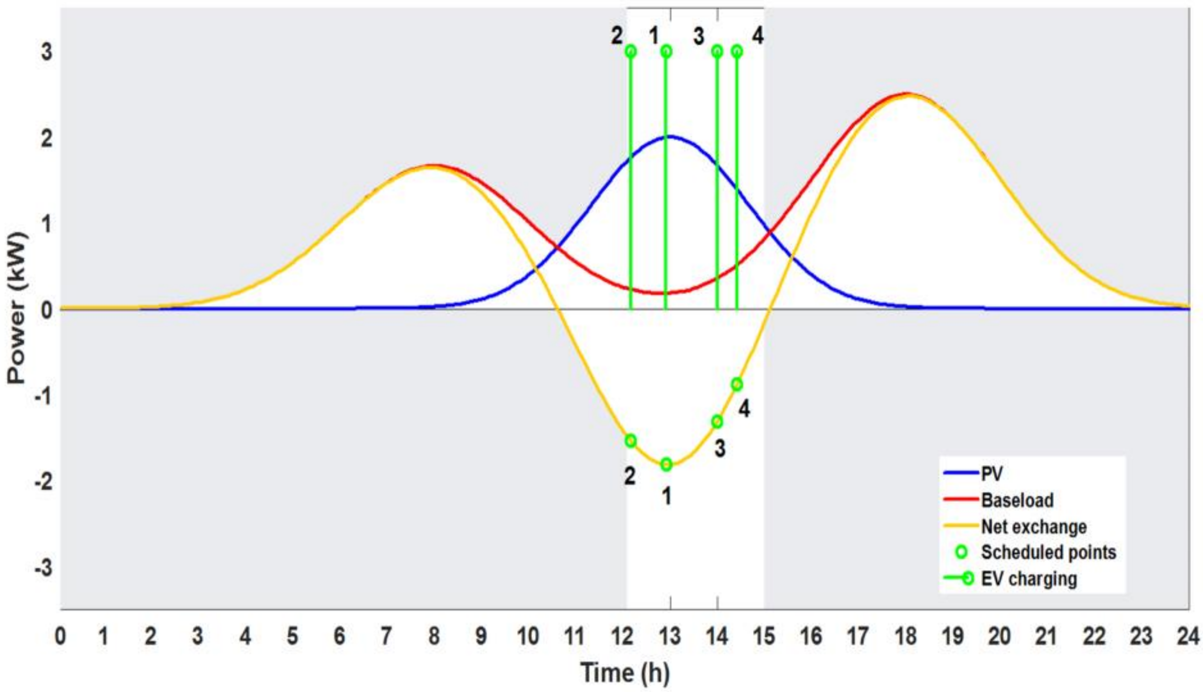

Figure 5: EFES Smart Charging Methodology

The methodology shown in Figure 5 was developed and used for the EFES pilot. It is designed to maximize energy autonomy. This also reduces the CO_2 emissions of the energy used to charge the vehicle by utilising local renewable generation (PV). In its most simplistic form, the EV is recharged when arriving home (typically 12-3PM) in ascending order (1,2,3,4) of the exchange curve. Any excess generation is then directed to the 'Maslow' energy storage unit (where available). If connected, the V2G unit is then used to discharge back to the site at times where demand exceeded generation from the PV (typically between 5am-11am and 3pm-10pm). Where the V2G unit is unable or has insufficient capacity to meet the sites demand, the energy storage unit is also discharged (if available).

3 Demonstrator Locations and Data Availability

The table below shows the demonstrator locations from which logged data is available for analysis:

Location	Vehicle to Grid	Battery Storage + PV
Loughborough private property (Unit A)	✓	✓
Manchester Science Park (later moved to Brighton private property) (Unit B)	✓	×
Coventry business property (Unit C)	✓	×
Leicester private property (Unit D)	×	✓

Table 1: EFES Demonstrator Locations

Data is available from 4 chargers and 2 battery storage units. 41 variables are logged on the V2G units and 61 variables logged on the energy storage units.

The scope of this document considers 2 important variables from the V2G units:

- *State of charge* (vehicle battery)
- *Vehicle plugged-in* (indication if the vehicle was plugged into the charger)

More analysis on energy to home and energy to grid may be possible with the other data files in the set, but the challenges faced in data analysis will be similar to this analysis.

3.1 Challenges

As this was a 'first of its kind' prototype demonstrator, it was inevitable that some issues would arise. Unfortunately, data quality and corruption was not monitored as well as would have been desired during the project (for more on this point, see Section **Error! Reference source not found.** - Lessons Learnt). T his led to a number of challenges when analysing the EFES data sets. This included the following:

- **Invalid timestamps**: Large portions of data was logged against invalid dates e.g. 1970.
- **Missing timestamps:** The data was logged at a 30 second resolution but there are many missing timestamps (ranging from a few minutes to many days).
- **Data completeness:** Many data sets are largely incomplete.
- **Ambiguity regarding variable information:** For some data sets it is unclear what information they contain.
- **Misaligned data:** Different variables are logged for different time periods.

In addition, the following known issues occurred during the project:

- There is data from the V2G unit at the Leicester private property (D) but there was only a storage battery installed, no EV.
- The V2G unit from Manchester Science Park had no data logged because the trial site chose to purchase a BMW i3 which does not support V2G.
- The Manchester unit was moved to a private property in Brighton (B).
- The Coventry unit (C) was installed at a business and was potentially used to charge multiple vehicles. There is no clear way to tell the different vehicles apart from the data sets.

