V2GB

Vehicle to Grid Britain

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Executive Summary

This study assesses the long-term viability of V2G in a changing power system in Great Britain (GB) as well as the early opportunities in British power markets. Drawing on the diverse expertise of consortium members Nissan Motor Manufacturing UK, Energy Systems Catapult, Cenex, Moixa, Western Power Distribution, National Grid ESO, and Element Energy, the project explores both near term niches and enduring large-scale opportunities for V2G to play a role in a flexible energy system in Great Britain.

The value of V2G

a. There is added economic value which can be accessed by using V2G chargers compared to Smart Charging. However the scale of this value per domestic customer is extremely variable and is impacted by a wide range of factors including: usage of the charge point, the behaviours of user(s), and charger location.

b. The plug-in rate is a key driver for value captured from V2G. Average plug-in rates currently appear to be low (around 30% of time plugged in) according to the EV charging data available to this project. In the case of a high plug-in rate driver archetype (75% of time plugged in) a 7kW V2G charger could capture annual revenues of around £436 - four times that achieved with the average plug in rate. Nearly all of this value would be from providing services to the System Operator (SO), mainly FFR.

c. There could be an opportunity for Smart and V2G charging to generate significant revenues where it is in a DNO congestion management zone. Using estimates of revenue from this nascent market, where congestion is acute and sustained, the value per EV could be £250/EV.year or more. The opportunity will be geographically restricted and the most valuable opportunities are expected to be time limited as they will compete with network upgrades.

d. On the wholesale electricity market, a simple Economy 7 tariff would unlock most of the value achievable with a responsive half-hourly tariff. This may change in the future, if price spreads and volatility increase. Using Smart and V2G charging as a flexible asset into the imbalance market could also support more responsive tariffs.

e. After FFR, additional grid services offer diminishing returns due not only to lower prices, but also the service is only required during certain windows during the year.

f. If grid services to the SO and DNO are excluded, then Smart Charging is able to capture 80% of the value of V2G.

The cost of V2G

g. The on-cost of providing bi-directional V2G charging is dominated by the hardware cost. This makes it challenging to generate positive net revenues; profitable opportunities are restricted to very narrow types of BEV users (e.g. high plug-in, home solar exists, and residing within a constrained network with a market mechanism to reward congestion management).

h. Top-down (learning rate) and bottom up (component based) projections of V2G costs aligned to predict a premium of ca £650-1150 for a 7kW V2G charger in 2030. Thus hardware is expected to continue to dominate annualised V2G costs (if depreciated over 5 years), and remains a major component of costs if depreciated over 10 years.

i. The requirement for the services of an aggregator also places restrictions on which business models can provide returns on investment, especially in the case of Smart uni-directional charging.

Risks to revenues

j. As EV numbers grow (alongside other flexibility assets), saturation could be reached in low-volume services, especially in System Operator services. There is significant risk to revenue for V2G, with at least half the overall revenue per EV at risk from falling FFR prices. Our analysis of 2030 revenues with low FFR prices (reflecting competitive supply) showed this service would no longer dominate residential V2G revenues.

k. Providing a Smart Charging and V2G congestion avoidance service to the DNO could become a significant revenue stream. However, markets are nascent and all projections should be treated with caution. Furthermore, these revenue streams are highly location specific (high value only where congestion is acute) and time sensitive (as the DNO may reinforce the network).

l. Any V2G-induced adverse impacts on the battery or on the driving experience need to be avoided; otherwise they could dominate costs and erode the value case.

Whole System value and decarbonisation potential of V2G

m. There will be an enduring value from variable/smart charging and V2G to the electricity supply chain, both in terms of local flexibility to the distribution grid and increasingly in energy arbitrage as price spreads and volatility increase with RES deployment.

n. By reducing the peak demand on the distribution grid, deployment of V2G could help save £200m of cumulative distribution network investment from 2020-2030 compared to unmanaged charging.

o. Relative to unmanaged charging, Smart Charging could generate GB whole energy system net savings of £180m annually (in 2030), with benefits throughout the GB power system. Additionally, V2G operation could generate a net saving of between £40M-90M/annum, depending on limits to V2G energy throughput.

p. V2G will compete with a range of technologies to provide flexibility to the system, in particular with stationary battery storage, 2nd life batteries, flexible gas plants, and Smart Charging.

q. Competition between flexibility sources means that the marginal value of flexibility reduces as its deployment increases. However there is a positive synergy when increasing both flexibility asset and VRES deployment; VRES induced variability provides the conditions to sustain cycling and revenues from flexibility assets, which in turn can reduce curtailment of renewable energy.

