D1.1 – Key drivers and dependencies for V2G

V2GB WP1 Literature review

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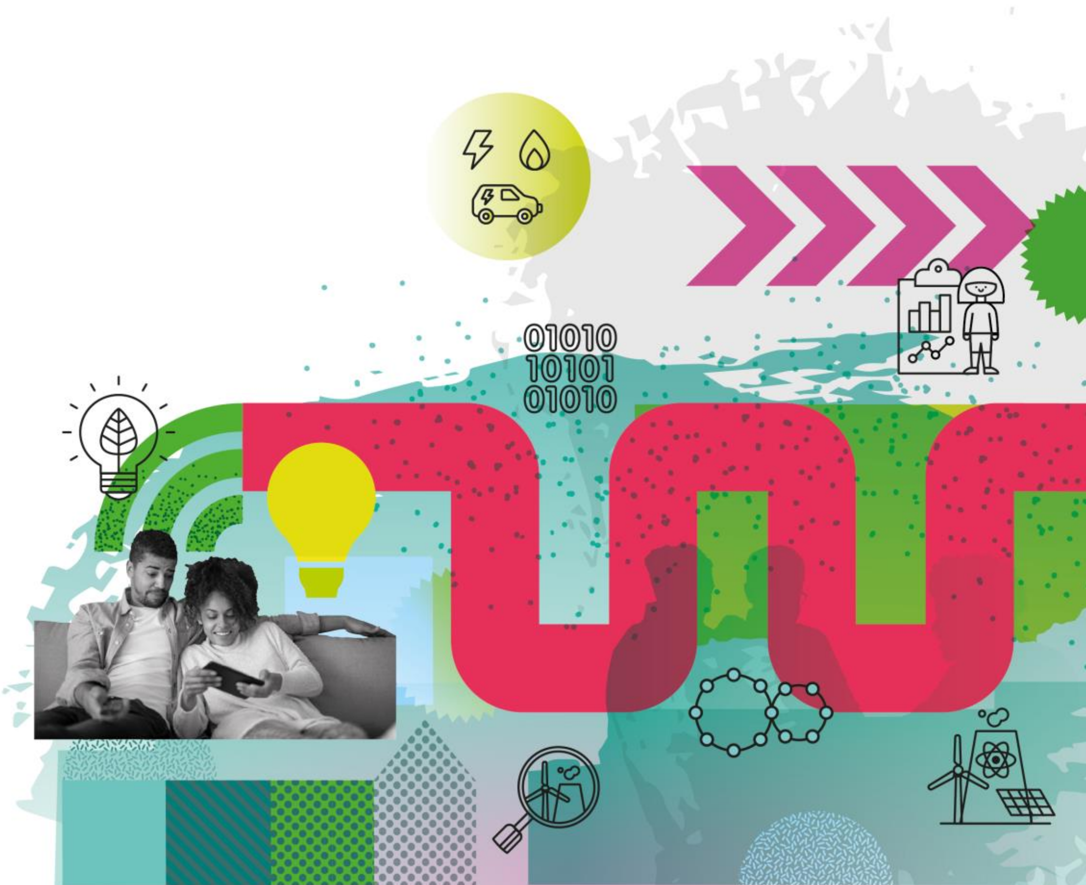

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Executive summary

The Vehicle to Great Britain (V2GB) project has been developed to: understand the long-term value of and short-term opportunities for Vehicle-to-Grid (V2G) in the UK; identify and evaluate business models for deploying V2G; and develop a sustainable routemap for scaling up V2G. Work package 1 (WP1) has investigated the long-term market value and where V2G might be applicable in a wider energy system context. This first report from the work package summarises the findings from the literature review and research to identify the drivers and dependencies that affect the value and viability of V2G. The outputs of this work have helped to inform the development of the scenarios for the second part of the work package, which includes the use of a modelling capability to help understand at what level V2G might be utilised in 2030. The final portion of the work package provides estimates of the system flexibility requirements and the V2G market potential.

The literature review has identified a variety of drivers and dependencies expected to influence the development of V2G. A subset of the drivers, classified by their characterisation of the electricity system have been examined within WP1:

- ***Price of accessible service*** – the price available to V2G for each electricity system service that it is able to access
- ***Volume of accessible service*** – the size of the market for each electricity system service that V2G is able to access
- ***Flexibility competition*** – the competitiveness of other means of providing flexibility, in particular for the services that V2G is able to access
- ***Intermittency*** – the level of supply intermittency in the electricity system (a cause of supply and demand imbalance)
- ***Demand variability*** – the level of variability in demand facing the electricity system (a cause of supply and demand imbalance)

Services accessible by V2G have been identified through the literature review. Of these, four main services are expected to be most suited to the performance characteristics of V2G, namely: Reserve power supply; Peak shaving; Renewable energy integration; and Frequency and voltage regulation. Estimation of the price and market size of the accessible services is covered in D1.3 – Long term estimates of size of V2G market.

