STORAGE & FLEXIBILITY NET ZERO SERIES

VEHICLE TO GRID

June 2020

Part of Energy Systems Catapult's
Net Zero programme, funded by:

Innovate UK

es.catapult.org.uk

Executive Summary

*This document forms part a series of reports, each of which investigates one technology area which has the potential to make a significant disruptive impact to the provision of storage and flexibility in a Net Zero energy system. The other reports can be **found here**.*

Vehicle-to-grid (V2G) technologies allow Electric Vehicles (EVs) to not only charge from the grid but also supply power back to the network. This report explores the potential value of V2G technologies in a Net Zero energy system compared to unmanaged and managed charging of EVs.

This analysis used ESC's Consumers, Vehicles and Energy Integration model (CVEI) to compare three EV charging scenarios under a Net Zero energy system pathway: V2G, unmanaged charging, and managed charging. For each scenario the role of flexible generation, grid-connected electricity storage, V2G storage and intermittent energy generation were compared.

Key findings from this analysis are:

- V2G could provide significant value to a Net Zero energy system; providing over 50GWh of flexible capacity by 2050.
- V2G is most favourable when compared to unmanaged charging of EVs; it can reduce the need for grid-connected electrical storage capacity.
- The value of V2G is less certain when compared to the benefits of managed charging although V2G does appear to provide additional value by reducing the requirement for grid connected energy storage technologies. This should be investigated further with consideration also given to the other value that V2G could provide over shorter timescales not represented within this modelling.

1.

2. Contents

3. Introduction

Vehicle-to-grid (V2G) technologies allow Electric Vehicles (EVs) to not only charge from the grid but also supply power back to the network at times of high demand. They are expected to play an important role in the decarbonisation of transport and energy systems.

The Vehicle to Great Britain (V2GB) project, which was completed in 2019[1], helped to understand the long-term value of and short-term opportunities for Vehicle-to-Grid (V2G) in the UK. The findings from V2GB helped to assess the potential market size for V2G, possible V2G revenue and the extent that it could influence the electricity generation system, EV uptake within the wider market and policy environment.

V2GB was a consortium project comprising Nissan Technical Centre Europe, Energy Systems Catapult, Cenex, Western Power Distribution, National Grid ESO, Moixa and Element Energy. ESC's role was to provide modelling support through the CVEI model, developed within the ETI's Consumers, Vehicles and Energy Integration (CVEI) project[2] and now owned by ESC. The CVEI model encapsulates the whole energy system, covering the different forms of energy supply, network infrastructure and end-use sectors, whilst providing a higher level of detail and reliability for the transport sector. This modelling capability originally incorporated the 80% 2050 greenhouse gas (GHG) emission targets, focussing on V2G utilisation out to 2030.

The findings of V2GB can be found here[1] but they include:

- V2G could help to save £200m of cumulative distribution network investment by 2030.
- Smart Charging could generate GB energy system net savings of £180m/annum, and V2G could save additional £40-90m annually in GB by 2030.
- To achieve wider uptake of V2G: barriers to residential charging need to be removed, cost of V2G hardware needs to fall, and consumer concerns around range need to be overcome.

This report builds upon the V2GB project to derive additional insights by updating the CVEI model to represent Net Zero greenhouse gas targets and building a separate V2G module to explore the opportunities for using V2G in the longer term up to 2050.

This report's primary objective is to assess the impact of the Net Zero targets on the uptake of V2G technologies and the value of V2G to provide flexibility over periods of several hours in a Net Zero energy system. It includes the following steps:

- Review existing V2G trials in the UK and worldwide.
- Examine the potential size of the market for V2G in the UK in 2050 (as opposed to 2030 in V2GB) in a Net Zero energy system.
- Investigate the impact of Net Zero targets on the utilisation and capacity of V2G.

---

[1] V2GB -Vehicle to Great Britain. Element Energy, 2019. https://es.catapult.org.uk/wp-content/uploads/2019/06/V2GB-Public-Report.pdf
[2] http://cveiproject.trl.co.uk/

4. V2G State of the art

To ensure that the assumptions made in the previous V2GB project are still relevant, a brief review of real-world V2G trials and technology deployment, both in the UK and globally, is presented here.

4.1. UK trials and technology deployment

Within the UK there are currently several real-world V2G demonstrator trials ongoing as part of the 'Innovation in Vehicle-to-Grid (V2G) Systems: Real World Demonstrators' competition run by BEIS, OLEV and Innovate UK. The competition was initiated in 2017 and a variety of projects received funding for their demonstrators which are expected to run for up to 3 years, some of which are summarised in Table 1[3].

The large-scale demonstrator projects were based around fleet vehicles and privately owned EVs. Many of the projects focused on creating market opportunities and business cases to encourage V2G uptake; for example, by evaluating the potential system benefits V2G can provide by increasing flexibility and how this could be monetised to benefit consumers. There was also a strong focus across the projects on gathering data around the attitudes of users of the V2G system and the likely rate of uptake.

Demonstrators that received funding agreed to publish a range of data at the end of the project. However, since projects will run through to 2021, data is yet to be published. When available, these data will be used to inform updates to models whilst validating existing assumptions and results.

Table 1: Real world demonstrator competition funded project summaries[3].

Project Title	Partners	Summary
PowerLoop	Octopus	V2G electricity can be used either within the home or sold back to the grid. Aim is to make the grid flexible and responsive and to balance the system.
e4Future	Nissan	Aggregator platform and V2G demonstrator. Aims to evaluate distinct customer group responses and use the data to test and refine business cases and reward mechanisms. Offers flexibility services to the grid.
V2GO	EDF Energy	Targeting fleets of vehicles with both V2G and V2Building services. Aims to improve network efficiency and energy security, to build confidence in fleet operators by demonstrating the benefits and services available.
Sciurus	OVO	V2G charges supplied to lease holder of Nissan Leaf EVs. Offering grid balancing services. Aims to assess consumer receptiveness and develop a long-term business case, targeted at the residential level.

[3] Results of Competition: Innovation in Vehicle-to-Grid Systems: Real-World Demonstrators. InnovateUK. 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681321/Innovation_in_Vehicle-To-Grid__V2G__Systems_-_Real-World_Demonstrators_-_Competition_Results.pdf,

4.2. Rest of the world trials and technology deployment

Several real world V2G trials of varying scale are being run outside of the UK, many focusing on services that V2G can provide to energy systems, how it can be monetised and consumer attitudes towards it. In terms of vehicle technology, Renault, Nissan and Mitsubishi are the most active in the sector[4] and predominantly working on DC charging solutions. There is also a strong focus on time-shifting charging demand (managed charging) and frequency response services.

The most advanced project outside of the UK demonstrating V2G's scalability as a frequency response service is the Parker project in Denmark. The project was in partnership with Nissan, PSA Group and Mitsubishi and concluded in January 2019. The project was a V2G demonstrator with three main areas of focus: grid applications, test protocols, and scalability and replicability. The demonstrator provided frequency containment services for up to 30 minutes, with a proven response time of less than 10 seconds. The project was concerned with commercial fleets with 50 V2G capable charge points installed at commercial premises. It offered mobility-as-service to customers for a monthly fee, which included the charger, where the use of V2G reduced charging costs[5]. The project was deemed successful with regards to frequency response services, however it encountered issues with long duration events, two-way energy loss and the impact of high taxes on EVs in Denmark at the time.

Another example is the Smart Solar Charging Project in the Lombok district in Utrecht. The project uses V2G technology, car sharing systems and renewable energy production (largely solar), to create a generation/charging ecosystem in the district. The project has expanded out to four other diverse areas in the city including the Houten school complex with a park and ride; the Utrecht Science Park where there is housing, education facilities and businesses; the high density urban Utrecht Central Station Area; and the Driebergen-Zeist railway station. The project has managed to demonstrate how V2G technology can mitigate the impact of rapid fluctuations in electricity generated by solar, of which there is an increasing amount connected to the power grid in the Netherlands[6].

In conclusion, trials outside of the UK have shown that public sites (universities, airports and large work sites) offer a good opportunity for V2G deployment, especially where renewable generation is part of the local ecosystem. V2G is likely to be initially marketed within the UK to commercial vehicle fleets. Commercial fleets, which are centrally managed and have more predictable or known usage patterns, offer an opportunity to engage large vehicle numbers while also increasing public awareness and consumer confidence in the technology. Proving the viability of V2G (technologies and business models) in the commercial fleet could encourage and support deployment in the private vehicle sector.