As a result, an additional data cleaning process was required to convert the data to something more usable. Unfortunately, even once cleaned, in some cases there was insufficient data quality to carry out the desired analysis.

4 Data Analysis

Due to the challenges described in the previous section, the scope of the current analysis is limited to SoC, vehicle plug-in timings and derivative analyses. In addition, some further analysis was not carried out due to the substantial time required to carry it out. By releasing this data to the public it is hoped that others will continue this analysis and further the learnings which can be gained from this trial.

The work flow for the data analysis is set out below:

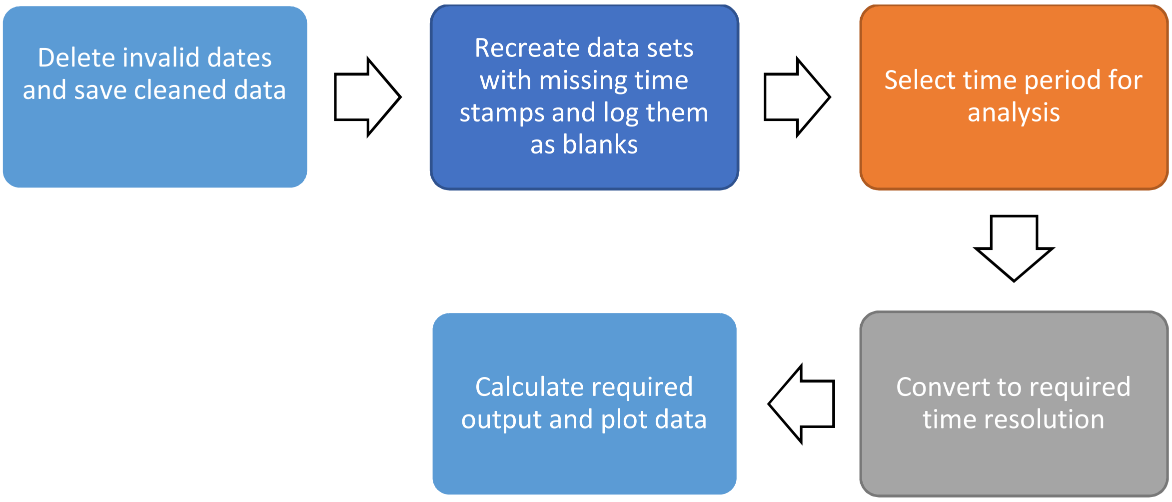

Figure 6: Data Analysis Work Flow

4.1 Method & Assumptions

Data completeness for each file is calculated as follows:

$$\frac{A \qquad D}{E \qquad a \qquad o \;\; D} \times 100$$

Data for each 30-seconds is assumed to start at 00 seconds and 30 seconds for the purpose of analysis. Blank data for any time steps is ignored when calculating minimum, maximum and mean values. Data analysis is presented at a 30-minute resolution derived from the original 30-second data. For SoC and plug-in data, the last value every 30 minutes is selected.

Prior to calculating mean values for SoC, any improbable changes in SoC are removed. Improbable SoC changes are calculated as follows (max charger power is set at 7kW):

$$I_i \qquad S \quad cha \quad > \frac{M \quad . \, P \qquad o \;\; Cha}{S \quad o \;\; V \;\; hic \quad B}$$

$$I_i \qquad S \quad cha \quad < -\frac{M \quad . \, P \qquad o \;\; Cha}{S \quad o \;\; V \;\; hic \quad B}$$

Calculation for V2G volume assumes that, all plug-in data matched with discharge of the EV battery indicates V2G. Maximum allowable discharge is set to 3kW per hour. Any discharge greater than 3kW is considered incorrect data.

5 Results

Although four demonstrator units were used during the trial, only two had data of sufficient quality to carry out meaningful analysis (for more on this point, see section **Error! Reference source not found.** ' Lessons Learnt'). Of the remaining data, Unit A had the most complete data sets, followed by Unit C. Minimal data is available from Unit B and it is likely that a fault on the unit has made the data mostly unusable. Data corruption when transferring between servers may also account for the poor data quality for Units B and D.

5.1 Unit A

5.1.1 State of Charge (SoC)

- 326 (of 376) days of SoC data were available. 50 days were logged empty.
- The white spaces represent missing data points.
- Data completeness: 84.87%
- Long periods with 0% SoC potentially represent incorrect data logging.
- There are also long periods of no change in SoC which could mean no vehicle being present.
- Period between October 2017 and January 2018 appears to show most change in SoC.

