cenex

Innovate UK

Department for Business, Energy & Industrial Strategy

Office for Zero Emission Vehicles

EV-elocity

Project Final Report

JUNE 2022

Lowering your emissions through innovation in transport and energy infrastructure

Executive Summary

Demonstrator Project

The EV-elocity Project was funded by Innovate UK, the Department for Business, Energy and Industrial Strategy, and the Office for Zero Emission Vehicles between September 2018 and January 2022. Using a grant of £3.77m, the project sought to Demonstrate Vehicle-to-Grid (V2G) in a range of real-world situations to gain technical, customer and commercial insights into this emerging technology.

Delivered Aims

Although a range of commercial and unfunded partners withdrew from the project in January 2020 (Kearney, Honda, Brixworth Technologies, E-car Club and Peel Land and Property), the consortium of Cenex, CrowdCharge, Leeds City Council, Nottingham City Council, University of Nottingham and University of Warwick collaborated to successfully deliver on the five main aims in a refreshed project from August 2020 onwards.

This final project report presents the findings and lessons learned through the project against each of the five aims.

Deploy a technology-agnostic backend system and UI – successfully delivered by CrowdCharge

ACTIVITIES:	INSIGHTS AND IMPROVEMENTS
A **new system architecture** was designed by CrowdCharge to connect, control and dispatch two types of chargers using the same backend system.	More extended end-to-end system testing would ensure asset management is working seamlessly with charger control
A **range of operators across the supply chain** were coordinated to install and commission 15 chargers across eight sites: hardware OEMs, asset managers, DNOs, installers, site fleet managers, site facilities managers, site electricians and consortium members.	A more formal commissioning process between hardware, software, asset management, operation and site teams would benefit future installations. Support for V2G involves a very different skill set to unidirectional chargers because most issues require detailed technical knowledge to address. The availability of a local site electrician is critical to uptime and having a user at the chargepoint significantly aides troubleshooting.
An **operational strategy** was designed for all chargers to focus on behind the meter activities at the vehicle-user-building interface, all whilst prioritising user needs. The project was delivered in a **range of scheduled and dynamic phases**, looking to optimise for least cost, optimise for least carbon and optimise to condition the battery.	Reductions of around one quarter in CO_2 emission were achieved by both scheduled and dynamic phases. Dynamic optimisation brought a modest 3% improvement in carbon intensity compared to scheduled optimisation. There is a clear trade-off between battery conditioning and cost- or carbon-optimisation: CO_2 emissions in the battery management Phase 4 were 16 – 17% higher than in the dynamic optimisation Phase 3.

Executive Summary

Demonstrate V2G at a range of UK locations – successfully delivered, although not as fully as hoped

ACTIVITIES:	INSIGHTS AND IMPROVEMENTS
Nine sites were recruited from and by the consortium partners. Each site was contracted for the duration of the project with the option to extend commercially after.	Not many vehicles are compatible with V2G and the limited charger sources do not always comply with site policies. Contract signature added around 3 months to the project. Upgrading sites which have matured their EV charging processes from dumb or smart charging to V2G is easier than those who are early in their electrification transition.
A range of **site surveys** were conducted, **DNO applications** made, **installers** contracted and **users** briefed to deliver the projects.	Site surveys should include analysis of the impact of V2G on wider site systems and controls. V2G installations require a more complex site survey to ensure safe and effective operations. The cost- and time-impact of significant power supply upgrades should not be underestimated. Suitably qualified and experienced electrical contractors should be able to install V2G chargepoints without significant difficulty. Guidance may be required around the use and usage of RFID cards to avoid mis-handling.
Two types of hardware were procured by the consortium partners through their own procurement processes.	Delivery of innovative projects within more traditional procurement structures is challenging and flexible routes to market are recommended for Public Sector Organisations. Local Authority ITT processes are not an effective or efficient route to procure V2G. V2G hardware currently has very long lead times.
After commissioning, **all installations required a range of troubleshooting** and use of the customer support systems.	Troubleshooting V2G installations will likely involve collaboration across the whole supply chain. V2G brings challenges as organisations have to adapt to and handle new interactions between departments. Continuity of staff and knowledge within partner organisations is essential to ensuring a good level of customer service.
The **sites received benefits from the V2G** installations, including cost savings, increased driver satisfaction and data.	Reliability of the V2G system is a hygiene factor. Without this exceeding 95%, customers will lose confidence and will not receive benefits from V2G. Charging schedules must be fitted to driver needs and deliver charge events to ensure user acceptance. V2G drivers report a high level of satisfaction with stable and reliable chargepoints. Prioritising the user experience will be important to ensure that control of the V2G system is not too complicated.

Executive Summary

Discover more about user behaviour and V2G operations – successfully delivered by University of Nottingham

ACTIVITIES:	INSIGHTS AND IMPROVEMENTS
The most **strategic locations for V2G** chargepoints were analysed using fleet telemetric data.	Telemetry data not only allows the identification of possible fleets to transition to electric but also compatibility with V2G and identification of the best locations to take advantage of long dwell times.
Vehicle usage, building energy demand, renewable energy generation and grid carbon intensity data were combined to explore **potential carbon emission reductions**.	Average CO_2 emissions from charging can be reduced by use of V2G at the vehicle-user-building interface. The application of machine learning to forecast 48 hours ahead is a powerful tool to reduce emissions further. Ultimately, the way energy storage (including the capacity of EV batteries) is managed has a significant effect on the benefits received.
The **likely presence of EVs near the V2G chargepoints** was examined to predict (dis)charging opportunities.	Predicting vehicle availability can support trading and vehicle utilisation decisions made by aggregation services. Automated Machine Learning was the most effective technique applied to predict vehicle locations with a 90%+ accuracy. Convolutional Neural Network methods could predict storage capacity and adapt to changes in the underlying fleet behaviour. Online Machine Learning was applied to enhance the model to continually refine predictions and adjust to disruptive events.
A set of **user surveys** were deployed to understand the impact on the drivers.	A limited sample means that the outcomes reported here are uncertain but being addressed in an ongoing and wider follow-up survey. The main challenges reported by users corresponded to technical issues with operating the chargers. Users themselves reported only very few benefits of V2G and felt they would need to make some changes to use the technology outside of the project. However, they felt that it might allow them to better charge their vehicle with solar energy and reduce CO_2 emissions or energy costs.

Executive Summary

Deepen understanding of the management of battery systems including opportunities to mitigate degradation and possible extend battery life – successfully delivered by University of Warwick

ACTIVITIES:	INSIGHTS AND IMPROVEMENTS
Long-term **Calendar Ageing** tests of Lithium-ion Nickel Manganese Cobalt batteries were conducted.	Degradation, State-of-Charge (SoC) and ambient temperature have a complex relationship. Capacity decreases more greatly at higher temperatures and SoCs.
Cycling Ageing tests were conducted by charging and discharging the cells repeatedly.	The rate of degradation is increased with greater charge throughput, especially if this is at relatively higher or lower temperatures.
A **combined degradation model** framework was created to calculate the total capacity loss.	The combination of Calendar Ageing and Cycling Ageing gives the overall degradation of the battery.
A range of **charging strategies** was designed to pre-condition the battery and analysed for its impact on degradation	Battery degradation for EVs with gentler driving profiles are harder to manage under V2G conditions due to a generally higher SoC at the point of plugging in. Balancing calendar and cycling ageing produces the strongest all-round performance, regardless of the intensity of driving. Where a vehicle is heavily used (and SoC is typically lower when it is plugged in), a time-shifted approach is the simplest and most effective way to protect the battery. The proposed charging strategies are capable of mitigating the total ageing process from 7.3 – 26.7% for the first 100 days of operational life. Battery life and be improved from 8.6 – 12.3% for one-year continual operation, compared to the reference ‘dumb charging’ strategy.

Executive Summary

Develop and extend an evidence-based techno-economic model of how V2G will be viable within the UK – successfully delivered by Cenex

ACTIVITIES:	INSIGHTS AND IMPROVEMENTS
A **range of data was collected** to support analysis across the project	Sites can be very different and are not directly comparable due to different demand profiles, vehicle usage and tariffs. Future projects would benefits from chargepoints and management systems which can reliably identify the plug-in and plug-out times of vehicles, as well as the vehicle identity. Hardware reliability and the lack of customer use through covid-19 undermined the quality of the data available for analysis.
Perfect foresight modelling was deployed to quantify the **best-case cost- and carbon-optimisations**	For sites where joint cost- and carbon optimisation is possible, the effective cost of carbon abatement achieved by the site is very small. Cost optimisations with a nominal 1p per tonne carbon price yield a significant carbon reduction. Carbon prices set at above £20/tonne provide sufficient incentives to reduce carbon further on the standard two-rate tariff, although, this threshold will vary, depending on the tariff. The peak for the UoW and NCC sites occurs at a carbon price of £200/tonne, where the effective cost of abatement for the site is £45/tonne.
The **value of V2G in general** was examined, based on the real-world data collected in the project	A V2G tariff optimisation can save around £100 per year per chargepoint on a two-rate tariff. With a smarter (e.g. half-hourly) tariff, theoretical maximum savings can be around £400 per year per chargepoint. Such tariffs are recommended for sites that have V2G and little other non-flexible demand on the same meter. Carbon savings can be up to around 450kg per V2G chargepoint per year when a carbon optimisation is used. Significant carbon savings (>180kg) can be made (at virtually no energy cost) when carbon is optimised as well as tariff costs. Therefore, carbon optimisation should be included in flexible V2G operation.

Contents

1 Introduction

1.a A coming Transport Revolution

In November 2020, the UK Government published a 10-point action plan for a "Green Industrial Revolution"[i]. The fourth point reads as follows:

Electric vehicles: Backing our world-leading car manufacturing bases including in the West Midlands, North East and North Wales to accelerate the transition to electric vehicles, and transforming our national infrastructure to better support electric vehicles.

In the accompanying documentation, the UK confirmed it would end the sale of new petrol and diesel cars and vans by 2030, ten years earlier than the UK's previous Industrial Strategy as laid-out in the *Road to Zero* publication. Furthermore, it was announced that all new vehicles would have to be 100% zero-emissions at the tailpipe by 2035, thus eliminating the sale of Plug-in Hybrid Electric Vehicles (PHEVs) from that point forward.

In July 2021, the UK Government expanded its action plan with its **Transport Decarbonisation Plan (TDP)**[ii]. This contained a raft of new and evolving proposals for cycling, walking, railways, maritime transport and aviation, all important areas for the UK's long-term plans to reach net-zero by 2050. Many policies on road transport were already well-established but the TDP extended proposals to cover zero-emission buses and coaches, freight and logistics, and transport planning.

Whilst the headline ban on the sale of new Internal Combustion Engine (ICE) cars and vans remains unchanged, a zero-emission delivery plan has been published, containing the outline of the regulations which will deliver it, including a Zero Emission Vehicle (ZEV) mandate[iii]. Importantly, this adds a commitment to introduce a new road vehicle CO_2 emissions regulatory regime in 2024.

1.b The impacts of EVs on the national grid

Over the past decade, electric transport has developed to become the dominant net-zero fuel for cars, two-wheelers and vans. The resulting collision between the transport and energy sectors brings both threats and opportunities.

The electrification of transport brings with it a significant increase in electricity consumption and the power flows at the distribution network level. This is happening at a time when traditionally-fuelled power stations such as coal and oil are limiting their running or closing, and inherently intermittent renewable sources are being brought on-stream. Consequently, it is well established that the electricity system is likely to come under significant strain in the coming decade. Indeed, the National Grid Future Energy Scenarios 2021 (FES) predict that up to 37.4 million EVs will be on UK roads by 2050. This could contribute an additional 25 GW demand onto the winter peak, reduced to around 10 GW if managed by smart charging[iv] **(Figure 1 - next page)**.

1.c The advent of Vehicle to Grid

Interestingly, a third line graces the FES chart. This shows that by combining vehicle-to-grid (V2G) with smart charging these peaks could be entirely mitigated, even reducing the overall demand by around 5 GW.

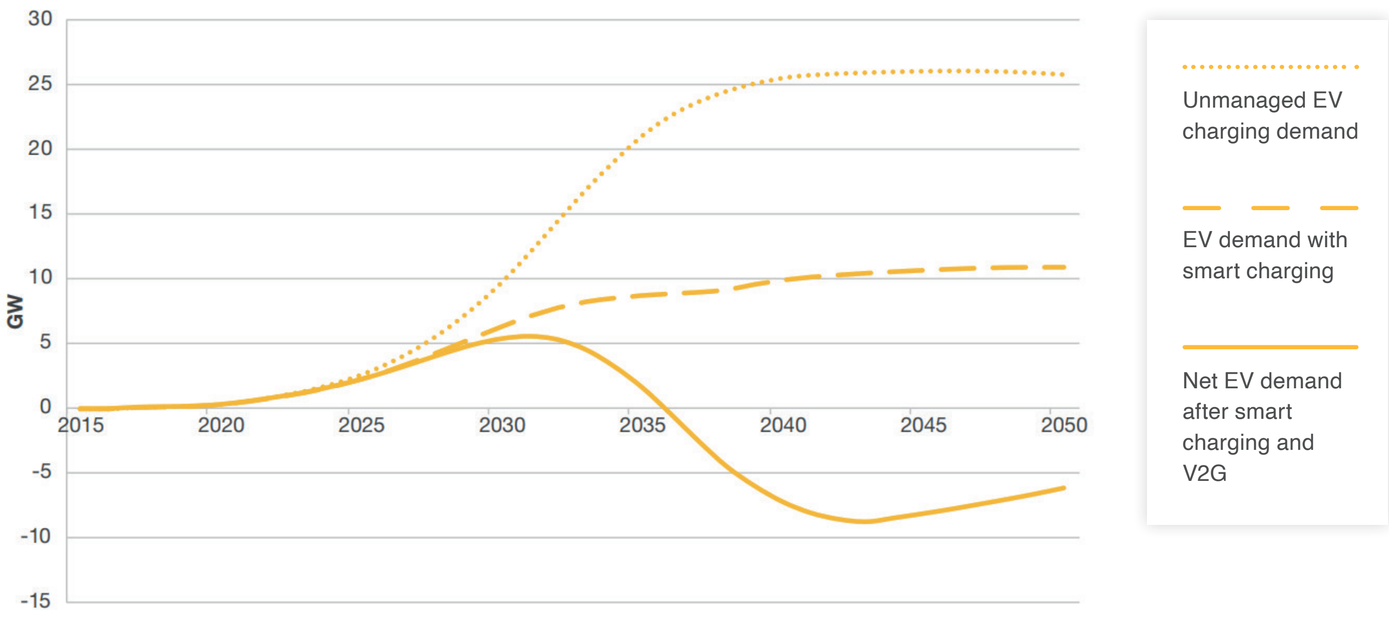

Figure 1: Electric Vehicle charging behaviour at winter peak demand.

The inclusion of V2G in FES 2021 forecast represents a significant coming-of-age for a concept posited as early as 1997 by Kempton and Letendre who wrote about "Electric Vehicles as a new source of power for electric utilities"[v]. Although the term V2G was not in-use, their description of the idea is uncanny for those working on V2G today. "Electric utilities could use battery vehicles as storage, or fuel cell and hybrid vehicles as generation …For a utility tapping vehicle power, the increased storage would provide system benefits such as reliability and lower costs, and would later facilitate large-scale integration of intermittent-renewable energy resources" *(ibid.)*.

Their foresight would prove prescient as the first V2G capable EV was launched ten years later – a converted Toyota Scion xB used by the University of Delaware and partners. Whilst the xB was only ever low-volume, the 2010 release of the Nissan Low Emission Affordable Family car (LEAF) heralded the start of wide-spread, commercially available Electric Vehicles (EVs).

Sadly, it was the 2011 Tōhoku earthquake, tsunami and resulting Fukushima nuclear disaster that kick-started an interest in V2G as a way of providing back-up power for homes and critical services. The Nissan LEAF used the CHAdeMO DC charging protocol which allowed research on V2G to move from theoretical to practical. The Nissan/Nichicon 'LEAF-to-Home' power supply system was released on 30th May 2012 and provided resilience to Japanese homes suffering rolling blackouts as all nuclear power stations were taken offline.

Since then, V2G projects have been established to explore this concept in thankfully less critical situations. Across the world, these have involved feasibility studies, proof-of-concepts and real-world demonstrators **(Figure 2 - next page)**. For more examples, the V2G hub documents current and past projects[vi].

1.d Innovate UK V2G Programme

Against this backdrop, the UK has emerged as a leader in the exploration and maturing of V2G. Through its Industrial Strategy, the UK Government has committed to be a world leader in shaping the future of mobility, and in the design and development

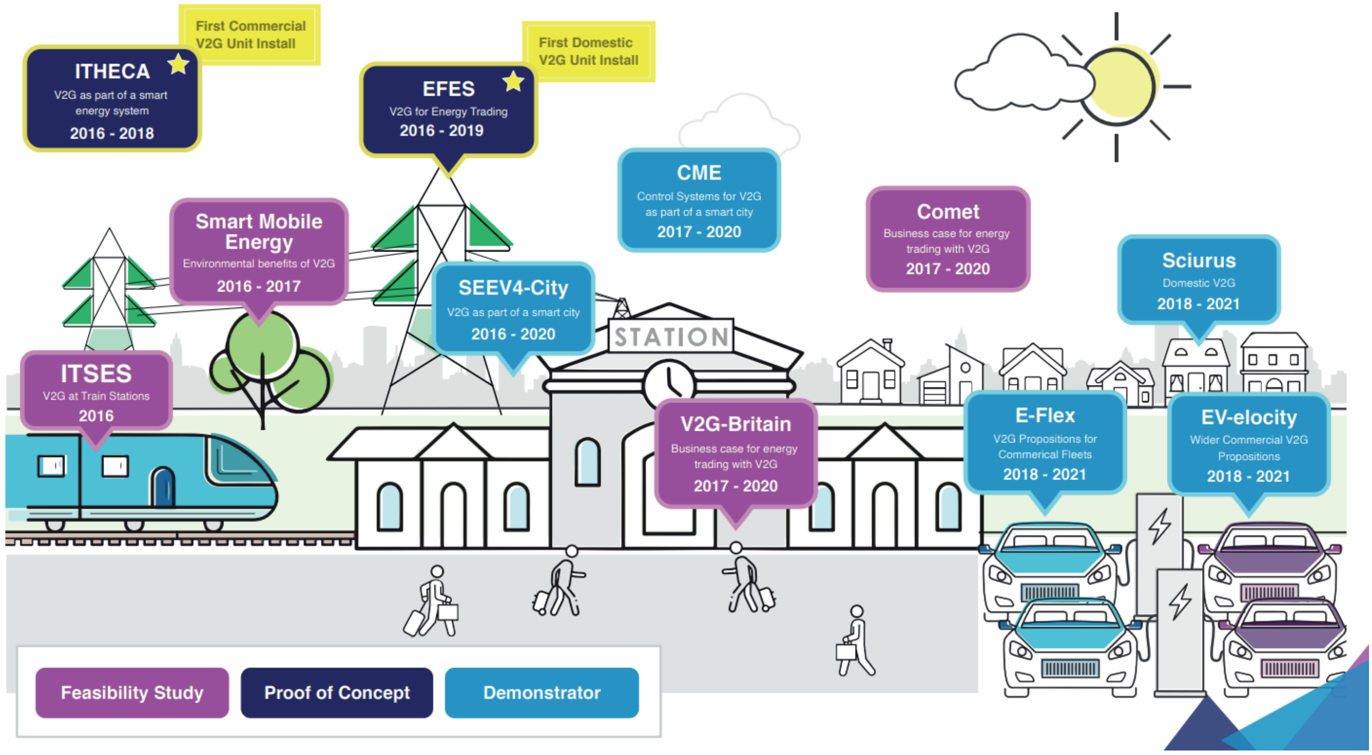

Figure 2: A history of recent V2G projects

of the clear technologies of the future. Vehicle-to-Grid (V2G) technologies offer an opportunity to enable Electric Vehicles (EVs) to deliver electricity back to the grid.

Over the last four years, Innovate UK has overseen a c.£30m Vehicle-to-Grid (V2G) programme funding 21 projects with 74 industry, government and academic partners. This programme explores and trials the technology itself in varying situations with a view to assessing the commercial opportunities that V2G might bring.

1.e Document Purpose

This document is the final report of the EV-elocity Project, part of the Innovate UK V2G Programme. It seeks to summarise the key observations, findings and insights from the project and is structured around our five aims, each addressed by the relevant consortium member.

Further project information, case studies and news from 2018 to 2022 can be found at: **www.ev-elocity.com.**

1.f Navigation

Key highlights are formatted like this (in any colour)

NOTE: Important caveats, assumptions or notes are highlighted like this (in any colour)

1.g Abbreviations

A full list of abbreviations and acronyms can be found in **Section 8** but key acronyms are used for the partners as follows:

- Cenex – CX
- CrowdCharge – CC
- Leeds City Council – LCC
- Nottingham City Council – NCC
- University of Nottingham – UoN
- University of Warwick - UoW

2 The EV-elocity Project

2.a Objective

EV-elocity **is one such demonstration project, running from September 2018 until January 2022. Originally a collection of public bodies, research and technology organisations, commercial companies and technology developers, it reformed in 2020 as a smaller consortium with a single objective:**

Demonstrate Vehicle-to-Grid (V2G) in a range of real-world situations to gain technical, customer and commercial insights into this emerging technology.

This replaced the former aim to test scalable business models to explore the value of V2G to the grid, local businesses and the customer.

2.b Project aims

This overall project aims to deliver this are described in **Figure 3**:

Deploy a **technology-agnostic backend system** and **user interface** to manage and operate V2G units and provide a **framework for research**.
Demonstrate V2G across a range of UK locations, **collecting data on charger**, **user** and **vehicle behaviour**.
Discover more about the **user behaviour** and **operation of V2G**.
Deepen understanding around the **management of the battery systems**, including opportunities to mitigate degredation and possibly extend battery life.
Develop an evidence-based techno-economic model of **how V2G will be viable within the UK**.

Figure 3: EV-elocity project aims

2.c Consortium

The project partners in the second half of the project are as follows:

- **Cenex (CX)** was established in 2005 as the UK's Centre of Excellence for Low Carbon and Fuel Cell technologies. Today, it 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. Cenex is one of the UK's leading experts in V2G and the overall project lead.
- **Crowd Charge (CC)** has extensive knowledge and experience of using their digital platform to manage smart chargers and V2G chargers.
- **Leeds City Council (LCC)** has a large number of EVs within their fleet which is expected to grow in the coming years. They have a keen interest in the business opportunity offered to them by V2G.
- **Nottingham City Council (NCC)** is a forward thinking Council engaging in the consortium to provide end user opinions and a clear uptake pathway through their EV procurement plan.
- **University of Nottingham (UoN)** is a leading UK university and the team has extensive knowledge on data analytics and algorithm and machine learning.
- **University of Warwick (UoW).** Warwick Manufacturing Group (WMG) is an academic department of the UoW and have expert knowledge on battery degradation, including in relation to V2G operation.

Before the consortium was reformed in 2020, the following organisations were also partners in the more commercially-orientated project:

- **Kearney** (former project lead) is a global management consulting firm. They are involved with some of the world's leading organisations, helping them to achieve immediate impact and growing advantage on their missions.
- **Honda** is a global vehicle manufacturer and the world's leading producer of internal combustion engines. It has recently released the Honda-e, a bi-directionally capable EV.
- **Brixworth Technologies** is a software house based in Milton Keynes using state of the art techniques and design practices to connect software and hardware, especially in the EV arena.
- **Ecar club (now Ubeeqo)** was the UK's first all-electric car club, operating emissions-free transport services.
- **Peel Land and Property** was an unfunded project partner and part of the Peel Group, being a key landowner of properties including Leeds Bradford Airport

NOTE: These former partners were approached to input into the report but all declined to contribute.

2.d Project structure

Following reformation in 2020, the EV-elocity project was structured around six work packages to ensure that the aims were achieved and the objective tackled effectively **(Figure 4)**.

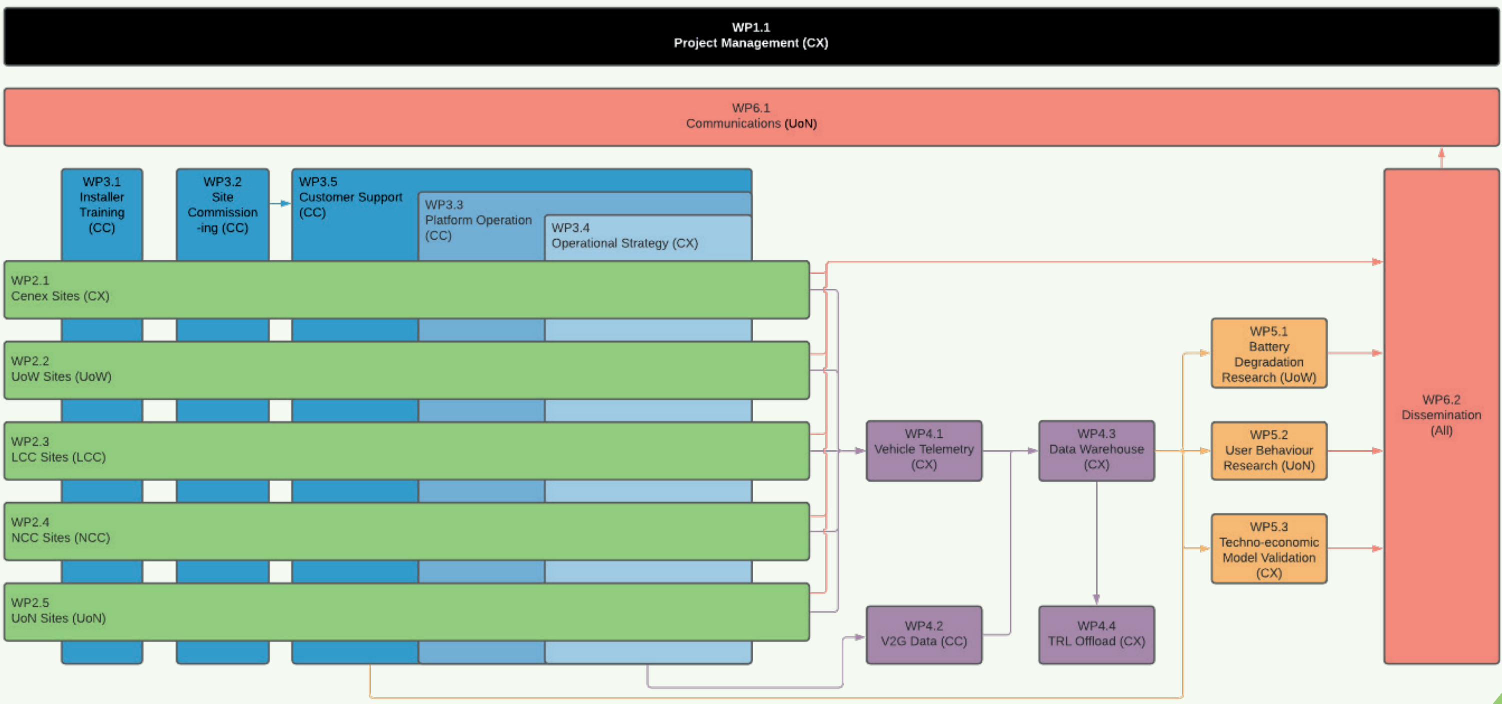

Figure 4: EV-elocity work packages

Each work package was assigned an owner (indicated by the partner acronym in **Figure 4**) who was responsible for describing the work package outputs, dependencies and managing the risks. **The overall work packages were as follows:**

WORK PACKAGE	TITLE	DESCRIPTION
WP1	Project Management	Ensure the project is delivered on-time, on-budget and on-quality.
WP2	Demonstration Sites	This work package includes the management of the participant sites, in cooperation with WP3.
WP3	V2G Operations	These work packages cover the commissioning, operation and support of the participant sites.
WP4	Data Collection	These work packages coordinate the collection of vehicle telemetry and charger data, project processing and delivery to Transport Research Laboratory (TRL).
WP5	Research and Analysis	These cover the three main research aims of the project; battery degradation, user behaviour and techno-economic modelling.
WP6	Dissemination	These work packages manage the external communications, dissemination and exploitation of the project.

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2.e Budget

The overall budget for the project was **£4.89m** including partner contributions, **with a total grant of £3.77m** provided by Innovate UK with its funder the Department for Business, Energy and Industrial Strategy (BEIS) and the Office for Zero-Emission Vehicles (OZEV).

3 Managing and Operating V2G Units

This section outlines the work and activities conducted by CrowdCharge to deliver the project's first aim:

Deploy a technology-agnostic backend system and user interface to manage and operate V2G units and provide a framework for research.

The system architecture is described before challenges and lessons learnt through the process of integrating the hardware into the backend system are presented. Then the chosen operational strategy is explained and the impact of this on the charger behaviour analysed.

3.a System Architecture

As with all V2G chargepoints, a system needs to be in place to manage and operate them. This includes the functions of asset management (is the system online), communicating the charging instructions and schedule, and sharing the charging session data. Due to there being two different hardware types, this was delivered in two ways.

3.a.i Nichicon Charger

The Nichicon V2G DC charger (**Figure 6**) was reversed engineered by CrowdCharge from the Japanese V2H LEAF-to-home product during 2017 and 2018 to trial and investigate V2G energy services in the UK market. To operate the 7 kW Nichicon V2G charger, a physical CrowdCharge controller box is required on site which connects via the mobile phone GSM network to the internet. This communication box allows the charger to be controlled remotely by the CrowdCharge asset optimisation platform. To do this, the charger is placed within a control and management architecture to ensure a connection was maintained with the Hangar19 asset management system and CrowdCharge backend **(Figure 7 - next page)**. This was deployed at Leeds City Council and University of Nottingham sites (see Section 4)b) on page 32 and Section 4)d) on page 38 respectively).