[4] V2G Global Road Trip. Everoze and EVConsult. 2018. https://everoze.com/v2g-global-roadtrip/
[5] The Parker Project: Final Report. Peter Bach Andersen. 2019. https://parker-project.com/wp-content/uploads/2019/03/Parker_Final-report_v1.1_2019.pdf
[6] Smart Solar Charging: Voltage Fluctuations in Power Grid. Smart Solar Charging. 2020. https://smartsolarcharging.eu/en/electric-vehicles-balance-out-voltage-fluctuations-in-power-grid/

5. Methodology

5.1. Background to CVEI

The CVEI model used within this analysis is composed of several individual models, termed modules for clarity[7]. Figure 1 shows a simplified schematic of these modules, their interactions and where key elements of the energy and transport system are represented. These modules are:

- ESME (Energy System Modelling Environment, ESC's primary least-cost optimisation national modelling tool[8]) – used for Net Zero energy system design and analysis
- MEDT (Macro Electricity Distribution Tool) – used for electricity distribution network analysis
- MCPT (Macro Charging Point Tool) – used for EV charge point analysis
- ECCo (Electric Car Consumer Model) – used for EV analysis
- V2G (Vehicle to Grid) – used for V2G availability analysis

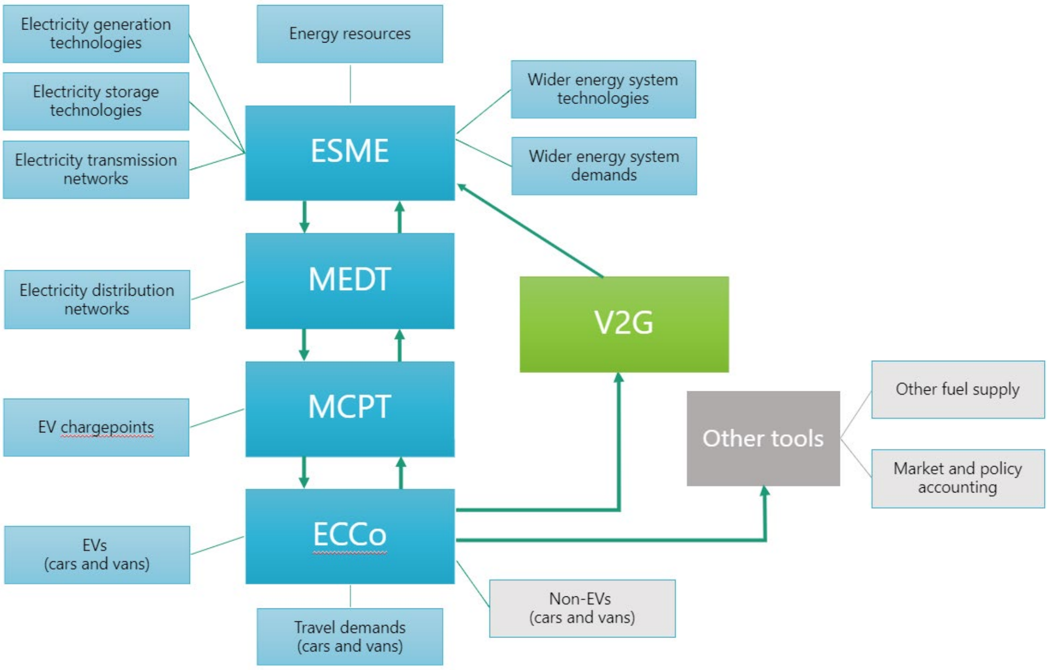

Figure 1: Simplified schematic of the CVEI modelling capability: the main tools, their interactions and where key elements of the energy and transport system are represented

5.1.1. V2G module

Within this deep dive the V2G methodology developed in the V2GB project was modified and upgraded to form a standalone V2G module in CVEI. Within the V2G module, a detailed picture of the available V2G capacity of the car and van parc can be examined. It takes outputs from ECCo and calculates the V2G capacity available in each hour for each season – ESME then uses these outputs to evaluate utilisation of available capacity. Five different seasons are modelled: winter weekend, summer weekend, winter weekday, summer weekday and peak weekday. The peak day is defined as a case with high energy demand and low generation from wind and solar, representing a 1 in 20-year event.

---

[7] Details on the tools are available in the V2GB report D1.2 – Long-term estimates of V2G opportunities. Energy Systems Catapult. 2018. https://es.catapult.org.uk/wp-content/uploads/2019/07/ESC_V2GB_WP1_D1.2_Long-term-estimates-of-V2G-opportunities_Final.pdf

[8] Energy Systems Modelling Environment. Energy Systems Catapult. 2020. https://es.catapult.org.uk/capabilities/modelling/national-energy-system-modelling/

5.2. Calculation of V2G capacity

V2G capacity is calculated in the V2G module and passed to ESME. Below is a brief description of the process and calculations involved.

5.2.1. V2G module and the calculation of V2G capacity

The calculations performed as part of this module were based on the methodology followed in the V2GB[Error! Bookmark not defined.] project. The calculations for the available V2G capacity in the V2G module consider:

- The number of charging events per day at the different charging locations taken from ECCo**Error! Bookmark not defined.**.
- The percentage of charging events starting in each hour at the different charging locations taken from ECCo.
- The usable battery capacity of the different types of EVs, i.e. BEV (battery electric vehicle), PHEV (plug-in hybrid electric vehicle) and RE-EV (range extended electric vehicle) taken from ECCo.
- The V2G parc profile, which includes the plugged-in profile of the EVs at the different charging locations based on NTS data.

The calculation for the available capacity of V2G is made in three stages:

- **Number of charging events starting per hour:** calculated using the number of charging events per day multiplied by the proportion of charging events starting in each hour.
- **Number of EVs plugged in per hour:** calculated based on the number of charging events starting per hour and the V2G parc profile. The V2G parc profile shows the length of charging events over a 24-hour period. Specifically, it shows if a vehicle is plugged in at given time (e.g. 1am) then for which hours of the day it will continue to be plugged in.
- **V2G capacity available in each hour:** calculated using the number of EVs plugged-in per hour (EVs plugged in at 25% State of Charge), the average usable battery capacity of the EVs and the proportion of usable battery for V2G shown in Figure 2.

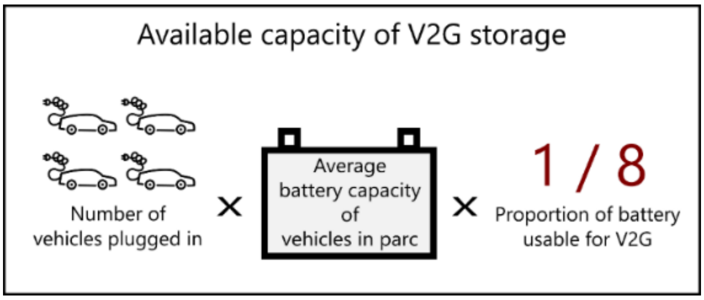

Figure 2: Calculating the aggregate V2G capacity available

5.2.2. ESME

ESME calculates the V2G utilisation for five time slices over a day (there is no distinction between weekends and weekdays in ESME). Therefore, the available capacity of V2G determined for each hour (for weekends and weekdays) needed to be converted to the five time slices represented in ESME, shown in Table 2. It should therefore be noted that in this report the value of V2G is only being assessed on its ability to provide flexibility for several hours at a time, the value it can provide on shorter timescales should be considered as further work.

Table 2: ESME time slice periods

Time slice	Time period
Morning	06:00-10:00
Mid-day	10:00-16:00
Early evening	16:00-19:00
Late evening	19:00-23:00
Overnight	23:00-6:00

A weighted average was used to accommodate the different hourly charging profiles for weekends and weekdays. The hour with the highest availability within each time slice was assumed to represent the availability for the entire time slice as seen in Figure 3.