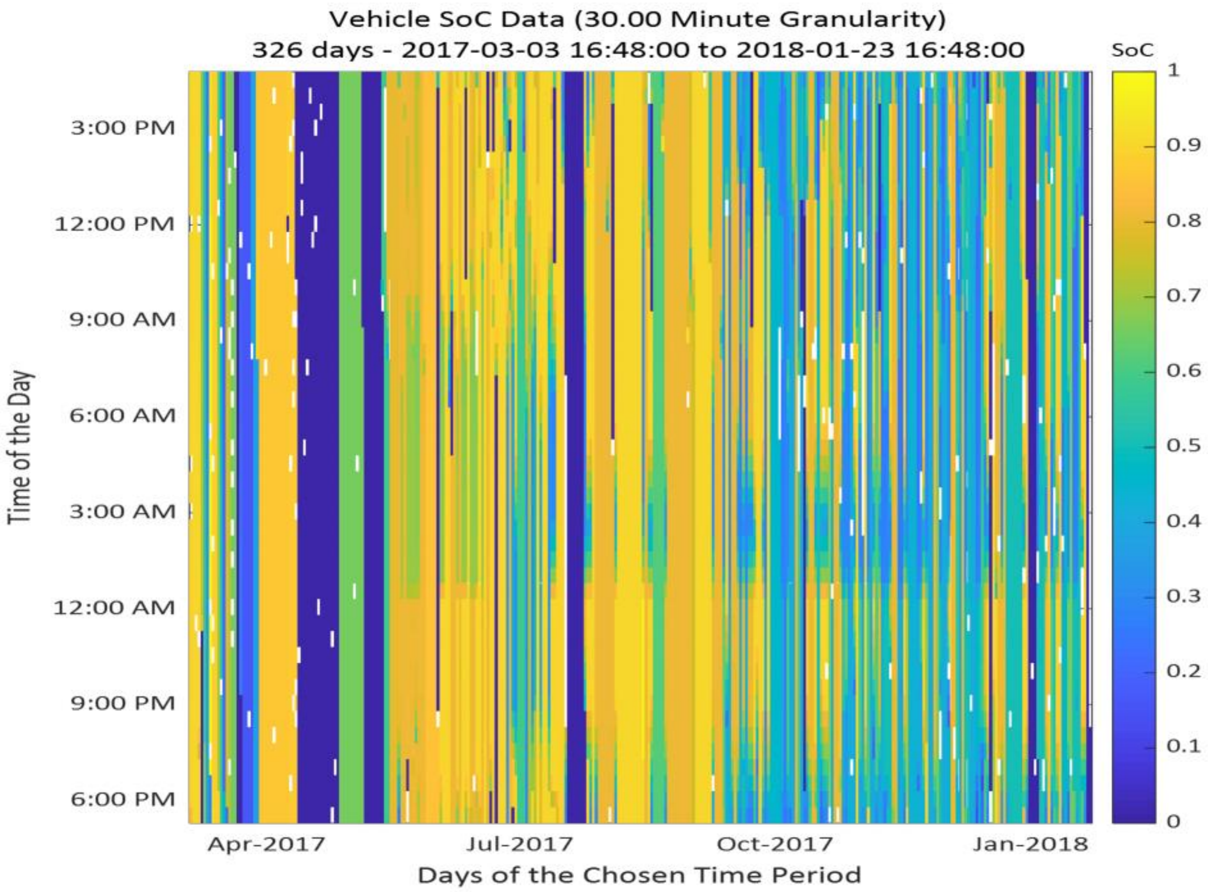

Figure 7: SoC Analysis (Unit A)

5.1.2 Mean of Change in SoC

- The plot shows mean of delta SoC for every half an hour.
- The change in SoC is small (order of 10^{-3} %).
- The smart charging methodology in the Loughborough Pilot was designed to maximize energy autonomy (not optimize charging cost).

- This could explain the unexpected drop after 12 AM if the household was using energy (e.g. running their washing machine over night).

Figure 8: Mean of Change in SoC (Unit A)

5.1.3 Snapshot of a day in October

- The plot shows SoC profile for a day with nearly complete data.
- Missing points are the gaps in the blue line.
- According to the smart charging methodology applied, the EV is charging between 12PM-3PM.
- The discharge occurring represents V2G or the EV being plugged in after a drive.
- Without knowing the household energy usage specifics or vehicle driving consumption, it is difficult to determine the reason for:
  - The discharges (i.e. V2G or driving)
  - The time of discharges

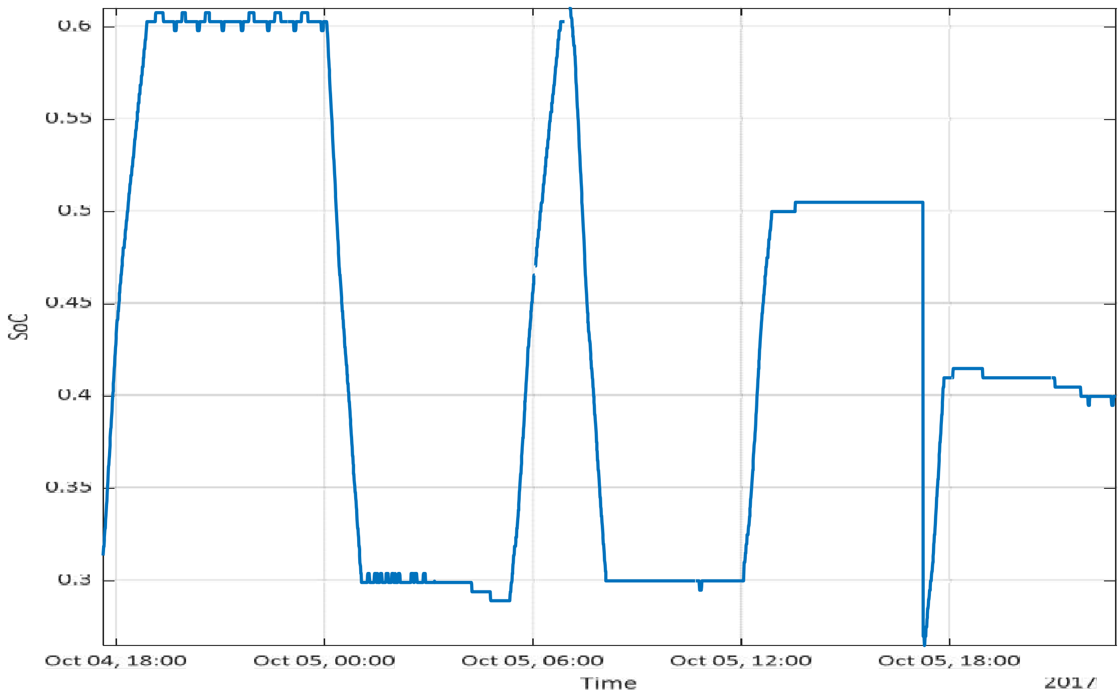

Figure 9: October Data Snapshot (Unit A)