The literature review has also identified flexibility providers that would offer competition to V2G, affecting its value. The principle flexibility competition comes from peaking plant, grid-connected electricity storage, in-home heat storage, domestic backup boilers and interconnectors. Alongside these, a series of other challenges facing V2G success have been identified through the literature review.

Intermittency and demand variability, meanwhile, form the basis for the recommendations for the energy system analysis to examine the long-term opportunity for V2G. This is covered in more detail in D1.2 – Long term estimates of V2G revenues.

The analysis has been carried out using modelling capability licensed to the Energy Systems Catapult and developed in the ETI's Consumers, Vehicles and Energy Integration (CVEI) project [1]. The modelling capability encapsulates the whole energy system, covering the different forms of energy supply, network infrastructure and end-use sectors, whilst providing a higher level of fidelity for the transport sector. This has been used to support the analysis of how intermittency and demand variability affect the utilisation of V2G out to 2030.

To carry out this analysis, two scenarios have been developed. Scenario 1 will be the baseline scenario where the UK is on track to meet it's 2040 ULEV targets and it's 2050 GHG emissions reductions. Scenario 2 will build on the baseline case by looking at the impacts of higher renewable generation and higher electrification of heating.

Other drivers and dependencies identified in the literature review and research but not examined in WP1, are put forward as recommendations for examination in other work packages:

- Number of electric vehicles (EVs) participating and proportion of their batteries that are available
- Temporal alignment of available EV battery capacity and relevant service requirements
- State-of-Charge (SoC) at the time the vehicle is plugged in and the capacity to accept or withdraw relative to service requirements
- Required SoC at the point in time the vehicle is unplugged
- Charge rate available during the period the vehicle is plugged in
- Impact on battery degradation

1. Introduction

1.1. Project Overview

Widespread deployment of electric vehicles (EVs) could mean the vehicle fleet represents an energy asset of national significance. Studies by partners in this project have shown how EVs can stabilise grids, delay infrastructure investments, increase the deployment of variable renewable energy technologies on grids, reduce curtailment, lower grid carbon emissions, and provide low cost energy for driving, all without interrupting the service provided to the driver. It has been proposed that Vehicle to Grid (V2G) can contribute to system flexibility and help achieve these outcomes and, in doing so, provide additional revenue streams to EV drivers that could boost ULEV sales.

There still remain significant gaps in knowledge on; potential V2G markets and revenue streams; competition with other technologies; driver behaviour and response to V2G; and commercial arrangements and legislative constraints. The V2GB feasibility study will examine these knowledge gaps and provide a sound basis upon which to build the sector. It will:

- **Assess the risk associated with V2G revenues in the long term --** identifying the key drivers and dependencies for future V2G revenues, and give long term estimates (ranges) of V2G revenues
- **Improve confidence in the availability of revenue streams near-term --** using high resolution models and detailed vehicle movement datasets to model revenues, portfolio dispatching, and impact of customer behaviour.
- **Identify and evaluate business models for deploying V2G --** providing recommendations on feasible and efficient business models, overcoming roadblocks and identifying industry enablers
- **Develop a sustainable routemap for scaling up V2G --** identifying V2G technology cost and performance thresholds and target markets as the sector (and competition) grows.
- **Project reporting and industry dissemination** -- using extensive dissemination routes across transport and energy sectors including Power Responsive, LCNI conference, auto industry.

1.2. Introduction to Work Package 1

Work package 1 (WP1) of the V2GB project has investigated the long-term market opportunity and potential revenues for V2G. The initial questions that need to be answered are; what is the potential size of the market for V2G in the UK? And what factors will influence the size of the market in the UK? The scope of this work package includes the following outputs:

- Examining the potential size of the market in 2030
- Establishing credible energy system compositions for 2030
- Outlining the competing ways in which system flexibility can be provided
- Identifying drivers of V2G market size and value (drawing on existing work where available)

The approach taken within the work package is to use current data and understanding to represent V2G in a whole energy system modelling environment and explore the opportunity for it to be used in the longer term; when there are a significant number of EVs on the road and the wider energy system has a greater need for system balancing. The work package itself has been broken down into three areas:

- Identification of key drivers and dependencies for V2G revenues – through a literature review and drawing on the sector expertise within the project team.
- Establish the long-term opportunity for V2G – through whole energy system analysis incorporating a V2G offering (that reflects EV deployment levels) alongside alternative means of providing flexibility.
- Estimate potential future value of opportunities – through further qualitative assessment of technical considerations, market size and price factors.

The work package is separated into three deliverables. Each deliverable will include a different part of the analysis. The deliverable outputs and the associated tasks within each deliverable are:

D1.1 – Key drivers and dependencies for future V2G revenues

- Review of literature on V2G value and system flexibility
- Identification of drivers

D1.2 – Long term estimates of V2G opportunities

- Design of energy system scenarios
- Adaptation of model to represent V2G and testing
- Gathering and processing of input data to develop the scenarios for the CVEI tool
- Analysis and processing of output data from the CVEI tool to answer the identified questions

D1.3 – Long term estimates of size of V2G market

- Estimation of system flexibility requirements
- Estimation of V2G market potential

The outputs from WP1 will help to support the other deliverables and provide guidance in the areas where V2G has its long-term value. It will also identify which drivers and dependencies are within the scope of this work package and those which could be analysed within other work packages.