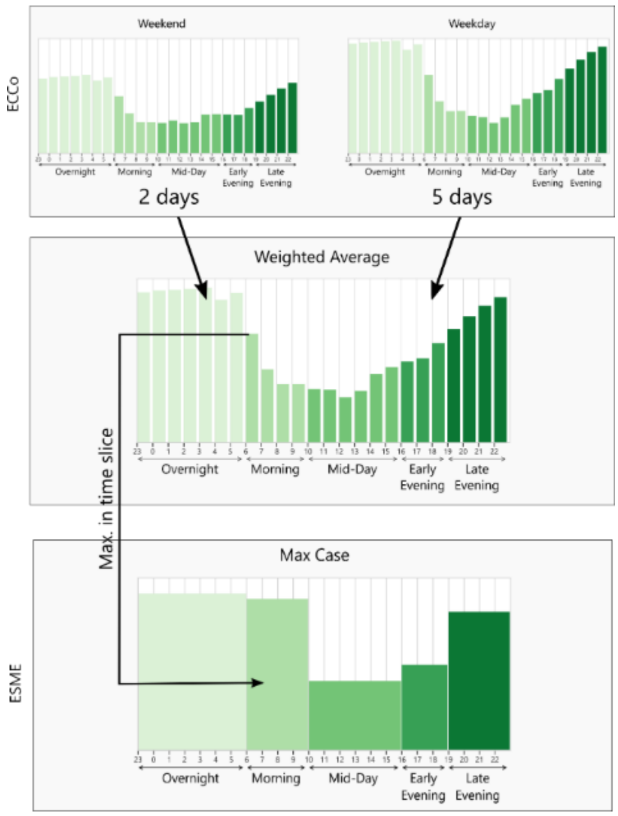

Figure 3: V2G availability profile

During each ESME time slice, the system may inject into or withdraw from the aggregate V2G storage as required, but the net injection/withdrawal may not exceed the amount of V2G available within that time slice, which was calculated in the V2G module. The state of charge at the end of each time slice carries forward into the next, with vehicles joining the V2G pool replacing any which have left.

5.3. Energy system scenarios and vehicle charging profiles

Multiple narratives were designed as part of the CVEI project[9] which define alternative environments, encompassing physical, commercial, policy and customer factors, which influence EV deployment and use. For this report and the V2GB project the Ultra-Low Emission Vehicle (ULEV) narrative is chosen. It assumes a transition to both BEVs and fuel cell vehicles (FCVs) is supported by central government via vehicle grants and infrastructure support including a carbon tax on liquid fossil fuels, in addition to fuel duty. Government leverages private investment in infrastructure, providing regulated returns. Centrally planned roll-out of infrastructure opens opportunities for demand management. Six different charging points are available: home, public, rapid, work, on street residential and depot. There are no new sales of internal combustion engine vehicles after 2040[10].

5.3.1. Vehicle charging scenarios

Three different vehicle charging scenarios were modelled under the ULEV narrative (see Figure 4) to examine variations in charging regimes and the availability of V2G technology. For all scenarios FCVs were made unavailable to investigate the maximum potential of V2G technologies.

Unmanaged Charging – No V2G Scenario

In this scenario there is no managed charging or V2G technology available (V2G module was disabled). When a vehicle is plugged-in, charging starts immediately and once charging is complete, there is no longer an energy demand from that vehicle.

Managed Charging – No V2G Scenario

In this scenario V2G technology is unavailable (V2G module was disabled), but a proportion of the plug-in vehicles on the road are engaged in managed charging. The ECCo module forecasts the shares of PiV (plug-in vehicle, including BEVs, PHEVs and RE-EVs) owners that charge under managed charging schemes. Managed charging is assumed to take place at home only. Managed charging shifts vehicle charging away from times of peak electricity demand to periods of lower demand. Two different managed charging schemes were modelled: User-Managed Charging (UMC)[11] and Supplier-Managed Charging (SMC)[12]. For more information on managed charging please refer to the CVEI report[9].

[9] Market Design and System Integration Report. Energy Technologies Institute. 2019. https://es.catapult.org.uk/wp-content/uploads/2019/11/CVEI-Market-Design-and-System-Integration-Report.pdf
[10] The modelling assumptions were made and implemented prior to the government announcement, in February 2020, that the ban on the sale of new ICE vehicles would be brought forward to 2035. This change could be included in further work surrounding this model.
[11]UMC: consumer shifting of charging load to cheaper periods
[12] SMC: more complete load shifting in which a third-party such as an aggregator optimises the charging profile against prices across the available plug-in window provided by the driver.

V2G Scenario

In this scenario all plug-in vehicles participate in V2G schemes (V2G module enabled). V2G bidirectional chargers are available at all home and workplace charge points. As per the V2GB project**Error! Bookmark not defined.** the V2G maximum case was assumed, meaning the maximum V2G capacity was available as shown in Figure 3. Vehicles are plugged in at 25% state of charge (SOC) and can either begin charging or are available for the grid to withdraw from. Vehicles are only unplugged when required for a journey. Charging profiles in the V2G scenario were the same as in the unmanaged charging scenario.

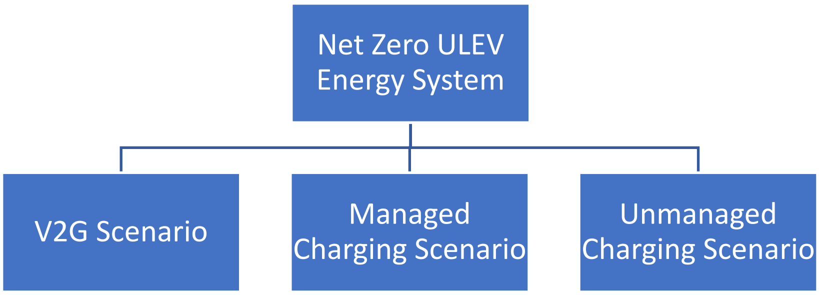

Figure 4: Modelling scenarios

Table 3 summarises the key features of the scenarios.

Table 3: Key features of modelled scenarios

Feature	**Unmanaged charging**	**Managed charging**	**V2G**
EVs participating (BEVs, PHEVs, RE-EVs)	All BEVs, PHEVs and RE-EVs	Proportion of BEVs, PHEVs and RE-EVs	All BEVs, PHEVs and RE-EVs
Charging strategy	Unrestricted charging	Managed, shifting demand away from peak times	Bidirectional unrestricted charging
Location where charging strategy is applied	All locations (home, work, rapid, public, on-road, depot)	Home	Home and work
V2G capable	No	No	Yes

As per the CVEI project work[9] distinct profiles for PHEVs and BEVs were considered.

5.3.2. Vehicle charging profiles

Unmanaged charging

Unmanaged charging profiles (used in the unmanaged charging and V2G scenarios) for at home and workplace charge points for BEVs are shown in Figure 5.

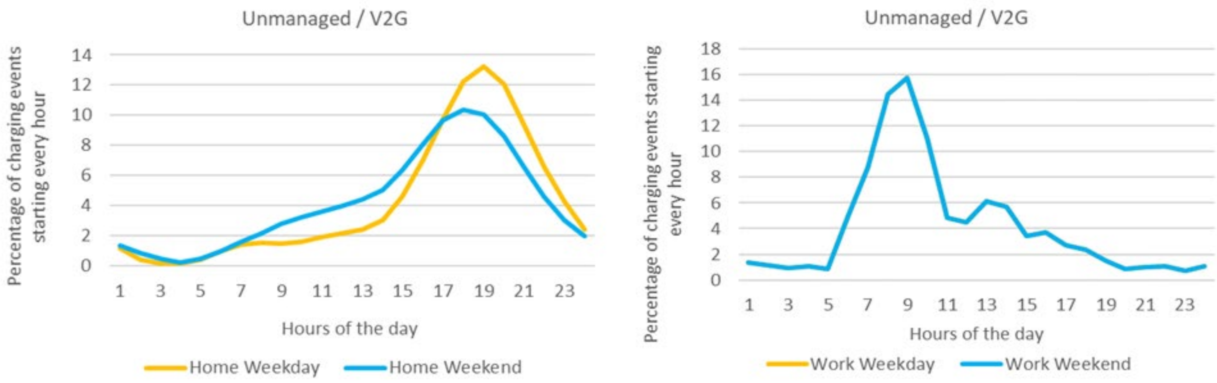

Figure 5: Hourly charging demand of BEVs for unmanaged charging and/or V2G scenarios at home (left) and at work (right). Due to a lack of data regarding weekends, charging profiles at work are the same on weekdays and weekends; a weighted average is used to combine both into a single typical day

Managed charging

Managed charging profiles vary seasonally to reflect seasonal changes in V2G tariffs. Figure 6 shows an illustrative example of charging profiles used in the UMC scenario. For more information on the development of charging profiles refer to CVEI report[9].