Figure 6: Nichicon charger

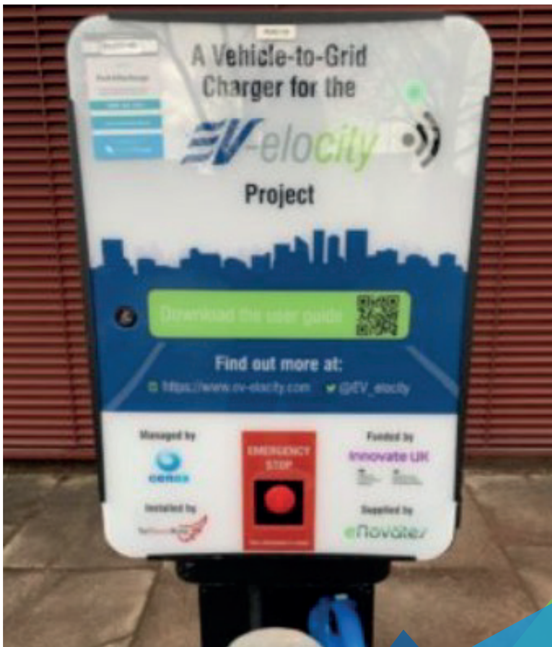


Figure 5: eNovates charger

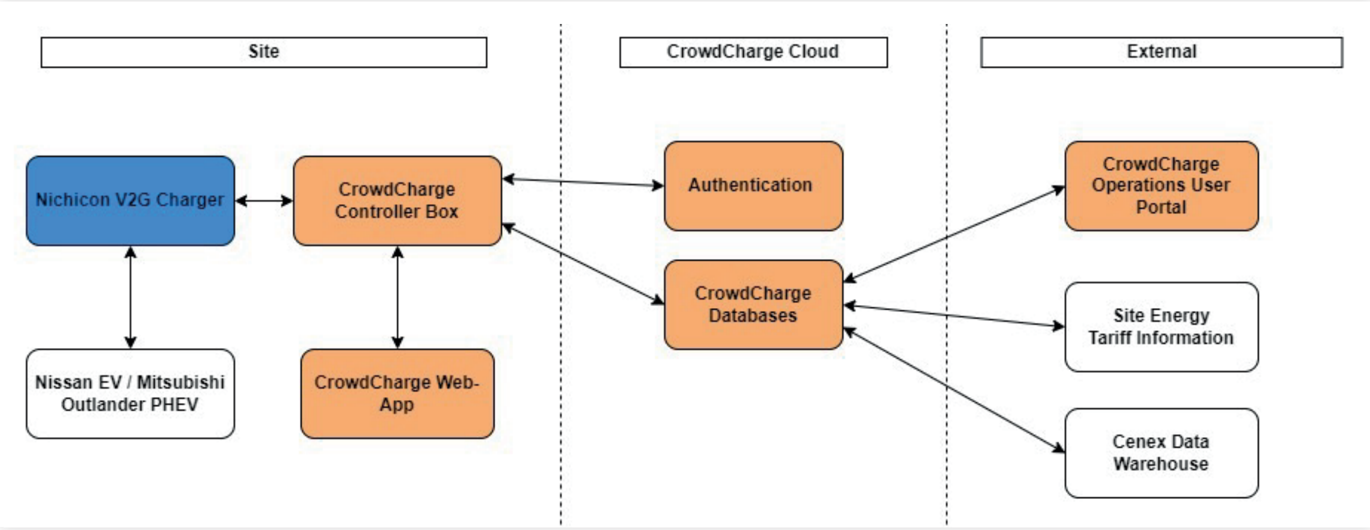


Figure 7: CrowdCharge architecture for Nichicon charger

3.a.ii eNovates Charger

The eNovates charger (**see picture in Figure 7**) was procured directly from Ecological Innovation in Belgium. Originally created in 2018 and 2019, this small post- or wall-mounted charger can charge or discharge at 10 kW over a three-phase connection. **Figure 8** shows how a virtual controller was created in the Hangar19 asset management system to enable connection and control from the CrowdCharge backend.

CrowdCharge were responsible for the delivery of energy optimisation on both the Nichicon and eNovates chargers. This platform underpinned the exploration of cost and carbon savings through smart and V2G charging, and the trialling of increasing battery longevity.

CrowdCharge contracted Hangar19, an engineering solutions company, who enable the development and delivery of EV services, equipment and associated energy infrastructure. A sister company – Park and Recharge – were responsible for the support services.

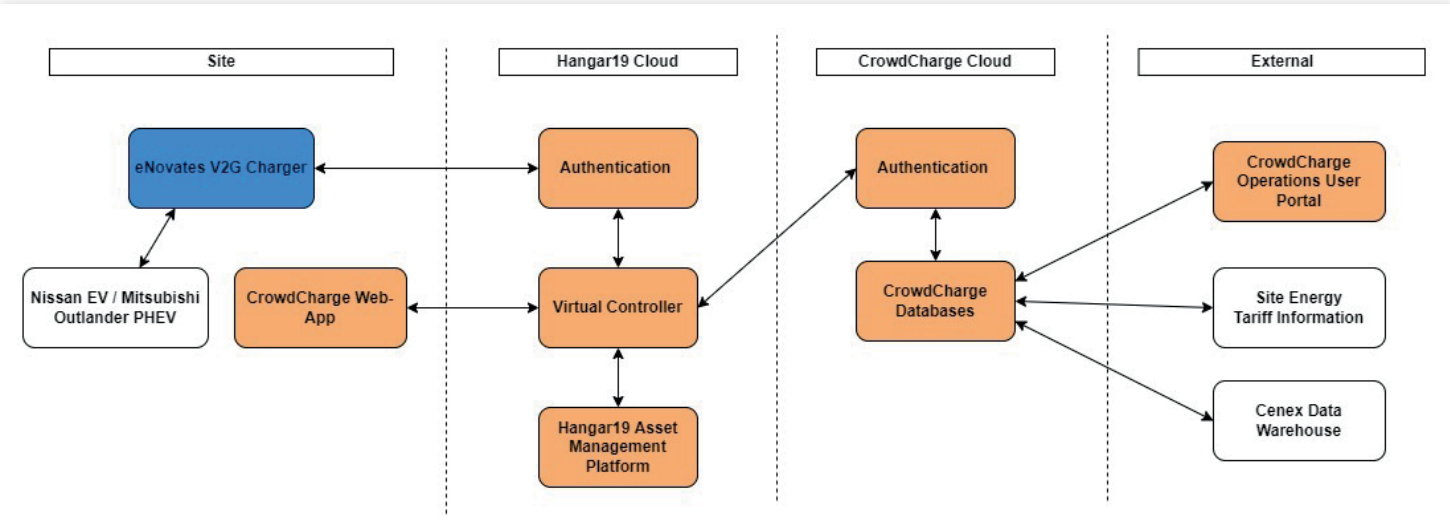


Figure 8: CrowdCharge architecture for eNovates charger

3.a.iii Challenges and Lessons Learned

Hardware Issues

The Nichicon V2G chargers have been used by CrowdCharge in other V2G trials so the operation and Asset Management connection was familiar. As the hardware support for these units were based in Japan, there was a risk that any faults which required escalation to the manufacture could take weeks or months to resolve due to the time difference and language barriers.

The eNovates units suffered suspected firmware or component failure in the first half of the customer trial. This was compounded by a lack of experience of the Asset Management team with the control and operation of the charger. The customer impacts of this are described in Section 4)a)iv) on page 30.

Before installing V2G equipment on any future trial, it is imperative the hardware is first tested with all the systems during a pilot stage to ensure an acceptable level of operation.

Difficulties in commissioning hardware on sites

There were difficulties at some sites when commissioning was scheduled. In particular, ensuring clear communication between the relevant organisations could have improved this to ensure all teams were ready.

For future deployments, it is imperative the lines of communication between the involved organisations are as streamlined as possible to avoid delays.

Future projects would benefit from a formal pre-agreed commissioning process where hardware, software, asset management, operation and site come together to sign-off the installation.

3.b V2G Operation

3.b.i Operational Strategy

Following the restart of the project in 2020, the consortium agreed to explore the cost, carbon and conditioning benefits of V2G behind the meter. This meant that the operation of the chargers was guided by the following principles.

Focus on behind the meter activities

Taking into account the partner's aims and needs, it was agreed that the Operational Strategy should not focused on grid services or revenue generation. Whilst Leeds City Council and Nottingham City Council are interested in revenue generation opportunities, this was lower down their list of priorities and is the area which has had most focus in terms of V2G projects in the wider Innovate UK programme. This focus linked well with the CrowdCharge activities to deploy a technology-agnostic system (as reported in this section).

Focus on the vehicle-user-building system

With the focus behind the meter, it was agreed that the inter-relation between the facility, user and battery would be of primary interest. It was noted that this linked well with the University of Warwick focus on the battery (see Section 6 on page 59) and the holistic approach that University of Nottingham planned to take for its analysis (see Section 5 on page 47).

All trial chargers complete the same tests at the same time

In order to test a range of scenarios, the project aimed to optimise all chargers according to the same principles at the same time. Therefore, where possible, the strategy outlined below was applied to all chargers at all sites simultaneously.

Prioritise user needs

Since this was a demonstration project, the partners agreed that users' needs should be prioritised. Therefore, the charger managers were asked to submit their State-of-Charge (SoC) preferences:

- Minimum SoC – this is a % SoC which the system will never discharge below and which the system will charge up to if the EV arrives at a lower SoC. Input was via the CrowdCharge interface.
- Target SoC – this is a % SoC at a particular time (i.e. 95% at 07:00) which the system will target and override any other strategy when it is necessary to hit this level. Input was via the CrowdCharge interface.

3.b.ii Trial Phases

In order to deliver the operational strategy, the demonstration stage of the project was divided into group phases as follows.

Baselining: Installation: Phase 1

This stage of the trial began from installation of the charger and ran until Phase 2a of the trial began. During this phase, charging was not optimised or able to be adjusted by the drivers. In essence, this represented 'dumb' charging where each vehicle received the highest-power charge as soon as they plugged in, with no discharging or export from the EVs. This also allowed drivers to become familiar with the newly installed hardware.

Fixed scheduling tariff optimisation: Phase 2a

Phase 2a introduced charging and discharging operations. A static calendar of charging and discharging was set according to the tariff of the site. Charging was scheduled in the cheapest period and discharging was in the most expensive. This phase ran for two months as an introductory test to ensure both the Nichicon and eNovates chargers were operating as expected and following the power commands issued by CrowdCharge. This also allowed time for some of the charge teething issues already mentioned to be rectified. Each half-hour of the week received a power setting ranging from +/-7 kW for Nichicons, and +/-10 kW for eNovates. **Figure 9 (next page)** shows an example of a schedule set for an eNovates site, which was agreed with the site and their drivers ahead of implementation.

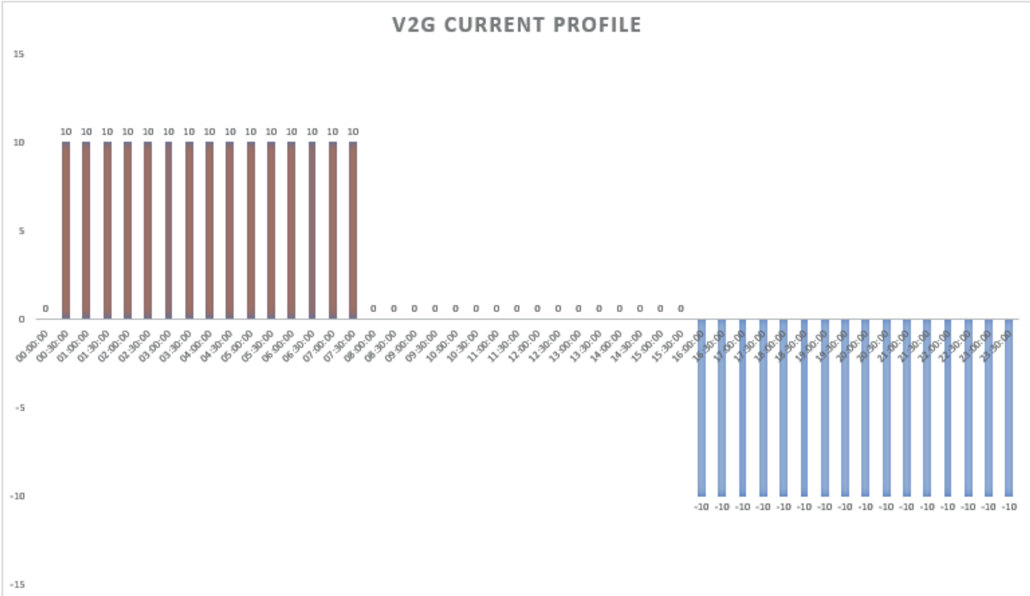
To ensure each site was always able to use their EVs, each site also confirmed a minimum SoC requirement at the start of the trial. This was for two reasons in order to deliver the principle of *prioritising user needs*. Firstly, if an EV plugged in and was below the minimum SoC threshold, the CrowdCharge platform would immediately charge to the minimum SoC, irrespective of the tariff cost. Secondly, when discharging, the EVs would not discharge lower than their minimum SoC.

Fixed scheduling carbon optimisation: Phase 2b

This phase followed directly on from Phase 2a but the charging/discharging schedule was based on a one-off snapshot of the UK electricity grid carbon intensity during Summer 2021.

Crowd Charge V2G Profile Name: V2GWMP001

Half hour ID	Start time (UTC)	Stop time (UTC)	Target power (kW)	Energy (kWh)
1	00:00:00	00:30:00	0	0.00
2	00:30:00	01:00:00	10	5.00
3	01:00:00	01:30:00	10	5.00
4	01:30:00	02:00:00	10	5.00
5	02:00:00	02:30:00	10	5.00
6	02:30:00	03:00:00	10	5.00
7	03:00:00	03:30:00	10	5.00
8	03:30:00	04:00:00	10	5.00
9	04:00:00	04:30:00	10	5.00
10	04:30:00	05:00:00	10	5.00
11	05:00:00	05:30:00	10	5.00
12	05:30:00	06:00:00	10	5.00
13	06:00:00	06:30:00	10	5.00
14	06:30:00	07:00:00	10	5.00
15	07:00:00	07:30:00	10	5.00
16	07:30:00	08:00:00	10	5.00
17	08:00:00	08:30:00	0	0.00
18	08:30:00	09:00:00	0	0.00
19	09:00:00	09:30:00	0	0.00
20	09:30:00	10:00:00	0	0.00
21	10:00:00	10:30:00	0	0.00
22	10:30:00	11:00:00	0	0.00
23	11:00:00	11:30:00	0	0.00
24	11:30:00	12:00:00	0	0.00
25	12:00:00	12:30:00	0	0.00
26	12:30:00	13:00:00	0	0.00
27	13:00:00	13:30:00	0	0.00
28	13:30:00	14:00:00	0	0.00
29	14:00:00	14:30:00	0	0.00
30	14:30:00	15:00:00	0	0.00
31	15:00:00	15:30:00	0	0.00
32	15:30:00	16:00:00	0	0.00
33	16:00:00	16:30:00	-10	-5.00
34	16:30:00	17:00:00	-10	-5.00
35	17:00:00	17:30:00	-10	-5.00
36	17:30:00	18:00:00	-10	-5.00
37	18:00:00	18:30:00	-10	-5.00
38	18:30:00	19:00:00	-10	-5.00
39	19:00:00	19:30:00	-10	-5.00
40	19:30:00	20:00:00	-10	-5.00
41	20:00:00	20:30:00	-10	-5.00
42	20:30:00	21:00:00	-10	-5.00
43	21:00:00	21:30:00	-10	-5.00
44	21:30:00	22:00:00	-10	-5.00
45	22:00:00	22:30:00	-10	-5.00
46	22:30:00	23:00:00	-10	-5.00
47	23:00:00	23:30:00	-10	-5.00
48	23:30:00	00:00:00	-10	-5.00



State of charge limits	%	kWh
Minimum state of charge	50%	15
Maximum state of charge	95%	28.5

State of charge targets	%	kWh	
Min state of charge at unplug	80%	24	By 7AM
Unplug time	07:00		
Plug in	20:00		

Day	Active
Monday	y
Tuesday	y
Wednesday	y
Thursday	y
Friday	y
Saturday	n
Sunday	n

Energy Tariff/Price Received
Yes

User Operational Limits Received
In part

Each site to confirm if they accept profile

	Site Accepted Profile
Name	
Date	

Figure 9: Example Phase 2a schedule for a site with eNovates charger

Dynamic scheduling tariff optimisation: Phase 3a

Following this static charging and discharging/exporting phase, the trial moved into a more dynamic optimising phase with live driver inputs via the CrowdCharge App. This meant switching from a calendarized profile to a dynamically-optimised system which considered driver inputs via the CrowdCharge web-app and the site's energy tariff. The CrowdCharge asset management platform then optimised charging to meet driver needs in the cheapest manner. This phase also included discharging from the connected EV during times of peak prices, typically in the early evening (5pm-8pm) and early morning (7pm-9pm) roughly.

Dynamic scheduling carbon optimisation: Phase 3b

This phase was identical to Phase 3b but the dynamic optimisation was based on a daily 24-hour forward forecast of the UK electricity grid carbon intensity.

Battery conditioning: Phase 4

This phase was somewhat different to the previous three in that the objective was to keep the EV's battery SoC at 50% for as long as possible, to minimise calendar aging (see Section 6 on page 59 for more details of the University of Warwick research behind this). Then the system would charge the EV to the requested level as set in the CrowdCharge Web-app.

Typical Trial Operation Close: 1st February 2022

At the formal end of the project, the trial closed and the remaining sites were moved to a dynamic tariff optimisation as tested in Phase 3a.

3.b.iii Trial Summary

Table 1 below details all customer charger sites and the date each phase of the trial began.

Table 1: Sites and trial phases

CUSTOMER	CHARGER SITE	CHARGER MAKE	PHASE 1 START	PHASE 2a START	PHASE 2b START	PHASE 3a START	PHASE 3b START	PHASE 4 START
Cenex	West Midlands Police	eNovates V2G	25-May-21	10-Jun-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
Cenex	West Midlands Police	eNovates V2G	25-May-21	27-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
Cenex	Loughborough University Science and Enterprise Park	eNovates V2G	25-May-21	10-Jun-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
Cenex	Worcester City Council	eNovates V2G	25-May-21	10-Jun-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
UoWarwick	Boiler House Car Park	eNovates V2G	01-Apr-21	17-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
UoWarwick	Boiler House Car Park	eNovates V2G	13-Apr-21	17-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
UoWarwick	Boiler House Car Park	eNovates V2G	01-Apr-21	17-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
LCC	Farnley Hall	Nichicon V2G	12-Feb-21	06-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
LCC	Knowsthorpe Gate	Nichicon V2G	n/a	n/a	n/a	n/a	n/a	n/a
LCC	Knowsthorpe Gate	Nichicon V2G	n/a	n/a	n/a	n/a	n/a	n/a
LCC	Knowsthorpe Gate	Nichicon V2G	n/a	n/a	n/a	n/a	n/a	n/a
LCC	Knowsthorpe Gate	Nichicon V2G	n/a	n/a	n/a	n/a	n/a	n/a
LCC	Knowsthorpe Gate	Nichicon V2G	n/a	n/a	n/a	n/a	n/a	n/a
UoNotts	Hallward Library	Nichicon V2G	11-May-21	18-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21
UoNotts	Hallward Library	Nichicon V2G	27-Jan-21	05-May-21	22-Jun-21	16-Aug-21	04-Oct-21	15-Nov-21

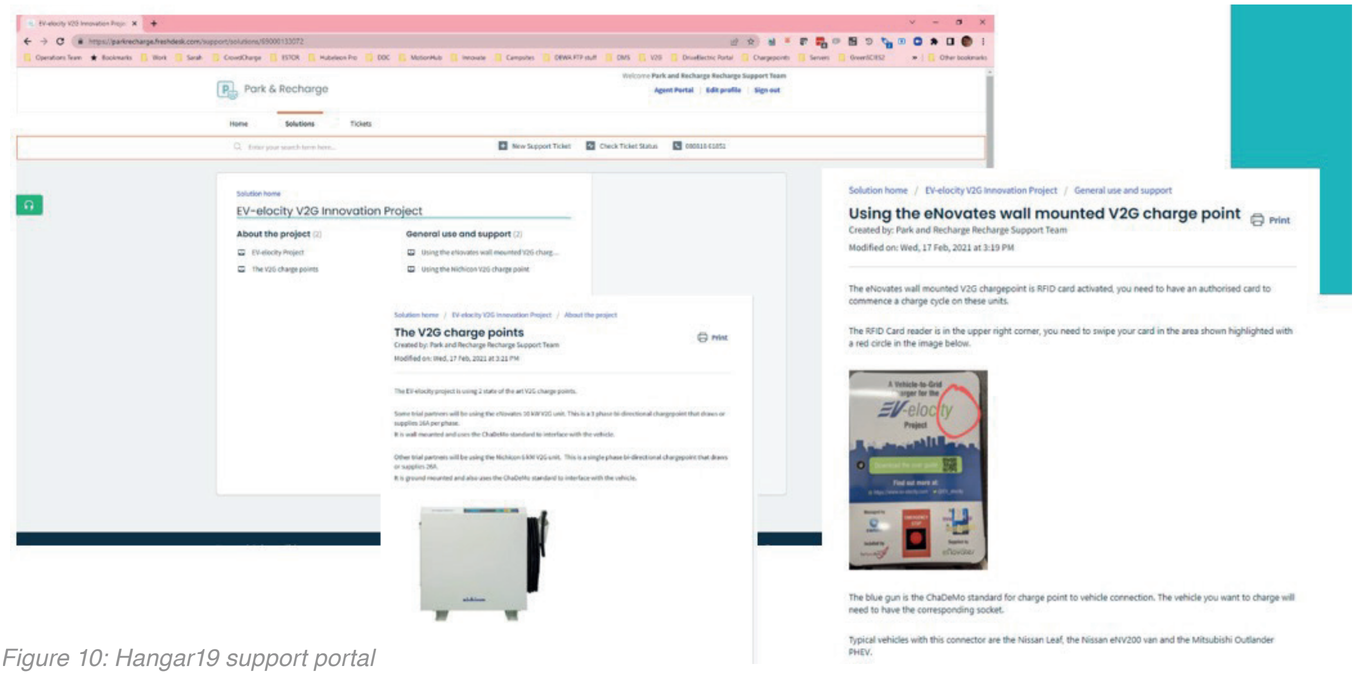


Figure 10: Hangar19 support portal

3.c Technical Performance

3.c.i Technical Support System

CrowdCharge subcontracted Technical Support to Hangar19, who had the following responsibilities:

- Provide communications solution for V2G units;
- Integrate eNovates V2G via OCPP v1.6 (with extensions for V2G);
- Link Hubeleon CPMS to CrowdCharge Energy Management;
- Provide end users with support; and
- Collect 'Engineering Data' from chargepoints.

A portal was created **(Figure 10 above)** to enable Technical Support to be delivered.

3.c.ii Communications Uptime

V2G chargers require a constant connection to the backend control and management solution. Therefore, communications uptime was monitored closely across all the sites.

Table 2 shows that there was significant variance between sites with West Midlands Police (S02) and the Cenex office (S01) recording significant periods offline (see Section 4 on page 27 for more details of the impacts).

DEVICE	SITE	UPTIME (%)
Cenex Office (PNR0151)	S01 - Cenex	58.8
West Midland Police V2G (PNR0152)	S02 - West Midlands Police	46.5
West Midland Police V2G (PNR0148)	S02 - West Midlands Police	97.2
Worcestershire CC V2G (PNR0150)	S03 - Worcestershire County Council	99.5
University of Warwick EV2 (PNR0458)	S04 - University of Warwick	97.9
University of Warwick EV1 (PNR0456)	S04 - University of Warwick	99.3
University of Warwick EV3 (PNR0149)	S04 - University of Warwick	98.0
Leeds City Council (ID15)	S05 - Farnley Hall S06 – Knowsthorpe Gate	99.9
University of Nottingham (ID13)	S08 - Creative Energy Homes	99.8
University of Nottingham (ID18)	S09 - Hallward Library	99.9

Table 2: Project-wide communications uptime

SITE / LOCATION	NUMBER OF TICKETS
West Midlands Police	2
Worcester	2
Cenex / Loughborough	3
Warwick	4

Figure 11: Tickets logged by site

3.c.iii Support Tickets

Every time an external customer contacted the support system, a ticket was logged. **Figure 11** shows that mostly sites with eNovates chargers had to contact the support line.

3.c.iv Technical Observations

By analysing the development logs, support tickets and project conversations, a range of site-specific observations can be made.

SITE	
S01 – Cenex Office	○ Useful in early system testing (supported development as a test bed). ○ Period of power outage. ○ Unit developed communication issues and was offline for approximately 2 months. ○ Further developed a fault with its energy meter blocking charging.
S02 – West Midlands Police	○ A difficult site to support due to understandable access restrictions and reports coming in after the event. ○ One unit depowered for large period of project so not online. ○ Minimal engagement of the site with support team. ○ Occasional use because it appears users lost trust in the unit's reliability to provide a charge. ○ Units still provided addition source of engineering data which was collected and uploaded.
S03 – Worcestershire County Council	○ Good communication with chargepoint through use of any network roaming sim and external antenna. ○ Tough for users as site had little to no GSM reception for phone calls for support of App usage. ○ Charger had series of faults which regularly cropped up requiring vendor visit. ○ Vehicle appeared to be left for long periods allowing CrowdCharge ongoing control and use as an asset.

SITE	
S04 – University of Warwick	○ High Use site, regular use. ○ Vehicles coming and going, on and off chargepoints as they were used for their daily use. ○ Good communication performance through project. ○ Reasonable performance functionally after service visits.
S08 & S09 – University of Nottingham	○ Excellent reliability with the Nichicon chargers. ○ The Nichicon are several years older in design than the eNovates chargers so the product is tried and tested technology and proved very reliable to date. ○ No technical faults although there were user operation queries initially. ○ Some confusion caused by users overriding scheduling settings by pressing buttons on the charger – rather than just using the app as intended. ○ CrowdCharge will review wording and user training materials moving forward.

Taking these results together, CrowdCharge and Hangar19 have reflected on the support system and logged the following lessons.

Hardware maturity is key for reliable fleet operations.

Support role for V2G requires very different skill sets because most issues require detailed technical knowledge to address.

The availability of a local site electrician is critical to uptime, especially with low maturity V2G units.

Support reporting significantly diverged from CrowdCharge's standard model due to the nature of the technical challenges encountered.

Having a user available at the chargepoint aides troubleshooting, which is much harder if reported after the event.

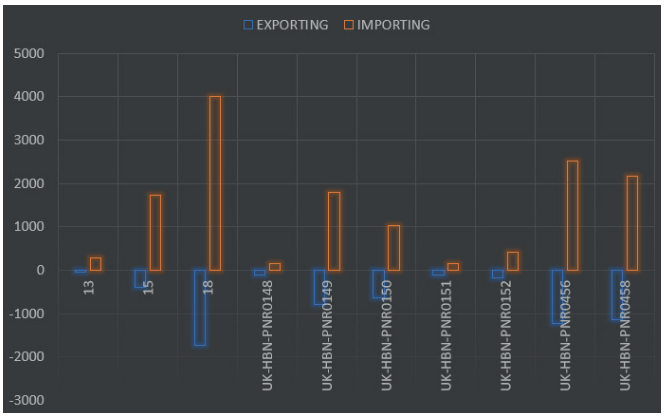


Figure 12: Import and export by charger in kWh

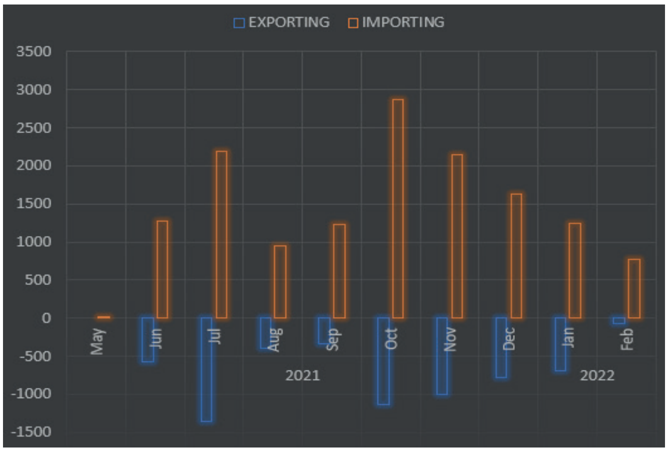


Figure 13: Import and export by month in kWh

3.d Analysis of Trial Phases

The performance of the sites throughout the trial was analysed by device. It is clear that all chargers imported and exported energy (**Figure 12**), and there was a reasonable distribution of usage by month over the trial (**Figure 13**).

By comparing the outcomes of **Phase 2a** and **Phase 2b** (next page), the difference between optimising for cost and carbon can be illustrated.