2. Identifying the drivers and dependencies

The approach taken to identify the drivers and dependencies includes a review of the current literature on V2G, this approach is taken as there is currently already a large body of work on V2G technology and how it might benefit the energy system. This analysis also includes a review of the literature on system balancing, this provides greater insight into the key system and grid requirements which can inform on the services in which V2G could participate, as well as the value of these services. Greater support to identify the drivers and dependencies for V2G will be sought from the wider project team, which contains a broad range of knowledge and experience in areas related to V2G. The assessment of the literature and support from the project team is expected to help in understanding the main drivers and dependencies as well as the areas in which there is a lack of research.

The review of the literature has been focussed into specific areas which will provide the information required to understand what the drivers and dependencies for V2G are. As described below these are: electricity system requirements; practicalities for V2G provision; and energy system operation and options for flexibility provision. This has informed the research and analysis for deliverable 1 as well as subsequent deliverables.

Table 1 – Areas of focus for literature review

Electricity system requirements	To understand the system value of V2G it is also necessary to understand the system and grid requirements. This includes the different services that are required to support the grid. The services each have different values and have different requirements for technologies providing that service.
Practicalities for V2G provision	The requirements for technologies providing the services also apply to V2G. The distinct nature of V2G, in that the storage offered primarily exists for another purpose (i.e. to deliver motive power to a vehicle), means there are practicalities that specifically apply to V2G that need to be considered. Alongside this there is the suitability of V2G to provide the services relative to competing flexibility technologies.
Energy system operation and options for flexibility provision	A review of the competing technologies is required to understand what V2G can offer over other technologies and, even if there is value, whether it can compete with other new and emerging technologies.

The literature review provides details of where the value of V2G could be within the energy system and what level of flexibility it could provide. The drivers and dependencies for V2G have been extracted from the review of the literature and grouped into categories. This has then helped to inform the areas which require further analysis.

3. Literature review

3.1. System requirements

V2G has the potential to be useful in providing support to the UK electricity grid, it will, however, be limited in which services it can provide due to technical and economic factors. Several studies have investigated which services would be the most appropriate for a V2G system to operate in. The following services have been identified as suitable for a V2G system to participate in [1] [2].

3.1.1. Reserve power supply

Reserve power supply has been noted by several sources to be a possible service which could be offered by V2G systems. A large scale V2G system could help maintain the balance in the power grid by injecting power. For example, hundreds of EV's could discharge their batteries simultaneously to provide the power needed for a small/medium sized factory. It has also been identified that reserve power services could be economically favourable as they are paid for by being available and not only when they discharge.

The difficulty in using a V2G system to provide reserve power would be in ensuring that the supply is always available to be called upon when it is needed. There have been suggestions that this service could be provided with the use of an aggregator. An aggregator would have the responsibility of ensuring that enough capacity is available.

3.1.2. Time of use optimisation

Time of use optimisation is a service which recognises the known variation of demand throughout a typical day. This includes both "peak shaving" and adding demand during periods of otherwise low demand to "fill troughs". In the case of the former, weekday peak demand occurs between 15:00 and 18:00 and EVs could provide peak shaving during this period (known as daily peak shaving) by strategically coordinating their charging and discharging. This would support the grid by charging the EVs at off-peak times and discharging at peak times. This is valuable to the system as it would significantly reduce the *peak-to-average* ratio by increasing the utilisation of the grid and therefore could potentially reduce the operational costs of the grid. Peak shaving can be partially carried out through managed charging of vehicles, however, a V2G system can provide further support by providing power to the grid. The benefit of this includes:

- Avoiding generation capacity build;
- Avoiding distribution and transmission network peaks or constraints, reducing and delaying infrastructure investment;
- Smoothing out price differentials between high and low demand, in response to time of use signals;
- Increasing demand during system minimums.

3.1.3. Renewable energy integration

A V2G system has been identified as a method which could help with the intermittent nature of renewable energy generation. This would work by EVs charging when there is excess renewable generation on the grid and then discharging when there is low renewable generation. The value of this would be increased utilisation of renewable energy and a lower cost of energy at times of low renewable generation as it would require less generation from fast start generators such as gas turbines which have higher generation costs [3].

3.1.4. Frequency and voltage regulation

Regulation services are required to maintain the frequency and voltage in the power grid. In the UK, National Grid is obligated to maintain a frequency of 50Hz plus or minus 1%. The frequency changes when there is a mismatch between the supply and demand of electricity in the grid. If the load requirement exceeds the generation, the frequency drops and additional power or reduction in load is needed. Conversely, when generation exceeds load, the frequency increases and a reduction in power or increase in load is required. This process is known as frequency regulation. This kind of service is fast responding with action required in the matter of seconds and is called upon multiple times in a day. There are distinct types of regulation services which vary by the speed of response required and how long a service can be sustained for.