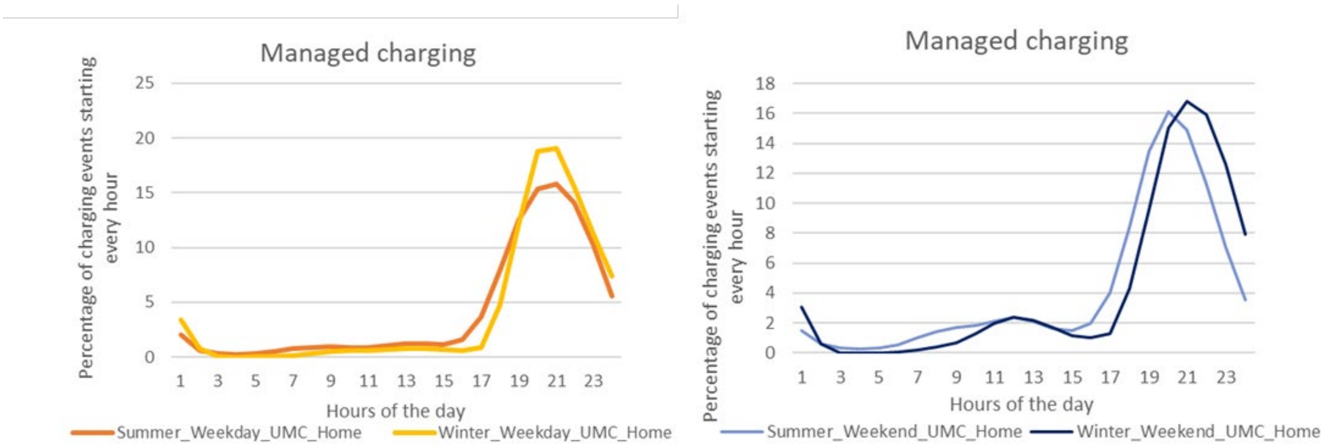

Figure 6: Hourly charging demand of BEVs for User-Managed Charging (UMC) scenario on weekdays (left) and weekends (right)

5.4. Assumptions

The assumptions used in the modelling are summarised below in Table 4 and are aligned to those in the V2GB project.

Table 4: Model assumptions

Assumption	Source/Reason for Assumption	Relevant Modelling Case
As of 2040, no new ICE vehicles are available	Road to zero targets.	All
Car segments (A to I and S) and van segments are included in the model		All
Fuel Cell Hydrogen Vehicles (FCHV) are not available at any point	To examine the maximum potential of V2G capability.	All
All plug-in electric vehicles can participate in V2G at all points in the modelled period	This provides an optimistic assumption about the opportunity for V2G, if all vehicle models, homes and workplace charge points were to enable this.	V2G
Vehicles participate in V2G when charging at home or at work	Based on parking durations, these offer the most plausible locations to offer V2G. Rapid charging is assumed not to be compatible with V2G.	V2G
Vehicles plug in at 25% state of charge (SOC)	Based on analysis of charging preferences[13].	All
When a vehicle plugs in it remains plugged in until it is needed. The length of time varies based on the hour it is plugged in and the location	The length of time is based on analysis of the National Travel Survey data[14].	All
A portion of the vehicle's nominal battery capacity is assumed to be "unusable"	Based on proprietary automotive battery data licensed to the ESC.	All
1/8th of the vehicle's usable batter capacity is available for V2G	Nissan guidance that 1/8th of the capacity is the maximum amount of the battery that may be used for V2G within 24 hours to comply with battery warranty conditions.	V2G
The V2G capacity available in any given hour is based on the average battery capacity of the vehicles in the parc	Analysis examines the aggregate available V2G storage capacity across millions of vehicles.	V2G
V2G storage has an efficiency of 91%	Based on the assumption that, if required, V2G could match grid-connected lithium-ion battery storage efficiency.	V2G
The minimum discharge rate of the V2G storage is the rated output of a single charge point	To provide a boundary condition that the lowest supply from V2G, when required, is that of a single connected vehicle within the aggregate pool of available vehicles.	V2G
The maximum discharge rate of the V2G storage is the number of charge points multiplied by the average rate of charging	Maximum supply from V2G constrained by the aggregate pool of available vehicles and rating of the charge points they are connected to.	V2G

[13] Transport for London and Future Thinking, 2015
[14] National Travel Survey. Department for Transport. 2010. https://www.gov.uk/government/collections/national-travel-survey-statistics

Energy resource availability	Overall availability accounts for variations in availability of energy resources, including solar and wind, across the UK. Solar availability varies both within day and between seasons.	All
V2G is assumed to have no CAPEX or OPEX	This provides an optimistic assumption about the opportunity for V2G and provides an assessment based on technical suitability alone. Data on V2G CAPEX and OPEX was limited and unverified.	V2G
The difference between weekday and weekend is not fully represented	The more detailed EV analysis which accounts for weekday and weekend variations in travel patterns is combined into a weighted average day for the energy system analysis.	V2G

6. Analysis of results

This section analyses the results from the three scenarios outlined above. The main aim is to evaluate the potential of V2G, not provide a detailed analysis of the energy generation landscape.

Section 4.1 evaluates the impact and potential value of V2G technologies on the Net Zero energy system. Sections 4.2 and 4.3 present comparisons between the V2G scenario vs. the unmanaged charging and managed charging scenarios respectively. Table 5 shows the summary of the comparisons presented.

Table 5: Scenario comparisons covered in this report

	Net Zero Target – V2G Scenario	Net Zero Target – Managed Charging Scenario	Net Zero Target – Unmanaged Charging Scenario
Net Zero Target – V2G Scenario		Yes	Yes
Net Zero Target – Managed Charging Scenario			No
Net Zero Target – Unmanaged Charging Scenario			

6.1. Analysis of the Net Zero V2G Scenario

V2G's role in a future energy system is dependent on the widespread uptake of EVs. In the Net Zero V2G scenario, the 2050 vehicle parc is 95.3% EVs (90% of which are BEVs), with the remaining EVs either PHEVs or RE-EVs, referred to solely as PHEVs going forward (Figure 7).

The profile of the vehicle parc is important as it directly informs the amount of V2G capacity available for the model to utilise. The available capacity of V2G is based on the aggregated battery capacity of the vehicle parc; this will be referred to as the V2G storage capacity.

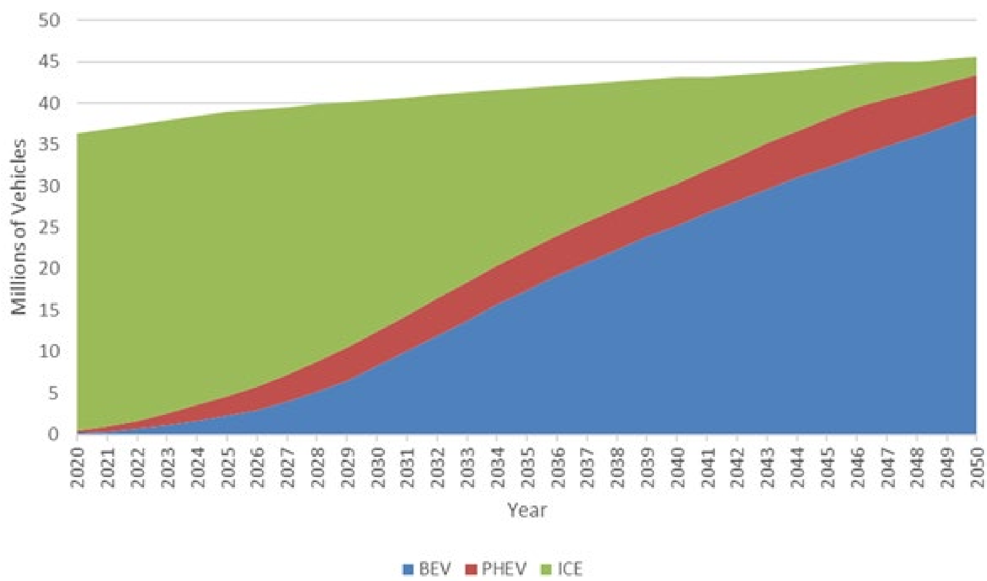

Figure 7: Vehicle Parc profile timeline Net Zero target, V2G Scenario

To provide some context as to where V2G may sit in the energy landscape of a Net Zero 2050 scenario we can examine the mix of generating capacity installed and the amount of electricity produced. Figure 8 shows the installed capacity and the annual electricity generation respectively, for the V2G scenario in 2050.