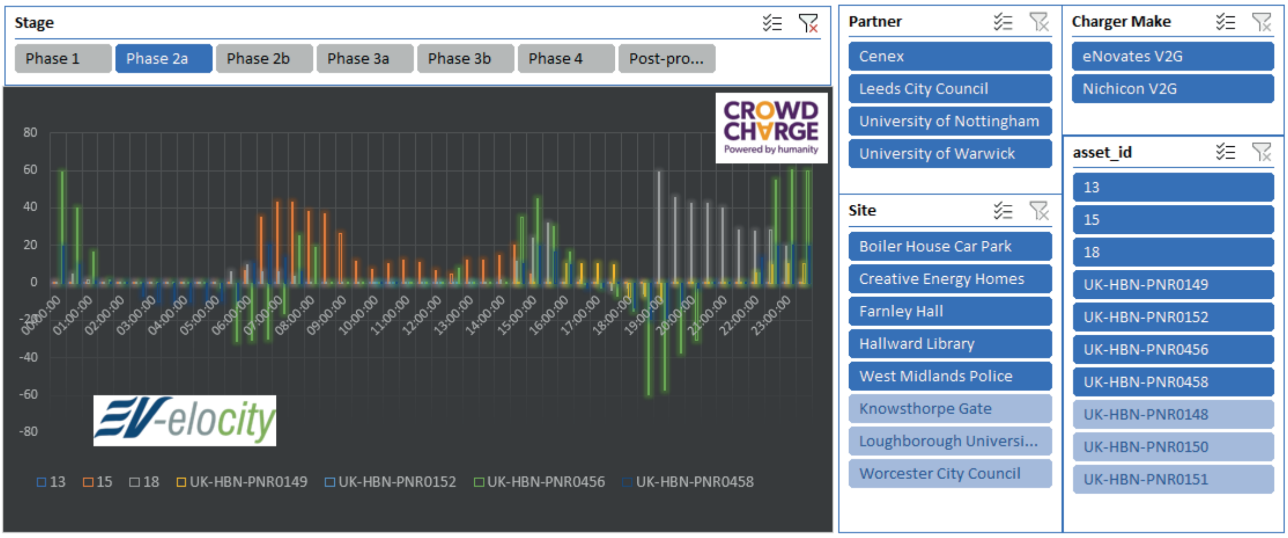


Figure 14: Example charger behaviour in Phase 2a

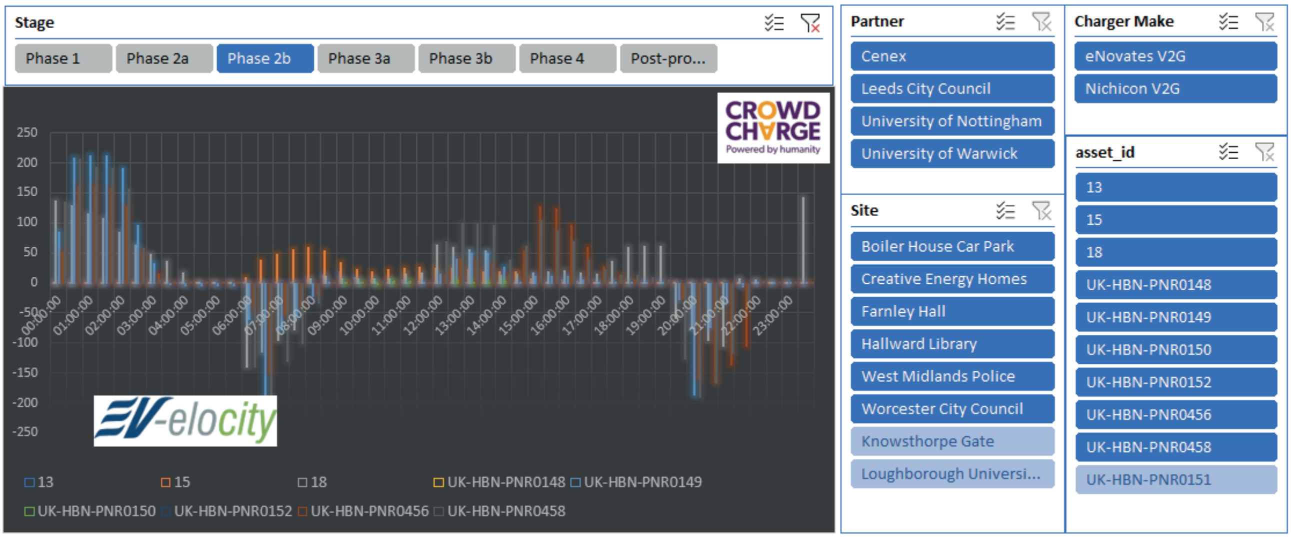


Figure 15: Example charger behaviour in Phase 2b

Phase 2a shows greater activity through the day and during the evening (**Figure 14**), whereas Phase 2b shows a significant shift of charging to the early hours of the night (**Figure 15**).

When dynamic optimisation was introduced in Phase 3, the structure of the energy tariff determined whether there was a difference. For instance, the majority of sites have a two- or three-rate tariff, so the Phase 3a dynamic scheduling more or less replicated the Phase 2 results.

For instance the charging period of the orange chargepoint (#15) in **Figure 14** is more-or-less mirrored in **Figure 16 - next page** between 6am and 9am.

In Phase 3b the aim was to reduce CO_2 overall. Therefore, a substantial increase in discharging behaviour was seen to reduce electricity consumption at times of highest carbon intensity (4pm to 9pm), followed by a big increase during the night to charge up and recover the exported energy when carbon intensity was lowest (**Figure 17 - next page**).

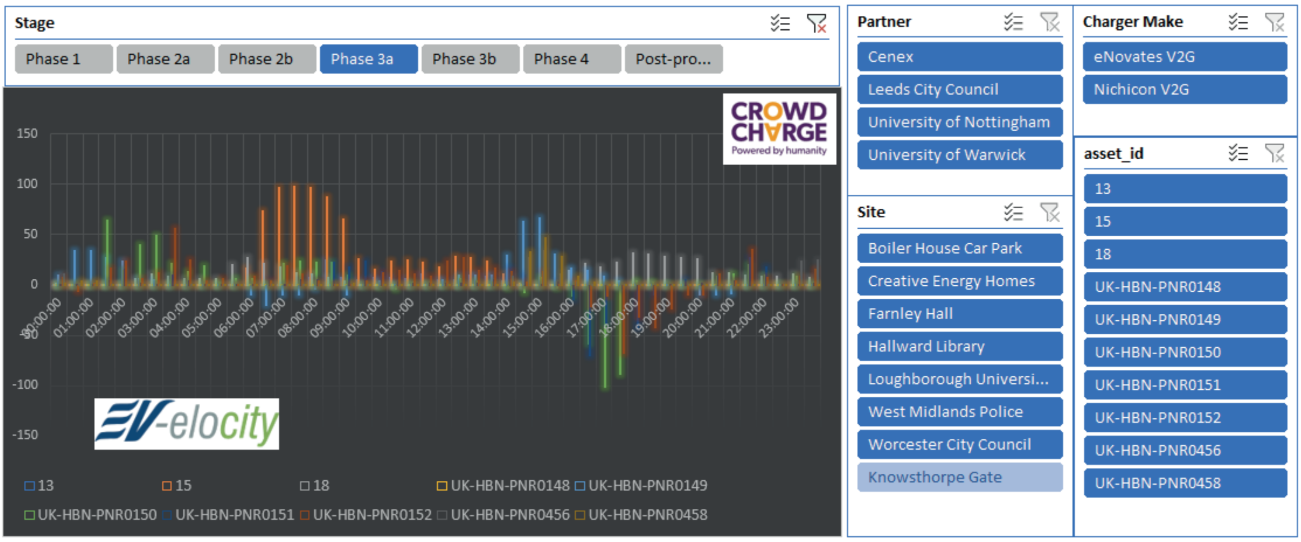


Figure 16: Example charger behaviour in Phase 3a

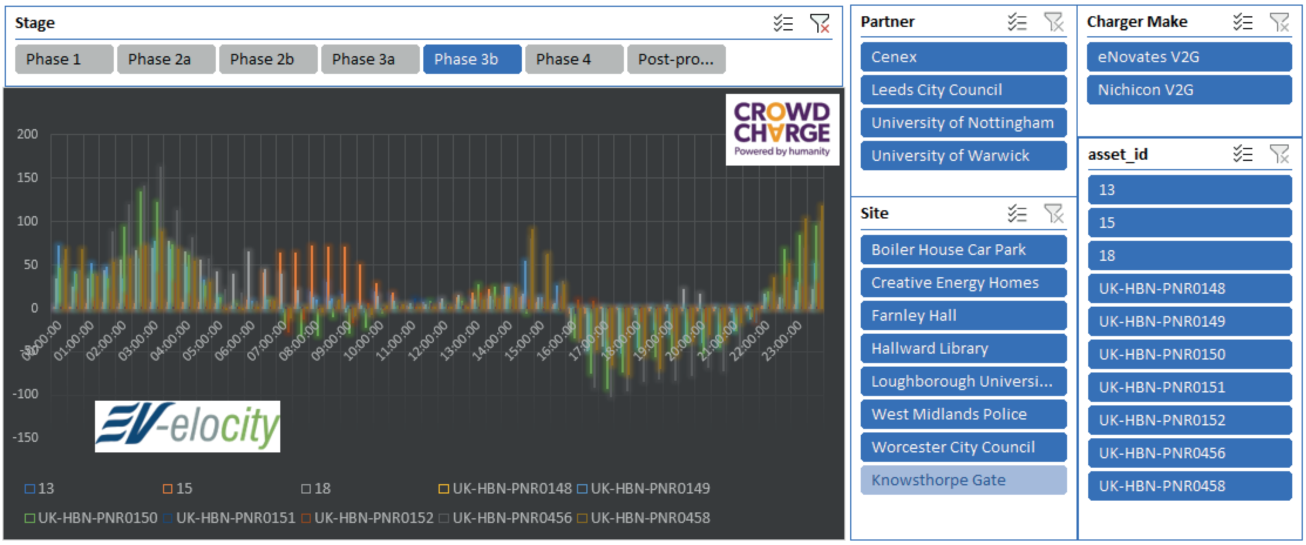


Figure 17: Example charger behaviour in Phase 3b

By comparing the distribution of energy by time of day to average grid carbon intensity (**Figure 18 - next page**), it can be seen that CO_2 optimisation reduces the average carbon intensity of energy significantly for fixed scheduling (by around a quarter) and similarly by a similar amount for dynamic scheduling. Furthermore, the dynamic scheduling reduces the average carbon intensity of energy consumed compared to fixed scheduling by around 3% when both methods utilise cost optimisation, or both utilise CO_2 optimisation.

Similar reductions in CO_2 intensity of charging can be achieved by either fixed or dynamic methods.

Dynamic optimisation for cost or carbon brings a modest 3% improvement in CO_2 intensity when compared to fixed scheduling.

Finally in Phase 4, a much more muted set of charging and discharging cycles is seen, building over the late afternoon and evening as vehicles arrive back and plug in, with sharp adjustments in the early morning to ensure the stated SoC was achieved ready for the vehicle use in the day (**Figure 19**).

Figure 18 also shows that prioritising the protection of the battery increases average charging CO_2 intensity as follows:

- 3.7% greater than Phase 2a;
- 34.8% greater than Phase 2b;
- 15.6% greater than Phase 3a;
- 17.4% greater than Phase 3b.

There is a clear trade-off between battery protection and cost- or carbon-optimisation.

Time	gCO2/kWh ave	Phase 2a	Phase 2b	Phase 3a	Phase 3b	Phase 4
00:00	154	40	204	17	138	0
00:30	153	27	352	18	117	-14
01:00	154	10	340	21	107	-9
01:30	154	1	334	58	147	-7
02:00	151	0	278	40	190	10
02:30	151	-3	134	32	272	18
03:00	150	-5	50	40	281	10
03:30	150	-5	17	49	217	60
04:00	149	-4	6	25	164	102
04:30	152	-4	-1	16	108	111
05:00	155	-6	-1	9	47	117
05:30	163	-17	-1	14	34	127
06:00	171	-2	-190	25	46	97
06:30	181	16	-316	42	65	270
07:00	188	23	-155	74	21	328
07:30	192	39	-109	72	22	125
08:00	196	29	-3	71	37	-115
08:30	192	19	39	83	64	25
09:00	191	13	30	49	11	125
09:30	190	6	20	31	11	43
10:00	187	4	15	26	30	-83
10:30	184	5	17	23	29	-113
11:00	182	6	23	24	12	-31
11:30	180	6	23	23	13	-26
12:00	178	4	93	28	16	10
12:30	178	7	135	40	23	19
13:00	177	6	133	35	52	20
13:30	177	6	126	34	56	30
14:00	178	8	56	42	79	17
14:30	180	38	74	66	134	13
15:00	186	46	132	86	82	48
15:30	191	40	120	36	52	64
16:00	197	18	100	11	-66	56
16:30	200	4	61	-56	-153	69
17:00	203	3	33	-62	-191	35
17:30	205	0	31	-66	-181	47
18:00	207	-19	39	-18	-127	23
18:30	208	-46	35	-9	-121	38
19:00	208	-13	33	4	-120	73
19:30	210	-2	-118	13	-91	62
20:00	208	5	-306	5	-94	56
20:30	206	22	-250	16	-105	44
21:00	200	20	-195	12	-66	48
21:30	194	14	-65	47	-26	33
22:00	185	26	5	23	54	31
22:30	176	57	2	6	106	12
23:00	166	55	1	26	168	3
23:30	159	45	72	28	210	2
Weighted gCO2/kWh		178	137	173	133	182

Figure 18: kWh charged by phase and time of day in comparison to average grid carbon intensity

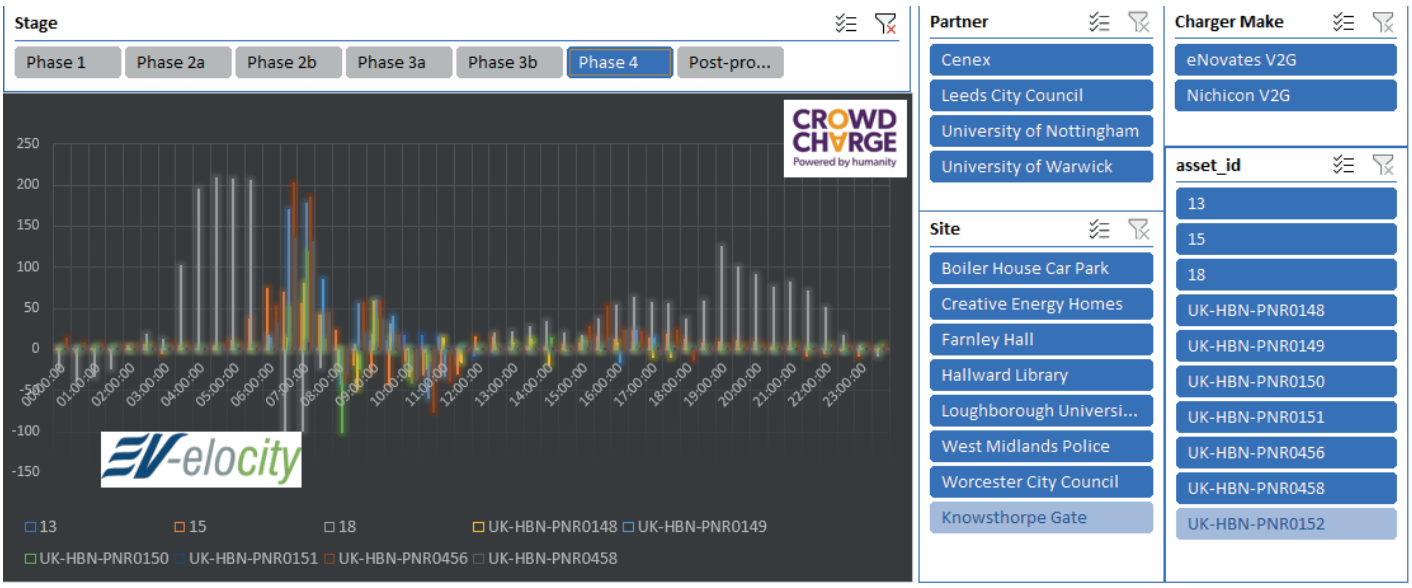


Figure 19: Example charger behaviour in Phase 4

3.e Conclusions

EV-elocity successfully deployed a technology-agnostic backend system and user interface
In examining the activities to manage and operate the V2G units, the following conclusions can be drawn:

System Design:

- End-to-end system testing should be conducted before deployment to ensure an acceptable level of operation.
- An asset management capability is needed in addition to the control capability where multiple hardware types are operated by the same system.

Deployment:

- Deployment of V2G units involves a range of operators from within the supply chain who must coordinate together.
- Defining and operating streamlined communications between the involved organisations is essential to avoid delays.
- Agreeing formal commissioning process between hardware, software, asset management, operation and site teams will greatly assist in the installation and commissioning process.
- Hardware maturity is key for reliable fleet operations.
- Support for V2G requires very different skill sets because most issues require detailed technical knowledge to address.
- The availability of a local site electrician is critical to uptime, especially with low maturity V2G units.
- Support reporting significantly diverged from CrowdCharge's standard model due to the nature of the technical challenges encountered.
- Having a user available at the chargepoint aides troubleshooting, which is much harder if reported after the event.

Operational Strategy:

- Similar reductions in CO_2 intensity of charging can be achieved by either fixed or dynamic methods.
- Dynamic optimisation for cost or carbon brings a modest 3% improvement in CO_2 intensity when compared to fixed scheduling.
- There is a clear trade-off between battery protection and cost- or carbon-optimisation.

4 Demonstrating V2G across the UK

This section outlines the work and activities conducted by various partners to deliver the project's second aim:

Demonstrate V2G across a range of UK locations, collecting data on charger, user and vehicle behaviour.

For each site a general description is given along with details of the vehicles and chargepoints installed there. The benefits which each site has captured from using V2G is explored along with highlights of the key problems and challenges experienced. Finally, the impact of V2G on the drivers is analysed, where applicable.

cenex

4.a Cenex

4.a.i Site Overview

Four sites were managed by Cenex for the EV-elocity project:

SITE ID	ADDRESS
S01	Cenex, LUSEP Campus, Loughborough University, Loughborough, LE11 3UZ
S02	West Midlands Police, Lloyd House, Birmingham, B4 6NQ
S03	Worcestershire County Council, County Hall, Worcester, WR5 2NP
S04	University of Warwick, Boiler House, Car Park 11, Coventry, CV4 7AL

During the recruitment phase of the project, two of Cenex's proposed sites withdrew from the project before chargers allocated to them were installed. This meant that WMP received a second charger and the UoW received a 'Cenex' charger in addition to those they installed themselves.

4.a.ii Vehicles and Chargepoints

Summary

SITE ID	VEHICLES	CHARGE POINTS
S01	Originally planned to be a 40 kWh Nissan LEAF, a company car used by a member of Cenex staff. However, due to the lack of office working during the pandemic, Cenex's 30 kWh Nissan LEAF pool car was used.	1 x eNovates 10 kW V2G unit, ground mounted with pedestal
S02	2 x 30 kWh Nissan LEAF vehicles. Both pool cars for use by staff and the Force photographer at West Midlands Police.	2 x eNovates 10 kW V2G units, wall mounted
S03	1 x 30 kWh Nissan LEAF vehicle. Previously used as a pool car but due to lack of office working during the pandemic used by Worcestershire County Council's Countryside Services team during the project.	1 x eNovates 10 kW V2G unit, wall mounted
S04	4 x Nissan e-NV200 estates vehicles on University of Warwick campus.	1 x eNovates 10 kW V2G unit, ground mounted with pedestal

S01 - Loughborough

The Loughborough chargepoint was installed adjacent to the Sir Dennis Rooke building on the Loughborough University Science and Enterprise Park (LUSEP). The parking area used is restricted by the front gate security staff of the University and a second barrier restricting access to the parking closest to the LUSEP buildings to certain staff, visitors, and deliveries.

A feeder pillar had already been installed by the University to support plans to deploy additional workplace EV charging in this car park, taking its supply from a switchroom in the Sir Denis Rooke building. Cenex received permission from Loughborough University to run the final circuit and communications router for the V2G chargepoint from the pillar.

G99 approval to install a generating asset was received from Western Power Distribution on 24th August 2020 and was valid for 12 months.

The installation was completed by The Phoenix Works during the week commencing 22nd February 2021. Delays were due the time taken for Loughborough University to agree the site participation agreement. The pedestal was mounted on a poured concrete pad with two bollards installed for impact protection.

S02 – West Midlands Police

The two West Midlands Police (WMP) V2G chargepoints were installed in the access protected multi-storey car parking for fleet vehicles at WMP's headquarters in central Birmingham. Power was taken from an existing distribution board in a switchroom adjacent to the car parking. The parking spaces selected for the V2G chargepoints were the two closest to the building. Both of these spaces already had 7 kW Swarco eVolt Smart Wallbox units installed and in use for charging of the site's four Nissan LEAFs. One of these was removed to make space for the V2G chargepoint whilst the other was left in situ as there was enough space to install the V2G chargepoint alongside.

G99 approval was received from Western Power Distribution on 25th September 2020. The installation was completed by The Phoenix Works during week commencing 14th December 2020.

Figure 20: S01 - Loughborough University

Figure 21: S02 - West Midlands Police

S03 – Worcestershire County Council

The V2G chargepoint at Worcestershire County Council (WCC) was installed in an underground car park at County Hall, WCC's headquarters. Electrical supply was taken from an existing distribution board in a switchroom located in the building behind the wall of the carpark on which the V2G chargepoint was mounted, resulting in a small cable run over the corridor and through the wall to the car park.

G99 approval was received from Western Power Distribution on 25th September 2020.

The installation was completed by The Phoenix Works during week commencing 14th December 2020. Due to the car park being underground, the router for communications had to be connected to an aerial located outside, a reasonable distance from the chargepoint.

S04 – University of Warwick

The installation at the University of Warwick (UoW) is described in Section 4.e (page 42).

4.a.iii V2G Benefits

From a site perspective, the benefits achieved by the V2G systems at Cenex sites was limited. This was partly due to a lack of use of the vehicles interfacing with the system over the pandemic period but primarily due to reliability issues with the system itself.

Cost

Both WMP and WCC had day/night energy tariffs with a small differential in pricing. The details are confidential so cannot be shared in this report. In addition, WMP had red/amber/green Distribution Use of System (DUoS) charge bands against which to optimise. However, the energy tariff at Loughborough University was flat and therefore there was no opportunity to optimise on cost. Therefore, an Octopus Agile tariff was simulated during the project's optimisation phase for cost.

SITE	DAY TARIFF	TIMES	NIGHT TARIFF	TIMES
S02 WMP	10.0119 p/kWh	07:30 – 00:30	8.75 p/kWh	00:30 – 07:30
S03 WCC	13.088 p/kWh	08:00 – 23:30	11.077 p/kWh	23:30 – 08:00

In addition, WMP had red/amber/green Distribution Use of System (DUoS) charge bands against which to optimise. However, the energy tariff at Loughborough University was flat and therefore there was no opportunity to optimise on cost.

Figure 22: S03 - Worcestershire County Council

Therefore, an Octopus Agile tariff was simulated during the project's optimisation phase for cost.

Carbon & Conditioning

The plug-in rate at all sites was very high with the vehicles being used even less frequently than usual due to the COVID-19 pandemic. At Loughborough, the Cenex car was connected for the majority of the time since the chargepoint was installed in February 2021. Likewise at WCC, the vehicle only saw infrequent use from the Countryside Services team. The two trial vehicles at WMP were the most regularly used, although the participants lost confidence in the V2G system over time due to the poor reliability of the charging system.

The opportunity for optimising carbon and conditioning at the Cenex sites was significant but this was not capitalised on due to the problems operating the system, as explained below.

4.a.iv Problems and Challenges

Recruitment Timings

Receiving approval from sites for the trial participant agreement delayed the installation of the chargepoints, particularly at Loughborough University. In terms of the physical and electrical installation works, these were all completed without issue.

Around 3 month's lag should be set-aside in future projects to allow for contract negotiations and delays on signatures.

A suitably-qualified and experienced electrical contractor should be able to install V2G chargepoints without significant difficulty.

System Reliability

However, the main challenges were associated with the commissioning and ongoing reliability of the wider V2G system. At first, the issue was thought to be with the hardware itself. Biweekly calls were setup with stakeholders from eNovates, Hangar-19, The Phoenix Works and Cenex to diagnose faults and implement fixes. This led to various attempted solutions:

- Updates to the firmware configuration of the chargepoints to a later standard (to match the standard being used by the two other eNovates chargepoints at UoW that were supplied at a later date);
- Replacements of fuses; and
- Replacement of the inverter at the WCC chargepoint.

None of these updates were successful in achieving long-term reliability of the V2G systems.

Owing to the immaturity of the systems, troubleshooting V2G installations will likely involve collaboration across the whole supply chain.

Various site visits by Hangar19 took place during summer 2021 to test the connection to the system with limited success: commands were sent to commence charges and discharges but the end-user experience was not responsive 100% of the time.

On the 1st and 2nd September 2021, an eNovates representative travelled to WCC, WMP and Loughborough. He brought spare parts to use in case the hardware was found to be at fault, although none of it was used. Using the eNovates control software, he was able to successfully charge and discharge from each chargepoint. This demonstrated that the root cause of the reliability issues was in the wider control system.

The known problems experienced with the eNovates setup are as follows:

- Charging sessions timing out during periods of inactivity (not charging or discharging). This required the session to be manually restarted remotely, otherwise the system would not control the vehicle state of charge as required by the site's operations.
- Chargepoints appearing offline and therefore it not being possible to even start a charging session. At the time of writing, the Loughborough chargepoint and one of the WMP chargepoints have been offline since November and October 2021 respectively).
- Issues with the charging or discharging setpoint at the start of the session. This was corrected by setting an arbitrary charge or discharge power in the system and then updating the setpoint to a lower power as required by the control logic.

Reliability of the V2G system is an essential hygiene factor for confidence in the system. Without this, no benefits will be yielded from V2G.

Mis-handling RFID cards

Finally, at WCC it was identified that the user had hole-punched the RFID card to attach it to the key-ring for the car keys of the vehicle rendering it unusable. This RFID card was replaced.

Better guidance may be required around the use and storage of RFID cards.

4.a.v V2G Impact on Drivers

The result of the reliability issues experienced is that all sites lost confidence in the system, including those which were more receptive to the potential issues that can be experienced in a research project.

Both WCC and Cenex regularly logged tickets to the Park&Recharge support system to highlight the issues with their systems. In several instances, drivers were not able to use the vehicle as intended as the system had not achieved the state of charge (SOC) requested at the required time.

These two organisations were able to accept the operational risk of continuing to attempt to use an unreliable system. However, WMP users simply reverted to using their existing AC charging after problems were repeatedly experienced with the V2G charging system.

Attempts to resolve the remaining issues were hampered by slow responsiveness of the support team and reliance on third parties. For example, a driver logging a support ticket that a vehicle is inoperable due to extremely low SoC might have to wait 24 – 48 hours for a response, at which point a system reset may need to be performed by a facilities or energy manager with permission to access the electronic feeders. Only after this could the fault be rectified, which sometimes was one or more weeks after the original issue was raised.

V2G's integration of energy and transport brings challenges as organisations have to adapt to and handle new operational situations.

4.b Leeds City Council

4.b.i Site Overview

Two sites were managed by Leeds City Council (LCC) for the EV-elocity project:

SITE ID	ADDRESS
S05	Leeds City Council, Farnley Hall, Hall Lane, Farnley, Leeds LS12 5HA
S06	Leeds City Council, Knowsthorpe Gate, Cross Green, Leeds LS9 0NP

As part of the council's wider work to improve air quality and decarbonise operations, there has been a steady transition to EV, which made the council and these sites ideal to be part of the EV-elocity project. LCC now has almost 400 electric vehicles on its fleet distributed across various services, locations and with different uses. Both locations host a number of EVs and have operated as depot sites for different services for many years.

4.b.ii Vehicles and Chargepoints

Summary

SITE ID	VEHICLES	CHARGE POINTS
S05	8 x Nissan eNV200 40kWh Acenta Van	1 x Nichicon 7 kW V2G unit, ground mounted
S06	11 x Nissan eNV200 40kWh Acenta Van	5 x Nichicon 7 kW V2G units, ground mounted

S05 – Farnley Hall

Farnley Hall is the head office of the Parks & Countryside service and the Nichicon chargepoint was installed to serve a number of Nissan eNV200 vans. The parking area is restricted for use by LCC vehicles, ensuring that only the project vehicles could access the chargepoint.

G99 approval to install the asset was obtained from Western Power Distribution and the charger was installed and commissioned by 4th Dimension Technology on 12th February 2021.

S06 – Knowsthorpe Gate

Knowsthorpe Gate hosts multiple services, including catering, passenger transport, environmental action services and many others. A number of Nissan eNV200 vans use the parking area, which is again restricted for LCC vehicles.

G99 approval to install the asset was obtained from Western Power Distribution and the charger was installed and commissioned by 4th Dimension Technology on 7th April 2021. Unfortunately, the site's load management system meant that the V2G system had to be switched off in August 2021 to avoid breaching a static load limit and taking vital on-site services offline.

Figure 23: S06 - Knowsthorpe Gate

4.b.iii V2G Benefits

For LCC, the primary objective of participation in the project was to generate better understanding and data on the potential for delivering energy savings through bi-directional savings. The potential to realise revenue from stored energy that could be released to the grid or utilised to support building energy demands was identified as a way to reduce electricity costs, balance supply and demand, and smooth potential cost peaks. Further utilisation of targeted charging to either reduce costs or optimise for renewable energy was also a key consideration.

If the potential for the savings or revenues could be determined and translated into measurable data, this could help further shape the business case to encourage broader uptake of EVs beyond the council fleet and into commercial fleets.

With the load management issue at Knowsthorpe Gate (see details, below), it has not been possible at the time of writing to determine if this has been achieved. However, the principles of the project results described in this paper will continue to be applied across LCC, especially as V2G becomes more mainstream.

4.b.iv Problems and Challenges

The challenges to delivery of the project have been varied.

Local Authority Procurement

Managing procurement with with Corporate Procurement Regulations (CPRs) for such a project was complex due to the lack of an established market, meaning a standard open procurement would not have been suitable. Whilst this could be managed, the need to operate in such an 'innovation' environment was a different challenge for the LCC procurement and commercial services team who needed to be clear on the bespoke requirements of the wider project as well as ensuring internal CPRs and delivery of best value were delivered.

Delivery of innovative projects within more traditional procurement structures is challenging and flexible routes to market are recommended for future Local Authority engagement in projects like this.

Other On-site Load Management

Local issues were also a significant challenge, particularly at Knowsthorpe Gate as already aluded. The hiatus in the EV-elocity project in 2020 created an 18 month delay between the initial site assessment and survey work, and the subsequent install and delivery of the chargers. In this time period an unexpected and unknown change occurred at the site and since this site was an operational environment, change freeze protocols (especially during the period the project was stood down) were not possible. The presenting issue was that the catering/meals services changed from having on-board ovens for meal cooking/preparation to on-site ovens which had significant power demand. A load balancing design and solution installed at the site had not been delivered as a dynamic solution. As such there were issues with demand exceeding availability and the load balancing for chargers had to be re-engineered to ensure that a dynamic solution was delivered.