There are multiple sources that suggest that V2G systems could play a role in offering regulation services and provide frequency support, there is, however, little in the literature that investigates the specific use of V2G for voltage regulation. The expectation is that voltage regulation through V2G would be more applicable at the distribution than transmission level. Given the high price of providing regulation services it has the potential to be an economic service for V2G systems to engage in [4] [5]. One study conducted in California found that for BEVs, regulation services would be the most profitable of the services to provide when compared to peak power and spinning reserve [6], however, this study looked at revenues for single EV owners and does not consider the size of the market for a specific service.

3.1.5. Current electricity system services

It is expected that the UK's future energy system will be significantly different from what it is currently. This is largely due to an increasing proportion of renewable energy predominantly from wind and solar generation, as well as many assets which are expected to come off the system in the near future, due to economic and environmental constraints [22]. A changing future energy system will result in the requirement for different and increasing ancillary services to support the changing electricity grid. Ancillary services are provided to the system operator to support the continuous flow of electricity and ensure that supply can always meet demand. The current ancillary services include the resources listed in [23]. However, these are currently being reviewed by the system operator in GB.

Table 2 – Current ancillary services

Black Start	Black start is the procedure to recover from a total or partial shutdown of the transmission system.
BM start up	On-the-day access to additional generation Balancing Mechanism units (BMUs) that would not otherwise have run.
Demand Side Response (DSR)	Demand side response (DSR) is all about intelligent energy use. Find out how DSR can help business and consumers save on total energy costs and reduce their carbon footprint.
Demand turn up	Developed to allow demand side providers to increase demand as an economic solution to managing excess renewable generation when demand is low.
Enhanced frequency response (EFR)	EFR is a service, open to both BM and non-BM providers to provide frequency response in one second or less.
Enhanced reactive power services	Provision of voltage support that exceeds the minimum technical requirement of the obligatory reactive power service (ORPS).
Fast Reserve	Fast reserve provides rapid and reliable delivery of active power through increasing output from generation or reducing consumption from demand sources.
Firm Frequency Response (FFR)	Firm Frequency Response (FFR) is the firm provision of dynamic or non-dynamic response to changes in frequency.
Mandatory frequency response (MFR)	Mandatory Frequency Response is an automatic change in active power output in response to a frequency change and is a Grid Code requirement.
Obligatory Reactive Power Service (ORPS)	Provision of varying reactive power output. At any given output generators may be requested to produce or absorb reactive power to help manage system voltages.
Short Term Operating Reserve (STOR)	Short term operating reserve (STOR) is a service that provides additional active power from generation or demand reduction.
Super SEL	The ability for synchronous generation to reduce their minimum generation level (SEL) in times of low demand on the system.
System Operator to System Operator (SO to SO)	SO to SO services are provided mutually with other transmission system operators connected to Britain's transmission system via interconnectors.
Transmission Constraint Management	Required where the electricity transmission system is unable to transmit power to the location of demand due to congestion at one or more parts of the transmission network.

3.2. Practicalities for V2G provision

In seeking to understand the potential for V2G it is necessary to examine the practicalities associated with providing it. There are a variety that are specific to V2G, i.e. do not apply to other means of providing storage and flexibility, simply because the battery that would enable the V2G offering primarily exists to provide an unrelated service, mobility. Drawing on the literature key practicalities are captured below.

3.2.1. Number of EVs participating and proportion of available battery capacity

The number of EVs in the vehicle parc clearly affects the overall level of V2G storage capacity that could be available. This would be limited by how many of those EVs are V2G capable. Research looking at global growth in the vehicle to grid market has estimated a compound annual growth rate of above 18% by 2021 [8]. However, this study does not give any specifics to the UK growth of the V2G market.

In turn, the proportion of V2G capable EVs that are made available to participate in V2G (e.g. by the vehicle owners) also affects the V2G storage capacity. There was little research identified that looks into the potential number of EVs that might participate in V2G systems.

Further to this, the battery capacities of the V2G capable EVs also determine the available V2G car parc storage capacity. In turn, the proportion of those battery capacities that are reserved or made available to participate in V2G offerings likewise influence the available V2G car parc storage capacity.

In combination, these set the upper limit for available V2G car parc storage capacity before addressing factors such as: the temporal alignment between this capacity and the service requirements; the state of charge and charging requirements of the vehicle whilst it is plugged in; and the charge rate accessible to the vehicle when plugged in.

3.2.2. Temporal alignment of available EV battery capacity and service requirements

Services are highly time dependent and necessitate flexibility providing solutions (such as a V2G system) to be available and have the capacity to deliver within certain time-windows. There are two main factors that affect whether a V2G system could offer a specific service; firstly, the vehicle must be plugged into a charge point and secondly the state of charge of the vehicle must be appropriate for what service it is trying to provide.