Recommendations

a. To maximise revenues from SO services, near-term deployment of V2G in the residential market should focus on consumer groups with plug-in rates much higher than average.

b. Positive net-revenues can emerge as a result of stacking of revenues. V2G developers should be prepared to stack revenues from multiple sources, to combat potential erosion of value (due to market saturation or time-limited revenue opportunities).

c. While passive EV charging may worsen congestion on distribution networks, where possible deployment of V2G should be focussed in areas where the DNO has acute congestion issues and will reward Smart and V2G charging for congestion avoidance.

d. Our analysis indicates a combination of nascent technology and scale production would reduce V2G hardware costs significantly. This must be achieved to permit V2G to operate profitably outside of niche areas and allow the technology to make a contribution to decarbonisation.

e. Commercial models must be developed that allow the hardware cost to be depreciated over long periods of time.

f. The current testing and participation regime for Balancing Services (predominantly Firm Frequency Response) results in prohibitively high costs for providers of domestic DSR. National Grid ESO should work with industry to develop innovative ways to meet the SO requirements, increase liquidity in Balancing Services markets and drive value for the end consumers.

g. To reduce concerns about range anxiety, consumers should have access to high-range EVs and have ample rapid charging availability. Business models will need to be developed to reduce customer concern about V2G-based adverse impacts on the battery. Feedback issues (such as larger batteries reducing plug-in times) will need to be evaluated as the sector develops.

h. The net positive contribution that Smart and V2G charging can make to GB Power system costs should be taken into account when considering support which allows the sector to become established. Long-term revenue certainty (such as provided by FITs to the PV industry) could be explored as a means of supporting early adopters of V2G.

Acknowledgements

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Contents

Glossary

Term	Explanation
Arbitrage	Net revenues generated by V2G selling electricity at a higher price than bought. This can be realised by selling electricity to an external party or by offsetting home electricity demand allowing to shift some of this demand to times of lower electricity prices.
Commercial EV	An EV used for commercial purposes. This includes e.g. fleets of delivery and taxi companies as well as car rental services. Commercial EVs differ from Residential EVs in terms of typical EV models as well as in terms of their driving and plug in patterns.
Customer	Business party for which products and services are developed and offered. This can be for example the EV owner (in the case of offering a service to reduce the EV owner's electricity bill) but also the System Operator (in the case of offering System operator services such as Frequency Response) or another stakeholder of the electricity system.
DNO services	Services offered to the electricity Distribution Network Operator (DNO). DNOs are beginning to develop markets for services helping them to operate the electricity distribution grid, such as local congestion management.
DTU	Demand Turn-Up is a service procured annually by National Grid ESO to help manage short term energy imbalances by paying I&C consumers to change their operating patterns. National Grid ESO is not procuring DTU in 2019 after a review of the service (https://www.nationalgrideso.com/balancing-services/reserve-services/demand-turn?market-information).
ENTSO-E	European Network of Transmission System Operators - electricity
FFR	Firm Frequency Response is the monthly tendered market used by National Grid ESO to commercially procure frequency response services
Import savings	Savings incurred by EV owners on their electricity bills as a consequence of shifting their electricity consumption to times of lower electricity prices via Smart Charging.
Peak day	The day which has the highest electricity demand of the year. Usually this day is in the winter months.
Plug-in rate	The percentage of hours per day for which the EV is connected to the EV charger.

Term	Explanation
Residential EV	An EV connected to a residential charger and used by the household..
Smart Charging	The percentage of hours per day for which the EV is connected to the EV charger.
STOR	The time and rate at which EVs charge is adjusted according to the needs of the electricity system while still satisfying EV drivers' driving requirements.
System Operator	The operator of the electricity transmission system. In Britain, The System Operator is National Grid ESO.
System Operator services	Services offered to the electricity transmission system operator to maintain frequency and voltage of the electricity grid within the statutory limits. Such services include Frequency Response, Reserve and Reactive Power.
TRIAD	The Triads are the three half-hour settlement periods of highest demand on the GB electricity transmission system between November and February (inclusive) each year, separated by at least ten clear days. National Grid ESO uses the Triads to determine TNUoS demand charges for customers with half hourly meters.
TRIAD Avoidance	The act of forecasting a likely Triad day and reducing demand or increasing onsite generation in order to minimise the calculated TNUoS demand charges for the following year. This has the benefit of avoided cost to the consumer, and avoided need for peak investment or constraint for the system operator.
Unmanaged charging	EV drivers plug in at the time of arrival and charge their EV at the maximum charger capacity until the EV battery is fully charged, without reacting to any signals or needs of the power system.
V2G	In addition to Smart Charging Capabilities, EVs can export electricity from their batteries back to the grid.