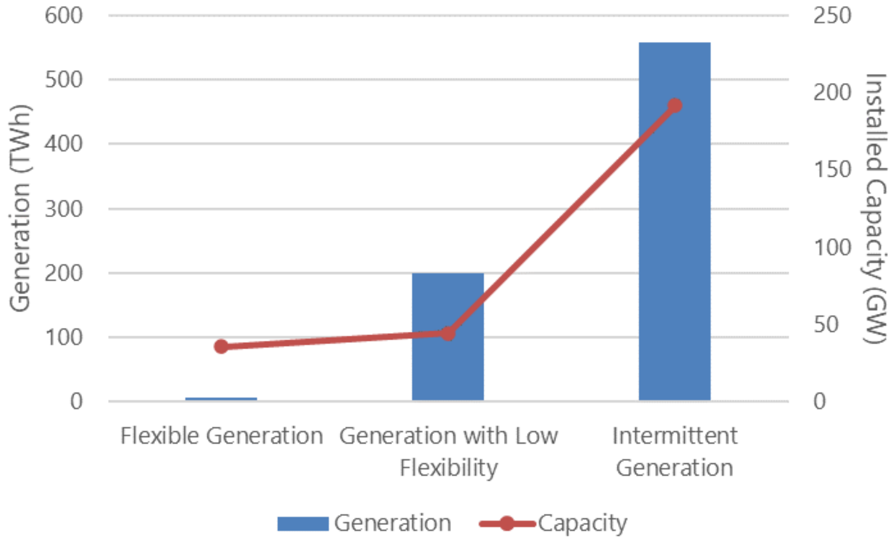

Figure 8: Electricity generation and installed capacity for Net Zero V2G scenario in 2050.

Roughly 190GW of intermittent generating capacity is installed supported by just under 40GW of dispatchable power. It is understood that the intermittent nature of renewables is likely to require support from flexible generation capacity to ensure peak demands are met at times of low renewable output. This is the area in which V2G could play a valuable role by reducing the required capacity of flexible generation whilst increasing utilisation rates of intermittent generation.

The direct competitor to V2G as a storage and flexibility service is grid-connected storage; particularly but not exclusively, batteries. The model results show the levels of grid-connected storage needed as well as the available storage capacity provided by V2G vehicles (Figure 9). Since the 2050 vehicle parc is largely EVs, the availability of V2G services limits the need for additional grid connected storage from 2020 to 2050. Instead, the increase in required storage capacity (to support higher levels of intermittent generation) is met by V2G technologies, which are assumed to be less expensive than the grid-connected alternatives.

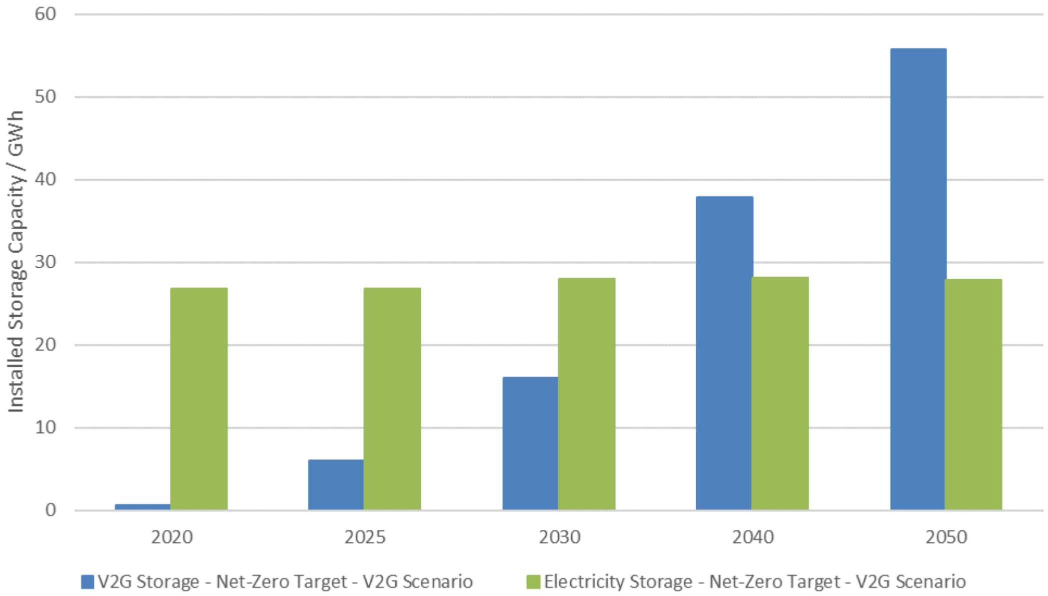

Figure 9: Installed capacity of grid-connected storage and V2G from vehicle parc for the Net Zero V2G scenario.

The utilisation of V2G storage capacity seen above needs to be considered to understand how it compares to grid-connected storage in 2050. Figure 10 shows during which time slices the grid is injecting into or withdrawing from the overall storage to meet demand on three different types of day in 2050: peak, summer and winter. Both grid-connected storage and V2G largely follow the same pattern of use, electricity injected into storage overnight and withdrawn in the early and late evenings. This is seen across all three types of day. In summer there is also some injection into both types of storage during the morning and mid-day time slices, probably due to surplus solar generation.

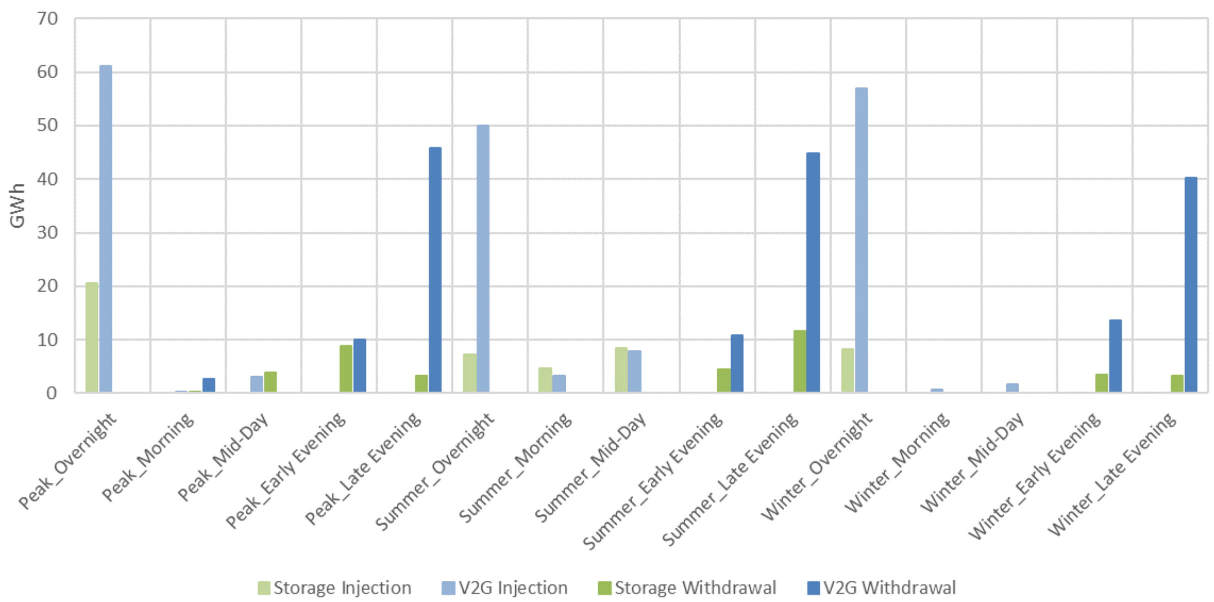

Figure 10: Injection and withdrawal to and from grid-connected storage and available V2G capacity for the Net Zero V2G scenario in 2050

The V2G storage, of which there is a higher capacity is also utilised more than the grid-connected batteries. Interestingly there are relatively similar levels of V2G utilisation across all three types of day. Always providing support at times of high demand no matter the time of year. The increased utilisation of V2G specifically in the late evening time slice, in all seasons, suggests a reduction in reliance on grid-connected storage utilisation and thereby installed capacity needed. Comparison between this scenario and the unmanaged charging scenario in section 4.2, demonstrates the impact that V2G capability has had.