Given that V2G is not the primary purpose of a vehicle, one approach would be to presume that it would be more efficient and viable for a V2G system to be utilised in more predictable services. Out of the services mentioned, peak shaving would be the most predictable and would provide greater clarity on how a V2G system might operate. There is also the benefit of the system working well where current energy demand peaks are. Renewable energy integration is less predictable and can vary from hour to hour and day to day, increasing the risk associated with providing this service. With V2G also having to balance the risk of EV availability and, more specifically, EV battery availability this risk is magnified.

Providing regulation services would require the service to be available throughout the day and would be more dependent on the number of vehicles connected rather than the state of charge of those vehicles, as the depth of discharge required is relatively small for frequency response services. The key factor is then whether enough vehicles are plugged into the grid throughout the day. It has been reported that throughout the day, on average as few as 2.5% cars are being driven. This means that over 90% of vehicles are parked throughout the day. If we assume that this same percentage of vehicle use persists for electric vehicles, then there should be a significant number of vehicles connected to the grid to be able to be provide this service. Alternatively, with a shift to different vehicle ownership models and an associated increase in utilisation of vehicles (for mobility), the number of vehicles connected to the grid would potentially be lower. In either case an underlying cause would be travel patterns and if these were to change then that would also be likely to affect the number of vehicles connected to the grid at any one time.

3.2.3. SoC at plug-in time and capacity to accept or withdraw relative to service requirements

The state of charge of the vehicle at the time it is plugged in is an important factor when considering which service a vehicle could provide to the grid. Investigations into this area, however, are nascent. Research underway in the CVEI and the Electric Nation projects is set to provide further information on how consumers would use their vehicles. The CVEI project will specifically draw on vehicle SoC information as a part of its analysis of charging behaviour.

Allied to this, is the required SoC at the time the vehicle is unplugged and the length of time the vehicle is plugged in for. This period of time needs to allow for the vehicle to get from the SoC at the time it was plugged in, to the SoC required to offer the V2G service, by the point in time the service is required; and subsequently get the vehicle to the required SoC for when the vehicle is unplugged, including accounting for any deficit from participating in the V2G service.

Of course, this is also influenced by the charge rate available during the period of time the vehicle is plugged in. In many cases this is likely to be determined by the location the vehicle is plugged in at, e.g. home, workplace, retail outlet, which is also a factor in the length of time the vehicle would typically be plugged in for.

3.2.4. Impact on battery degradation

Significant work has been carried out on the impacts of participating in a V2G system on car battery degradation. Physical degradation of the battery is quantified in two ways:

Firstly, there is capacity fade which affects the range of an EV. Secondly, there is power fade, which is the increase in internal resistance of the cell and limits the power capability of the system and decreases the efficiency of the vehicle. It is well documented in literature that battery degradation is more pronounced with increased capacity throughput [12]. Therefore, a vehicle participating in V2G will have increased battery degradation. Some research has shown that an intelligent V2G system could counteract the implications of the increased capacity throughput while there is also some who have argued that it is possible to reduce battery degradation through a V2G system. There are conflicting findings from different studies as to the impact of different methods of V2G charging. A modelling study has shown that delayed charging can extend the battery life by 1.5 years [13], while another study has shown that the impact of delayed charging is negligible [14].

The literature has also suggested that the service that is provided has an impact on the degradation of the battery. If batteries were used to provide fast reserve services and were deeply discharged, this caused an increase in the energy throughput and hence an increase in battery degradation [15]. This study suggested that for PHEVs having a depth of discharge of 30% would require battery replacement biennially while a depth of discharge of greater than 30% would increase the battery replacement to annually.

From the literature it is apparent that there is still uncertainty around the level of degradation of an electric vehicle's battery which participates in a V2G system. The current research suggests that the level of degradation is related to how the battery is used and is not only related to the number of cycles but also the depth of discharge during a cycle. This indicates that the service the vehicle is providing to the grid will have a significant impact on the battery degradation and hence the economics of participating in a V2G system. However, as mentioned above, providing certain services to the grid may extend the battery life by over a year.

3.2.5. Competitiveness of other means of providing flexibility

Whether V2G is used will also depend on what alternatives for providing flexibility are available. Any V2G service will ultimately be competing with these other means of flexibility. Those that cater to services that V2G could access are most relevant. Table 3 covers some of the main alternatives for providing flexibility for the system requirements listed in section 3.1.