5.1.4 Plug-in Data

- The vehicle was plugged in ***46% of the time in 309 days****.
- The white areas in the top figure represent gaps in the data.
- The vehicle availability profile shows an expected trend:
  - The vehicle was plugged in after 12PM at least until 3PM (charging period)
  - The highest plug in rate was in the evenings and overnight

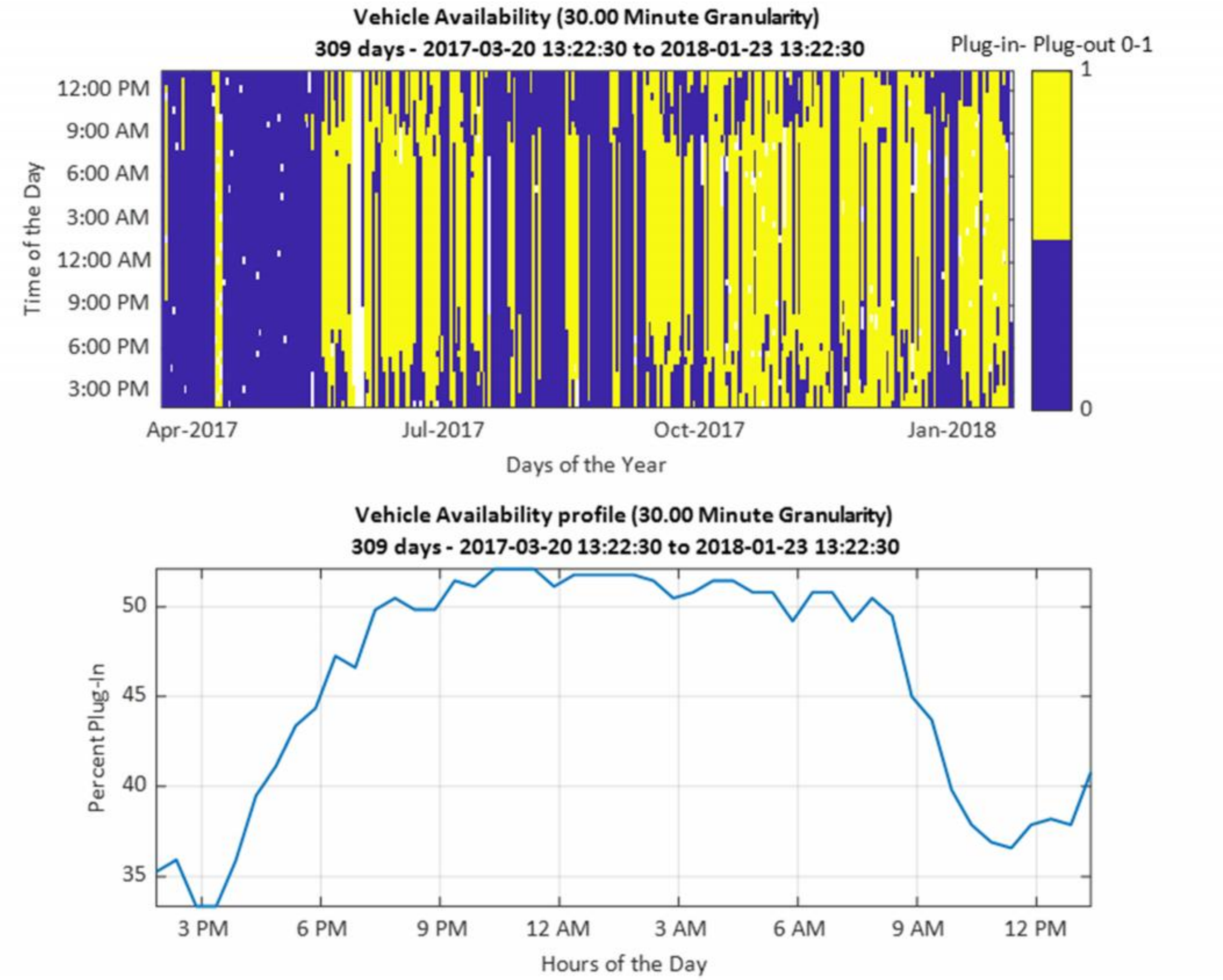

Figure 10: Vehicle Availability (Unit A)

5.1.5 Unit A Results Summary

- Matching the two data sets for Unit A shows ***1896 kWh*** *of V2G export over* ***309 days***.
- This equates to approximately ***6.14 kWh per day*** in the period.
- Considering that an average semi-detached home in the UK uses approximately 10kWh of electricity per day, the data shows that V2G could provide 61.4% of this demand.
- This calculation is only for a single Unit. More real-world data on similar households would be more representative.

5.2 Unit C

Unfortunately, due to incompleteness of data, less analysis was possible for other sites compared to Unit A. Unit C is the next most complete data source; however, data analysis was limited to the following topics:

- State of charge (SoC)
- Plug-in data

5.2.1 State of Charge (SoC)

- 584 days of SoC data are available from the business property V2G unit in Coventry.
- Data Completeness: 72.58%
- This V2G unit was used by more than one vehicle, therefore it is difficult to analyse in depth.
- Long periods of missing data and long periods with no change.