Introduction

Introduction

Vehicle-to-grid (V2G) technologies are expected to play a key role in the decarbonisation of Britain's transport and energy systems. Connecting millions of EVs and coordinating their charging and discharging would minimise the costs of EV charging while allowing the grid to balance the integration of high levels of variable renewable energy sources.

This feasibility study V2GB - Vehicle to Grid Britain is part of the Vehicle-to-Grid competition, funded by the Office for Low Emission Vehicles (OLEV) and the department for Business Energy and Industrial Strategy (BEIS), in partnership with Innovate UK.

Drawing on the diverse expertise of consortium members Nissan, Energy Systems Catapult, Cenex, Moixa, Western Power Distribution, National Grid ESO, and Element Energy, the project explores both near term niches and enduring large-scale opportunities for V2G to play a role in a flexible energy system in Britain.

The project has four primary objectives.

Assess the long-term market opportunity

To assess the potential size of the market for V2G in the UK in the long-term, by establishing the underlying drivers for market needs. This fills a gap in stakeholder understanding of the long-term viability of V2G, distinguishing V2G from other future sources of flexibility and evaluating the size of the opportunity across several scenarios.

Identify early opportunities

Understand the potential customers of V2G and identify the most promising archetypes. Evaluate possible V2G revenue streams in the near term and identify which ones offer highest revenue over the short term. Perform a detailed evidence-based analysis of key customer and revenue stream combinations to quantify likely near term revenues that V2G can capture.

Getting started

The study identifies and analyses business models and value chains to understand how V2G should be structured to be commercially viable.

Support scale up

The study will explore pathways for scaling up a V2G business to play a full role in a flexible and efficient energy system. The project will determine what performance thresholds are required to maintain and grow the market as it transitions from early adopters towards representative EV clients.

Long-term market revenues and drivers

2.1 Introduction

This chapter summarises the work performed by the Energy Systems Catapult under the Innovate UK funded project V2G-Britain. Work Package 1 (WP1) investigates the long-term market value and where V2G might be applicable in a wider energy system context. WP1 is focussed on the 2030 horizon and is separated into three deliverables with each deliverable including a different part of the analysis.

The first report from WP1 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.

2.2 Literature review

The literature review identified the services that are accessible by V2G and these are shown in the diagram below.

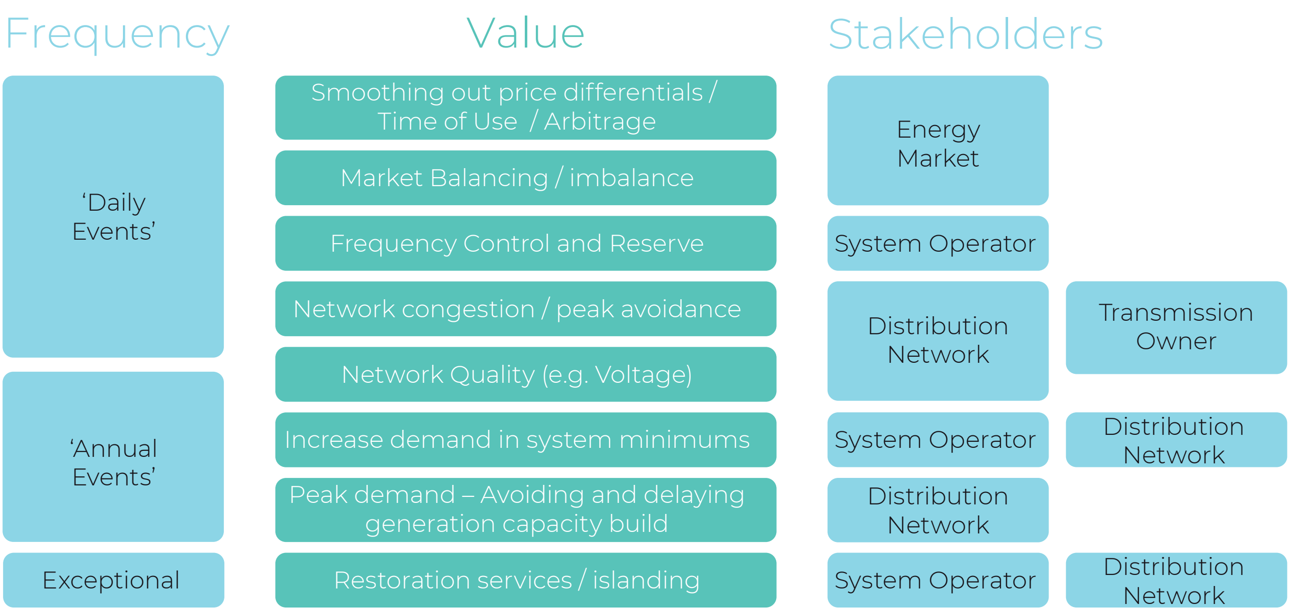


Figure 1: value streams accessible by V2G

The literature review has also identified competing flexibility providers to V2G and a series of other challenges. The principle flexibility competition comes from peaking plant, grid-connected electricity storage, in-home heat storage, residential backup boilers and interconnectors.