Table 3 – Flexibility options for key system requirements

Reserve power	Reserve is used to replace unexpected shortfalls in energy, whether this is due to plant loss or unexpected variations in demand or energy production from intermittent sources. Typically, reserve is called on to provide additional generation or reduction in demand within 15 minutes and therefore service providers need to ramp up relatively quickly. Consequently, reserve is provided by increasing output from part loaded large scale generation, starting gas turbines or reciprocating engines from standstill or demand side response. Frequently demand side response is provided from back up generation within industrial and commercial sites, however, pure demand side response offerings are growing in number. As previously mentioned, it is economic to use technologies with low capital cost for reserve power as they are only used for a relatively small number of hours in the year. This means that V2G systems could be competitive with current technologies in providing this service. There may, however, be some difficulties in supplying the same level of power that a gas turbine plant could provide, although this could be resolved through aggregation services.
Time of use optimisation	Peak shaving is currently carried out in response to network capacity charging signals or high energy market prices. Typically, this is through demand side response where consumption from the grid is reduced over peak periods. The main contributors to this service are large industrial and commercial customers and small to medium enterprises. While these may be competing markets, there is still further potential to reduce daily peaking and flatten out the daily load profile [10].
Renewable energy integration	The technologies that V2G would be competing against in a renewable energy integration market are other energy storage technologies although the service can also be provided through interconnectors. There is a wide variety of different technologies that could offer this service. These include: • Pumped Hydro • Battery Storage • Power to Gas • Compressed Air Energy Storage To support renewable energy integration the technologies used in this market must have appropriate capacity and be cost effective.
Regulation	Different regulation services require different response times, varying from 1s to 20s. Within the UK frequency regulation is predominantly carried out by CCGTs, pumped storage and demand on low frequency relays [11]. There has been a recent increase in the use of dedicated batteries in GB to supply fast frequency response to address Rate of Change of Frequency issues associated with a fall in system inertia. Static batteries represent the biggest competitor to a V2G system given their technical similarities. Differences between them would stem from the capital cost associated with using V2G and battery storage and their respective availabilities.

3.3. Energy system operation and flexibility provision

Flexibility in the energy system is of vital importance to ensure that heat and electricity is available when there is a demand. The very nature of energy system operation is about satisfying variability in demand. However, this has been impacted in recent years by the increase in renewable generation and the preference it is given over fossil generation. Because of this flexibility requirement, certain technologies are used to support the system and help provide the required flexibility.

For example, flexibility in the energy system, from technologies such as electricity storage, heat storage and interconnectors, provide three key sources of value [17]:

- They reduce the capacity of low carbon generation needed to achieve carbon reduction targets by improving the utilisation of intermittent low carbon generation;
- They enable system balancing at a lower cost by displacing more expensive flexibility options such as peaking plants;
- They improve the utilisation of existing conventional generation and defer investments in transmission and distribution network reinforcement.

3.3.1. Peaking plant

Peaking plants have been used for those times of the day when there are hikes in the power demand on the grid. The most common technology used for providing this service is a gas engine. They have relatively high efficiencies and a low switch on price as well as having fast ramp rates which have the technical requirements needed by National Grid, the system operator, to provide fast reserve [16].

3.3.2. Grid connected electricity storage

Grid connected electricity storage is an alternative to peaking plants which can provide energy when demand is at its peak. In the transition to a low carbon energy system it has been indicated that energy storage will be important in providing flexibility to allow for a robust energy system. There are numerous types of energy storage which can be grouped into one of three types of storage; mechanical, chemical and electrical. Several sources indicate that the main service grid connected electricity storage can be used for is as a mechanism to store excess energy that is produced from renewable generation such as wind or solar. This allows for a greater utilisation of low carbon electricity.

While grid connected electricity storage can be used to improve the utilisation of renewable energy it also can be used to provide other ancillary services given the technical capabilities of the technology. The fast response time of electricity storage means that they are, from a performance stand point, well suited to providing services such as frequency response and peak shaving [18].

3.3.3. Domestic heat storage

Heat storage in homes can store excess energy provided by renewable energy in the form of hot water. This may come from any of a number of different renewable technologies, including; heat pumps, domestic solar or domestic wind. Domestic heat storage allows for energy produced at times of low demand to be stored and utilised at peak times. This therefore reduces the demand for the provision of heat at peak times and allows for greater renewable energy utilisation when using technologies such as heat pumps [18].

3.3.4. Domestic backup boilers

As with domestic heat storage, boilers can operate in support of electrified heating systems, in particular heat pumps. The combined systems, often referred to as hybrid heat pumps, offer the opportunity to reduce both the capital cost of the domestic heating system and local network reinforcement requirements [19]. In aggregate, as well as reducing network reinforcement requirements, these systems can reduce the capacity of generation plant required to satisfy demand, particularly peaking plants [20].

3.3.5. Interconnectors

Interconnectors allow for electricity to be transmitted across borders. The UK currently has 4 GW of interconnector capacity [22] and there is another 12.2GW of capacity in the pipeline for 2025. It is known that interconnectors can provide support to the grid over various timescales [15];

- Over a period of seconds to minutes, interconnectors can stabilise power networks, e.g. through frequency response;
- Over a period of hours interconnectors can provide additional secure capacity, e.g. during peak demand or an outage;
- Over a period of hours to days interconnectors can help to balance intermittent generation, e.g. PV and wind;
- Over a period of months interconnectors can help with seasonal imbalances of supply and demand; and
- Over a period of years interconnectors can provide a net supply of energy to meet the annual electricity demand.