6.2. Unmanaged Charging scenario to V2G Comparison (Net Zero)

To be able to draw conclusions regarding the impact and the value of V2G, we can compare the unmanaged charging scenario and the V2G scenario. The same input charging profiles were used for the two scenarios as showed in Figure 5. The unmanaged case represents a system where EVs are available and the charging demand is present but V2G does not materialise.

Vehicle parc is similar among the two Net Zero scenarios as seen in Figure 11. The difference is minimal and more precisely the percentage of plugged-in vehicles (BEV and PHEV) in 2050 in both scenarios is around 95% (95.15% in unmanaged charging scenario and 95.10% in V2G scenario).

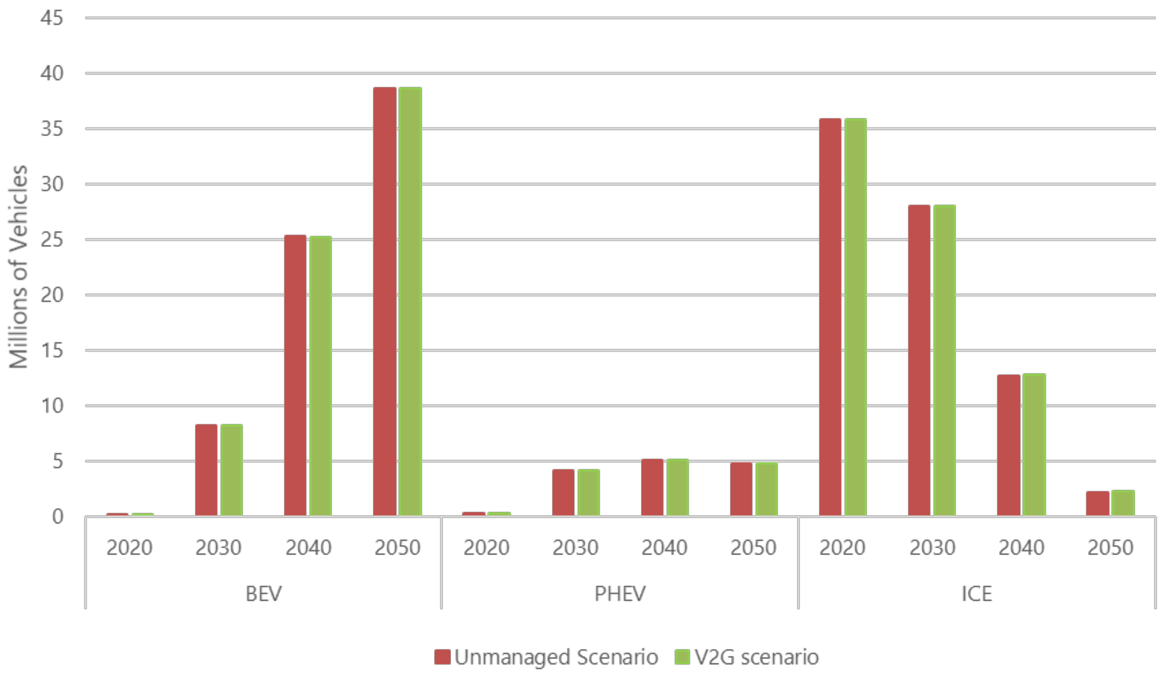

Figure 11: Car and Van parc - Unmanaged charging and V2G scenarios

The differences in the installed electricity generation capacity and annual electricity production between the V2G scenario and the Unmanaged charging scenario in 2050 are seen in Figure 12. The differences between the scenarios are small in both capacity and generation terms in 2050.

The total annual electricity production by 2050, the annual electricity production from flexible generation, as well as the annual electricity production from intermittent generation is higher in the unmanaged scenario compared to the V2G scenario, a difference of 0.3%, 1.8% and 0.3% respectively. The annual electricity production from low flexibility generation is higher in the V2G scenario compared to the unmanaged charging scenario, a difference of 0.1%. These differences are small suggesting that V2G does not negate the need for much flexible generation and so there is limited value in replacing flexible generation with V2G.

Similar patterns to 2050 were noticed in 2030 as well. The total electricity capacity from 2030 to 2050 has increased significantly as expected.

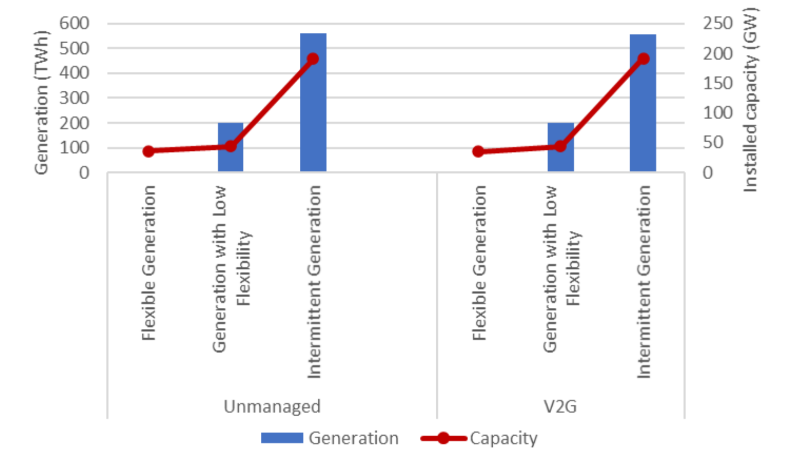

Figure 12: Electricity generation and installed capacity 2050 – Unmanaged charging and V2G scenarios

Figure 13 shows the installed electricity storage (V2G and grid-connected storage) capacity under each scenario. Comparing the storage requirements in the unmanaged charging scenario and in the V2G scenario, when V2G is not available, additional grid connected storage capacity is needed for the system to balance supply and demand. There is a 91% difference in the grid connected storage capacity between the two scenarios. As seen in Figure 13 the total storage capacity is higher in the V2G scenario compared to the unmanaged charging scenario in both 2030 and in 2050. In 2050 there is an 11% difference in the overall capacity of storage between the V2G and unmanaged charging scenarios. This is supported by the higher utilisation of storage capacity in the V2G scenario compared to the unmanaged charging scenario as shown in Figure 14. This graph illustrates the high levels of storage utilisation in both scenarios where, grid-connected storage and V2G storage are aggregated in the V2G scenario. The annual daily average of electricity withdrawn from storage in the V2G scenario is 8GWh higher than for the unmanaged charging scenario. The annual daily average of electricity injected into storage in the V2G scenario is 7GWh higher compared to the unmanaged charging scenario.

When compared to unmanaged charging, this analysis suggests that V2G is valuable – by substantially replacing investment into grid connected electricity storage.

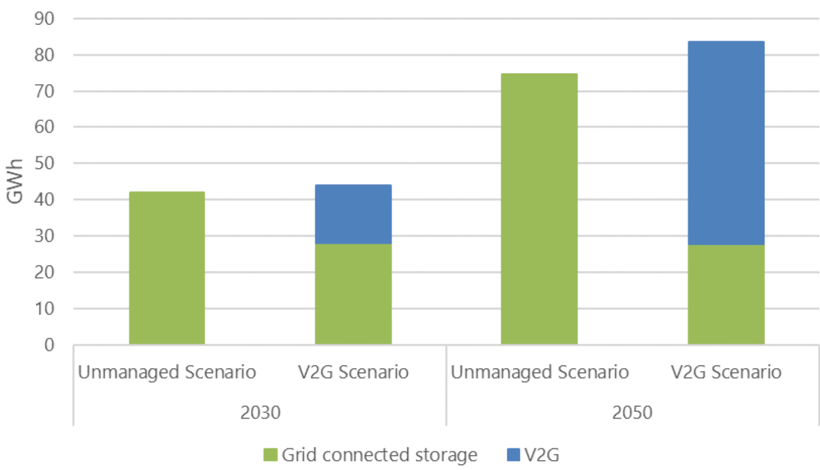

Figure 13: Installed annual storage capacity – Unmanaged charging and V2G scenarios