2.3 Energy system modelling

The subsequent analysis draws on the key drivers and dependencies identified from the literature review and 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. 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 enable the analysis, V2G has been incorporated into a whole energy and transport system modelling capability. This approach has identified some valuable high-level conclusions about the impact of V2G on the whole energy system and the role it can play. The analysis has not taken account of additional cost of equipment required to enable V2G nor the impact on battery degradation.

The role of V2G was assessed through two main scenarios; in the baseline scenario the energy system in 2030 is modelled which is consistent with a trajectory to meeting the UK's 2050 greenhouse gas emissions targets. The second scenario was a sensitivity analysis considering the impact that high intermittent generation volumes will have on the system. Two alternative vehicle charging strategies were also modelled for each of the scenarios: an unmanaged charging case, where it is assumed that V2G is not deployed; and a managed charging case. These alternative charging strategies were used to understand the potential impact that V2G could have on the energy system. The main conclusions from the modelling work were:

V2G reduced the requirement for additional grid-connected electricity storage in 2030 and the need to use that storage.

Figure 2 and Figure 3 show both the injection into and withdrawal from V2G. In some cases, V2G is not used because the available capacity is not there, i.e. the vehicle is not at the required state of charge or plugged-in. In both days (peak and winter) during the overnight periods energy is injected into the aggregated V2G storage. During the summer day, the utilisation of vehicle storage capacity is close to zero; this is a result of low electricity demand.

2.3 Energy system modelling cont...

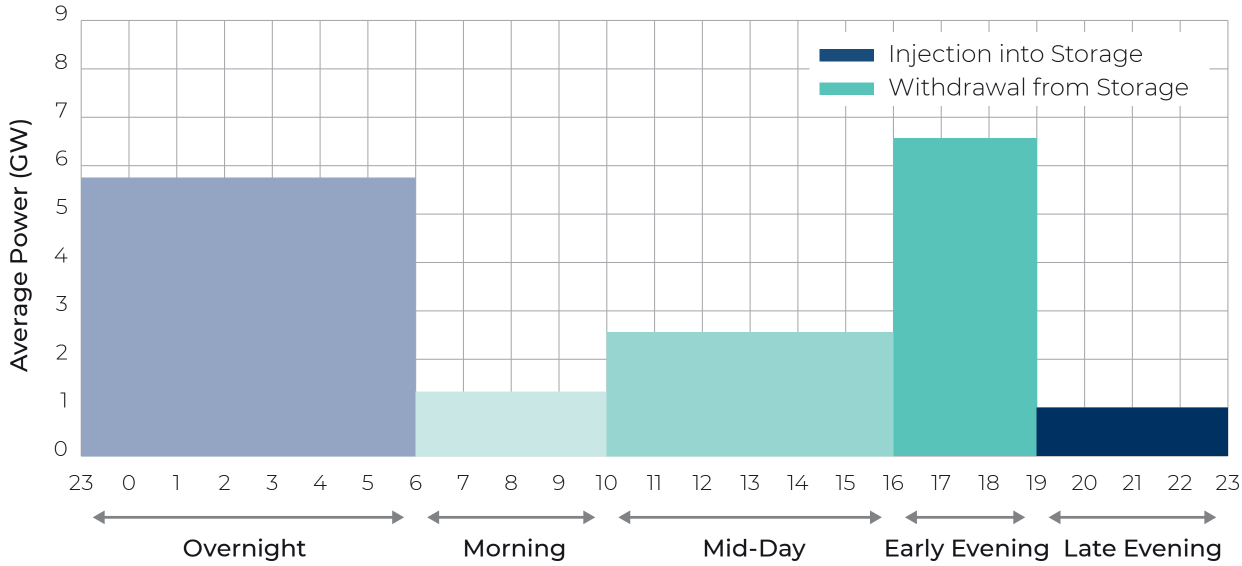


Figure 2: 2030 – V2G injection and withdrawal during peak day – Baseline scenario