4. Drivers and dependencies

4.1. Drivers of V2G value

From the literature review and WP1 workshops a list of drivers and dependencies have been identified. These drivers can be separated into two categories; electricity system factors and vehicle availability factors.

4.1.1. Electricity system factors

Price of accessible service

The literature review has identified services expected to be most appropriate for a V2G system to operate in. However, to ensure that V2G is economically viable, the service it is providing needs to be valuable. The four different services identified have different prices associated with them. The value of a service can be understood to be a function of the price and volume of the service.

It has been identified that regulation services, specifically frequency response, currently offer the highest price of the services available. In contrast, time of use optimisation, including peak shaving, is understood to offer a lower price.

Volume of each accessible service

The volume of each service, or size of each market, is a function of the demand for the service and the number of stakeholders capable of providing that service as well as the cost of the specific technologies that can cater to the service.

Regulation services, in particular frequency response, are currently low volume services. Time of use optimisation, meanwhile, is a much higher volume service.

Flexibility competition

While V2G may be able to provide flexibility through certain services, there are also other technologies that it must compete with in accessing these services. The competitiveness of V2G will be dependent upon several factors, which includes the service being available when it is required, the cost of V2G and the technical capability of V2G to provide the service relative to the competing technologies. To carry out such an analysis it is therefore necessary to understand what the competing technologies are which provide flexibility and their technical and economic impacts.

Intermittency

Intermittency is a problem caused by the uncontrollable variation in renewable generation. This is one of the drivers for providing flexibility to the grid through energy storage. It is preferable to utilise as much renewable generation as possible, however, in circumstances where the supply of generation outweighs demand, a significant proportion of that renewable generation can be wasted. Energy storage can be used as a method of collecting the extra energy generated and utilising it at a time when there is a low production of renewable generation. As there is an expectation that the amount of renewable generation will increase over time, it is to be expected that there will be an increasing amount of generation that could be wasted and hence greater storage capacity is required.

Demand variability

Demand variability represents the change in energy usage throughout the day and throughout the seasons. There are certain times at which demand is high e.g. early evening and times when demand is significantly lower e.g. overnight. The variation in demand causes peaks and troughs in the energy requirements and therefore the energy system needs to be designed for peak energy demand. If the peak energy demand increases, the generating capacity also needs to increase. This is therefore a driver for a V2G system which can provide energy at peak times and hence reduce the requirement for increasing capacity.

4.1.2. Vehicle availability factors

Number of EVs participating and proportion of batteries available

The number of EVs participating will affect the potential of V2G technology. To make V2G economically viable there must be a large enough number of EVs participating which also have a proportion of their batteries available to be used by the grid. If this is not available, then there will not be enough capacity to provide the relevant service.

Temporal alignment of available EV battery capacity and service requirements

Even if there are enough vehicles that are willing to participate in V2G there is also a barrier in the alignment between when the vehicle is plugged in and when the service is required. If services are required when too few EVs are plugged in, e.g. when a substantial proportion are on the road, then the service will not be able to be provided.

SoC when the vehicle is plugged in and the capacity to accept or withdraw relative to service requirements

The state of charge of the vehicle when the vehicle is plugged in will impact the use of V2G to provide the different services. If at peak electricity times EVs are plugged in and have little or no charge they will not be able to participate in providing peak shaving. This therefore requires a greater understanding of the state of charge at plug in times and when services are required.

Required SoC at the point in time the vehicle is unplugged

The state of charge the vehicle user requires when the vehicle is unplugged and the point in time which it is required by are constraints around which both the charging and V2G service need to be managed.

Charge rate available during plugged in time

The charge rate is an important factor when considering V2G. If an aggregator wants to be able to provide a service whilst also ensuring the EV owner has the desired state of charge when the vehicle is unplugged, the charge rate will be needed to understand whether the EV will be able to participate in providing a service.

Impact on battery degradation

Battery degradation has a different effect on V2G compared to the other vehicle availability factors. Battery degradation has a long-term effect on the vehicle. This may impact V2G participation if V2G has a detrimental impact on the battery.

4.2. Services accessible by V2G

There are 4 main services to which the performance characteristics of V2G would be expected to be most suited:

- Reserve power supply – is a service which requires the technology to be available for instances where a surge of power is needed to support industry or unanticipated demands.
- Time of use optimisation – is a service where, for example, charging is shifted away from times of peak demand and utilised in periods of low demand.
- Renewable energy integration – allows for greater renewable energy utilisation by storing excess renewable energy and discharging that energy when renewable energy production is low and demand is high.
- Frequency and voltage regulation – are services used to maintain frequency and voltage on the grid.

4.3. Competing flexibility providers

Alternative means of providing flexibility that have been identified as influencing the value of V2G to the system:

- Peaking plant and coupled large scale gas/hydrogen storage would be a competing technology in providing reserve power and daily peak shaving services.
- Grid connected electricity storage, across a range of technologies at both distribution and transmission network levels could compete against V2G technology in all services depending on the technology used.
- Domestic heat storage, when used in conjunction with electrified heating may be a competing method of reducing daily peaks in electricity demand.
- Domestic backup boilers, when used in conjunction with electrified heating would compete in the same way as domestic heat storage and provide flexibility by reducing daily peak demand for electricity.
- Interconnectors may compete in all the same services which have been identified for V2G.