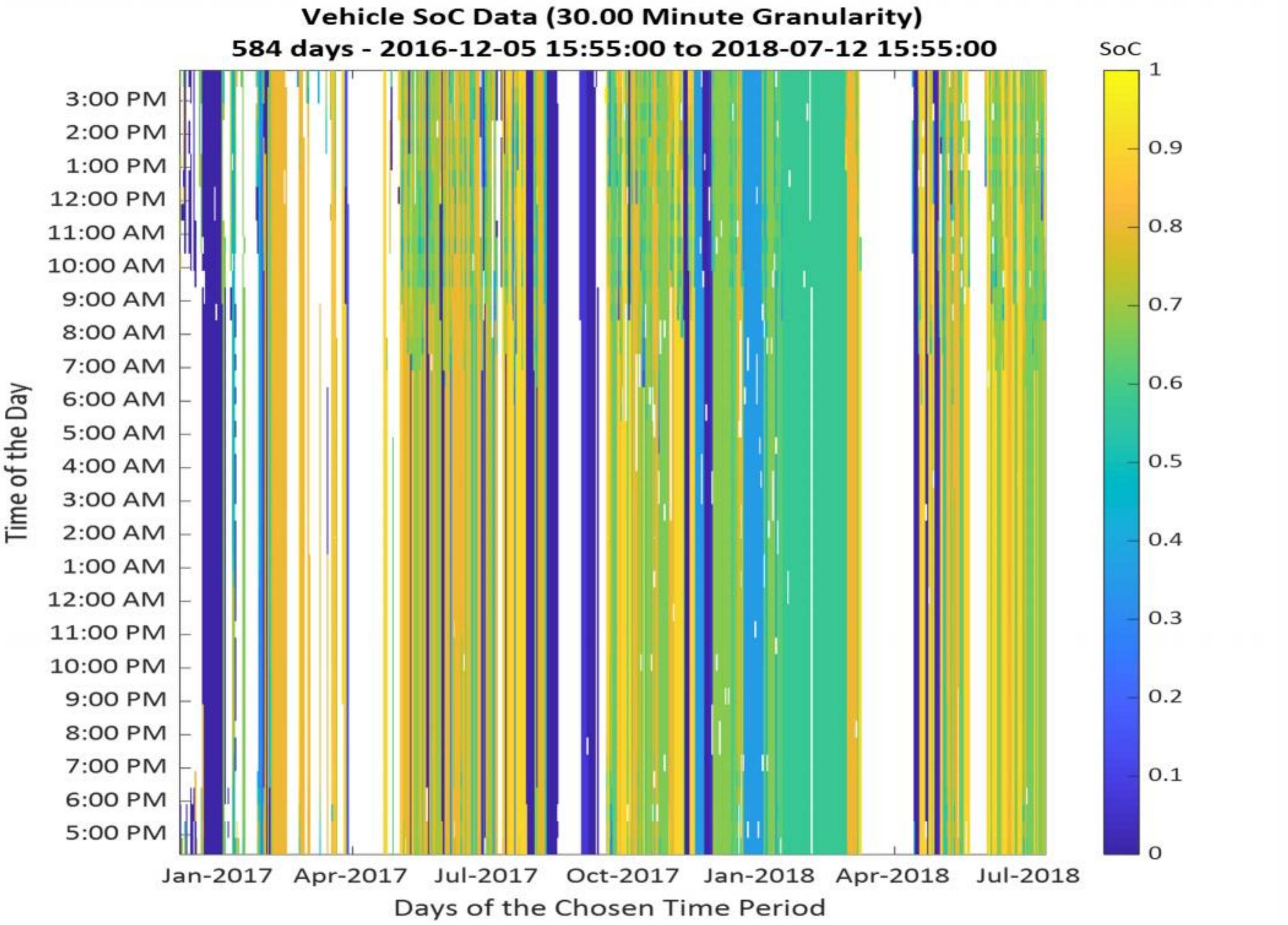

Figure 11: SoC Analysis (Unit C)

5.2.2 Plug-in Data

- The vehicle was plugged in 18.24% of the time in 526 days.
- The vehicle availability trend shows the vehicle or vehicles are plugged in during the day.
- This is as expected for a business where employee's personal vehicles are being plugged in when they arrive for work.