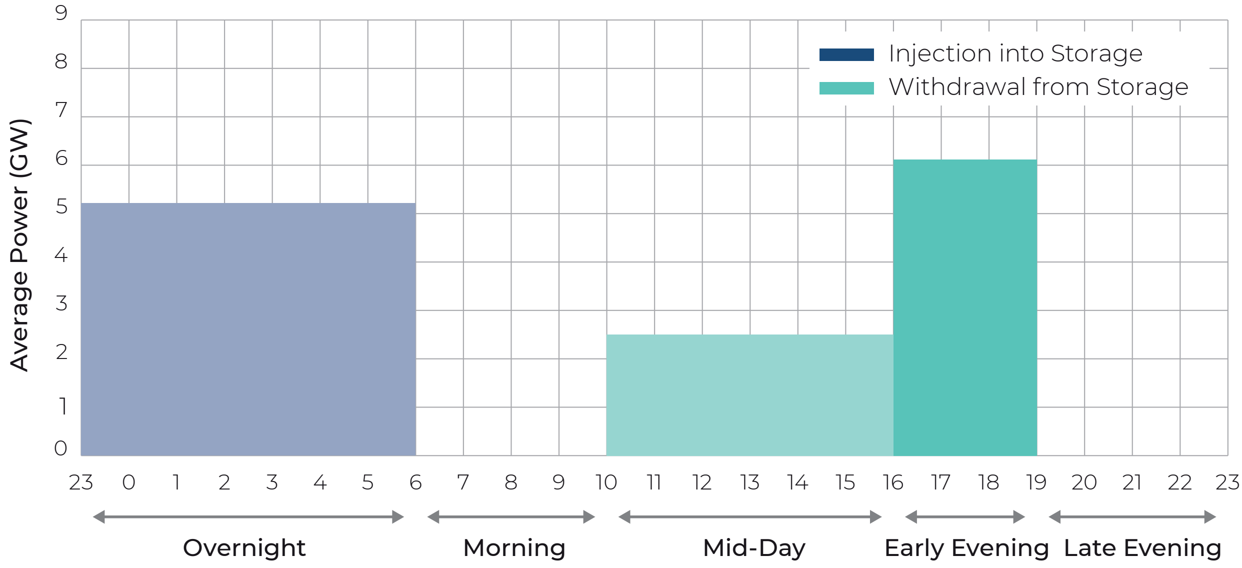


Figure 3: 2030 – V2G injection and withdrawal during winter day – Baseline scenario

Figure 4 and Figure 5 show the injection and withdrawal from V2G in the peak and winter days. Solar power is not available overnight and flexible generation is reduced overall in the high flexibility scenario, more specifically in the overnight period it is reduced by 35%. Therefore, there is no available energy to fully charge and utilise V2G in the winter overnight period, which leads to reduced utilisation during the day.

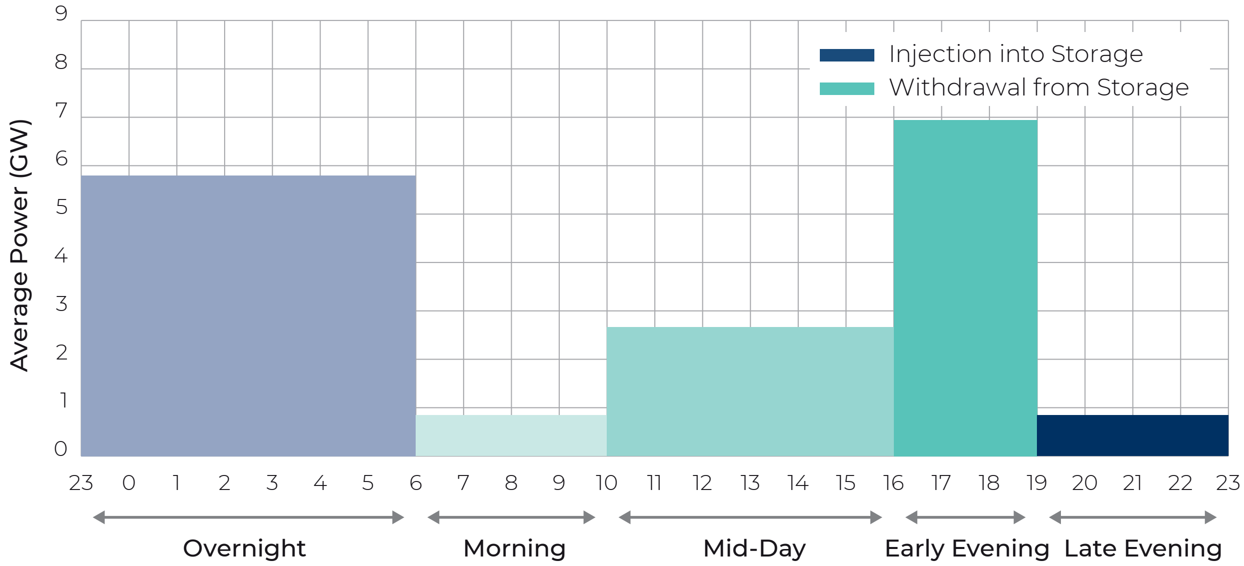


Figure 4: 2030 V2G injection and withdrawal during peak day – High flexibility scenario