Ironically, this is exactly the sort of scenario that V2G should be able to handle and indeed fix through the provision of extra on-site capacity when discharging the vehicles. However, this was not an option for the project and so it had to wait for external dependencies to be cleared. A third party contractor had to be challenged on the basis of what had been specified for the load balancing in comparison to what had been delivered. These issues meant that there were prolonged periods without V2G functionality in order to maintain the operational viability of the site.

An analysis of the potential impact of V2G on wider depot systems and controls should be included in any site surveys.

The presence of V2G capability should be considered in the procurement or upgrade of site-wide load management systems.

Partner Selection

As mentioned above, the other key challenge for LCC was the period when the project was put on hold in 2020. A number of key participants and the project lead withdrew from the project, meaning that those remaining and Cenex who took the lead had a significant challenge to re-define and revive the project whilst also seeking to maintain deliverables against time, cost and quality. The reasons for the partner withdrawl were complex and would have been difficult to foresee. However, it might be that increased due diligence on potential partners may be an important lesson to be learnt here.

Better due diligence on the suitability of proposed consortium partners might help to avoid potential withdrawals from collaborative projects.

4.b.v V2G Impact on Drivers

Despite the technical issues, there has not been any negative feedback of note from LCC operational staff, drivers or those who have used the V2G units. The installation process was well managed by the sites and the project partner who delivered the installations. An advantage is that the units and electric vehicles were not a radically new challenge for drivers as LCC was already well on the path of EV uptake and drivers were typically using existing vehicles they were well used to charging. The sites used and the patterns of work undertaken were largely compatible with the projects protocols that were applied to V2G units, so there was not challenge or objection from drivers. Nonetheless, the system managers from CrowdCharge and Hangar19 have engaged with LCC consistently and clearly.

Upgrading sites which have matured their EV charging processes from dumb or smart charging to V2G is an easier process than those who are still early in their electrification transition.

Nottingham City Council

4.c Nottingham City Council

4.c.i Site Overview

One site was managed by Nottingham City Council (NCC) for the EV-elocity project:

SITE ID	ADDRESS
S07	Nottingham City Council, Eastcroft Depot, London Road, Nottingham, NG2 3AH

Eastcroft Depot is an operational site to the South East of Nottingham City, with a history of energy innovation through its proximity to the city's incinerator and associated district heat network. The Depot is occupied by a number of Nottingham City Council (NCC) Services areas, including Highways, Waste, Neighbourhood Services, Energy Services, Fleet Services and Catering. The site is the proposed location for a number of innovation projects, including this project.

4.c.ii Vehicles and Chargepoints

Summary

SITE ID	VEHICLES	CHARGE POINTS
S07	4 x Nissan Leaf 40kWh 36 x Nissan eNV200 40 kWh	None installed

S07 – Eastcroft Depot

Unfortunately, NCC has received an unprecedented number of hurdles and setbacks during this project, which has greatly restricted its ability to meet the timescales and participate fully in the project.

At project inception, Eastcroft Depot had six small, independently-metered electricity supplies, the majority of which were at capacity. This configuration proved to be a major obstacle to the expansion of the EV Fleet, as well as the delivery of the V2G & Energy Storage system projects. Consequently, no additional EV charging could be installed at the site, including equipment funded through this project and others such as the CleanMobilEnergy project[vii]. Furthermore, carrying out other basic improvement projects on-site, such as the installation of electric heating, created the risk of electrical infrastructure being overloaded.

In order to unlock the potential of electrifying the Eastcroft Fleet, an independent feasibility study was commissioned to examine consolidating supplies on-site into one upgraded connection. This was agreed and contractors have been on-site since July 2021, with the works nearing completion. This has been a project which has cost almost £1M in its own right and has taken around 3 years to complete. The upgrade leaves the site with a new High Voltage (HV) connection, capable of future capacity upgrades, which should future proof it from changes in the fleet energy consumption mix, especially as it transitions away from liquid fuels.

However, the power upgrade works also added a large cost burden to ongoing project budgets, and has forced the re-evaluation of project elements, including the proposed Energy Storage System (ESS), until the remainder of any allocated contingency budget becomes clear. The uncovering of contaminated land during on-site works, as well as other obstacles, has been steadily reducing these funds.

Therefore no chargers have been installed at the site at the time of writing.

The cost and time impact of significant power supply upgrades in urban brown field sites should not be underestimated.

4.c.iii V2G Benefits

The anticipated benefits of reduced operational costs and enabling the fleet to assist in meeting NCC's 2028 net-zero target have therefore not materialised. Nonetheless, the V2G project is still proceeding despite the EV-elocity project finishing. The upgraded HV power supply and an 800 Amp feeder pillar in the proposed location mean that V2G units will be able to be installed and commissioned when the time is right. NCC will learn from the other findings in this project and apply these into its ongoing project deliveries.

4.c.iv Problems and Challenges

Aside from the obvious challenges outlined above, the NCC team has also encountered other problems.

Staff turnover

The whole project has also been affected in one way or another from high staff turnover, compounded by the large number of project stakeholders involved. This was not confined to the Council; the DNO HV Planner changed 3 times during this project, causing delays in contract implementation and communication difficulties regarding DNO expectations and programming.

Ensuring continuity of staff and knowledge within partner organisations is essential to prevent unnecessary delays on the critical path.

Night working

Unfortunately, one of the results of delays was that necessary road excavations occurred during the Christmas moratorium, which demanded night-working, at a significant cost hike.

Driver Habits

The majority of NCC's fleet is based at Eastcroft, including vans, cage tippers, sweepers and minibuses. This fleet is gradually being converted to be one of the UK's largest Local Authority EV fleets, with around 220 EVs. Two electric Refuse Collection Vehicles (eRCVs) entered service in late 2020 and a further six are on order. This is remarkable growth, considering that there were only 19 EVs in the Fleet 5 years ago, and demonstrates the commitment for change within the Council.

It was anticipated that difficulties would arise as fleet users familiarised themselves with operating EVs. However, these never really materialised with efficient and effective use of the current charging infrastructure bedding into the culture. Although the installation of V2G equipment has not yet been completed, the changes in driver behaviour during the gradual transition to EV over the past 5 years should enable the efficient use of V2G chargers for bi-directional operations.

Sites with a mature EV charging culture are likely to transition to V2G operations more easily.

Local Authority Procurement

Invitations to Tender (ITTs) for V2G equipment and an ESS issued in 2021 were also beset with complications. Compliant bids came in significantly higher than the available budget. Rapidly rising costs due to world resource shortages have not helped. A revised reissue of the V2G ITT in January 2022 also provided little in the way of workable solutions. Further investigations into a viable solution continue. It is expected that the ESS will not be delivered in order to continue with the V2G (which is the key asset of the project). However, this is under review in 2022 once other costs related to the power upgrade have been clarified.

With such an immature product, traditional Local Authority ITT processes have not proved an effective or efficient route to procure V2G and associated energy storage equipment.

4.c.v V2G impact on Drivers

Recommendations regarding drivers' perceptions of V2G cannot be given yet for the stated reasons. However, the following additional lessons have been learnt:

- Assessment of on-site power supplies are essential, as it is unlikely that they will be capable of accepting any large-scale take-up of EVs, without upgrading, or other form of mitigation. In our case, complexity was added to a relatively straightforward process by large-scale, on-site complications, as well as costs of grid reinforcement. The timescales needed for these aspects should not be under-estimated, but here, have been difficult to control.

- The rapidly rising costs and shortages in world resource markets has further compounded things, and the impact of this has been difficult to assess and predict (especially with overall project timescales), adding unprecedented financial risk to projects.

The University of Nottingham

4.d University of Nottingham

4.d.i Site Overview

Two sites were managed by the University of Nottingham (UoN) for the EV-elocity project:

SITE ID	ADDRESS
S08	University of Nottingham, University Park Campus, Creative Energy Homes, Nottingham H.O.U.S.E
S09	University of Nottingham, University Park Campus Hallward Library - Security Offices

UoN's facilities are spread across 8 campuses, with two being overseas. UoN's University Park Campus in Nottingham is often used as a living testbed for a number of research projects, particularly ones focused on CO_2 emissions reduction. It was selected as a site due to its existing infrastructure and easy access to data (new and historical), which allowed EV-elocity's work to focus on the nexus of transport, buildings and energy. The campus infrastructure and services are very much like those of a small town, making is a great testbed for technology trials prior to deployment in the 'real world'.

UoN has a fleet of 50 vehicles providing services such as maintenance, security, mail, transport, grounds and catering services around the campuses. Researchers from the *Transport, Mobility and Cities*[viii] and the *Buildings, Energy and Environment*[ix] Research Groups collected and analysed various datasets to understand the fleet's needs, including telematics, service requirements, users' needs, building energy demand and renewable energy generation from University Park Campus.

4.d.ii Vehicles and Chargepoints

Summary

SITE ID	VEHICLES	CHARGE POINTS
S08	1 Mitsubishi Outlander PHEV	1 x Nichicon 7 kW V2G unit, ground mounted
S09	1 Nissan eNV200 40 kWh	1 x Nichicon 7 kW V2G unit, ground mounted

The analysis of the behaviour of the University fleet was conducted in an early stage of the project to understand the main dwell location of the vehicles on campus (see Section '5. User Behaviour and Responses to V2G'). The outcomes of this analysis allowed to identify strategic locations for V2G chargers. This information in conjunction with the site surveys revising connection feasibility and the vehicles compatibility, were the factors determining the location of the V2G demonstrators at the Creative Energy Homes and Hallward Library (**Figure 24** - next page).

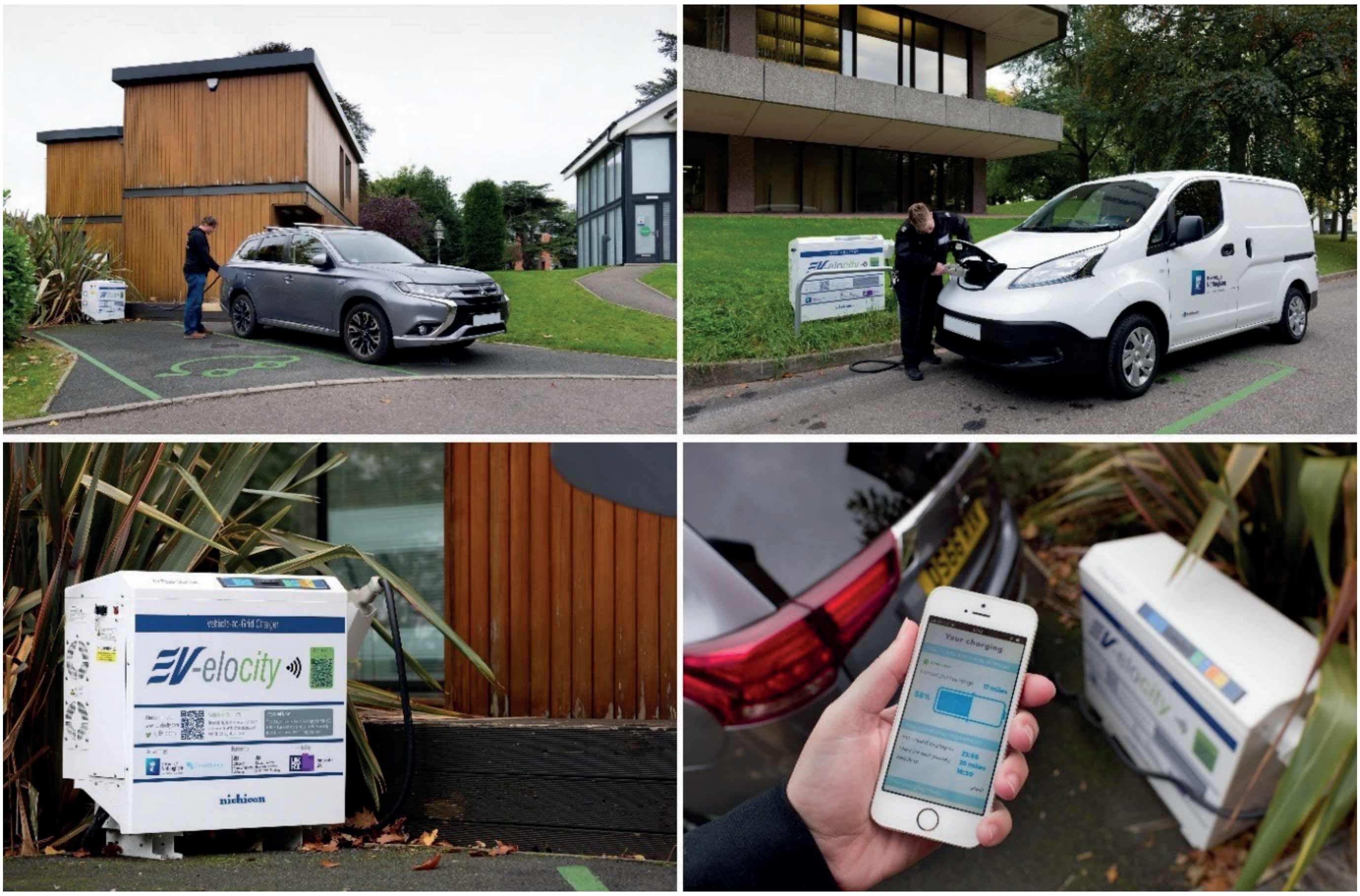


Figure 24: S08 - Creative Homes and S09 - Hallward Library

S08 – Creative Energy Homes

The Creative Energy Homes is a sustainable housing development at the University Park Campus showcasing low-energy homes, renewables, micro-grids, energy storage, demand-side management and other strategies to reduce CO_2 emissions. The V2G charger was installed outside of the Nottingham H.O.U.S.E (Home Optimising the Use of Solar Energy). This house is used by UoN research staff as offices and primarily operating between 9am and 5pm. Due to the building fabric efficiency and renewable energy generation from photovoltaic panels, this house typically generates more electricity than it requires on a regular day.

A Nichicon V2G single phase 6kW bi-directional charger was installed on the 27th January 2021. The charger is controlled using the CrowdCharge App, which is available to the trial participant. The vehicle at this site was a Mitsubishi Outlander owned by a UoN staff member, who typically connected between 9am and 5pm on weekdays.

S09 – Hallward Library

The Hallward Library building was inaugurated in 1972 and is one of the most iconic buildings of the University Park Campus. It operates from 8am to 2am most of the time, maintaning a high energy demand for at least 18 hours every day. The headquarters of the fleet participating in the V2G trial are located in this building and the second Nichicon V2G charger was installed on the 5th of May 2021. The vehicle connecting to this charger was a Nissan e-nv200 from the University fleet, mainly used between 7am and 7pm. This vehicle was also used from time to time during night time depending on the fleet demand.

4.d.iii V2G benefits

The team produced the papers *The Role of Electric Vehicle Charging Technologies in the Decarbonisation of the Energy Grid* and *Establishing a Case for Predictive Machine Learning to Optimise Vehicle-to-Grid Charging for Reduced Carbon Intensity in the Built Environment.* The results are described in Section 5 of this report (page 47) and demonstrate that V2G can support the reduction CO_2 emissions from the built environment and energy systems.

These two papers evaluated real-world ICE fleet vehicles behaviour data from 2019 and simulated different scenarios for EV charging infrastructure. The outcomes suggested that the average CO_2 emissions of the building, vehicles and energy grid can be reduced by using V2G and data integration. For instance, a building with a net CO_2 emission of 199,711 kg CO_2 per year would increase emissions to 203,029 kg CO_2 when charging 19 electric vehicles in an unmanaged way. However, by using a predictive V2G charging scheme, this figure could be reduced to 193,466 kg CO_2.

4.d.iv Problems and Challenges

Although the longest and most stable operating site in the project, a range of challenges were encountered at different stages.

Vehicle V2G Compatibility

Due to the limited type of vehicles compatible with the V2G chargers, it was difficult to recruit participants. The V2G proposal had to be aligned with the University EV charging infrastructure and expectations (e.g. usability, maintenance, operation, sustainability strategy, among others).

As ground works were required for the installation, technical discussions and permissions were also required to be able to commence works.

Currently, not enough vehicles are compatible with V2G and the limited range of chargers may also not comply with site policies.

Purchase

Finding V2G providers and obtaining different quotes for comparison was difficult. At the beginning of the project, there were long lead times to deliver the V2G chargers to the UK of around three to four months from contract.

Projects should account for long lead times on V2G hardware.

Installation

Site surveys in multiple locations were required to assess the feasibility of installing V2G chargers on campus. The feasibility is highly dependent on the power capacity and distance to the connection, as this may increase the costs of the installation. Moreover, installations in conservation/listed buildings can be more expensive due to limited power supply and restrictive planning laws. The installation costs were therefore highly variable across sites and providers.

V2G installations require a more complex site survey than 'normal' chargepoints to ensure that it can operate safely and effectively.

Charger Operations

In general, the V2G chargers performed well over the trial. The events reported were the following:

- In Phase 1, when the charger was operating with the fixed schedule, the participants were not able to see the battery state of charge and therefore it was difficult to know if the vehicle was ready to be used.
- A couple of times during Phase 1, the vehicles were not charged as expected by the participants. Therefore, the charging schedules had to be re-reviewed to guarantee the state of charge at the end of the charging sessions.
- In Phase 3, the participants reported that the CrowdCharge app did not allow scheduling of the charging session starting and finishing on the same day. This was a constraint for vehicles connecting solely during daytime that should be easily addressed through software development.

Ensuring that charging schedules are suited to driver needs and deliver charge events every time is important to ensure high acceptance from users.

4.d.v V2G impact on drivers

As part of the project, a User Survey was delivered to all sites (see Section 5 on page 47 for more details). For the UoN site, four participants from Hallward Library and the Creative Energy Homes completed the survey.

Amongst other things, the participants reported the following advantages and disadvantages of charging their electric vehicle using V2G:

V2G ADVANTAGES	V2G DISADVANTAGES
At home the ability to have a vehicle-to-building energy store to utilise renewables and dynamic tariffs to reduce bills, to provide grid services	If you arrive to use your car and the battery does not have enough capacity as it has been in discharge mode - controls are essential but can never take account of an unexpected event
Agree with the principle of electric vehicles however the charging times are restrictive	The charging times are restrictive for our departments' usage
Solar energy charging	Not being able to use the vehicle over night
Cheaper solar energy	None
None	Lack of need to go to office due to covid remote working

Other headlines from UoN participants were:

- All participants reported that the V2G hardware was extremely easy to use.
- All participants reported that it was easy to learn how to charge their vehicles.
- Most participants reported finding it hard to ensure the vehicle was sufficiently charged.
- All participants agreed that V2G can support reducing CO_2 emissions.

- Most participants think that V2G can reduce the cost of charging their vehicle.
- Participants were mainly neutral about being able to fulfil their charging requirements during the fixed schedule phase. This perception was improved in the later phases.
- Participants reported that the charging schedules were not easy to understand.
- Two participants reported changes in their routine to be able to use V2G such as: times of vehicle usage were restricted, changes to work schedules were applied and other vehicles were used.
- One of the participants with a management role would recommend using V2G to charge other vehicles from their fleet.
- Final suggestions from participants:
    - It would be easier to use an app and not a link to a web app.
    - Increasing the charging speed to be able to use the vehicles for longer periods.

The V2G charger was rated as extremely easy to use. However, a charging status visualisation would be required to allow users know when the vehicles are sufficiently charged.

It was perceived that V2G can support reducing carbon emissions and charging costs.

Participants struggled to understand charging schedules.

4.e University of Warwick

4.e.i Site Overview

One trial site was managed by the University of Warwick (UoW) for the EV-elocity project

SITE ID	ADDRESS
S04	Car Park 11, Boiler House, University of Warwick, Coventry, CV4 7AL

Warwick Manufacturing Group (WMG) is an academic department of the University of Warwick. Three parking spaces at Car Park 11 in front of the "Boiler House" were requisitioned for the V2G trial of the EV-elocity project. The site is solely used for parking of UoW service vehicles belonging to the Estates team.

During the project, these three parking spaces and its V2G chargers were used as normal by the selected vehicles of the Estate team during the project. Vehicles were used by drivers following their typical shift-patterns and on-campus duties.

4.e.ii Vehicles and chargepoints

SITE ID	VEHICLES	CHARGEPOINTS
S04	4 x Nissan eNV200 40 kWh panel vans	3 x eNovates 10 kW V2G unit, ground mounted with pedestal

Figure 25: S04 – Charger points at the Boiler House, University of Warwick.

There are four Nissan eNV-200 panel vans employed for the V2G trial, each with a 40kWh 350V lithium-ion battery pack. The vehicles are equipped a 3.3kW on-board AC charger and a CHAdeMO DC charger connector for rapid charging up to 50kW DC charging. As with all the other vehicles in the project, each vehicle has a unique ID number, allocated by Cenex. This ID is held, along with any partner-specific IDs in the pseudonymisation table in a secure folder within Cenex server.

Three V2G chargers, which are manufactured by eNovates, were installed. The chargers have 10kW of rated power, 50 – 500VDC of voltage range. The charge points use CHAdeMO 2.0 (backward compliant) connectors, which are commonly used EV charger plugs. The charge points are fully controlled by either manually using RFID cards on the charger or automatically using the CrowdCharge mobile app.

4.e.iii V2G benefits

WMG have published two peer-review papers, which are "Vehicle-to-Grid Aggregator to Support Power Grid and Reduce Electric Vehicle Charging Cost" (DOI: 10.1109/ACCESS.2019.2958664) and "A Study of Reduced Battery Degradation Through State-of-Charge Pre-Conditioning for Vehicle-to-Grid Operations" (DOI: 10.1109/ACCESS.2021.3128774), dealing with reducing the charging cost and minimising battery degradation when participating in V2G operations. The earlier introduced the strategies to distribute the energy of a fleet of vehicles in V2G aggregator to support the grid during peak and off-peak time to reduce the charging cost. The latter proposed several V2G charging strategies based on separate experimental Calendar and Cycling aging data and a verified complete battery ageing model to minimise battery degradation during the vehicle parking period. The detail of the papers is described in Section 5 (page 47). According to the outcomes, V2G can support the reduction of charging cost and help minimising battery ageing, which is the benefit which UoW sought to achieve at the site.

4.e.iv Problems and challenges

V2G operational data management

In order to supervise V2G operational process and optimise the charging strategy, charger and vehicle data should be monitored and logged during operation. Depending on the data-sample rate, large amounts of data communication and storage are necessary. In addition to vehicle and charger level data, UoW researchers also accessed laboratory based ageing data to facilitate the training and initial validation of the ageing model.

Large amount of data traffic and data storage are required to log and store the V2G data.

4.e.v V2G impact on drivers

Based on the optimised charging profiles (i.e. optimised carbon, cost and battery ageing) for each charger (see Section 3.b.i on page 16), there should be no direct impact to the driver due to the pre-defined constraints SoC which maintains the available power in the battery and ensures sufficient amount of energy for driving during a working day around the UoW campus.

- The drivers can keep using their vehicles daily as normal after using V2G charger;
- The drivers can perform charging process via either RFID cards or CrowdCharge mobile app whenever they want or at the end of working day; and
- In urgent cases, the V2G charger can be used for any other CHAdeMO-compatible vans when needed.

The vehicles employed for the trial are used at daytime only from 7am to 5pm, so they can always be connected to the charger overnight so that the optimised algorithm can be deployed during the charging time without interruption. This meant they were operationally well-suited to V2G operations.

However, one of the chargers was consistently unreliable and so drivers took to charging at the other two or at other facilities on-site. This meant that the number of charging sessions at this charger was much smaller than the others.

V2G can theoretically be almost invisible to drivers if it is working - but in reality, a lack of reliability makes this difficult.

4.f Conclusions

EV-elocity demonstrated V2G across a range of UK locations, although not as fully as anticipated.

In examining the V2G demonstration activities, the following conclusions can be drawn:

Site Recruitment:

- Currently, not enough vehicles are compatible with V2G and the limited range of chargers may also not comply with site policies.
- Around 3 months' lag should be set aside for contract negotiations and delays on signatures.
- Upgrading sites which have matured their EV charging processes from dumb or smart charging to V2G is an easier process than those who are still early in their electrification transition.

Site Surveys:

- Site surveys should include analysis of the impact of V2G on wider depot systems and controls.
- V2G installations require a more complex site survey to ensure safe and effective operation.
- The cost and time impact of significant power supply upgrades in urban brown field sites should not be underestimated.

On-Site Delivery:

- A suitably-qualified and experienced electrical contractor should be able to install V2G chargepoints without significant difficulty.
- Guidance may be required around the use and storage of RFID cards to avoid mis-handling.

Procurement:

- Delivery of innovative projects within more traditional procurement structures is challenging and flexible routes to market are recommended for future Local Authority projects like this.
- With such an immature product, traditional Local Authority ITT processes are not an effective or efficient route to procure V2G and associated energy storage equipment.
- Projects should account for long lead times on V2G hardware.

Troubleshooting:

- Troubleshooting V2G installations will likely involve collaboration across the whole supply chain.
- V2G brings challenges as organisations have to adapt to and handle new operational situations.
- Continuity of staff and knowledge within partner organisations is essential.

V2G Benefits:

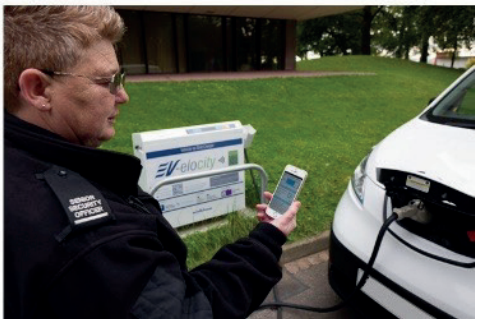
- Reliability of the V2G system is an essential hygiene factor for confidence in the system. Without this, no benefits will be yielded from V2G.
- Ensuring that charging schedules are suited to driver needs and deliver charge events every time is important to ensure high acceptance from users.
- When stability and reliability is delivered, V2G drivers report a high level of satisfaction, although slightly more constrained by the need to be always plugged in.
- Prioritising the user experience will be important to ensure that control of the V2G system is not too complicated – e.g. a visualisation of charging status or easier to understand schedules.
- Large amount of data traffic and data storage are required to log and store the V2G data.

Proposals to Overcome Challenges:

- Better due diligence on the suitability of proposed consortium partners might help to avoid potential withdrawals from collaborative projects.





5 User Behaviour and Responses to V2G

This section outlines the work and activities conducted by the University of Nottingham (UoN) to deliver the project's third aim:

Discover more about the user behaviour and operation of V2G.

In this section, an analysis of UoN's fleet use is reported. The analysis gave insights into the best locations for V2G chargers and prediction of vehicle availability. The benefits of integrating data from multiple sources to address the project questions are also described, alongside a method to calculate how using V2G to result in reduction in CO_2 emissions.

5.a Strategic Location of V2G Chargers

5.a.i Fleet Journey Analysis

The patterns of operation of UoN's fleet were evaluated and some of the results were published in the paper *Decarbonising our transport system: user behaviour analysis to assess the transition to electric mobility*[x]. In **Figure 26**, a 'simultaneous use' analysis of the vehicles during 2018 is illustrated. This enables the visualisation of how many vehicles were active at the same time and understand the fleets' patterns of use in a 24 hour period. Fleets 1, 2, 4, 5 and 6 remained stationary during the night and fleet 3 was operational 24/7. Fleets 1, 4, 5 and 6 had a clear pause of activities at midday whereas fleets 2, 4 and 5 had a very defined start and end of operation.

Most of the UoN fleets can be charged overnight (except Fleet 3).

Moreover, fleets 1, 4, 5 and 6 would allow EV charging from local renewable solar PV generation as they were stationary over lunchtime.

The team undertook an evaluation of the potential for CO_2 emissions reductions. The results indicated that the transition to electric could reduce annual CO_2 emissions by between 54% and 73% against a baseline grid factor of 278 g/kWh (**Table 3**).