4.4. Challenges facing V2G success

A series of challenges facing V2G success are listed in Table 4 alongside associated contributing factors.

Table 4 – Challenges and contributing factors facing V2G becoming a success

The potential for increased battery degradation (both in terms of capacity fade and power fade)	- Increased battery throughput which results from providing a V2G service. - Use beyond certain depths-of-discharge. - In contrast, some research indicates increased battery life under certain circumstances.
Temporal alignment of "V2G capacity" with service requirements	- SoC when the vehicle is plugged in. - The period of time which the vehicle is plugged in. - The charge rate available whilst the vehicle is plugged in. - The SoC the user requires when they unplug the vehicle. - The portion of overall battery capacity allocated for V2G. - The service withdrawal requirements whilst providing the V2G service. - The tension between offering battery capacity and limiting battery degradation.
Level of value to system that can be accessed by enabling actors	- The extent to which "stacking" of services is required to derive value. - The value of the service versus the cost of operating V2G. - Managing risk around V2G capacity availability.
EV owner willingness to participate	- The differing needs of private and commercial owners. - The level of convenience associated with participating in a V2G offering. - The perception of risk (in terms of battery degradation and vehicle utility) versus the level of reward.

5. Implications for the analysis in WP1

In developing the scenarios there are certain drivers and dependencies that have been identified that can be represented within the modelling capability that is available. There are also some drivers and dependencies that cannot. The scenarios for the modelling will focus on those drivers categorised within the electricity system factors.

Within the electricity system factors the dependencies that are represented within the modelling capability are the intermittency and the demand variability. The intermittency of energy generation is accounted for with the renewable energy generating technologies. The model uses historical profiles to show when there is and isn't renewable energy being generated. The same method is used for developing demand profiles and therefore allows V2G systems within the model to react to intermittency and variability.

Competitiveness of other means of flexibility will be represented within the model which contains other storage technologies as well as fast responsive generators. Based on cost and other technical parameters the model will then decide which technology is most suitable to provide the flexibility it needs.

The intermittency and demand variability are the two parameters that will be the focus of the scenarios to be tested in the modelling work. A brief description of the scenarios are as follows;

Baseline 2030 scenario

The baseline scenario represents an energy system that by 2030 is on track to meeting the 2040 ULEV targets that have been set by government and is also on a trajectory to achieving the 2050 greenhouse gas emissions targets of an 80% reduction in GHG emissions from a 1990 baseline. This scenario should give an indication of the value of V2G in a wider system context when trying to reach government targets.

High flexibility 2030 scenario

The high flexibility scenario will use the same targets as the baseline but will also test the impacts of increased renewable generation and greater electrification of heat. This will test the impact of high intermittency and demand variability on the level of V2G that is utilised. In this scenario there will be an approximately 18% increase in installed capacity of renewable generating technologies in 2030 than in the baseline scenario and 20% greater electrification of heating. This is achieved through a combination of heat pumps and electric resistive heating.

6. Recommendations and implications for other work packages

WP1 will test certain drivers through the modelling capability. These drivers are those that have been grouped under the title of electricity system factors. However, there are other drivers for V2G that have been identified through the literature review process which will not be tested in WP1. These are those that have been grouped as vehicle availability factors and include the following drivers and dependencies:

- Number of EVs participating and proportion of their batteries available that are available
- Temporal alignment of available EV battery capacity and relevant service requirements
- SoC at the time the vehicle is plugged in and the capacity to accept or withdraw relative to service requirements
- Required SoC at the time the vehicle is unplugged
- Charge rate available during the period the vehicle is plugged in
- Impact on battery degradation

The above parameters are those which are specific to the vehicles and the EV owners. To understand the effects of these dependencies will require more detailed analysis of how vehicles will participate in a V2G system and how using V2G might impact the vehicles themselves. This analysis is beyond the scope of WP1. Of the drivers and dependencies categorised in the vehicle availability factors, impact on battery degradation is the area in which there has been the most research, as indicated within the literature review. Carrying out further analysis within this area would require experimental work which would be outside the scope of the project. It would therefore be recommended that the focus in other work packages be on the other five parameters listed. This would provide the greatest benefit as there is little research carried out on the number of EVs that might participate in a V2G system in the UK and limited analysis on how the state of charge of EVs would impact the viability of the development of V2G.

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8. Appendix

8.1. Acronyms

CVEI	Consumers, Vehicles and Energy Integration
ETI	Energy Technologies Institute
EV	Electric vehicle
LCNI	Low Carbon Networks and Innovation
SoC	State-of-charge
ULEV	Ultra low emission vehicle
V2G	Vehicle-to-grid
V2GB	Vehicle 2 Great Britain
WP	Work package
WP1	Work package 1

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