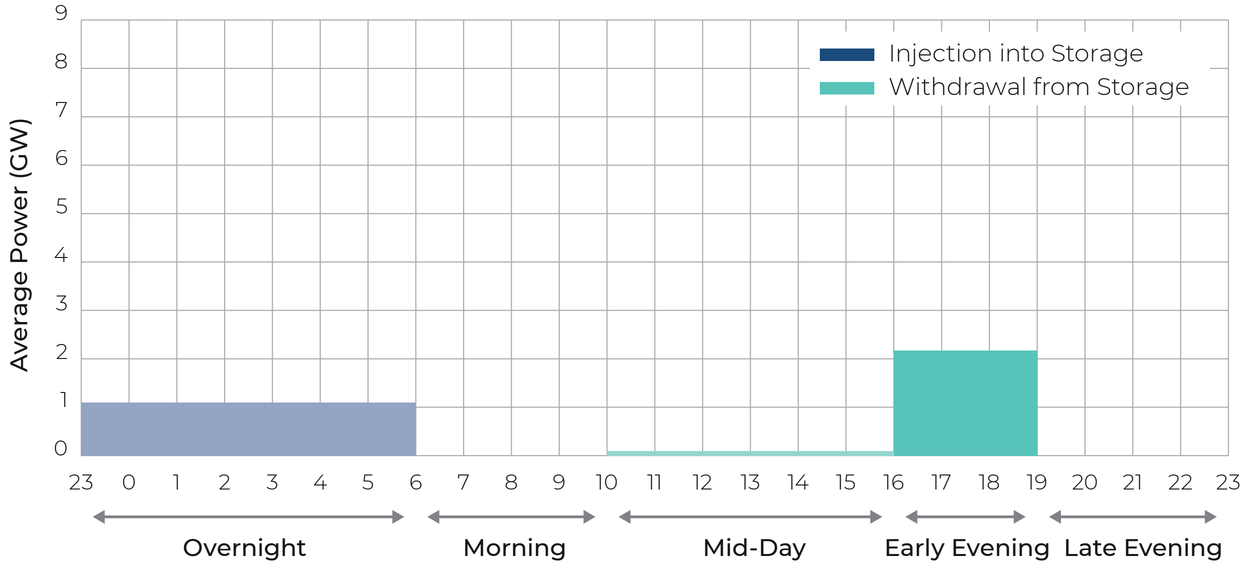


Figure 5: 2030 V2G injection and withdrawal during winter day – High flexibility scenario

When V2G was deployed, the installed capacity of flexible generation plants, e.g., Combined Cycle Gas Turbines (CCGTs), was reduced.

Furthermore, the CCGTs that were present had a higher utilisation levels when V2G was deployed.

2.3 Energy system modelling cont…

The differences in the installed electricity generation capacity and annual electricity production between the case where V2G is deployed and when V2G materialises are seen in Figure 6. The installed capacity of plants with low flexibility and intermittent generation sources remain the same in both cases, whereas flexible generation installed capacity is higher in the unmanaged charging case. The same can be seen in the annual electricity production. The electricity generated from flexible plants is higher when V2G is not deployed (Figure 7).