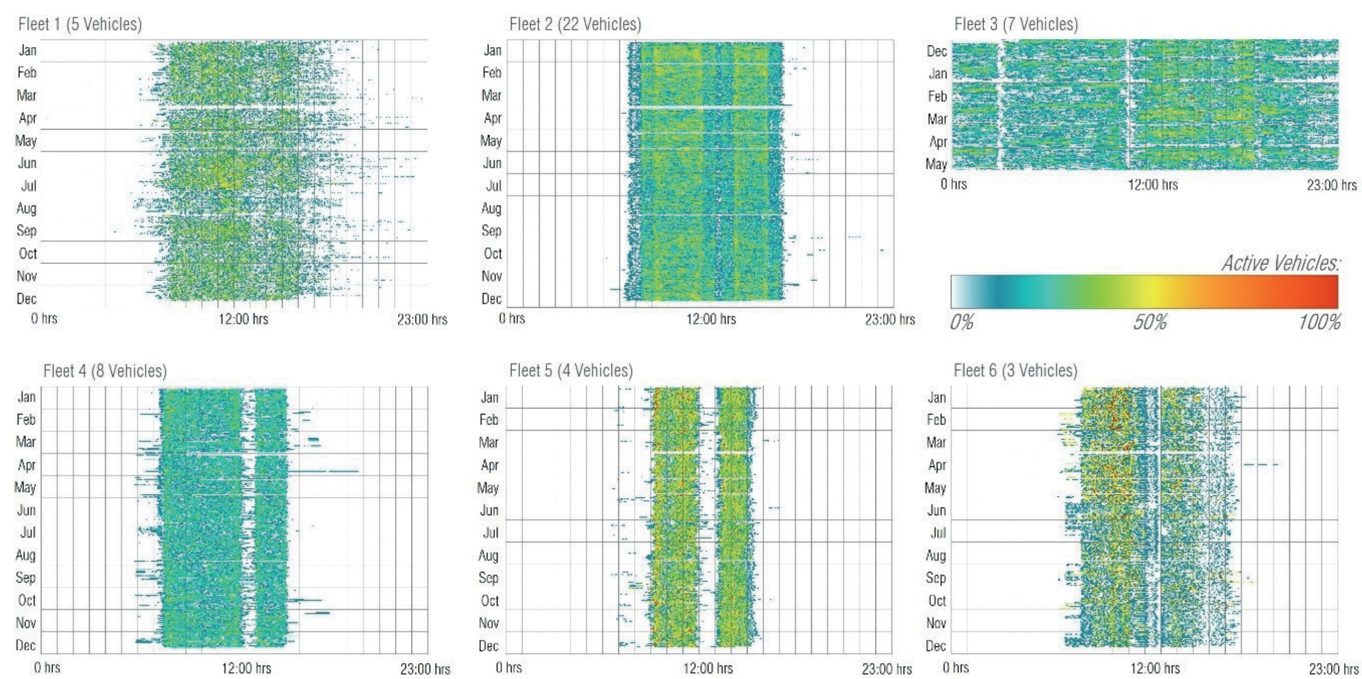
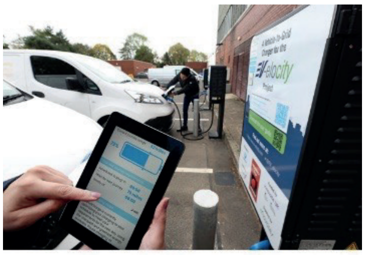


Figure 26: Simultaneous use of vehicles analysis

FLEET	DIESEL VEHICLES		ELECTRIC VEHICLES		% CO_2 EMISSION REDUCTION
	YEAR FUEL COST	YEAR CO_2 EMISSIONS [Grid factor 278g/kWh]	YEAR FUEL COST	YEAR CO_2 EMISSIONS [Grid factor 278g/kWh]	
1	£936	1505 kg CO_2	£123	410 kg CO_2	73%
3	£3906	3728 kg CO_2	£512	1714 kg CO_2	54%
5	£821	1261 kg CO_2	£108	361 kg CO_2	71%
6	£2785	3792 kg CO_2	£364	1221 kg CO_2	68%

Table 3 - Costs and carbon emissions Diesel vs. Electric Vehicle & the percentage carbon emissions reduction

A further analysis using telematics data from 2019 was conducted to identify the best locations for V2G chargers. This study evaluated one-year's data from 48 vehicles, equating to 184,899 journeys **(Table 4)**. The mean distance travelled by these vehicles in a day was between 14 to 42 miles, whilst the maximum distance registered in a day was 155 miles.



FLEET	NUMBER OF VEHICLES	MEAN DAILY DISTANCE (MILES)	MAXIMUM DAILY DISTANCE (MILES)	MEAN DISTANCE PER JOURNEY (MILES)	MAXIMUM DISTANCE PER JOURNEY (MILES)
1	5	14.3	70.6	0.8	59.9
2	20	14.5	83.5	1.3	33.5
3	7	42.6	154.9	1.8	59.0
4	9	15.7	148.4	1.5	74.4
5	4	27.5	110.6	1.4	46.6
6	3	42.2	99.3	2.4	46.6

Table 4 – Mean and maximum distance travelled per journey and per day

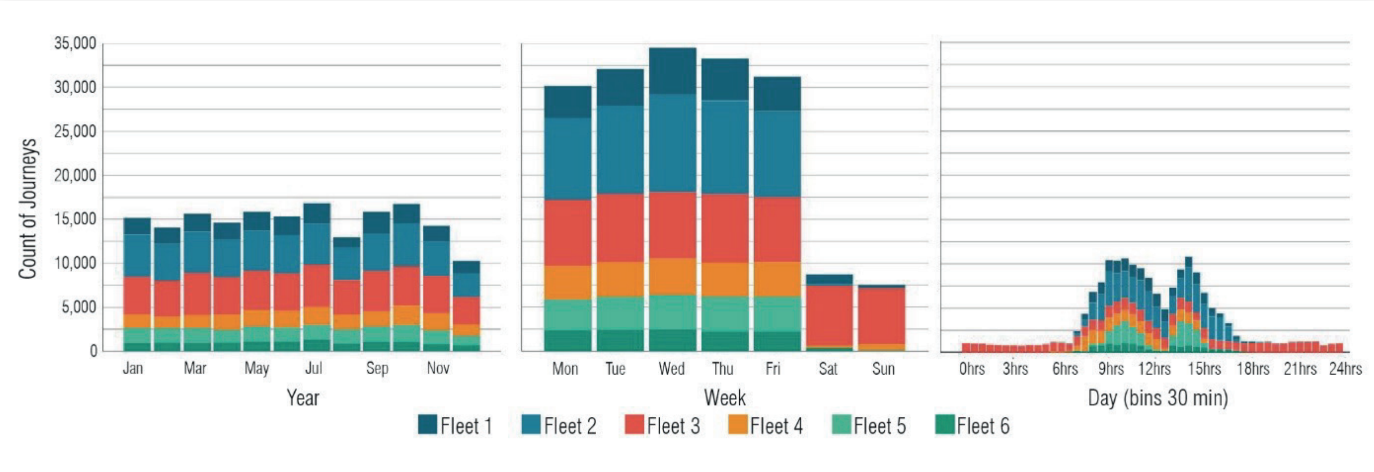


Figure 27: Distribution of journeys by fleet

Figure 27 illustrates the frequency distribution of the journeys according to the month, day of the week and time. The annual distribution shows that the operation of the fleet is reduced in August and December, during key holidays. The weekly distribution indicated that most of the fleets significantly reduce operations over the weekend, with exception of fleet 3. The day analysis shows two peaks of usage, between 9am and 11am, and 3 and 5pm. Again, fleet 3 was the only one operating 24/7.

Significant CO_2 savings are possible by switching more UoN vehicles to electric.

5.a.ii Geospatial Analysis

A geospatial analysis of the main dwell locations of the vehicles was conducted to produce a heat map to highlight the most strategic locations for V2G infrastructure (**Figure 28**). Long dwell events (over 60 minutes) were filtered out as they are not representative of normally usage. The map includes four of UoN's campuses which are in close proximity (University Park Campus, Jubilee Campus, King's Meadow Campus and the Medical School). Red indicates areas with higher number of dwell events.

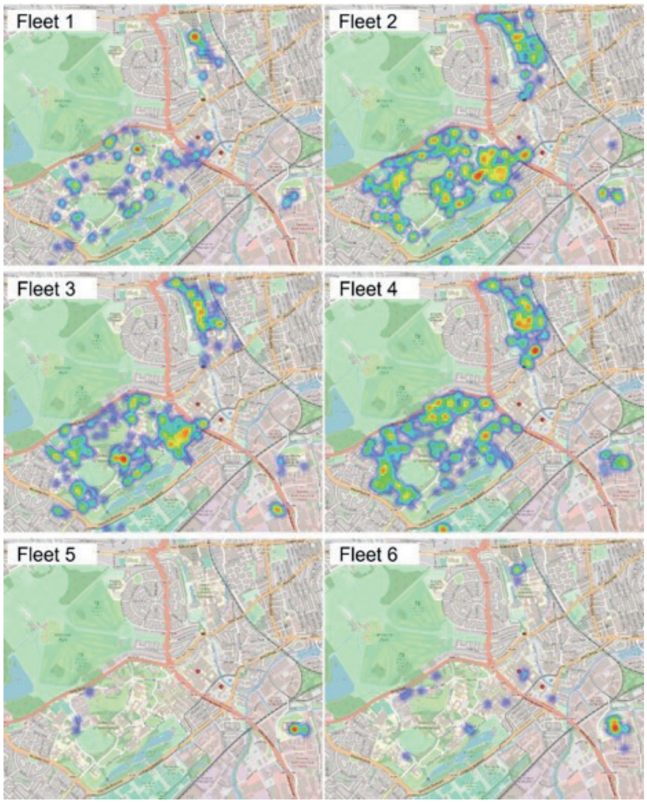


Figure 28: Fleet dwell time analysis

This analysis identified the optimal charging locations for fleets 1 and 5 as the hotspots are in the north sector of the University Park Campus, Jubilee Campus Parking and King's Meadow Campus. For other fleets, multiple locations for charging infrastructure should be considered. The geospatial analysis allowed the team to highlight possible locations for V2G charging infrastructure based on long dwell events. The researchers also conducted observational studies, spending time with each fleet user group to understand their needs and limitations. The outcomes informed the choice of sites for further surveys, which were undertaken before deciding on the location of the V2G chargers' installation. The site surveys looked at parking availability, proximity to power stations, power capacity to add charging infrastructure, groundworks required to install chargers and permits.

Vehicle use behaviour analysis can support the strategic location of V2G infrastructure and assess the feasibility of fleets to transition to electric mobility, and to the integration of V2G.

5.b Reduction of CO_2 using V2G

5.b.i Data Integration

A further line of investigation by the UoN team was to propose methods to reduce CO_2 emissions using V2G. To achieve this, the researchers integrated the datasets of vehicle use behaviour, building energy demand, local renewable energy generation and grid carbon intensity (**Figure 29**). This analysis included creating a strategy for charging/discharging the vehicles that took these variables into account, as published in the paper *The Role of Electric Vehicle Charging Technologies in the Decarbonisation of the Energy Grid* [xi].

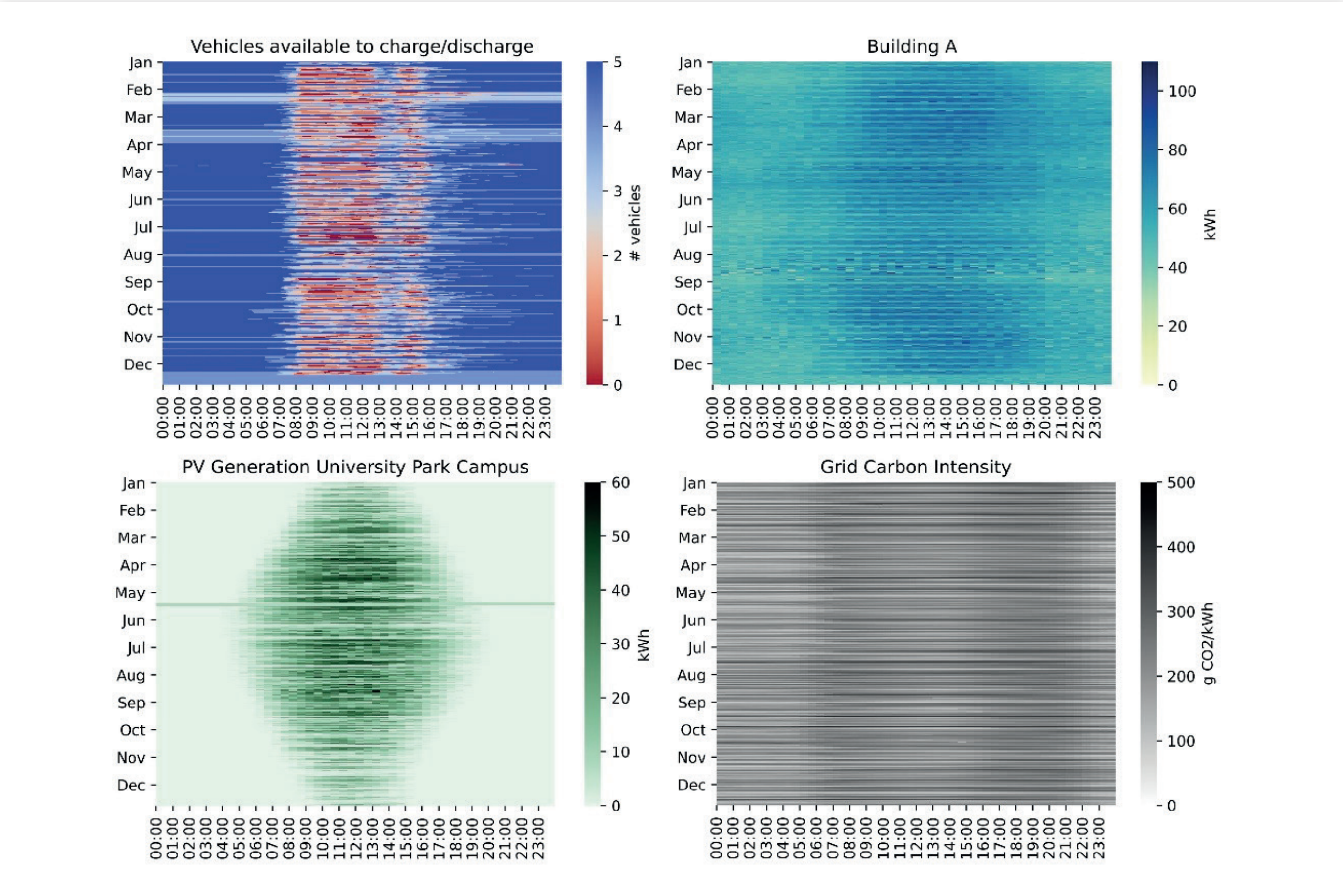


Figure 29: Clockwise from top-left: Fleet availability to charge; electricity demand of Building A; grid CO_2 intensity; and campus solar generation

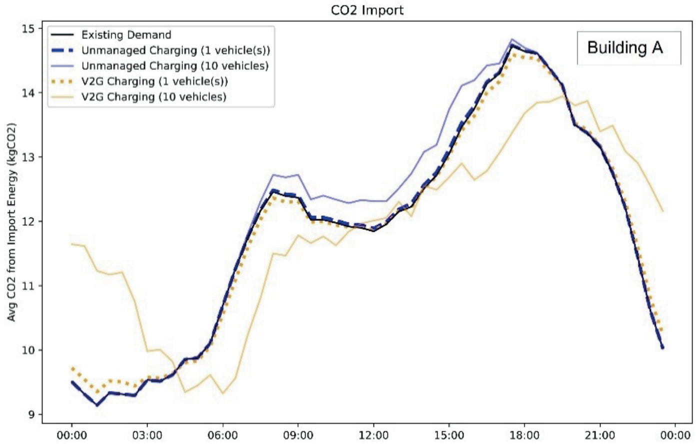


Figure 30: Carbon emissions imported for Building A

The results indicated that V2G could reduce the average CO_2 emissions of the system by prioritising charging when the grid carbon intensity was low. V2G was able to shift energy demand to periods when renewable energy generation was high and the grid carbon intensity was low, without impacting current service provision (**Figure 30**).

For instance, in one of the tested scenarios including a building with an annual energy demand of 478 MWh and 10 electric vehicles, V2G reduced the average carbon intensity per kilowatt from 223.8 gCO_2/kWh (with a baseline demand of the building without electric vehicles) or 224 gCO_2/kWh (with unmanaged charging) to 218.9 gCO_2/kWh using V2G.

V2G can reduce the average carbon intensity per kilowatt, despite the increased energy demand from EV charging.

Use of short-term prediction tools extends the savings significantly.

5.b.ii Optimising CO_2 emissions from V2G

Following the previous publication, a further analysis was developed using machine learning to optimise the reduction of CO_2 emissions from the system. This study included historical data from 19 vehicles, energy demand from one building, renewable energy generation on campus, and UK grid carbon intensity. The scenarios included a control scheme based on a perfect foresight model.

The results indicated that the average carbon intensity per kilowatt was reduced from 194 gCO_2/kWh with a baseline demand from the building (without the vehicles) to 192.7 gCO_2/kWh using a static V2G control scheme, and reduced further to 185.5 gCO_2/kWh with a 48h ahead predictive model.

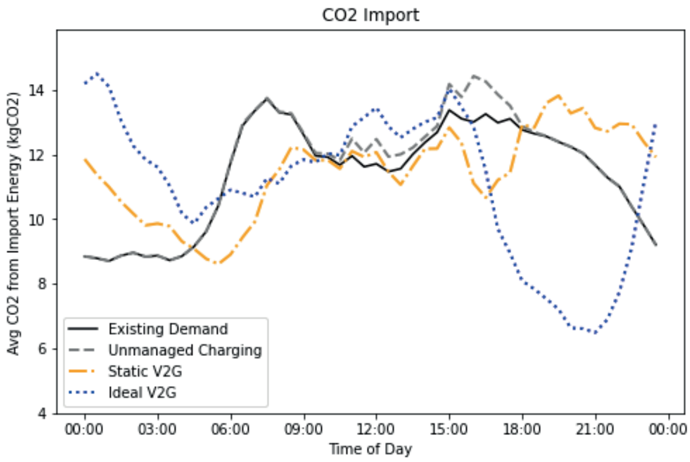


Figure 31: Average daily CO_2 import over one year under three V2G scenarios

Figure 31 presents the impact of energy transfer from the fleet on the total system CO_2 production. With the two V2G schemes, the load of EVs was largely deferred to lower-intensity times of day. Additionally, vehicles discharged to the building (or grid) when carbon intensity was high, effectively allowed a reduction in CO_2 emissions from the building demand.

This analysis is presented in the paper *Establishing a Case for Predictive Machine Learning to Optimise Vehicle-to-Grid Charging for Reduced Carbon Intensity in the Built Environment* that will be presented at the EVS35 Conference, Oslo (June 2022).

V2G can enable a reduction in CO_2 production of the building system.

However, the way that the energy store is managed can have a significant effect on the benefit provided.

5.c Predicting Vehicle Locations and Storage Capacity

V2G services have the potential to utilise a population of electric vehicle batteries to provide the aggregated capacity to participate in power and energy markets. Such participation relies on the prediction of available storage capacity and vehicle availability to support the reliable delivery of agreed reserves at a future time. Therefore, the UoN team developed a series of studies with simulated scenarios using historical data from UoN fleet to demonstrate how machine learning could support and optimise V2G with forecasting models.

In the paper *Where will you park: Predicting Vehicle Locations for Vehicle-To-Grid*[xii], the team presented an evaluation of three learning models. Cumulative Moving Average (CMA), Exponential Moving Average (EMA) and Automated Machine Learning (AutoML) approaches were used to predict the parked locations of vehicles from the University fleet and their proximity to six proposed V2G charging stations on the campuses. The outcomes suggested that Automated Machine Learning was the most accurate technique with an accuracy of 91.4%. **Figure 32** compares the accuracy of each model to predict vehicle availability according to the periods (term/non-term and holiday/non-holiday).

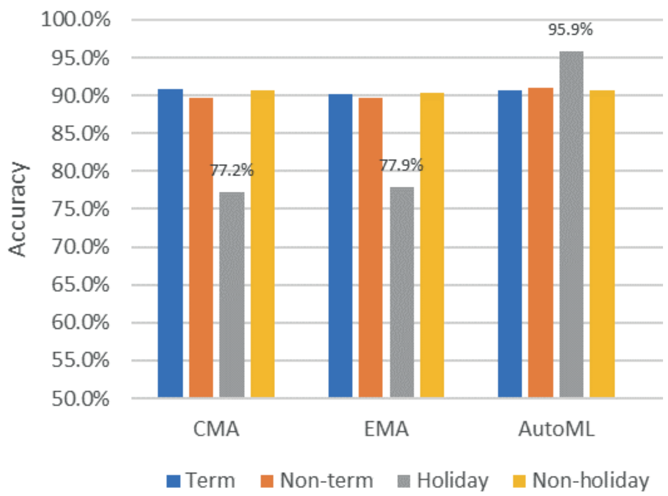


Figure 32: Accuracy of the three models for term/non-term periods and holiday/workdays. Data labels show accuracy for holidays

While this predictive capability would be of value to a V2G aggregation services, the incorporation of other factors, such as the state of charge of the battery would be required to implement it.

Therefore, further studies on predicting storage capacity were developed. The paper *We got the power: Predicting Available Capacity for Vehicle-to-grid Services using a deep recurrent neural network*[xiii] presents a convolutional neural network (CNN-LSTM) time series forecasting model to predict the available storage capacity from a fleet of 48 vehicles for the next 24 hours.

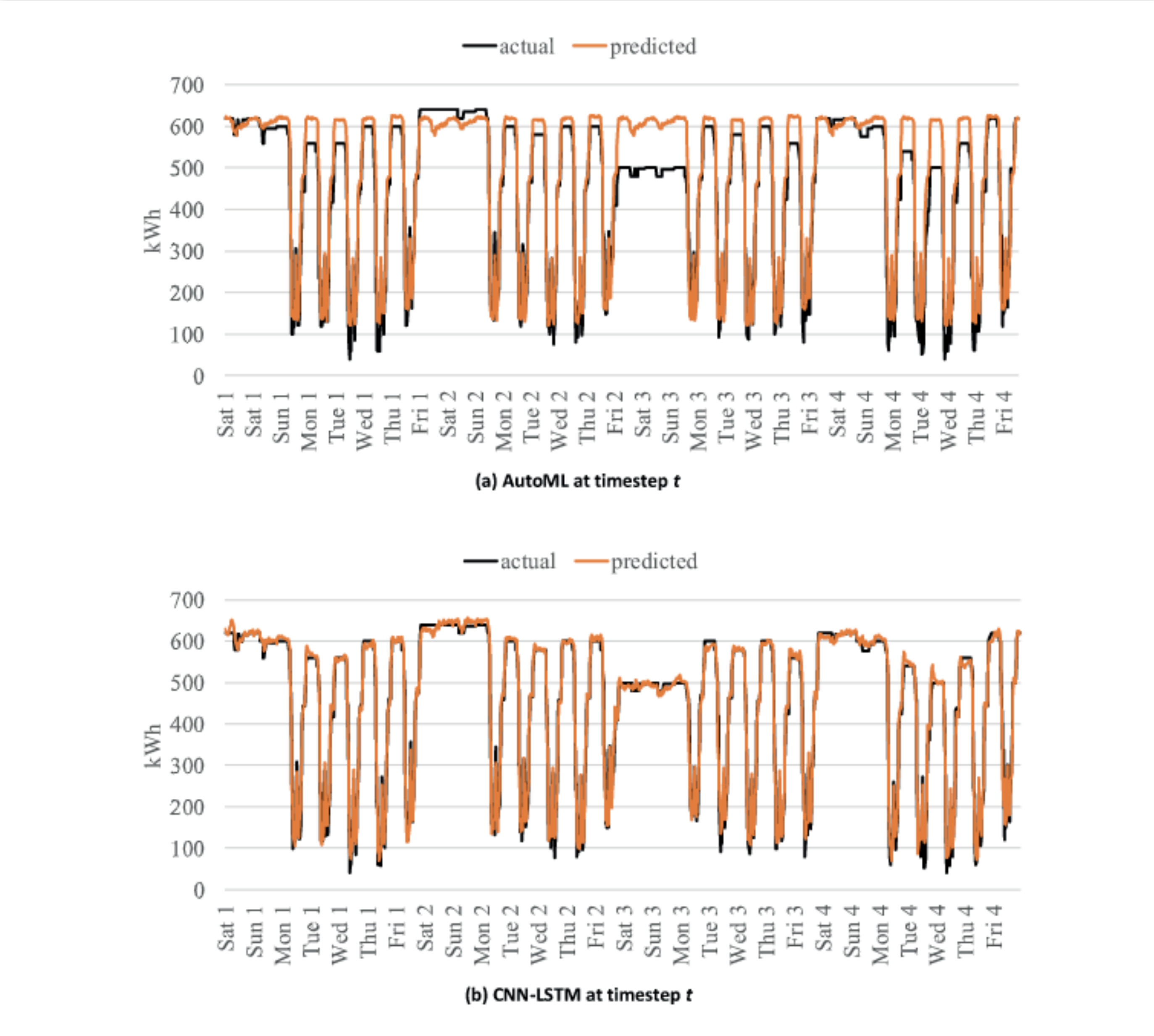


Figure 33: Actual vs predicted capacity for a sample 4-week period. AutoML regressor (a); CNN-LSTM model (b)

Figure 33 presents the actual vs predicted storage capacity of the vehicles using AutoML and CNN-LSTM. To effectively operate, V2G aggregated services will require knowledge of previous energy export events to predict the impact of upcoming events. The work published in this paper contributed to the development of models that have the capability to adapt in the near-term period.

Nevertheless, the team acknowledges that further studies would require a larger dataset from a more complex operation including:

- scaling the service with additional vehicles and fleets;
- dealing with inevitable heterogeneity of vehicles, batteries, driving styles and chargepoints; and
- optimising revenue from multiple potential market opportunities.

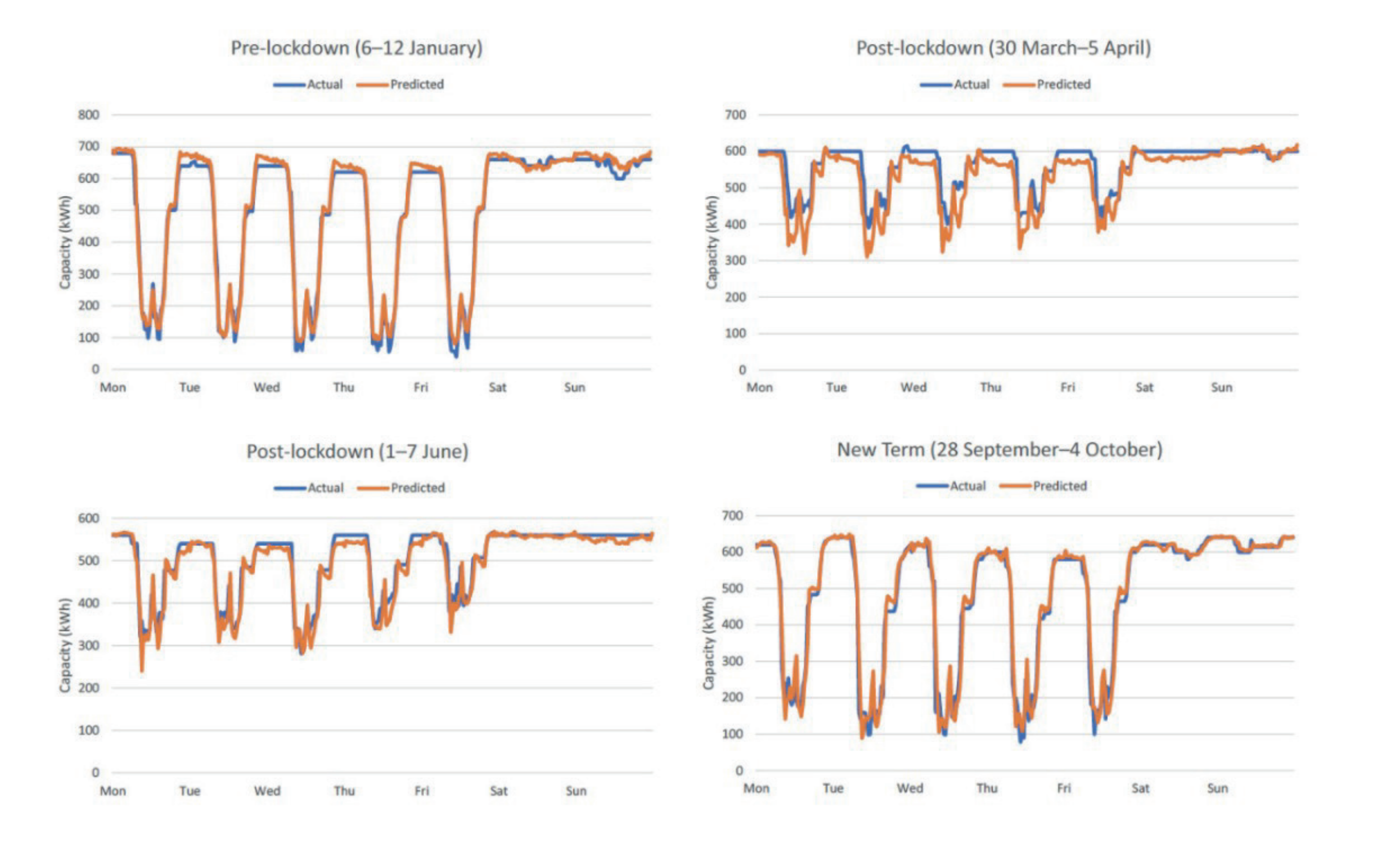


Figure 34: Actual vs. predicted capacity using the online machine learning model for 4 sample weeks

The Coronavirus pandemic declared in 2020 resulted in closures of the university and substantial changes to the behaviour of the university fleet. The paper *Online Machine Learning of Available Capacity for Vehicle-to-Grid Services during the Coronavirus Pandemic*[xiv] presents the data analysis of vehicle storage capacity pre-lockdown and post-lockdown. The tests evaluated the accuracy of the previously developed prediction models (Convolutional Neural Network) and integrated Online Machine Learning to enable the network to continually refine its predictions based on observed behaviour. An improvement in prediction error of 51% was demonstrated using the latter in the period following the disruptions. The comparison of the actual versus the predicted capacity over four different periods pre-lockdown and post-lockdown is illustrated in **Figure 34**.

The outcomes of this work contributed to the understanding of behavioural changes that can affect the storage capacity and vehicles availability to connect to V2G. The development of adaptable predictive models is critical to add resilience to the V2G system for disruptive events.

Forecasting techniques can support trading and vehicle utilisation decisions made by emerging V2G aggregation services in the critical near-term period.

Vehicle availability and battery storage capacity can be integrated to the V2G system to allow participation in power and energy markets.

5.c.i Survey Details

The *V2G User Survey* was designed to gather participants' perception over the project. This section can report partial outcomes due to a low response rate.

With the aim of increasing the sample size, researchers from UoN joined efforts with the Technology Research Laboratory (TRL, Innovate UK's chosen programme analysts) and Imperial College London to design and deliver a more robust survey across the wider Innovate UK programme. This was released on the 21st of March 2022.

NOTE: The survey of the wider sample base is in progress and therefore not reported on this document[xv].

Sample

The answers received from the EV-elocity project correspond to seven participants from different V2G sites:

- Five of them were vehicle users, one was a fleet manager and one was domestic user charging at work.
- Four of the sites started to operate on or before March 2021 and one site in September 2021.
- Three of the chargers were used by a single vehicle and the others were shared with one and three additional vehicles.