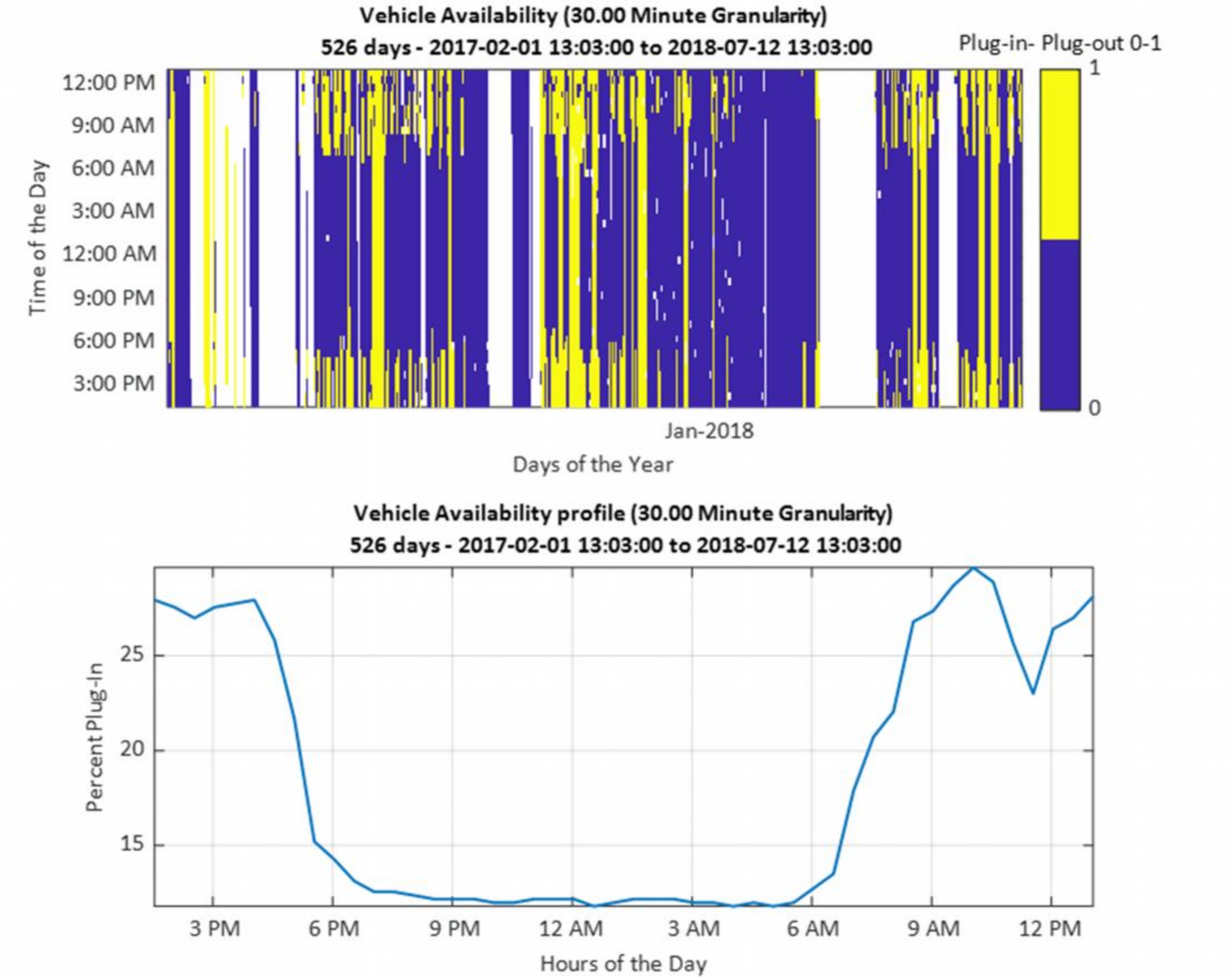

Figure 12: Vehicle Availability (Unit C)

5.3 Unit B

- This unit was moved from Manchester to Brighton.
- It is known that initially the unit was not connected, which is clear from the data.
- Any data after October 2017 also appears to be incorrect.