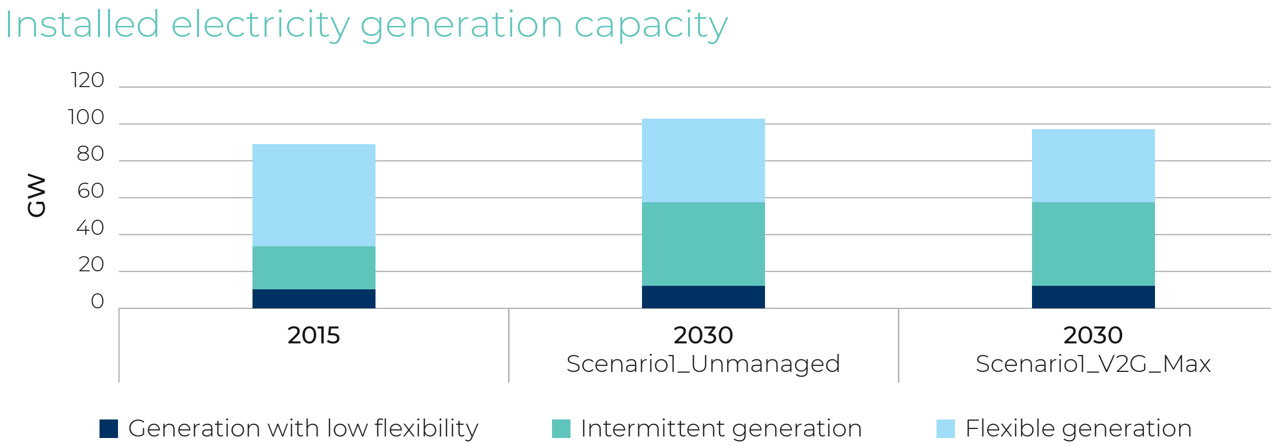


Figure 6: 2030 – Installed electricity generation capacity – Baseline scenario, Unmanaged charging and V2G cases

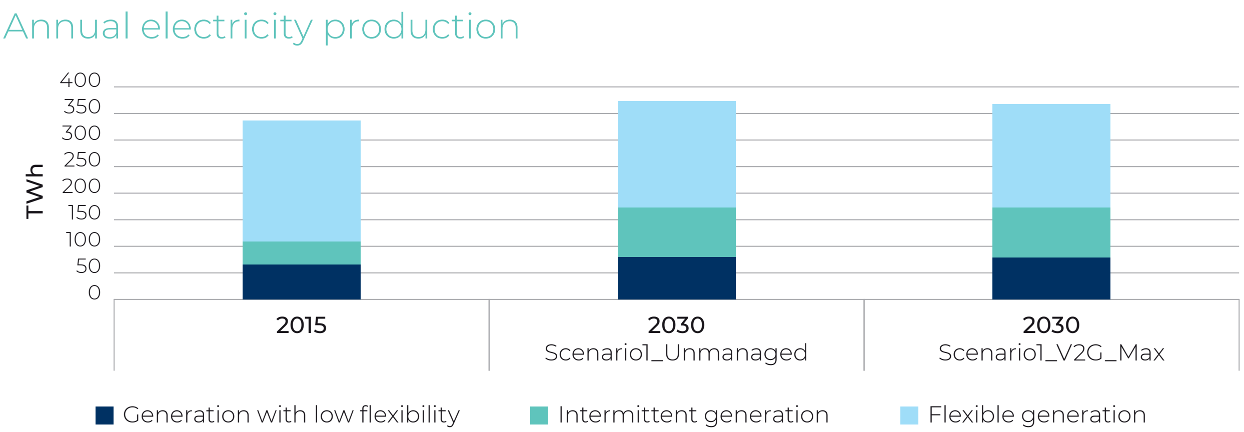


Figure 7: 2030 Annual electricity production – Baseline scenario: Unmanaged charging and V2G cases

The impact of V2G on the installed capacity and generation from flexible plants is seen in Figure 8. The installed capacity is higher in the unmanaged charging case by 5GW, generating 2% more energy. Even though the flexible generation installed capacity is higher, the utilisation of the plants is lower when compared to the V2G case.