Charging Routine

Two participants reported that they charged their vehicle from Monday to Friday at the end of the day. Three participants said they charged overnight between 7pm and 7am every day, and one participant between 7am and 5pm. The vehicle participating only during Phase 2 was a pool car connecting almost constantly without regular usage.

5.c.ii Results

The following insights into challenges with V2G were captured:

PHASE 1

- The chargers regularly crash and stop working
- Charger not used in this period due to issues with the charging system
- Faults due to card not working
- Operators not knowing how to use the charger
- Not being able to use the vehicle overnight
- Lack of need to go to office due to covid remote working

PHASE 2

- The chargers regularly crash and stop working
- Reliability of the charging system. Errors which interrupt the charging session.
- Operators not knowing how to use the charger
- Vehicle only available at 50% charge first thing in the morning
- Not being able to use the vehicle overnight
- Inconvenient times

PHASE 3

- University closure points due to COVID
- Inconvenient times

The following insights were captured into the advantages of V2G.

PHASE 1

- Near full charge every morning
- Other vehicle to use
- Solar energy charging

PHASE 2

- Near full charge every morning
- From the viewpoint of the user: none
- From the viewpoint of the organisation: using an old depreciated asset for research purposes.
- Other vehicle to use
- Cheaper solar energy

PHASE 3

- Free solar energy

The respondents were also asked whether they had changed their routines.

CHANGES IN NORMAL ROUTINE TO INTEGRATE V2G	
Route	2 participants
Schedules	2 participants
None	4 participants
Other	3 participants
Comments	- Parking at different location - Use of another vehicle - Topping up at another public charger due to low battery state of charge in the morning - Restricted times of vehicle usage

Table 7: Changes to routine reported through the user survey

Perception on the V2G trial

Participants were asked about their level of agreement with some statements. It is clear that participants think V2G can support reducing CO_2 emissions and the cost of charging their vehicles (**Figure 35**) although participants had a strong disagreement regarding the ease of understanding the charging schedules.

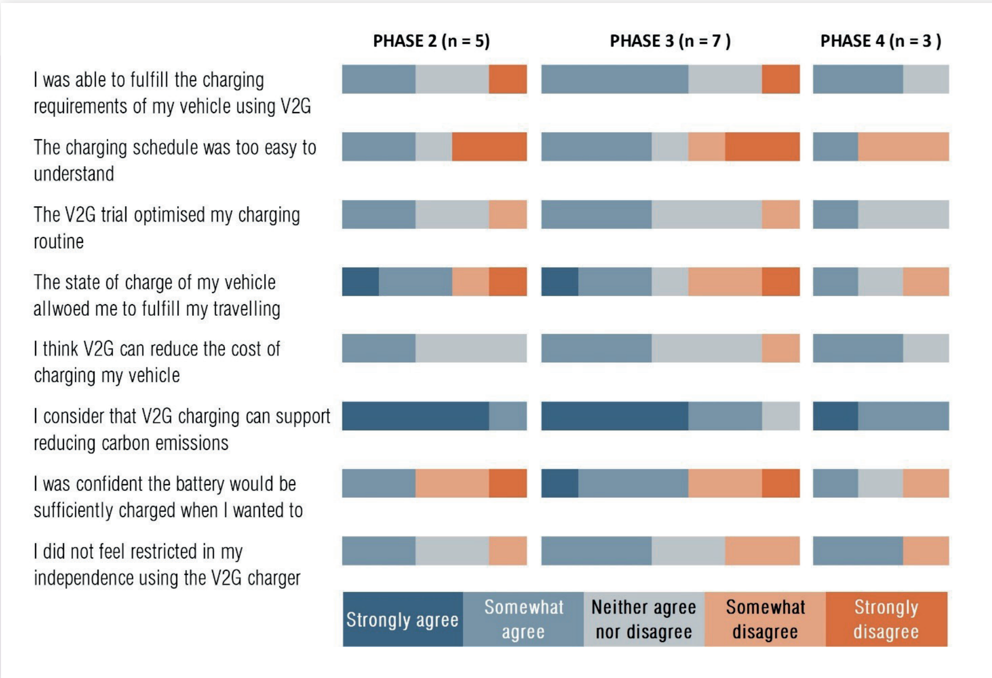


Figure 35 - Participants' agreement/disagreement with some statements.

NOTE: The different sample size in each season is due to trials starting at different times and the timing of this report with regards feedback on Phase 3.

Comments to the usability of the V2G charger:

The following verbatim comments were received:

There is a knack to the swipe card technique.

The charge point itself is very easy to use, but this does not mean that the system is reliable.

The need for the card swipe and the card to be present makes the process less suitable for a pool car. Just asking users to plug it in and check its charging is a challenge.

It is 'idiot proof'.

There is no visibility of the charging cycles that there are being instructed due to the V2G system. The CrowdCharge app should give control of the vehicle usage but [I am] unsure of reliability.

Recommending V2G for other vehicles in the fleet

Responses were equally split. The verbatim comments followed in the same vein as the other insights:

But only if the reliability can be improved.

On the basis of this trial alone - no, simply due to the reliability of the charging system hardware/ software. In principle, yes.

The process is currently too complicated.

To work on a 24/7 rotation, we would need to double the fleet.

Recommending V2G to Other Users

Responses were divided. The verbatim comments received were:

But only if the reliability can be improved.

For private use.

I like it, it is the way to go.

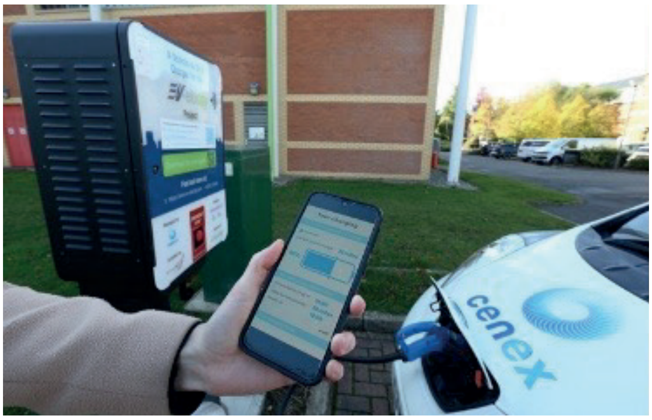
The partial results correspond to a limited sample. However, it is possible to draw some conclusions, below:

Technical challenges with the V2G chargers and time restrictions on the use of the vehicles were the main reported barriers.

Users reported very few benefits of V2G and felt they would need to make some changes to upgrade to V2G charging.

Integration of renewable sources and successful operation of the V2G chargers were some of the advantages reported.

Participants think V2G can support reducing CO_2 emissions and the cost of charging their vehicles.



5.d Conclusions

EV-elocity discovered more about user behaviour and V2G operations.

In examining the V2G user behaviour and responses, the following conclusions can be drawn:

Location of Chargepoints:

- The vehicle behaviour analysis allowed identification of possible fleets to transition to electric and compatible to integrate vehicle to grid.
- The geospatial analysis of the vehicles' long dwell events allowed potentially strategic location for V2G chargers on the University campuses in Nottingham to be identified. This gave confidence that site surveys could be commissioned.

Reduction of CO_2:

- The method developed to integrate data from vehicle usage, building energy demand, renewable energy generation and grid carbon intensity reduced average CO_2 emissions from the system.
- Use of machine learning further reduced CO_2 emission by using a 48 hour forecast.
- The CO_2 emissions reduction proved that the way energy storage is managed can have significant effect on the benefit provided.

Prediction of Vehicle Locations:

- Predicting vehicle location and storage capacity can support trading and vehicle utilisation decisions made by aggregation services in the near-term period.
- Vehicle availability and battery storage capacity can be integrated to the V2G system to allow participation in power and energy markets.
- Automated Machine Learning was the most accurate technique to predict vehicle location for V2G. Convolutional Neural Network (CNN-LSTM) could predict storage capacity and adapt in the near-term period. However, by applying Online Machine Learning, the model was enhanced to allow the system continually refine predictions and be prepared for disruptive events.

User Survey Results:

- The outcomes of the survey are uncertain due to a limited sample, which is being addressed by a follow-up survey.
- The main challenges reported by users on the V2G trial corresponded to technical issues to operate the V2G chargers.
- Users reported very few benefits of V2G and felt they would need to make some changes if they were to use it outside of the project.
- However, the main advantages related to the capacity to charge the vehicle with solar energy and cheap/free energy.
- Participants think that V2G can help reducing CO_2 emissions and energy costs.

6 The Impact of V2G on Battery Degradation

This section outlines the work and activities conducted by the University of Warwick to deliver the project's fourth aim:

Deepen understanding around the management of the battery systems, including opportunities to mitigate degradation and possibly extend battery life.

The University of Warwick team engaged in EV-elocity not only as a trial site (see Section 4.e on page 42 for more details) but also to evaluate and analyse the reduction of battery degradation. This is achieved through various control strategies to pre-condition the State of Charge (SoC) of EV batteries participating in V2G scenarios when parked.

Firstly, semi-empirical models were developed to predict the battery capacity fade due to calendar and cycling ageing. The parameters of the models were identified and verified using experimental data of long-term ageing tests under different laboratory conditions for both calendar and cycling ageing. A single lifetime ageing model was constructed by combining the calendar and cycling ageing models to facilitate the prediction of total battery capacity loss under different EV operational profiles.

Then five charging strategies including conventional and smart charge approaches were developed followed by the simulation and comparative analysis, allowing a range conclusions to be drawn.

NOTE: The published, peer-reviewed paper presenting these results can be found here[xvi].

6.a Battery Degradation Model Development

The rate of battery degradation is governed by how batteries are stored and utilised. This is typically characterised by ageing stress factors including:

- Temperature;
- SoC;
- Charge throughput;
- Depth of discharge (DoD); and
- C-rate.

Literature shows that the causes of capacity fade can be categorized into two groups: calendar ageing and cycling ageing.

Calendar ageing is mostly affected by the storage temperature, SoC and time which represents how long the battery placed in the storage or in resting state. Cycling ageing is typically influenced by ambient temperature, number of charge cycles or charge throughput, C-rate and DoD.

To understand the battery ageing behaviours and support model parameter identification and verification, long-term ageing tests of brand-new Lithium-ion Nickel Manganese Cobalt (NixMnyCo1-x-y) oxide cathode and LiC6 (graphite) anode cylindrical cells were conducted. The model code of the cells under tested is INR21700 M50 manufactured by LG Chem. with a nominal voltage of 3.63V and rated capacity of 5.00Ah. The lower and upper cut-off voltages recommended by the manufacturer are 2.5V and 4.2V respectively.

The aim of this long-term ageing tests was to estimate the evolution of the capacity fade for different use-cases. The batch of cells were divided into two groups, one group was for calendar ageing tests and the other one was for cycling ageing tests. In each condition, three cells were used to ensure the consistency of the results and to reduce the negative impact of cell-to-cell variations. At the beginning of the ageing tests, the cell characteristics were known, and their State of Health (SoH) was normalized to 100%.

6.b Calendar Ageing

Calendar ageing experiments were performed by storing the cells at different temperatures and SoCs. In this study, the total storage time of the cells is 57 weeks (equivalent to about 400 days). The calendar test matrix consists of two sets of cells, one set employed for model parameterisation (training purposes) as shown in **Table 8** and the second for model validation as depicted in **Table 9**.

Table 8: Battery calendar ageing training data

SoC (%)	STORING TEMPERATURE (°C)			
	0	25	45	60
0	3 cells	3 cells	3 cells	3 cells
2	3 cells	3 cells	3 cells	3 cells
5	3 cells	3 cells	3 cells	3 cells
10	3 cells	3 cells	3 cells	3 cells
30	3 cells	3 cells	3 cells	3 cells
50	3 cells	3 cells	3 cells	3 cells
60	3 cells	3 cells	3 cells	3 cells
70	3 cells	3 cells	3 cells	3 cells
80	3 cells	3 cells	3 cells	3 cells
85	3 cells	3 cells	3 cells	3 cells
90	3 cells	3 cells	3 cells	3 cells
95	3 cells	3 cells	3 cells	3 cells
100	3 cells	3 cells	3 cells	3 cells

Table 9: Battery calendar ageing validation data

SoC (%)	STORING TEMPERATURE (°C)		
	15	35	55
20	3 cells	3 cells	3 cells
75	3 cells	3 cells	3 cells

Before and during the ageing tests, capacity measurements were made at specific time intervals equivalent to about 14 days to generate a set of initial cell capacities and to quantify the calendar capacity loss of the cells. For each storage temperature and SOC condition, three cells were employed to identify the mean and variation of capacity loss across the cells. The capacity reductions versus storage time due calendar ageing are depicted in **Figure 36**.

The figure shows the complex relationship between degradation, SoC and ambient temperature. For high ambient temperatures, capacity reduced by circa 15-20%, whereas for zero degrees capacity reduction was typically limited to 5% for all SOC conditions. The error bars on each graph take into account that multiple cells were tested and there a mean and variance exists for each characterisation point.

Degradation, SoC and ambient temperature have a complex relationship but capacity decreases more quickly at greater ambient temperatures.

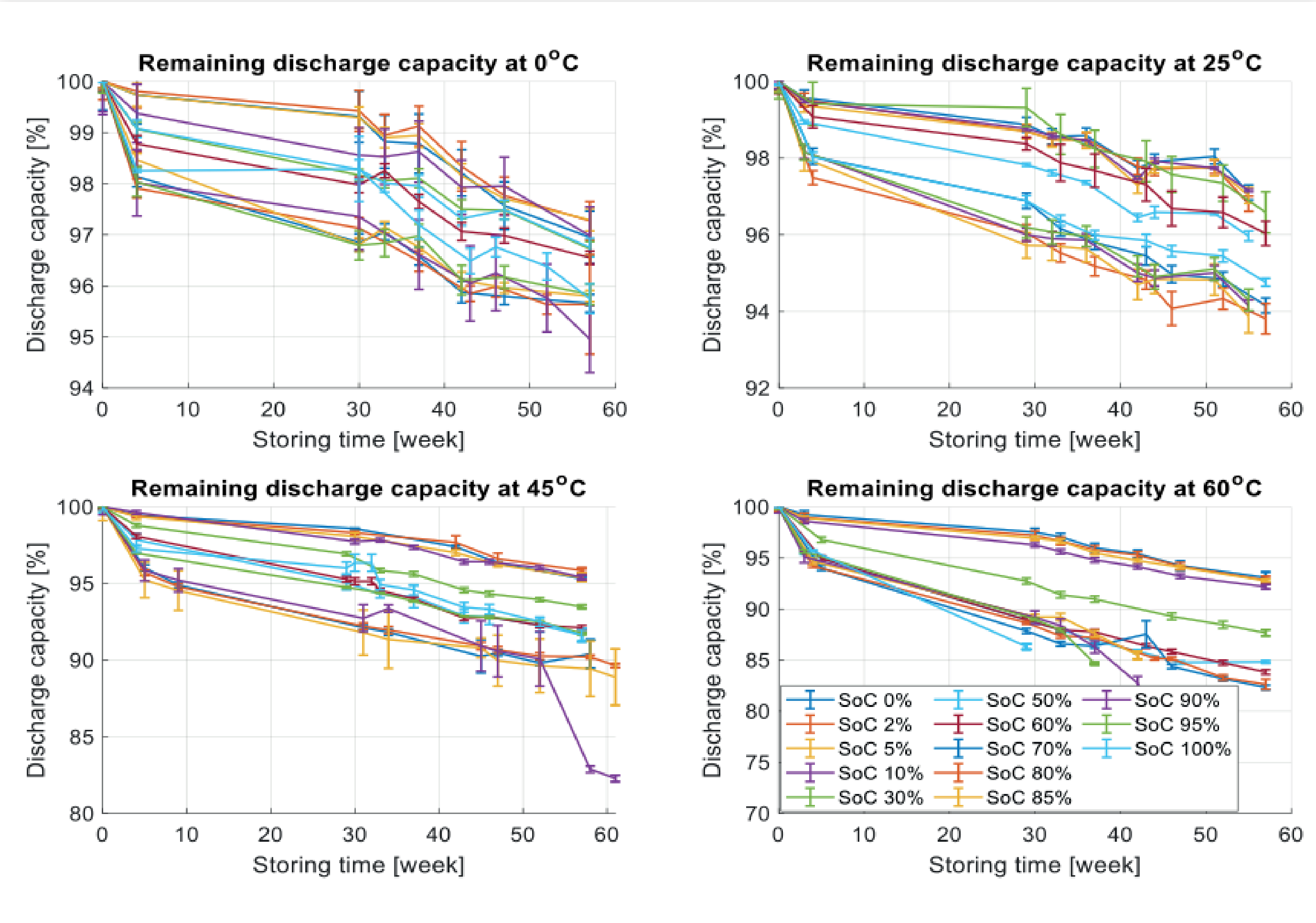


Figure 36: Remaining discharge capacity under calendar ageing for different storage temperatures

6.c Cycling Ageing

Cycling ageing tests were conducted by charging (CHA) and discharging (DCH) the cells repeatedly at different C-rates and temperature conditions (**Table 10**). In these tests, the charging C-rates was limited at 0.3C as recommended by the manufacturer. The discharging current rates were varied at 0.3C, 1C and 2C, respectively which covers the full range of operation at normal and peak load. The DoD of these cycling ageing tests was considered as of 100% of the cells were fully charged and discharged at desired C-rates and temperature.

Figure 37 presents the remaining cell capacity due to cycling ageing at different C-rates and temperatures. It is noteworthy that the desired temperatures in this study was restricted at 0°C, 10°C and 25°C due to the limitations of experimental capability and local laboratory access, which means that the temperature influence of the developing model is limited within such these bounds.

TEMP (°C)	C-RATES		
	0.3C CHA/ 0.3C DCH	0.3C CHA/ 1C DCH	0.3C CHA/ 2C DCH
0	3 cells	3 cells	3 cells
10	3 cells	3 cells	3 cells
25	3 cells	3 cells	3 cells

Table 10: Battery cycling ageing test data

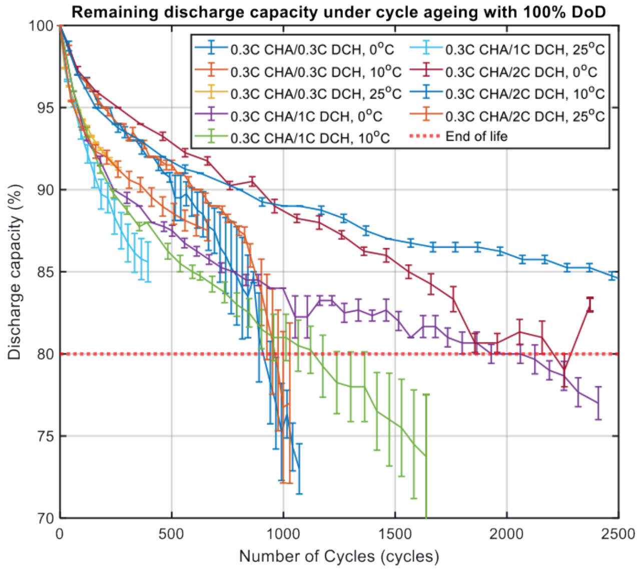


Figure 37: Remaining discharge capacity under cycle ageing with 100% DoD

This graph clearly shows that the rate of degradation increases as the charge-throughput increases. The least ageing occurs when the battery is cycled at 25°C. Exercising the battery at relatively higher/lower temperatures will increase the level of capacity fade.

The rate of degradation is increased with greater charge throughput, especially if this is at relatively higher or lower temperatures.

6.d Combined Ageing Model

Figure 38 shows schematically the combined degradation model framework. It is noteworthy that the total capacity loss can be calculated based on the combination of calendar and cycling ageing accordingly. This combination was considered in many studies in the literature as the best approach for estimating total battery ageing.

The overall degradation of a battery is the combination of calendar ageing and cycling ageing.

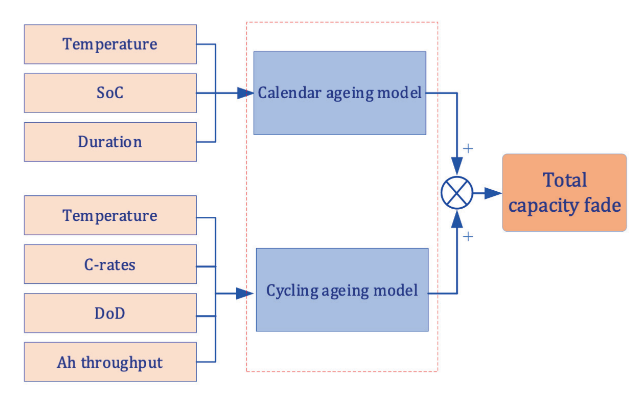


Figure 38: Combined degradation model framework

6.e Charging Strategy Investigation

6.e.i Scenarios

In order to understand the impact of pre-conditioning on degradation, a set of five strategies were defined (**Table 11**).

Table 11: Charging strategies

ID:	TITLE:	DESCRIPTION:	EXAMPLE:
STD CHA	Standard charging	Conventional 'dumb' charging	EV battery is fully charged as soon as it is connected to the charger, then left at 100% SoC until departure.
TS CHA	Time-shifted charging	Smart-charging method with delayed charging	EV battery is left at SoC and is charged at appropriate time to be 100% at departure.
SC V1G	Smart charge V1G	Smart charging without feeding back into the grid	EV battery is left resting at SoC (or an SoC with smaller calendar aging rate), then charged at an appropriate time to be 100% at departure.
SC V2G	Smart charge V2G	Smart bi-directional charging	EV battery is discharged to the SoC with lowest calendar aging rate, then charged at an appropriate time to be 100% at departure.
SC VxG	Combined SC V1G and V2G	Blended approach	A combination of SC V1G and SC V2G that considers the trade-off having extra cyclic aging to achieve optimal SoC vs reduction of calendar ageing at optimal SoC.

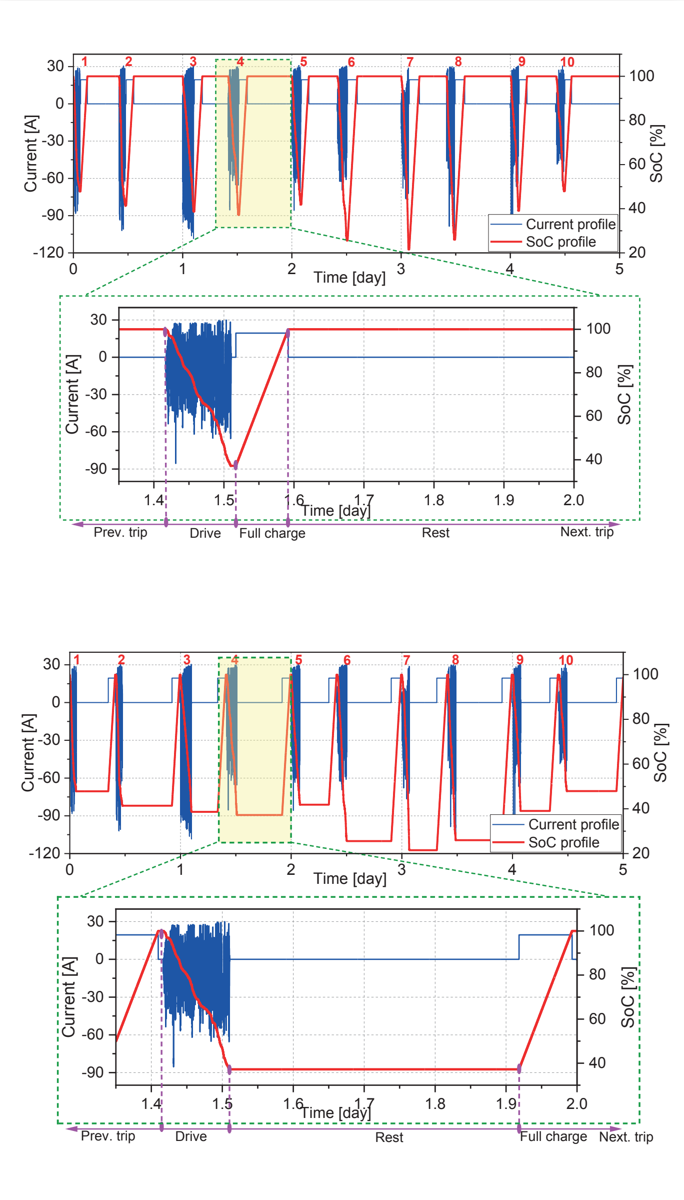


Figure 39: Example STD CHA (top and TS CHA (bottom)

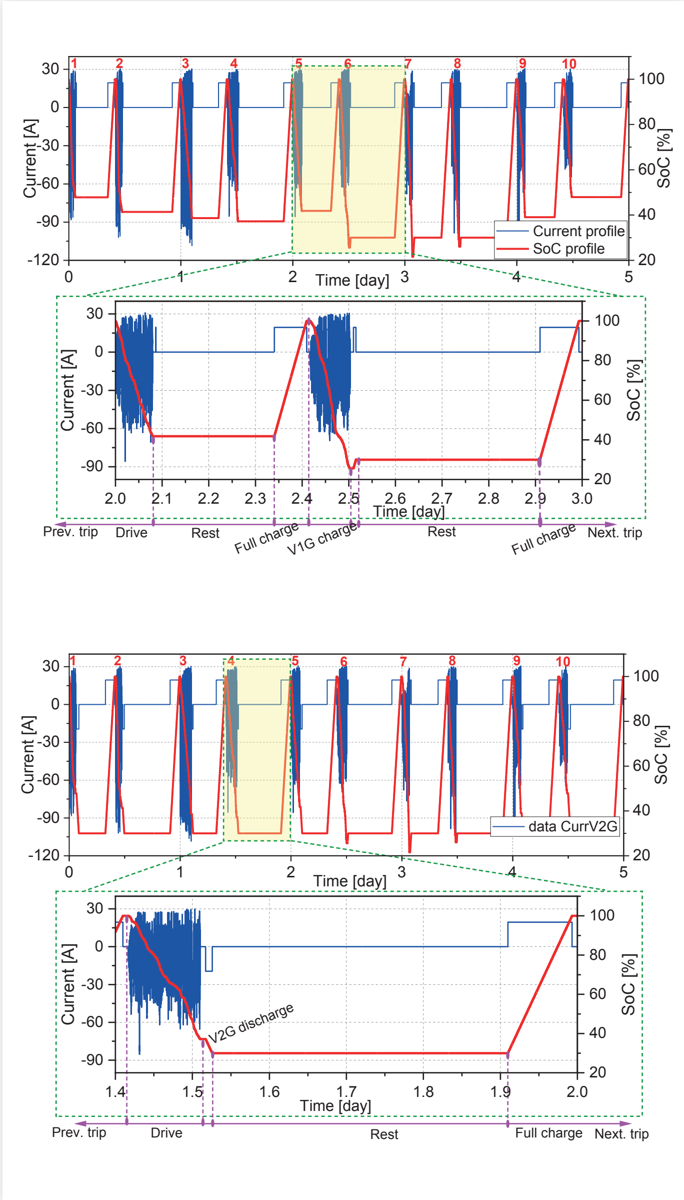


Table 12: Example SC V1G (top) and SC V2G (bottom)

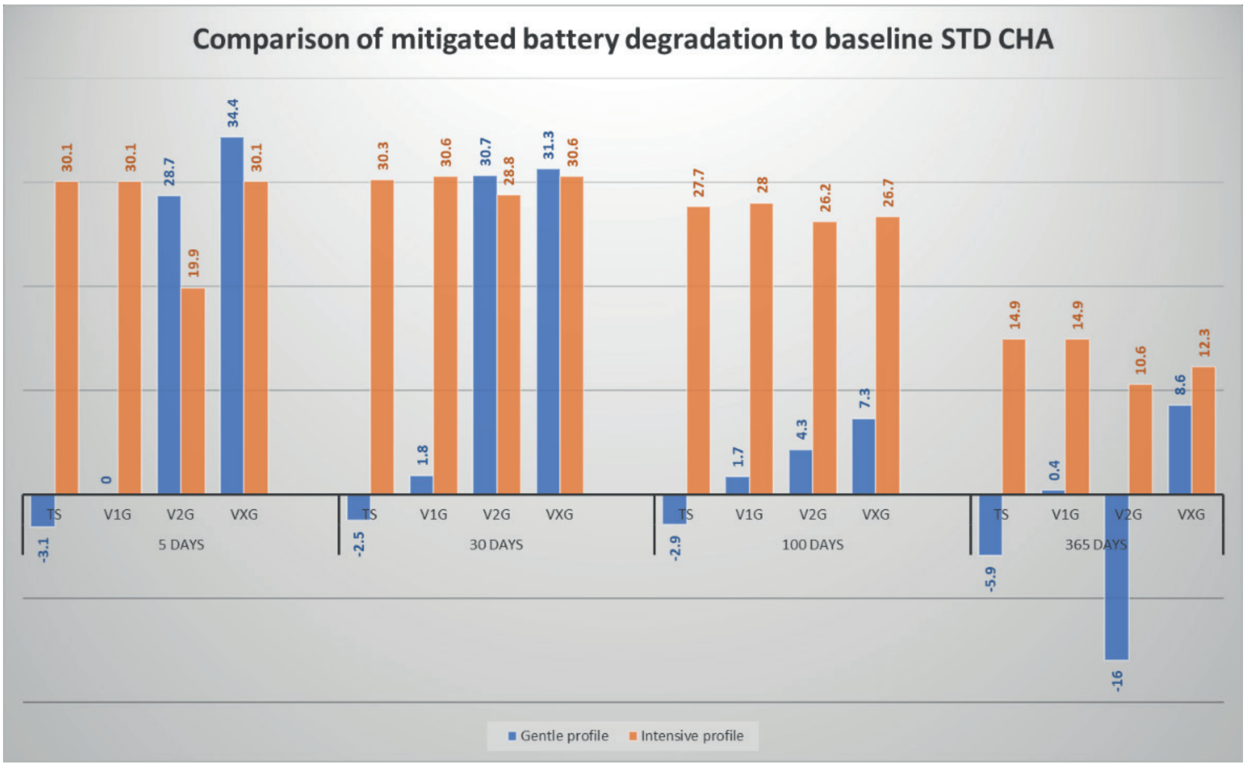


Figure 40: Comparison of impact of different charging strategies on battery degradation

6.e.ii Results

A subset of results are summarised in **Figure 40** in comparison to the baseline STD CHA strategy.