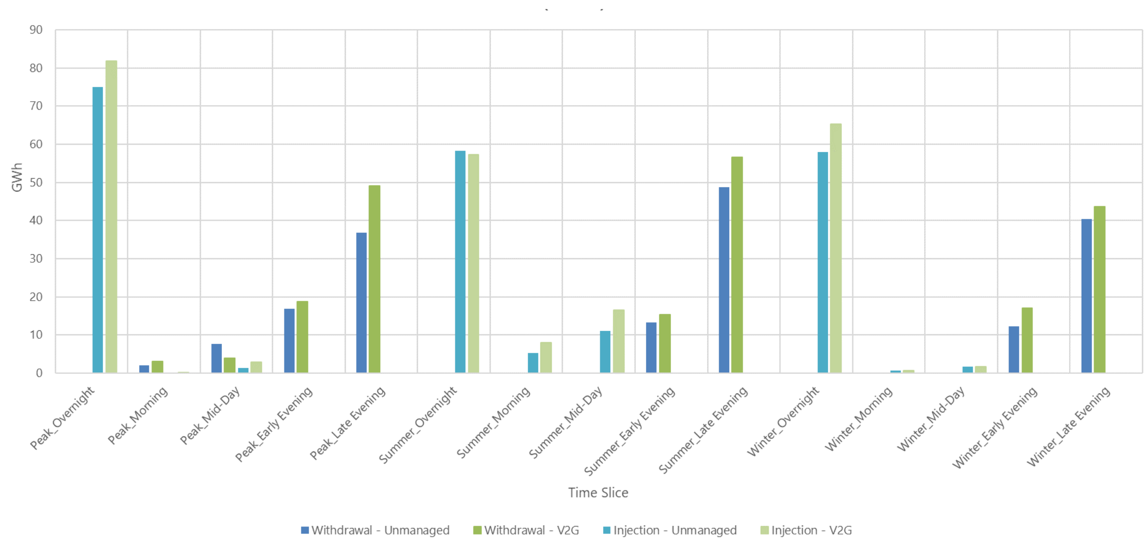

Figure 14: Withdrawal from and injection into total storage capacity for the Net Zero Unmanaged Charging and V2G scenarios in 2050

6.3. V2G to Managed Charging Comparison (Net Zero)

The final scenario compares the V2G and Managed Charging scenarios, where no V2G technology is rolled out but charging demand can be shifted to off-peak times. This comparison allows conclusions to be drawn on what, if any, benefits the additional capability of V2G can offer over the implementation of managed charging.

As with the previous comparison the vehicle parc is extremely similar between these two scenarios, with the vast majority of the parc made up of BEVs, approximately 95% by 2050. The electricity consumption levels by 2050 are also very similar, at 709TWh, an increase of 403TWh over 2030 levels. The breakdown of the consumption by sector can be seen below in Figure 15.

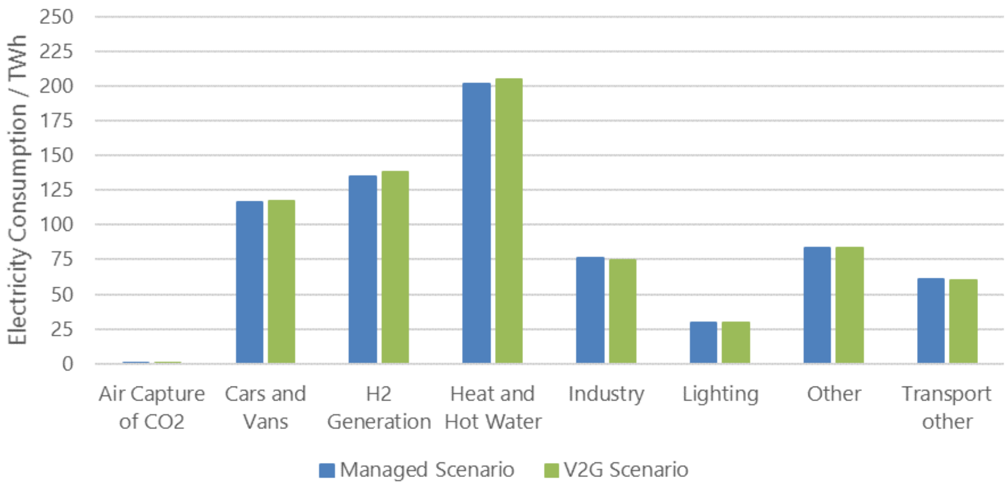

Figure 15: Annual electricity consumption in 2050 by sector - Managed Charging and V2G scenarios

The installed generation capacity and the actual generation in 2050 for the managed charging and V2G scenarios can be seen in Figure 16. It shows that for 2030 and 2050 the mix of generation types is very similar, albeit with 6GW more installed capacity in 2050 with the V2G scenario. More precisely, in the V2G scenario the flexible generation capacity and the intermittent generation capacity are higher compared to the managed charging scenario, a difference of 4.7% and 3.4%

respectively. On the other hand, the generation with low flexibility is higher in the managed charging scenario compared to the V2G scenario, a difference of 4.1%.

Figure 16 illustrates that the reliance on intermittent generation technologies is very high by 2050 for both scenarios. It can also be seen that there is very small utilisation of the flexible generation. Although the installed flexible capacity increases between 2030 and 2050, the utilisation of the flexible generation has dropped from 31% in 2030 to 2% in 2050, for both the managed charging and V2G scenarios.

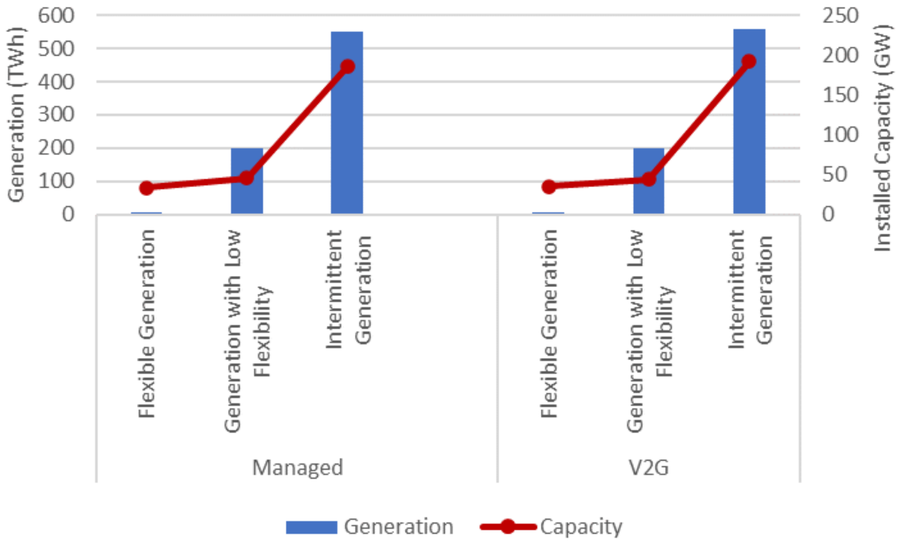

Figure 16: Electricity generation and Installed capacity- Managed Charging and V2G scenarios by generation flexibility type

The most substantial differences in the two scenarios can be seen in the capacity and utilisation of the electricity storage. Figure 17 shows that in both 2030 and 2050 the total available storage, (grid connected storage and V2G storage) where available, is higher in the V2G scenario. In 2050 there is a 77% difference in overall level of storage between the V2G and manage charging scenarios. The flexibility from EVs in the managed charging scenarios reduces the need for storage capacity. However, the grid-connected storage is higher in the managed charging scenario (37 GWh) compared to the V2G scenario (27.9 GWh). In general, when V2G is present in the energy system(the V2G scenario) it drives a higher level of storage capacity but there is an advantage of V2G storage which is a relatively low cost to the consumer, as it reduces the grid connected storage significantly which is associated with higher cost. The flexibility from EVs is used in both scenarios but utilised in different ways, in the managed charging scenario the charging demand can be shifted to off-peak times and in the V2G scenario the V2G storage capacity replaces a significant amount of grid connected storage. The increased need for balancing in the V2G scenario can also justify the higher installed flexible capacity and the higher utilisation of these flexibility technologies compared to the managed charging scenario.