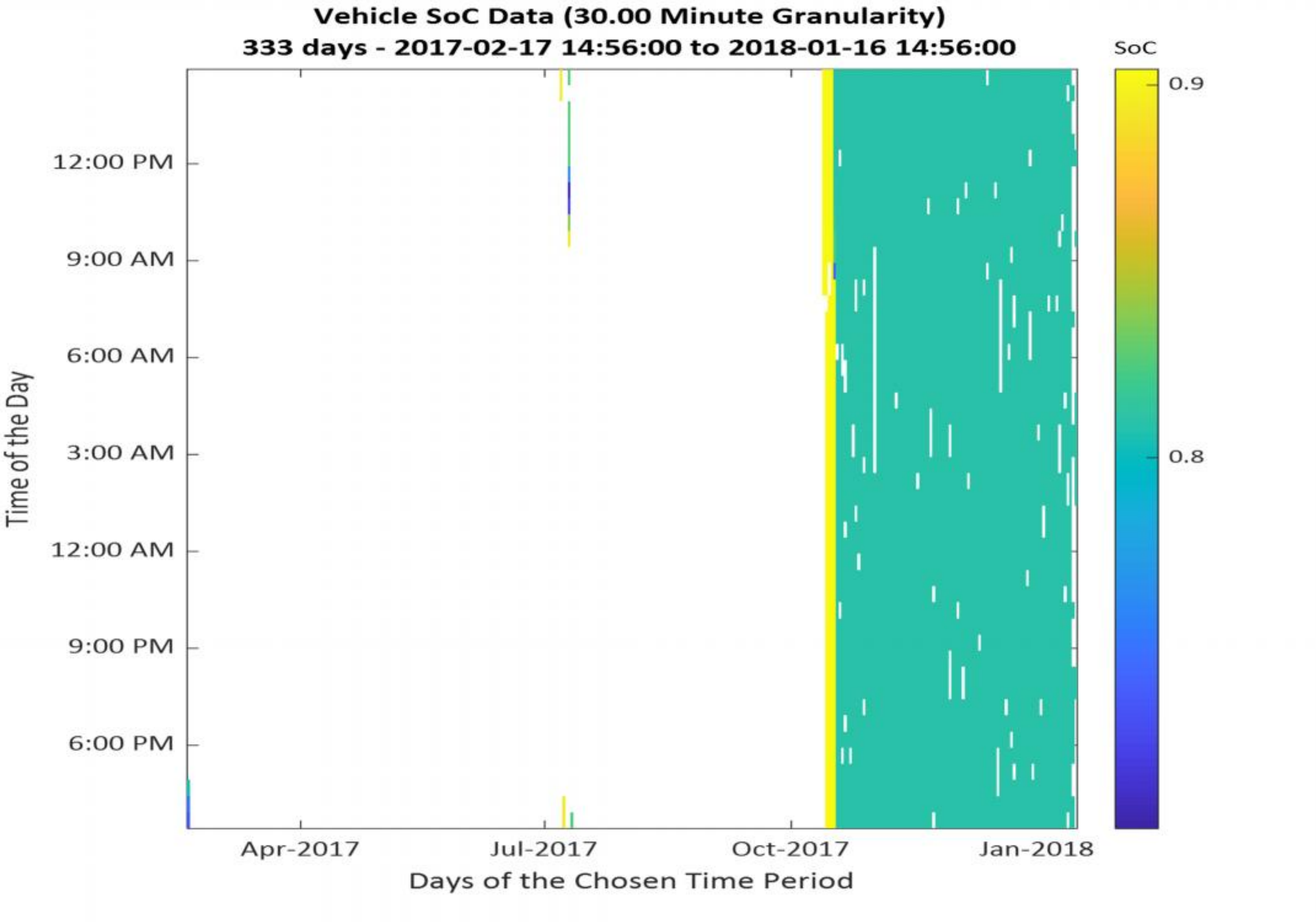

Figure 13: SoC Analysis (Unit B)

5.4 Modelling tools - Eva[e]

As well as the V2G units, Cenex has used the learnings from the V2G project to develop Eva[e], a simulation tool demonstrating the revenue or cost savings of utilising electric vehicles (EVs) with vehicle-to-grid (V2G) technology. Eva[e] uses stochastic probability models to understand real-world vehicle usage, building demand and electricity market data to evaluate the techno-economic benefits of smart charging and V2G in a variety of usage scenarios.

A public version of Eva[e] is available online (https://evae.cenex.co.uk). This is simplified version of the full Eva[e] model and acts as an online assessment tool which provides bespoke and comprehensive techno-economic analysis of smart charging and V2G business case for the following scenarios;

- Building self-consumption/peak shaving with or without PV
- Energy market trading, such as Firm Frequency Response (FFR), Short Term Operating Reserve (STOR) or selling into the wholesale market.

6 Conclusions

The aim of the EFES project was to demonstrate that V2G could be used in the real-world to provide both local and national energy service through a Virtual Power Plant. To this end, the project was highly successful, leading to the first installations of domestic V2G units in Europe, as well as significantly reducing the form factor compared to previous V2G prototypes. The unit was able to successfully integrate with existing energy systems through the BEMS to optimise its operation and achieve the greatest value for the end user. The EFES project was also used to develop the eva^e tool which is available online to help potential owners of V2G understand the value which V2G could achieve. This is available online at:

https://evae.cenex.co.uk

The data analysis also led to the following key conclusions:

- V2G Unit A (Loughborough) has logged the most complete data sets and therefore provides the greatest opportunity for analysis.
- Analysis indicates a total of 1896 kWh of V2G in 309 days, giving an average of 6.14 kWh/day. This is equivalent to just over 60% of the typical daily demand for a domestic property in the UK.
- Despite some data issues, vehicle availability profiles can have been generated for Unit A and Unit C by ignoring or ‘filling in’ the missing data using common data analysis methods.
- The vehicle at the private household in Loughborough (Unit A) was available (plugged-in) 46% of the time in 309 days.
- There are a reasonable number of data points available for Unit C (Coventry), but long portions of gaps and being used by more than one EV makes it difficult to draw out many clear conclusions from the data.
- Unit B (Manchester-Brighton) has a data completeness of only 27.5% (Appendix I), and the existing data appears incorrect because there is negligible change in the SoC.

The data from this trial is available for free download from the Cenex website (**www.cenex.co.uk**) with the aim of supporting the development of new products and services in the area of V2G. The data is broken down by unit (A – D). Where available, the data is then further broken down into data from the energy storage system (ESS) and the vehicle-to-grid unit (V2G). The ESS and V2G folders each contain 28 .CSV files, with each .CSV file containing three columns covering the date, time and ‘value’. The description and unit for each file is given in Appendix A.

6.1 Recommendations

The EFES project was one of the first real-world demonstrator projects carried out by many of the members of the consortium. This created a steep learning curve for the team. The following lessons have been learnt and applied to improve the delivery of more recent projects:

- **Check data regularly *during* collection rather than afterwards:** Prototype and early stage production units are inherently unreliable and subject to issues and failures. It is recommended in particular that the quality of data being collected should be checked on a regular basis throughout a project in order to identify any issues and to allow timely resolution.
- **Make stakeholder education an early priority:** When working with new technologies, it is easy for simple mistakes to be made when stakeholders do not fully understand the requirements. In this case, the procurement team for one trial site overruled the request to purchase Nissan LEAFs (which are V2G compatible) and chose to purchase BMW i3’s to better align with the needs of the organisation. However, as a result the site was no-longer able to participate in the project (BMW i3’s were not at the time warrantied for V2G). This indicates the importance of engaging with key stakeholders and providing clear education and guidance early on in a project; especially where new technologies are involved.