It can be seen that some of the pre-conditioning strategies improved battery life when operating with a gentle driver profile (blue), due to the higher starting SoC. However, SC V2G appears to degrade the battery faster due to increased charge throughput with an increased 16% capacity loss after one year. Nonetheless, the SC VxG strategy did deliver an improvement in battery life because it balances both ageing of the SC V1G and SC V2G, resulting in an 8.6% of battery degradation after one year.

Gentler driving profiles are harder to manage under V2G conditions due to the higher SoC at the point of plugging-in.

For the *intensive* driver profile (orange), all pre-conditioning strategies improved battery life significantly (10.6 – 14.9%). The TS CHA provided the most gain (14.9%) over one year for this cell type with least complexity. This corresponds to the Phase 4 approach tested at the sites (see Section 3.b.i on page 16 for more details). SC V1G and SC V2G strategies demonstrated the advantages in reducing the ageing rate of the battery while the SC VxG strategy demonstrated its capability in balancing the performance of SC V1G and SC V2G to achieve the best performance.

Balancing calendar and cycling ageing produces the strongest all-round performance regardless of intensity of driving.

Where the vehicle is heavily used, a simple time-shifted approach will best protect the battery.

6.f Further Research

A number of further research topics were identified during this work, as follows:

- Complete validation of the degradation models with extended ageing data to fully verify the applicability of the models under different operating conditions.
- Better support the evaluation of the degradation models, to enable a comparison to be made between the model presented here and different methods of ageing model construction, such as fully empirical models or physics-based models. This will require the formulation of appropriate datasets to allow model parameterization in each case.
- Employ the developed models to evaluate the battery degradation with actual V2G scenarios (such as frequency regulation, peak shaving and load levelling). These tasks can be conducted when the battery is in resting mode, after the SoC pre-conditioning process.
- Additional research on the influence of ambient temperature on the ageing behaviour should be considered. This requires the construction of a more diverse dataset in which a wider range of ambient temperatures are investigated for both calendar and cyclic ageing.
- The results will vary with changes in form factor and chemistry. Further research is therefore required to understand the transferability of the methodology.

Due to the limited time of V2G data collection and the limited diversity in driving behaviour and charging process, which is strongly dependent on the driver manner, it was difficult to employ the collected data to completely validate the model. Long-term charger and vehicle data will be needed to fully validate and evaluate the performance of the proposed model.

6.f.i Dissemination

Furthermore, there are several activities that the research outcomes of the project can be employed. Especially for Research and Teaching activities within the University and National/International dissemination contributions.

Education - WMG specialises in postgraduate education and training for Industry in the area of sustainable, low carbon and advanced propulsion system, e.g., the Faraday Battery School, MSc Sustainable Automotive Engineering, MSc Smart, connected and Autonomous Vehicles, MSc in Energy Storage and HV Systems module and the Masters level Technical Accreditation Scheme for industry.

https://warwick.ac.uk/fac/sci/wmg/education/wmgmasters/courses/

Research outcomes will be further disseminated through the EPSRC funded Energy Storage SuperGen (where Warwick is a member); the APC Energy Storage hub that is located at Warwick; the Faraday Institution where Warwick is a founding member and the WMG HVM Catapult.

6.g Conclusions

EV-elocity deepened understanding around the management of the battery systems, including opportunities to mitigate degradation and possibly extend battery life.

In examining the impact of V2G on battery degradation, the following conclusions can be drawn:

Calendar Ageing:

- Degradation, SoC and ambient temperature have a complex relationship
- Capacity decreases more quickly at greater ambient temperatures.

Cycling Ageing:

- The rate of degradation is increased with greater charge throughput, especially if this is at relatively higher or lower temperatures.
- The least cycling ageing occurs at 25°C.
- V2G can enable a reduction in CO_2 consumption if used in a fleet context

Degradation:

- The overall degradation of a battery is the combination of calendar ageing and cycling ageing.
- Gentler driving profiles are harder to manage under V2G conditions due to the higher SoC at the point of plugging-in.
- Balancing calendar and cycling ageing produces the strongest all-round performance regardless of intensity of driving.
- Where the vehicle is heavily used, a simple time-shifted approach will best protect the battery.
- The proposed charging strategies are capable of mitigating the total ageing process from 7.3 – 26.7% for the first 100 days of operational life.
- They gradually vary to 8.6 – 12.3% for one-year continual operation compared to the reference standard charging approach.

7 Evaluating the Viability and Value of V2G

This section outlines the work and activities conducted by Cenex to deliver the project's final aim:

Develop an evidence-based techno-economic model of how V2G will be viable within the UK

This section first discusses Cenex's existing REVOLVE model and the carbon optimisation enhancements made during the project. Then an analysis is made of the available data. A case study on the University of Warwick fleet is presented, along with the results for this site. A second application of the model to the Nottingham City Council fleet is presented, along with results for this site. A summary of results is given to support conclusions about the value of V2G to reduce cost and carbon.

7.a Cenex's REVOLVE Model

The REVOLVE model is a perfect foresight optimisation model capable of simulating the behaviour of many V2G chargepoints at a half hourly granularity over an entire year. The model can be run in an 'unmanaged' mode, where EVs are assumed to charge fully as soon as they are plugged in. Or it can be run in an optimised mode, where the energy cost for the site (or portfolio of chargepoints) is minimised through timely charging and discharging of the chargepoints. In this mode, EVs are guaranteed to be charged with enough energy for their upcoming journeys and additional constraints such as minimum allowable State of Charge (SoC) are also observed.

This model has been enhanced for the EV-elocity project so that an alternative optimisation based on carbon can be performed. The optimisation is based on a half-hourly varying grid carbon intensity (for which data is readily available from National Grid ESO). In the model, a site is deemed to consume carbon based the amount of energy and carbon intensity at the time that energy is imported. The site is credited carbon if it exports energy, again at the grid carbon intensity rate at the time of the export.

Furthermore, a fixed carbon price can be assigned in the model and accounted-for during cost optimisation. This has the effect of minimising both the cost of energy and the cost of carbon.
By running the model in cost-, carbon- or joint-optimisation modes, a theoretical upper bound for the value of V2G can be analysed.

7.b Fleet Telematics

The Cenex data team developed a new telematics and data warehousing solution to collect data from the trial sites, both from the chargepoints themselves and also from loggers in the EVs. This allows an understanding of the site energy and fleet behaviour to be constructed.

To run the REVOLVE model, EV plug-in and plug-out times need to be understood in order to calculate how much energy they need to perform their journeys. After analysing the data collected from the chargepoints, it was discovered that there was no reliable way to identify which vehicle had plugged into the chargepoint.

Future projects would benefit from chargepoints and management systems which can identify reliably the plug-in and plug-out times of vehicles.

Future projects would benefit from chargepoint management systems which log the identity of the user or vehicle which is plugged in.

By processing the data from the loggers in the EVs, an approximation of the timing and location of charging events was made. Combined with the energy requirements for the journeys, this gave sufficient information for the REVOLVE model.

Initially, data from the CANBus loggers was analysed by aggregating it to a half hourly granularity and categorised into different event types:

- Park (at the V2G chargepoint);
- Park Remote (charging at some other chargepoint);
- Drive; or
- Missing.

Figure 41 shows a heatmap of these categorised events for the Influx loggers.

The heatmap shows that the data is of variable quality, with some data missing (i.e. vehicle 1030), and some EVs appear never to be plugged into the V2G chargepoint (i.e. vehicle 1053).

By calculating the percentage split of event types for each EV over the available data period, the EVs with an expected split of event types can be identified (**Figure 42 - next page**).

Of all the EVs, only five have a reasonable proportion of Park events to support analysis with REVOLVE. Of these, vehicles 1031 to 1033 were selected as they not only had realistic plug-in events but also belong to the UoW site, allowing them to be modelled together to give a complete site view.

Hardware reliability and lack of customer use of the chargepoints undermined the quality of the data available for analysis.

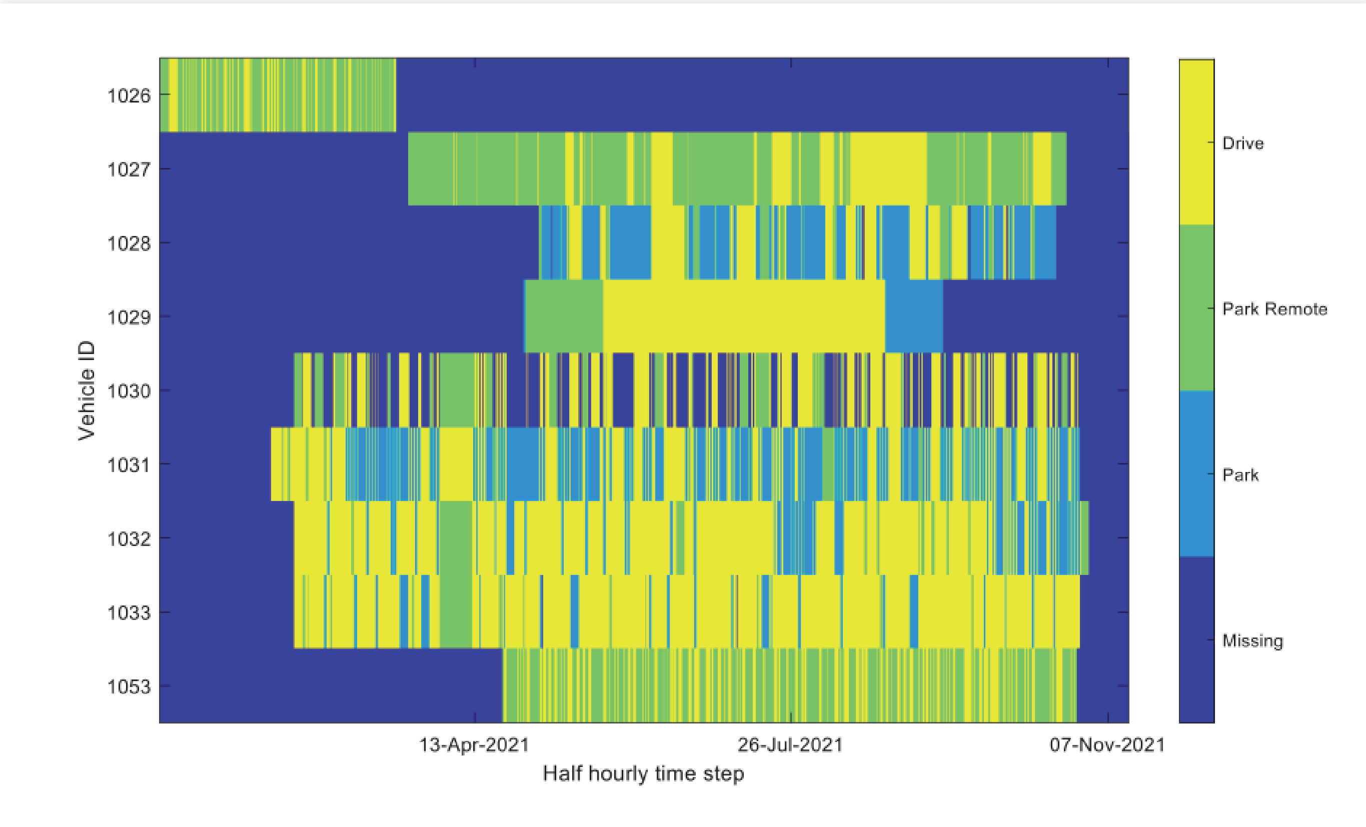


Figure 41: Heatmap of Influx logger data

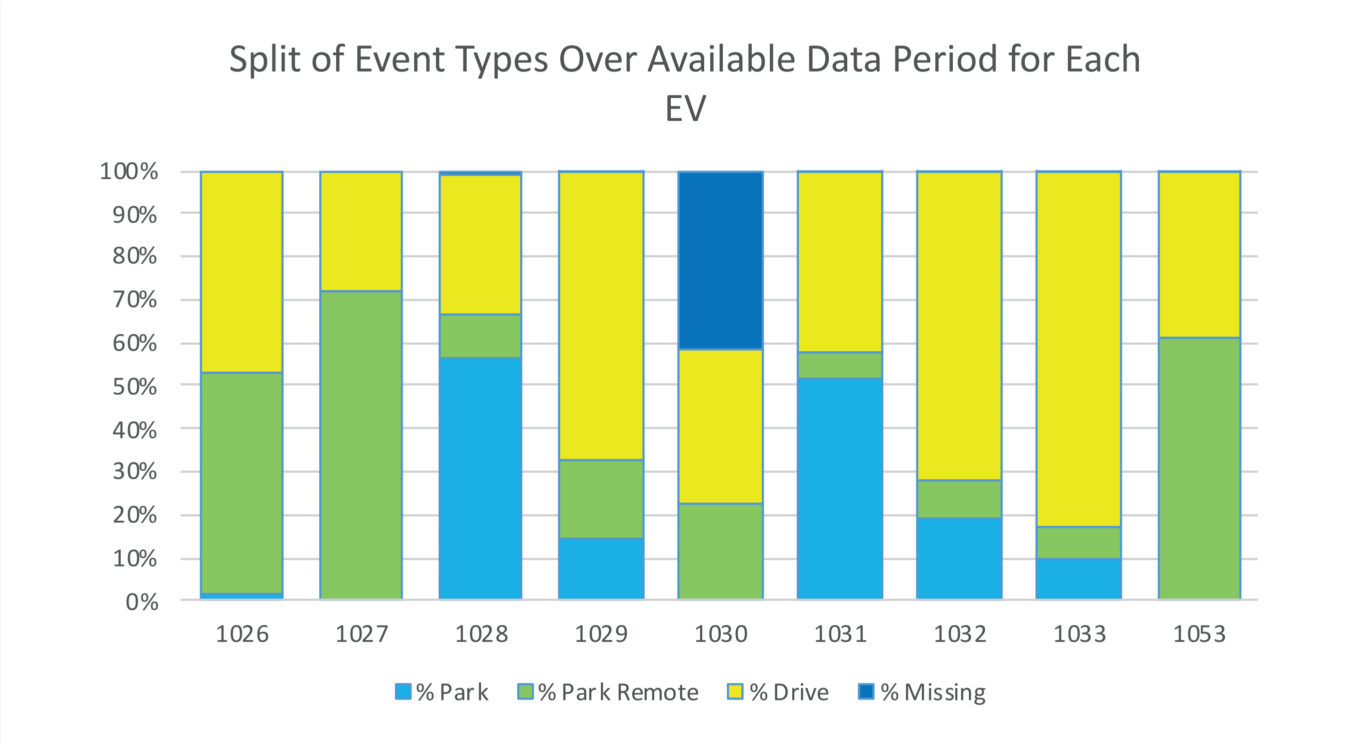


Figure 42: Split of Event Types for Influx Loggers

WARWICK
THE UNIVERSITY OF WARWICK

7.c Case Study - University of Warwick

7.c.i Model Setup

For the University of Warwick site, the three EVs were modelled in REVOLVE and assumed to plug into one of the three V2G chargepoints, each of which are eNovates V2G units with 10 kW charging and discharging capacity. The tariff for the site is a simple two rate tariff.

The V2G units are located “behind the meter” and there is sufficient additional demand on the site that the total discharge from all three V2G units is very unlikely to outweigh the onsite consumption. Therefore, export was assumed to be zero.

The grid carbon intensity is modelled at a half-hourly granularity using data available from National Grid ESO. The site is credited carbon for any energy it exports at the grid carbon intensity at the time.

The REVOLVE model was run for a period of 266 days (38 weeks) from 12th Feb 2021.

7.c.ii Plug-in Availability

The following figures show the average plug-in availability for weekdays (**Figure 43 - next page**) and weekends (**Figure 44**) for each of the EVs. These figures show a clear distinction between the use of the three EVs, and that there is virtually no vehicle activity or change of event status at weekends.

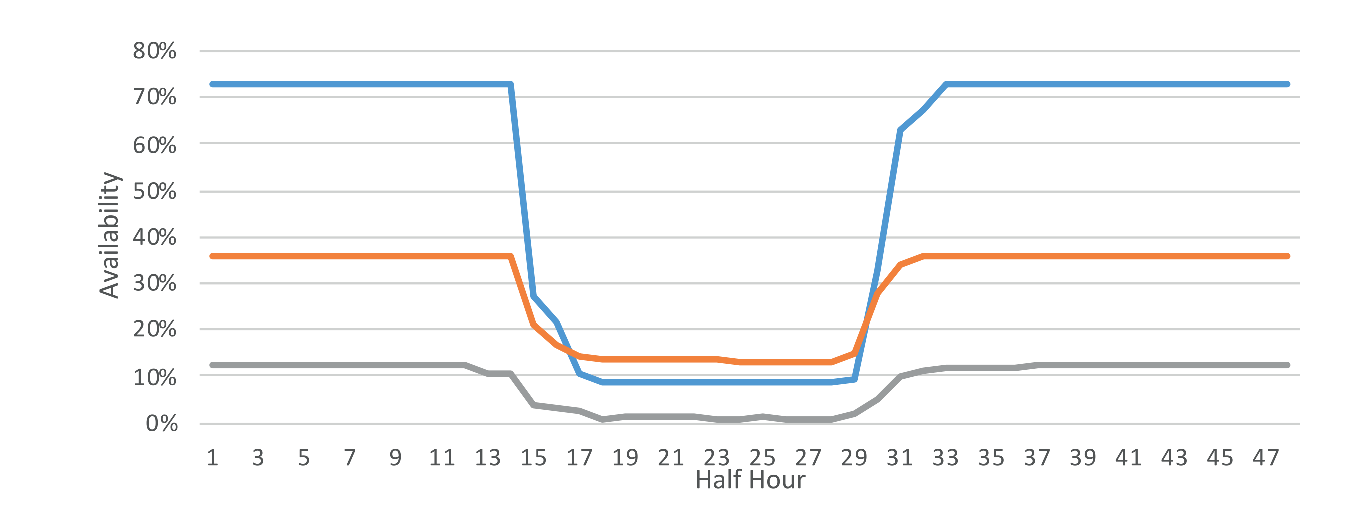


Figure 43: Weekday Plug-in Availability UoW

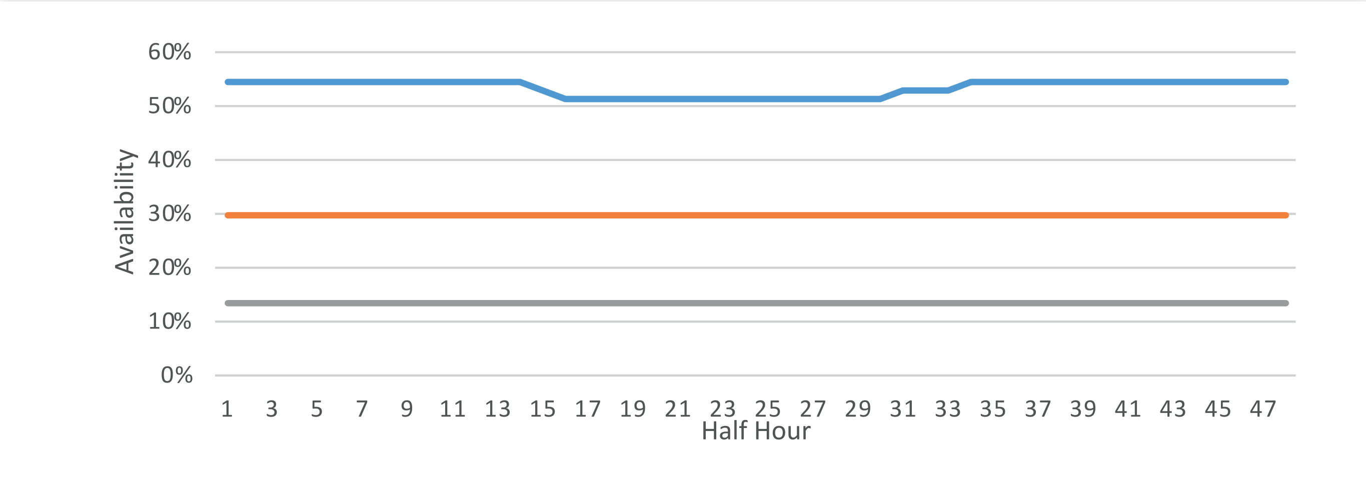


Figure 44: Weekend Plug-in Availability UoW

Over the entire period, the average plug-in availability of the three EVs was 31%. The total charging demand was 3,824 kWh.

The usage profiles of the EVs at UoW don't present a particularly strong V2G use case due to the low plug-in availability rates (31%).

7.c.iii Results

The REVOLVE model runs were performed in three modes:

- **Unmanaged:** Where EVs always charge to full once plugged in;
- **Carbon Optimised:** Where V2G is used to minimise the corresponding amount of carbon used from the electricity; and
- **Cost Optimised:** Where the electricity tariff costs are minimised.

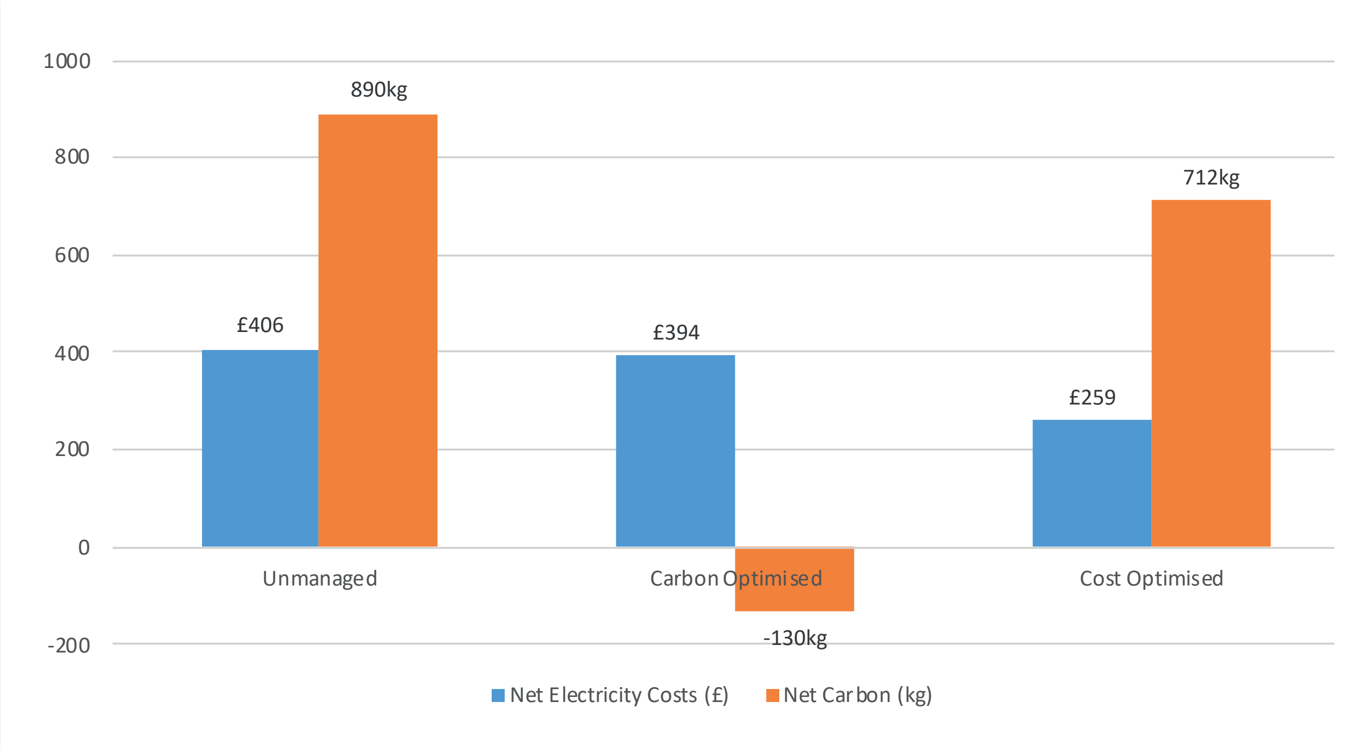


Figure 45: Cost & Carbon Totals for UoW Site Runs

Separate Carbon and Cost Optimisation

The results combine all three vehicles and are shown in **Figure 45**.

Carbon Optimisation could reduce carbon by 1,020 kg over the period. The model adjusts the timing of charging and discharging to achieve this carbon reduction versus the Unmanaged case. **Figure 45** also demonstrates that the Carbon Optimisation manages to result in a slightly reduced cost of £12. This is likely due to a weak correlation between the cheaper overnight tariff periods and the lowest carbon intensity periods.

The significant carbon savings result in a net negative carbon position. This means that through energy arbitrage, the V2G units have been able to save more carbon across the energy system than the associated carbon emissions of the electricity used to charge and drive the EVs.

The cost optimisation in **Figure 45** manages to save £147, which it does by arbitraging between the peak and off-peak tariff periods. Interestingly, this optimisation also manages to make significant carbon savings (though it has no incentive to do so). Whilst the very lowest carbon intensity may not necessarily occur during the off-peak tariff times, these times do have lower carbon intensity on average, which produces these carbon savings.

Pure carbon optimisation delivers significant CO_2 reductions and a slight cost reduction.

Upscaled to a full year, the UoW could save up to 1,399 kg CO_2 through carbon optimisation and up to £202 through cost optimisation across their three vehicles.

Optimising Both Cost and Carbon

After optimising cost and carbon separately, the next question is whether benefits can be gained by optimising both. This is to discover the price at which carbon needs to be set in order to encourage significant carbon savings.

The REVOLVE model was run a number of times in the cost optimisation mode, but each time with the carbon price set at a different level. The result of this analysis is shown in **Figure 46** (below).

With a carbon price of zero, the total carbon impact is 712 kg (blue line). However, at a negligible price of 1p per tonne, the carbon impact is reduced to 405 kg without any cost implication. Beyond that, the carbon price needs to rise above £20/tonne before significant additional carbon savings are made. At £500/tonne, the carbon impact is negative 69 kg, not far off the upper bound of negative 130 kg impact achieved by the pure carbon optimisation.

The result of increasing the carbon price on the unmanaged cost, is clearly seen as a corresponding increase in cost (grey line). However, jointly optimising cost and carbon is able to mitigate almost all of the carbon price increases (yellow line).

For sites where joint cost and carbon optimisation is possible, the effective cost of the carbon abatement achieved by the site is very small.

Cost optimisations with a minimal 1p per tonne carbon price yield a significant carbon reduction.

Carbon prices set at above £20/tonne provide sufficient incentives to reduce carbon further on the standard two-rate tariff. However this threshold will vary, depending on the tariff.