The V2G scenario does not only adopt a higher total storage capacity but also higher storage utilisation compared to the managed charging scenario as shown in Figure 18. This figure demonstrates the high levels of storage utilisation in both scenarios where grid-connected storage and V2G storage are aggregated in the V2G scenario. As seen previously most injection happens overnight and most withdrawal during the early and late evenings. The annual daily average[15] of electricity withdrawn from storage in the V2G scenario is 47GWh higher than that of the managed charging scenario. The annual daily average of electricity injected into storage in the V2G scenario is 52GWh higher compared to the managed charging scenario. However, the annual daily average

[15] Average of winter and summer days only, a peak day is a test condition to assess extreme system conditions and is not expected to occur regularly

of utilisation of grid connected storage (i.e. excluding V2G storage) is higher in the managed charging scenario compared to the V2G scenario (a difference o8GWh greater in injection and 7.8GWh in withdrawal). This suggests that there is an advantage that V2G can offer in the 2050 Net Zero environment, as it reduces the amount of grid-connected storage that would be required, while still offering the flexibility services needed to support the high levels of intermittent generation.

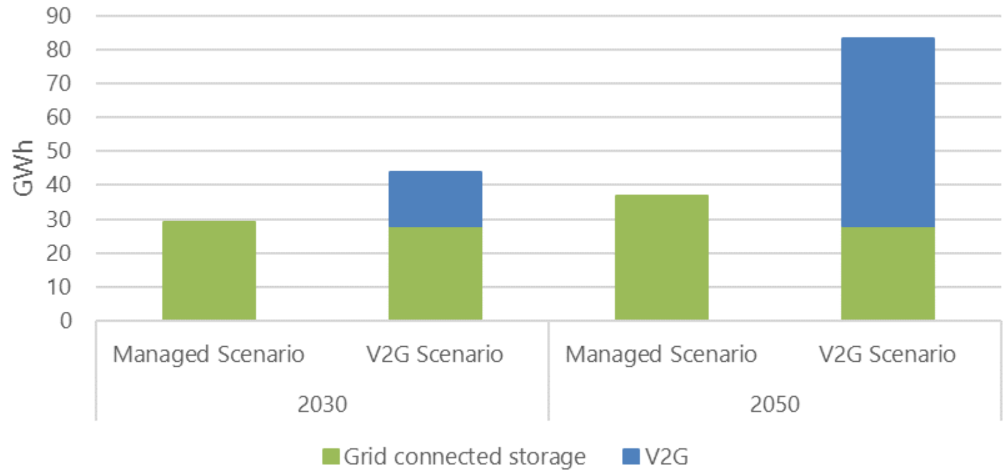

Figure 17: Available capacity of grid-connected storage and V2G for the Net Zero Managed Charging and V2G scenarios.

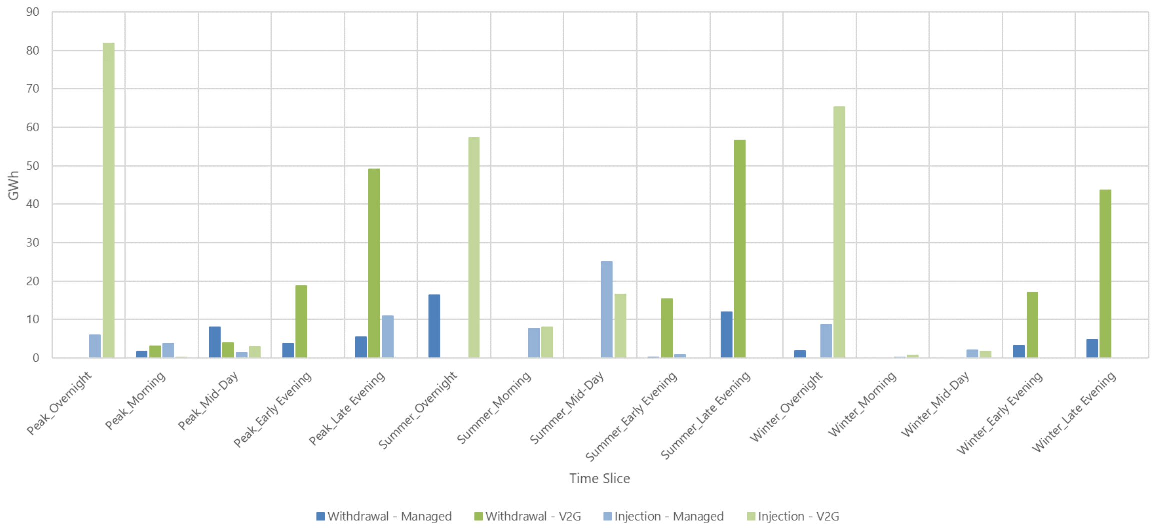

Figure 18: Withdrawal from and injection into total storage capacity for the Net Zero Managed Charging and V2G scenarios in 2050.

The difference between the amount of electricity withdrawn from storage on a winter day is 51GWhbetween the two scenarios, with 60.6GWh withdrawn in the V2G scenario and only 9.8GWh in the managed charging scenario. The model is choosing to have high levels of utilisation of this flexible V2G storage when it is available. This again suggests that there is an advantage that V2G can offer, as it reduces the amount of grid-connected storage that would be required, while still offering the flexibility services needed to support the high levels of intermittent generation.

In summary V2G appears to have some value above and beyond managed charging alone by reducing the need for grid connected storage but its value is quite marginal and requires more investigation – particularly when considering other value that V2G could provide over shorter timescales not represented within this modelling.

7. Conclusions

This report has investigated the potential benefits that can come from introducing V2G technologies into the electricity generation system as part of the road to meeting the Net Zero emissions target by 2050. Electric vehicles are set to drastically change the vehicle parc of the UK over the coming decades and V2G technologies offer opportunities to capitalise on the EV parc's electricity storage capacity.

The analysis for this project has been carried out using the modelling capability used for the Vehicle to Great Britain (V2GB) project, which was on a trajectory to achieving an 80% reduction in GHG emissions from 1990 levels by 2050. This modelling capability was updated and used in combination with the results from the V2GB project, to assess the value V2G storage can potentially bring to a Net Zero energy system landscape.

Three different charging scenarios were explored within Net Zero targets: Managed, Unmanaged and V2G. The V2G scenario was compared to the unmanaged and managed charging scenario to address the objectives of the project. In all three scenarios, EVs were forecast to make up 95% of the vehicle parc in the UK by 2050. Unless V2G is deployed they would lie unused for large portions of the day[16], missing the chance for them to be integrated into the grid to supply and store electricity when needed. The analysis focused on comparing flexible generation, grid-connected electricity storage, V2G storage and intermittent energy generation.

The first part of the analysis took a detailed look at the Net Zero target V2G scenario to explore how the Net Zero targets as well as the V2G capacity and utilisation affect the energy system. The results showed that when available, V2G is used within a Net Zero energy system, alongside other forms of storage to minimise the capacity of low utilisation flexible generation. V2G appears to be preferable to grid connected storage which are associated with higher costs. Additionally, V2G storage was utilised to similar levels no matter the type of day, or season, implying it is required year-round to meet electricity demand in a Net Zero environment.

When compared to a scenario without any managed charging, V2G provides value by displacing substantial amounts of grid connected storage. When compared to a scenario with managed charging, the benefit of V2G is lessened although there appears to be some value above and beyond managed charging alone by reducing the need for grid connected storage. This should be investigated further with consideration also given to the other value that V2G could provide over shorter timescales not represented within this modelling.

In conclusion, according to this analysis there is an advantage when V2G is available since the need for grid-connected technologies is reduced. A scenario where both V2G and managed charging is available should be examined further in future work to understand if a combination of the two charging regimes provides a greater benefit to the energy system than either alone.

---

[16] Plug-in Vehicle Behaviors: An analysis of charging and driving behavior of Ford plug-in electric vehicles in the real world. Boston, D., and Werthman, A. 2016. https://www.mdpi.com/2032-6653/8/4/926

Authors:

Despina Yiakoumi, Lowri Williams, Daniel Murrant, Vilislava Ivanova, Arianna Griffa

Energy Systems Catapult supports innovators in unleashing opportunities from the transition to a clean, intelligent energy system.

Energy Systems Catapult
7th Floor, Cannon House
18 Priory Queensway
Birmingham
B4 6BS

es.catapult.org.uk
insightsandevidence@es.catapult.org.uk
+44 (0)121 203 3700