- **Treat staff turnover as a key risk and plan for successful handovers:** One of the key risks in any project is retention of key personnel; particularly in the automotive and technology innovation spaces where certain skills are highly sought-after. However, there are ways to mitigate this risk. One key area experienced with EFES was around naming of data streams. It is important that data streams are either labelled as to provide clear guidance as to what is being measured, or a key should be readily available. This is a simple process which can be implemented from the outset as long as staff turnover is treated as a significant project risk. Simple project documentation processes and handover methodologies can also be used to ensure learning is captured at key stages throughout the project, minimising the impact of staff turnover.
- **Plan data activities and requirements from the start:** Another common issue in technology trials and which was also experienced in EFES was relating to data streams. The project started with the view of utilising the standard data streams recorded by the hardware, rather than specifying the data to align with the format and content required to support later data analysis. It is therefore essential to have a clear view at the start of any new project around what analysis will be carried out and the inputs required to do so.
- **Understand the key project dependencies, no matter how small, and manage as risks:** Most technology trials and demonstrators are unable to operate in isolation and therefore dependencies exist with a wide range of existing systems. Within this project, it was found that internet/router issues resulted in loss of data. Loss of power at the building would also impact the unit, sometimes resulting in units failing to restart and requiring manual intervention. A key method for tackling this issue in future would be to design units with limited data storage capacity so that when there is no connection to the internet, the unit stores the data locally and sends it in packages later on. Regardless of the specific dependency, by identifying dependencies and potential 'weak spots' in the full trial architecture, these can be managed from the outset as risks, including developing proactive mitigation plans rather than relying on reactive 'problem solving'.
- **Protect your data:** For most modern projects, the most valuable output is the data. It is therefore worth planning ways to protect this data. In the case of EFES, part way through the project the server used to collect and store the data had to be changed. This resulted in loss of data for a period, as well as loss and corruption of some existing data during the transfer process. This is difficult to plan for, but the use of multiple, independent servers for data collection so as to provide a back-up service for critical data could have protected against this issue.
- **Expect the unexpected and allow sufficient contingency to manage it:** Most projects experience unexpected changes at some point, and it can be extremely difficult to plan for this. This is indicated by various of the points above. While some can be managed or mitigated, there will always be some unexpected elements which arise. It is therefore important to include some level of 'contingency' within a project. One good way of doing this is to plan for a lessons learn session at certain key stages throughout the project. These could be 1-week blocks in the plan where nothing else is planned. If everything is going to plan when the project reaches one of these milestones, then the week can be used to review key learning accelerate critical path activities, but where issues have arisen this gives some space for partners to recover lost time and put reactive or proactive plans in place to help recover the project.

Cenex has been involved in running and managing innovative technology trials and research in the automotive and energy industries since 2005. For support with product development, market insight or technology trials and demonstrations, contact us at:

info@cenex.co.uk

Appendix A – Data Definitions

File Name (ESS)	Description	Unit
battery_amphours	Battery capacity in amphours	Ah
battery_capacity	Battery Capacity	Unknown
core_battery_soc	State of Charge of the battery	0 to 1
core_power_ac_ac-consumption	Household Power consumption	W
core_power_ac_ac-solar-production	Power produced by PV	W
core_power_ac_battery-to-meter	Power from battery to meter	W
core_power_ac_cons-from-battery	Power consumption from battery	W
core_power_ac_cons-from-grid	Power consumption from grid	W
core_power_ac_cons-from-solar	Power consumption from solar	W
core_power_ac_consumption	Empty	
core_power_ac_grid-to-meter	Power from grid to meter	W
core_power_ac_meter-to-battery	Power from meter to battery	W
core_power_ac_meter-to-grid	Power from meter to grid	W
core_power_ac_solar-production	Empty variable	
core_power_dc_all-solar-store-to-battery	Power from PV stored in the battery	W
core_power_dc_battery	Power exchange from the battery	W
core_power_dc_dc-solar-production	DC power generation (not applicable here)	W
core_power_dc_solar-production	Empty	
current_battery	Battery current	A
datalog	Data and data clean up information	NA
derived_acExport	Test parameter	
derived_acLoad	Test parameter	
derived_power_ac_battery-export-to-grid	Empty	
derived_power_ac_grid-import-to-battery	Empty	
derived_power_ac_grid-import-to-home	Empty	
derived_power_ac_solar-export-to-grid	Empty	
derived_power_ac_solar-store-to-battery	Empty	
voltage_battery	Battery voltage	V

File Name (V2G)	Description	Unit
battery_amphours	Battery capacity	Ah
battery_capacity	Battery capacity	Unknown
core_battery_soc	Battery State of Charge	0 to 1
core_power_ac_battery-to-meter	Not applicable in V2G or empty	
core_power_ac_consumption	Not applicable in V2G or empty	
core_power_ac_grid-to-meter	Not applicable in V2G or empty	
core_power_ac_meter-to-battery	Not applicable in V2G or empty	
core_power_ac_meter-to-grid	Not applicable in V2G or empty	
core_power_ac_solar-production	Not applicable in V2G or empty	
core_power_dc_battery	Not applicable in V2G or empty	
core_power_dc_consumption	Not applicable in V2G or empty	
core_power_dc_solar-production	Not applicable in V2G or empty	
core_system_status	System status	
current_battery	Battery current	A
datalog	Data and data clean up information	
derived_acExport	Test	
derived_acLoad	Test	
derived_power_ac_battery-export-to-grid	Empty	
derived_power_ac_grid-import-to-battery	Empty	
derived_power_ac_grid-import-to-home	Empty	
derived_power_ac_solar-export-to-grid	Empty	
derived_power_ac_solar-store-to-battery	Empty	
vehicle_battery_capacity_HWh	Vehicle battery capacity	Wh
vehicle_battery_remaining_HWh	Vehicle battery remaining	Wh
vehicle_plugged-in	Vehicle plug in flag	0 not plugged, 1 plugged
vehicle_plugged-in_trigger	Unknown	
vehicle_unplugged_trigger	Unknown	
voltage_battery	Battery voltage	V

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