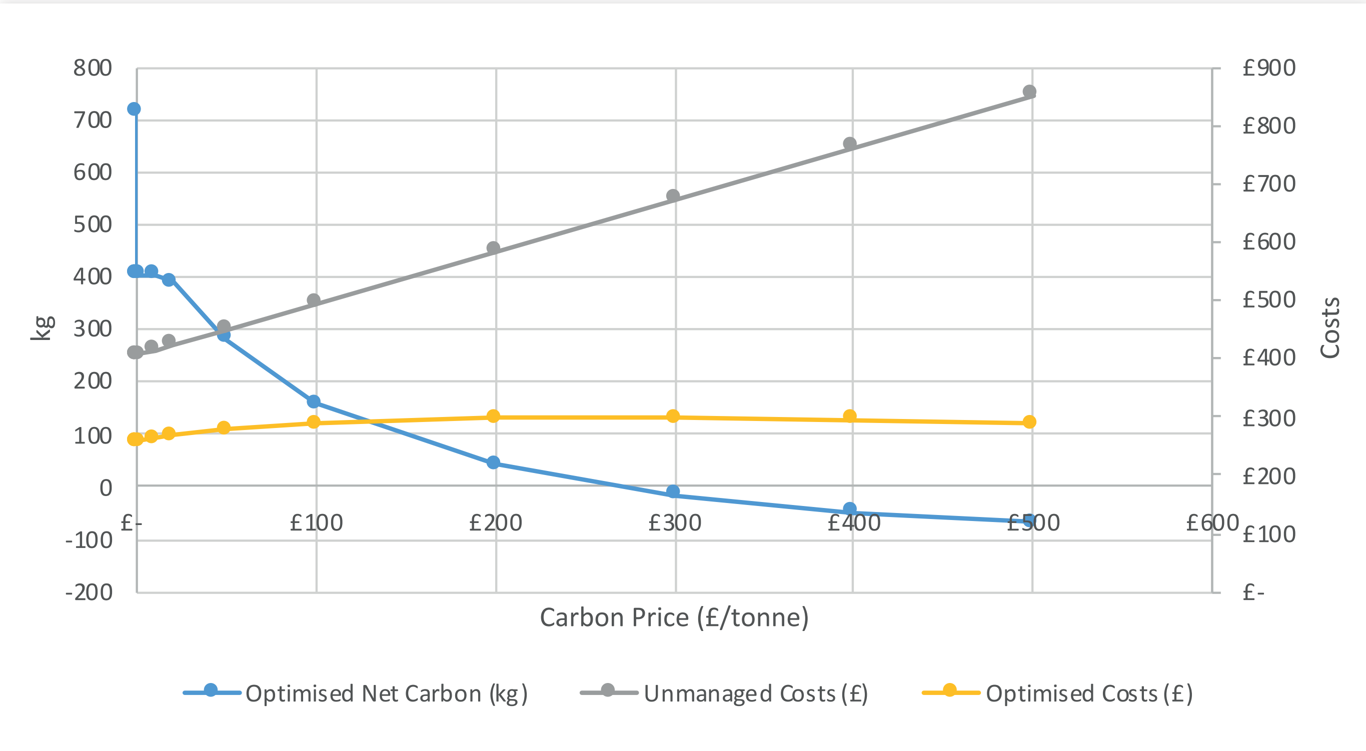


Figure 46: Carbon Price Sensitivity

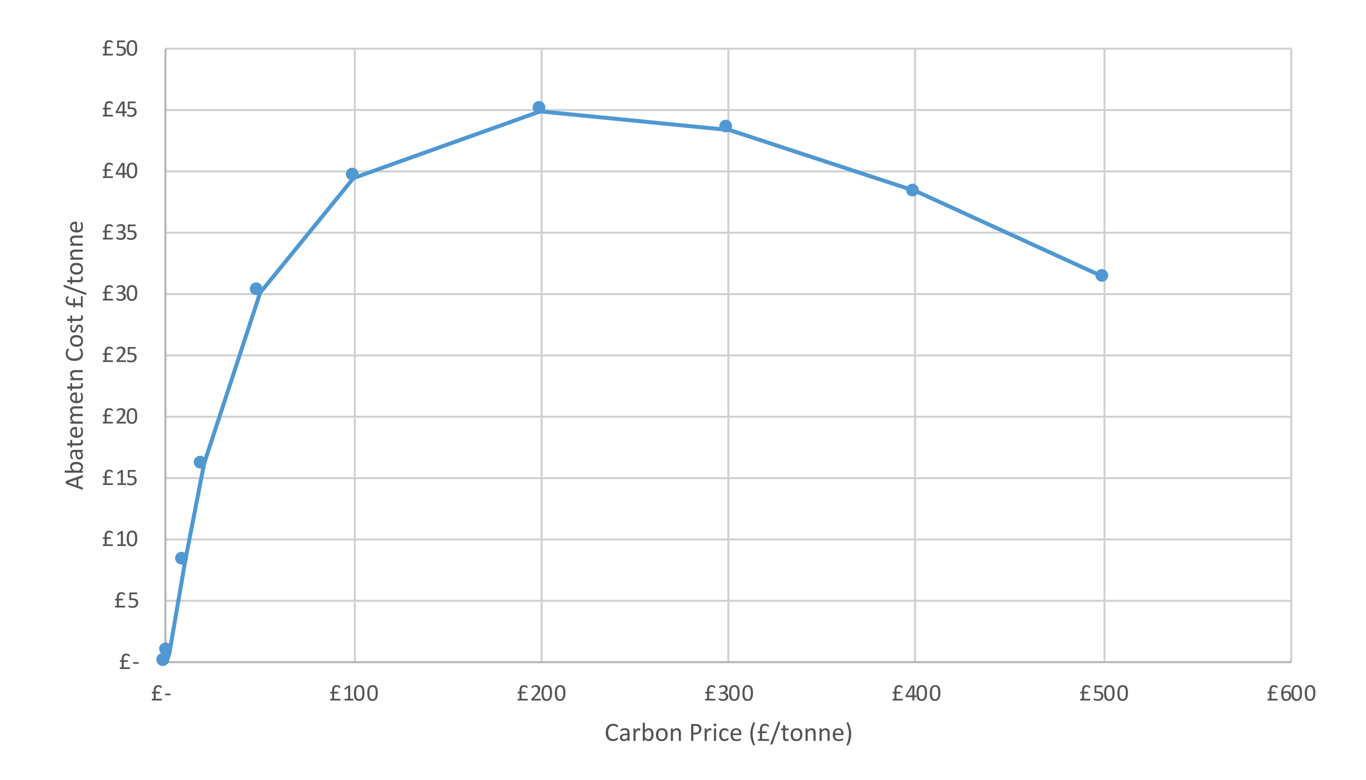


Figure 47: Carbon Abatement Costs for UoW

Figure 47 shows the effective carbon abatement cost (excluding V2G charger hardware costs) for a site applying this cost optimisation.

The peak occurs at a carbon price of £200/tonne, where the effective cost of abatement for the site is £45/tonne.

At the end of January 2022, the actual carbon price (UK ETS) was around £85/tonne, which would provide a sufficient signal to reduce emissions (by >400kg in this case) if it were passed through to the electricity consumer. This >400kg carbon savings translates to >180kg on a full year per EV basis.

7.c.iv Carbon Savings from Using a Dynamic Tariff

The analysis above shows the cost and carbon savings associated with optimisation under the current two rate electricity tariff at the site. However, with a smarter tariff more effective carbon savings may be possible.

A dynamic tariff was constructed based on half hourly APX SPOT prices for the period, with the addition of Distribution Use of System (DUoS) charges for the sites (LV Site specific DUOS rates for WPD East midlands). This resulted in a half hourly varying tariff which reflects wholesale electricity prices and to a certain extend carbon intensity. The REVOLVE model was run again in both the carbon and cost optimisation modes for this new tariff. The results of this are shown in **Figure 48** (next page).

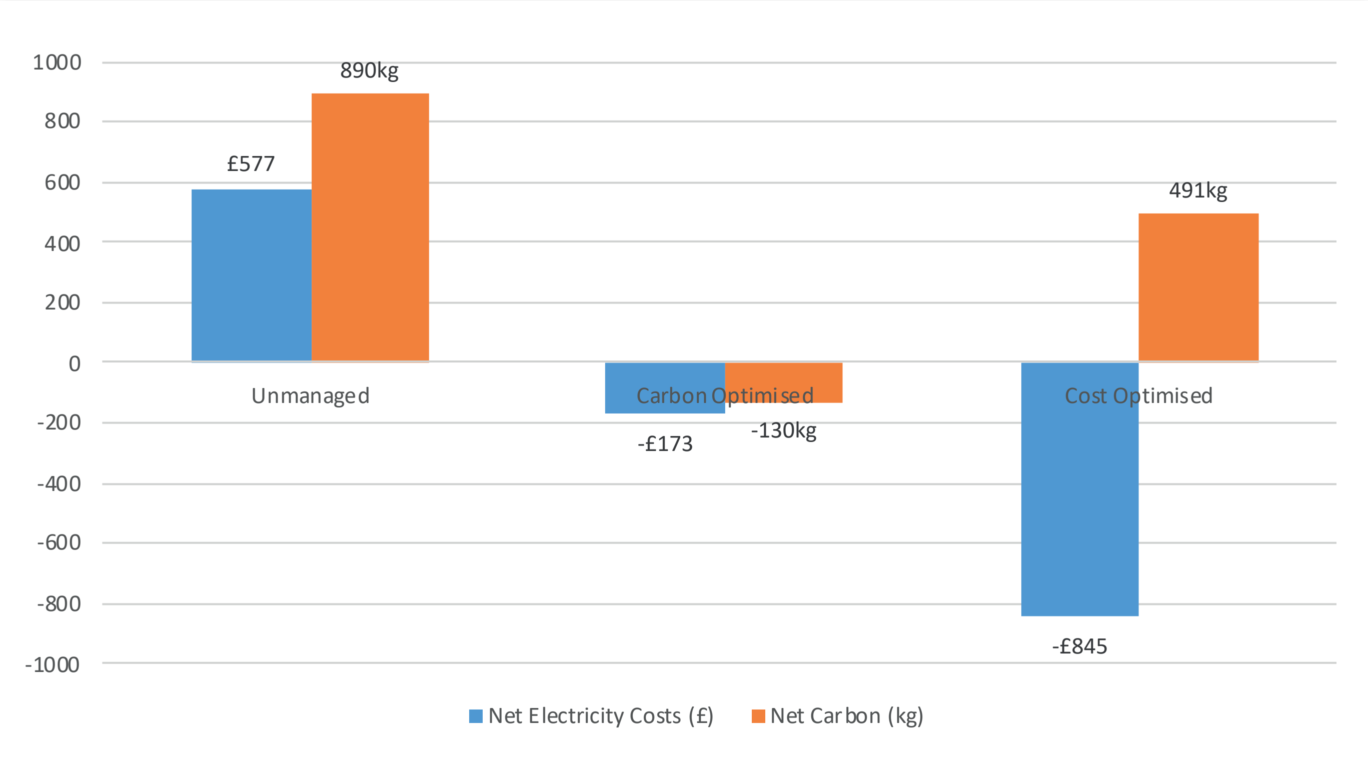


Figure 48: Cost & Carbon for UoW Site Runs with Dynamic Tariff

Compared with the previous runs (with the two-rate tariff, shown in **Figure 45**) the Carbon Optimisation achieves significantly greater cost reduction, being £750 less than the Unmanaged case. More notably, the Cost Optimisation not only achieves a better cost reduction (£1,422), but also a significantly greater carbon reduction than with the two-rate tariff.

Applying a dynamic electricity tariff at the site significantly increases the tariff cost savings possible with cost optimisation, and also improves carbon savings of a pure cost optimisation with a zero carbon price.

If these results are scaled up to a full year, then the Cost Optimisation would save £386 per EV over the year.

These results show that the dynamic tariff used not only gives a greater opportunity for cost-based optimisation, but that the tariff also represents carbon intensity better than the two-rate tariff. Whilst the carbon savings here are significant, they still aren't as much as from the cost-based optimisation with just a 1p per tonne carbon price.

7.d Case Study – NCC, LCC and UoN

7.d.i Plug-in availability

Data from commercial loggers used at three sites (NCC, LCC and UoN) were made available slightly later in the project but were processed in a similar way to the Influx loggers. The results contain data from 51 different EVs across four different sites, visualised as before in **Figure 49** (next page).

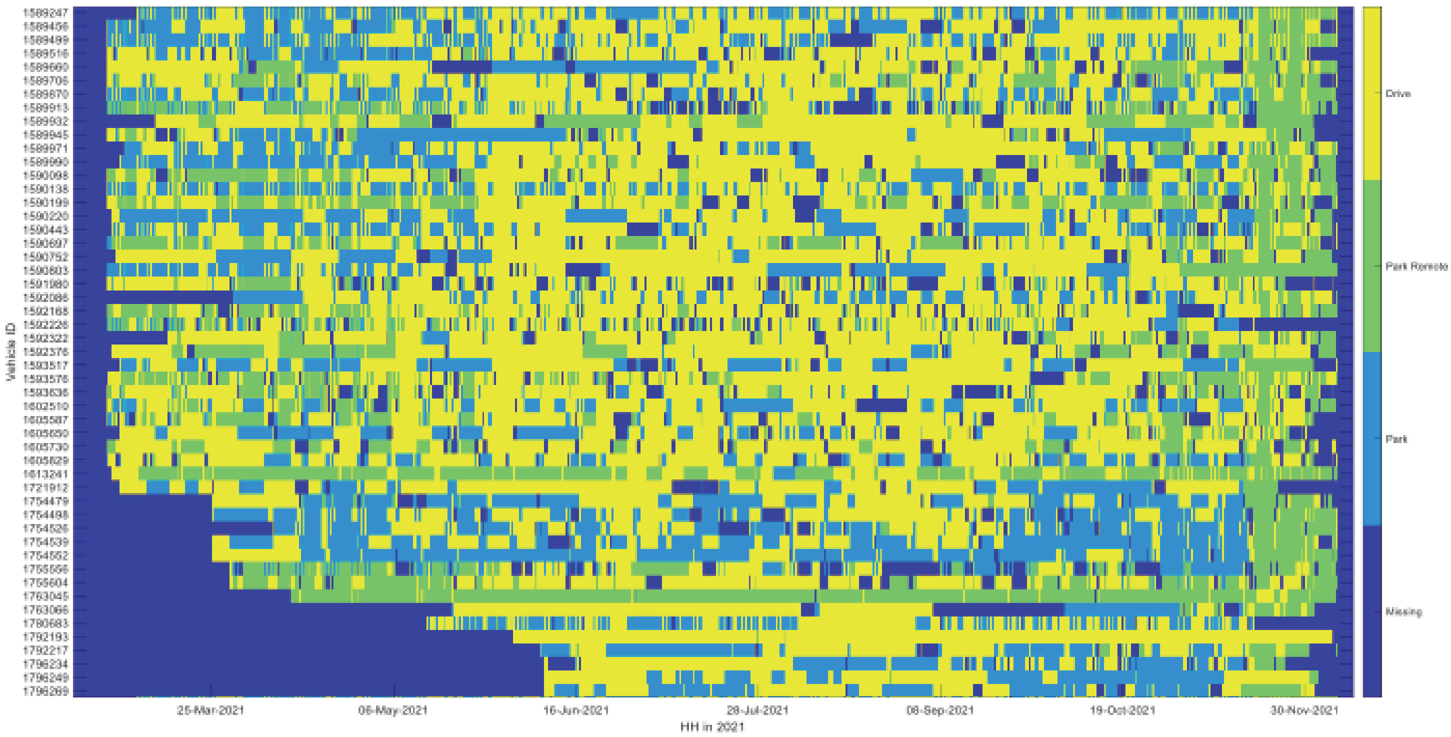


Figure 49: Heatmap of Masternaut Logger Data

The data was cleaned, and datasets were removed where there were large gaps in the data, lack of events, or less than 10% of the total time was flagged as a Park event. The proportion of time spent in each event in the remaining data sets are presented in **Figure 50**.

Three sites (Eastcroft Depot, LCC Farnley Hall, UoN Hallwood) were taken forwards for further analysis using the REVOLVE model.

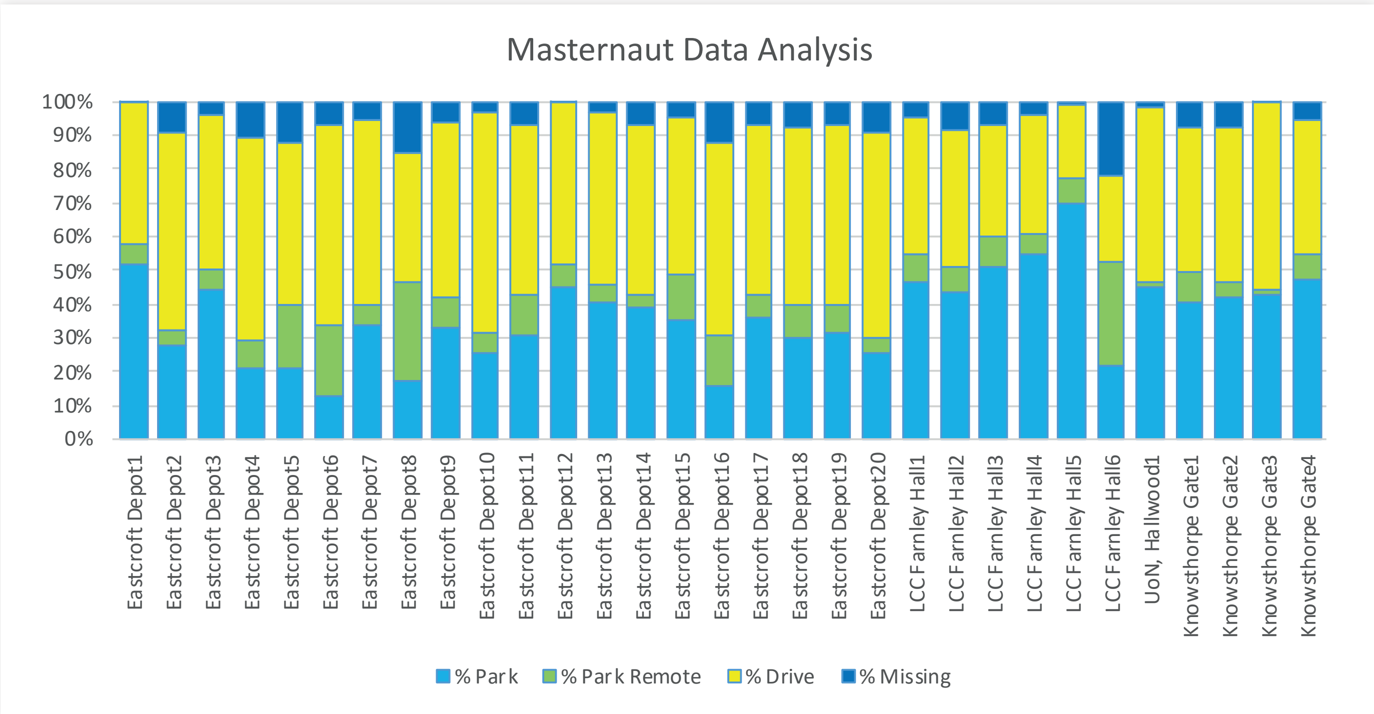


Figure 50: Split of Event Times for Cleaned Masternaut Loggers

7.d.ii Site Analysis

Each of the sites analysed had different characteristics. For the UoN Hallwood site, no demand data was available for inclusion. To facilitate the analysis, the demand has been assumed to be high enough such that a single 6kW V2G Nichicon unit never results in a net site export of electricity. Details for each site modelled are given in **Table 13**.

For each site, an unmanaged run and an optimised run was performed in REVOLVE for the data period available. The Eastcroft Depot site was optimised based on cost, whilst the other two were optimised on carbon so as to align with the site's intentions.

SITE NAMES	UoN, HALLWOOD	FARNLEY HALL	EASTCROFT DEPOT
No. of days of analysis	189	238	259
No. of EVs	1	6	20
No. of V2G chargepoints	1	1	50
No. of smart chargepoints	1	5	0
Assumed EV battery Capacity (kWh)	40	40	80
On site demand included?	No	Yes	Yes
Total Journey Demand (kWh)	1,176	6,315	19,657
On Site Demand (kWh)	0	85,509	230,247
Mean EV Plug-in Availability	45%	50%	32%
Tariff	Single Rate	Single Rate	Two Rate
Optimisation Type	Carbon	Carbon	Cost

Table 13: Sites Modelled in REVOLVE

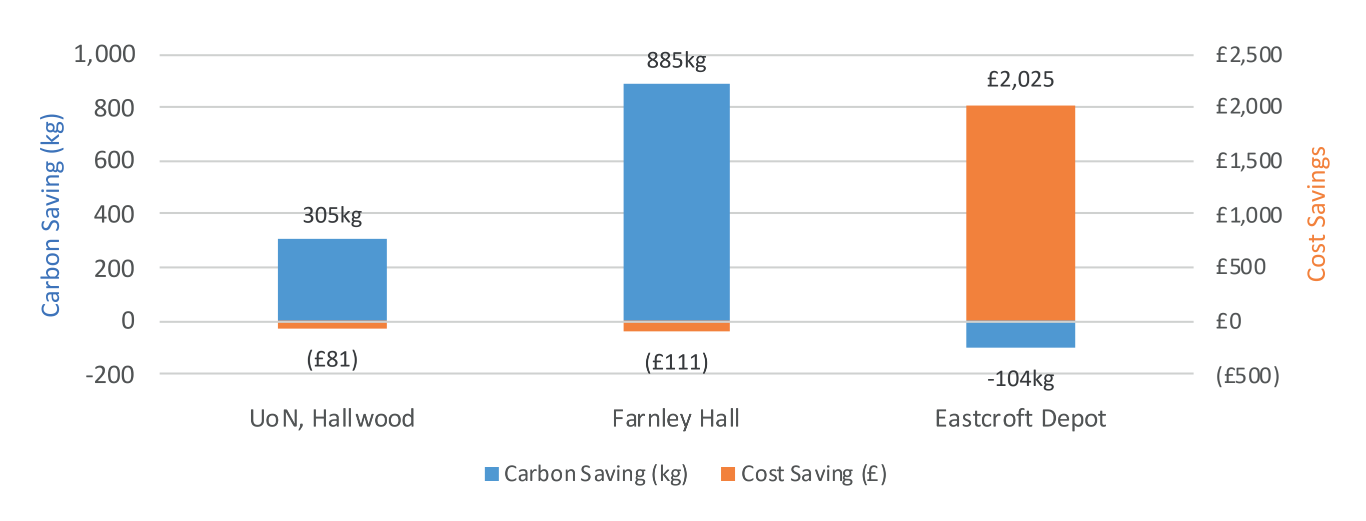


Figure 51: Site Carbon and Cost Savings upscaled to Full Year

7.d.iii Results

The summary results are shown in **Figure 51**, upscaled to a full year for the whole site.

With one EV, UoN Hallwood site was able to save 305kg of carbon, whereas the Farnley Hall site could save 885kg with six EVs (but only one V2G chargepoint). Both of these come at a higher cost due to the greater volumes of energy required because of round trip losses with the V2G units.

The Eastcroft Depot site, which was cost optimised, was able to save over £2,000 across the fleet of 20 EVs. This site had a simple two rate tariff applied (16p/kWh weekdays 6am-10pm, 12p/kWh at other times), so savings were made by charging during the off-peak periods, then discharging and offsetting some of the site demand during peak periods. Note that this approach did increase the carbon impact, this is due to the energy tariff and the grid carbon intensity not being perfectly aligned.

NOTE: Given the differences in the situations across the different sites, it is difficult to compare the results.

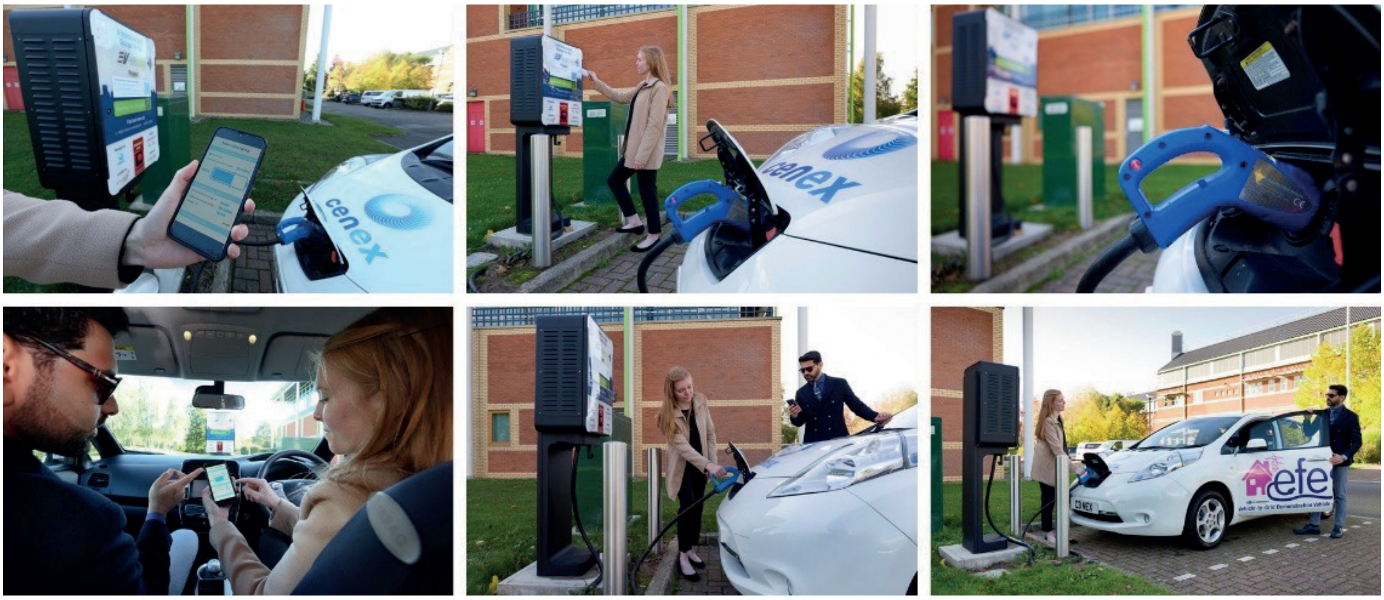
EV plug-in availability is a key driver for cost savings from V2G optimisation.

The tariff used is important. Tariffs with greater volatility provide greater opportunity for savings.

Carbon savings are also driven by the EV plug-in availability.

However, if carbon is optimised in isolation, this does come at a financial cost arising from round-trip energy losses.

Finally, it should be noted that the grid carbon intensity varies significantly throughout days and weeks. Since different periods of data were available during 2021, these different data periods enable sites to save different amounts of carbon based on this varying carbon intensity volatility.



7.e Summary

This work package has cleaned, analysed and taken into simulation the data from two sources (Influx loggers and Masternaut loggers). Due to issues with data quality, project delays, and actual use of the chargepoints on the sites, the relatively high volume of data originally collected was reduced to 30 vehicles and chargepoints over four sites.

The diversity across the sites in terms of data period, chargepoint make and EV use cases, mean that results between sites are not directly comparable.

Results for all sites are summarised in **Table 14** (next page).

Savings from the carbon optimisation (on a per-year per-vehicle basis) vary from 147kg to 466kg. Whereas savings from a cost optimisation (on a per-year per-vehicle basis) vary from £67 to £101.

The cost optimisation figures for Eastcroft and UoW (both of which have two-rate tariffs) are not sufficient to justify the investment in V2G. However, this is not surprising as the tariffs at the sites are not very suitable for V2G optimisation, having only two rates and a modest difference between them. Additionally, no other revenue streams such as wholesale optimisation, or ancillary services provision were included in this analysis as this was out-of-scope. However, when the Dynamic Tariff was applied at the UoW site, this resulted in a very reasonable £386 per year per EV saving.

The carbon savings from the optimisation are perhaps more significant. The UoN Hallwood sites was able to half the associated carbon from EV charging. Whereas the UoW site could reduce associated carbon emissions to below zero. This means that through energy arbitrage, the V2G units at the UoW site would have been able to save more carbon across the energy system than the associated carbon emissions of the electricity used to charge and drive the EVs.

NOTE: More detailed results from the sites are available in the full Work Package 5.3 report.

	SITES	UoN, HALLWOOD	FARNLEY HALL	EASTCROFT DEPOT	UoW	UoW	UoW
Unmanaged Case	Total Energy Imported (kWh)	2,479	141,840	353,224	5,572	5,572	5,572
	Import Carbon (kg)	548	29,986	74,205	1,221	1,221	1,221
	Import Costs (£)	£421	£24,113	£51,568	£557	£557	£557
Optimised	Optimisation Type	Carbon	Carbon	Cost	Carbon	Cost	Cost (Dynamic Tariff)
	Net Energy (kWh)	2,956	142,494	364,340	6,665	7,138	7,563
	Net Carbon (kg)	243	29,102	74,309	-178	977	674
	Net Cost (£)	£502	£24,224	£49,543	£540	£355	-£1,159
Full Year Savings	Carbon Saving (kg)	305	885	-104	1,399	244	548
	Cost Saving (£)	-£81	-£111	£2,025	£17	£202	£1,159
Per EV Savings	Carbon Saving (kg)	305	147	-5	466	81	183
	Cost Saving (£)	-£81	-£19	£101	£6	£67	£386

Table 14: Summary full year equivalent results

7.f Conclusions

EV-elocity developed and extended an evidence-based techno-economic model of how V2G will be viable within the UK.

In examining the value of V2G, the following conclusions can be drawn:

Data Collection:

- Sites can be very different and are not directly comparable, due to different demand profiles, vehicle usage and tariffs.
- Future projects would benefit from chargepoints and management systems which can identify reliably the plug-in and plug-out times of vehicles.
- Future projects would benefit from chargepoint management systems which log the identity of the user or vehicle which is plugged in.
- Hardware reliability and lack of customer use of the chargepoints undermined the quality of the data available for analysis.

UoW Site-Specific Insights:

- The usage profiles of the EVs at UoW don't present a particularly strong V2G use case due to the low plug-in availability rates (31%).
- Pure carbon optimisation delivers significant CO_2 reductions and a slight cost reduction.
- Upscaled to a full year, the UoW could save up to 1,399 kg CO_2 through carbon optimisation and up to £202 through cost optimisation across their three vehicles.

Cost and Carbon Optimisation:

- For sites where joint cost and carbon optimisation is possible, the effective cost of the carbon abatement achieved by the site is very small.
- Cost optimisations with a minimal 1p per tonne carbon price yield a significant carbon reduction.
- Carbon prices set at above £20/tonne provide sufficient incentives to reduce carbon further on the standard two-rate tariff. However, this threshold will vary, depending on the tariff.
- The peak occurs at a carbon price of £200/tonne, where the effective cost of abatement for the site is £45/tonne.

Value of V2G:

- On a simple two rate tariff, a V2G tariff optimisation can save around £100 per year per chargepoint.
- However, with the use of a smarter tariff (e.g. varying half hourly) savings can be around £400 per year per chargepoint. Therefore, such tariffs are recommended for sites that have V2G and little other non-flexible demand on the same meter.
- Carbon savings can be up to around 450kg per V2G chargepoint per year when a carbon optimisation is used.
- Significant carbon savings (>180kg) can be made (at virtually no energy cost) when carbon is optimised as well as tariff costs. Therefore, carbon optimisation should be included in flexible V2G operation.

8 Abbreviations

ACRONYM	EXPANSION
AC	Alternating Current
BEIS	Department for Business, Energy & Industrial Strategy
CC	CrowdCharge
CHAdeMO	A DC charging protocol
CMA	Cumulative Moving Average
CNN	Convolutional Neural Network
CPMS	Chargepoint Management System
CX	Cenex
DC	Direct Current
DNO	Distribution Network Operator
DUOS	Distribution Use of System
EMA	Expotential Moving Average
EPSRC	Engineering and Physical Sciences Research Council
ESS	Energy Storage System
ETS	Electronic Tracking System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FES	Future Energy Scenarios
GSM	Global System for Mobile Communication
GW	Gigawatts
HV	High Voltage
ICE	Internal Combustion Engine
ITT	Invitation to Tender
LCC	Leeds City Council
LEAF	Low Emission Affordable Family car
LUSEP	Loughborough University Science and Enterprise Park
LV	Low Voltage
NCC	Nottingham City Councilo
OCPP	Open Charge Point Protocol

ACRONYM	EXPANSION
OZEV	Office for Zero Emission Vehicles
PHEV	Plug-In Hybrid Electric Vehicle
PV	Solar Photovoltaic Electricity Generation
REVOLVE	A perfect foresight cost- and carbon- energy optimisation model by Cenex
RFID	Radio-Frequency Identification
SC	Standard Charging
SOC	State of Charge
TDP	Transport Decarbonisation Plan
TRL	Technology Readiness Level
UI	User interface
UK	United Kingdom
WCC	Worcestershire County Council
WMG	Warwick Manufacturing Group
WMP	West Midlands Police
WPD	Western Power Distribution
ZEV	Zero Emission Vehicles

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