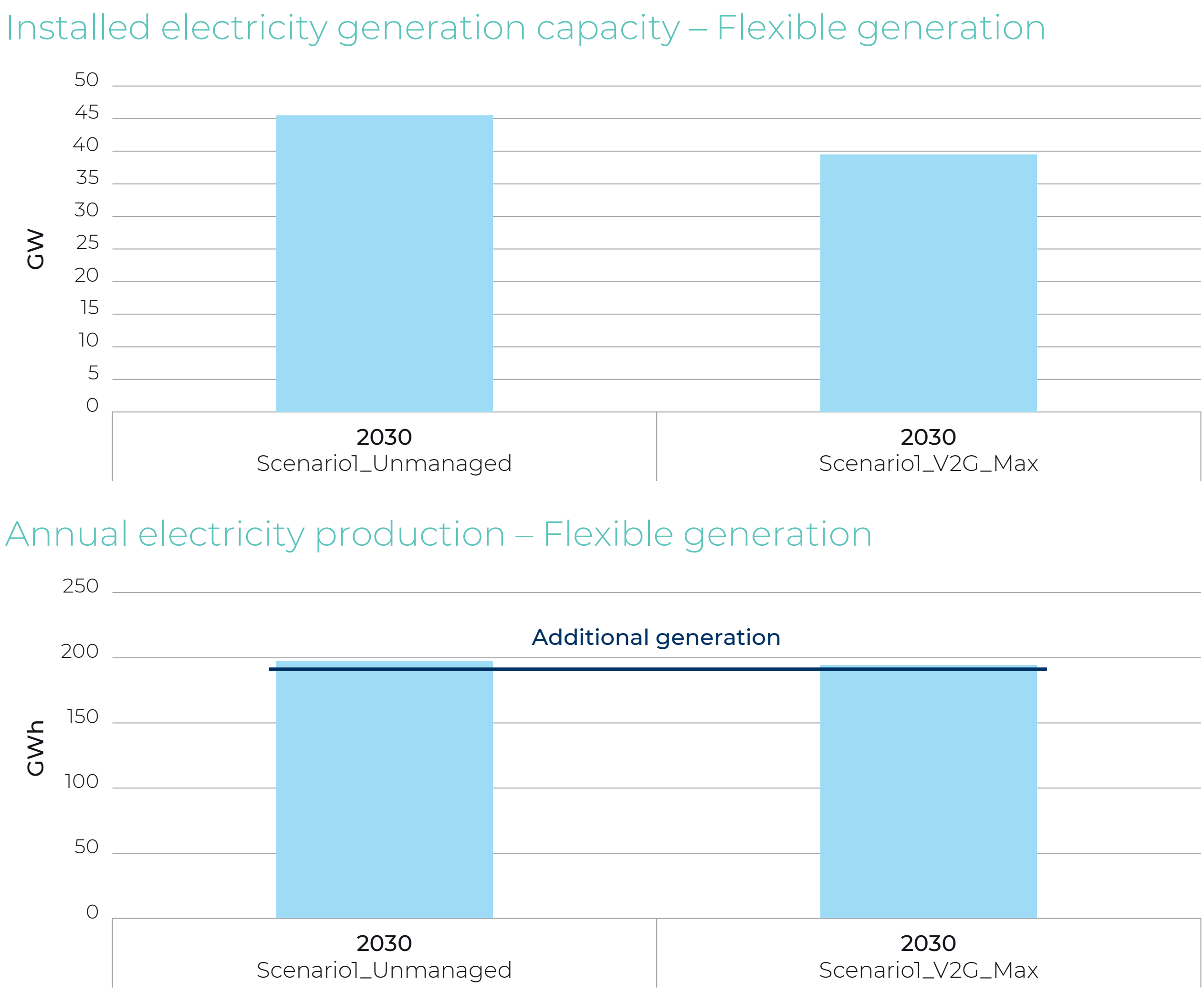
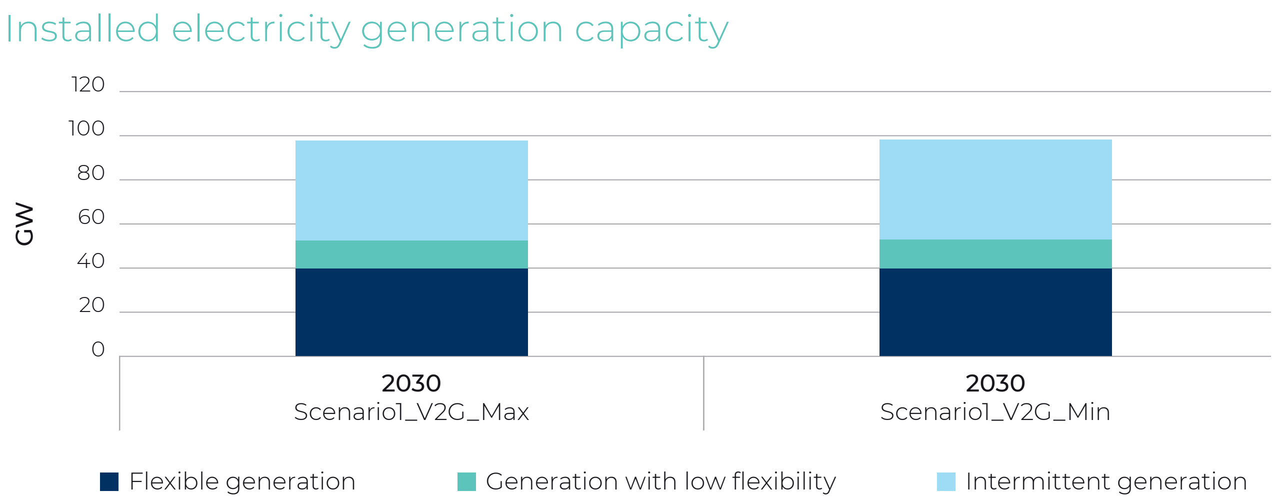


Figure 8: 2030 – Installed electricity generation capacity (top) and annual electricity production (bottom) from flexible plants – Baseline scenario: Unmanaged charging and V2G

There are diminishing returns associated with increased availability of V2G i.e. the flexibility market is finite.

2.3 Energy system modelling cont...



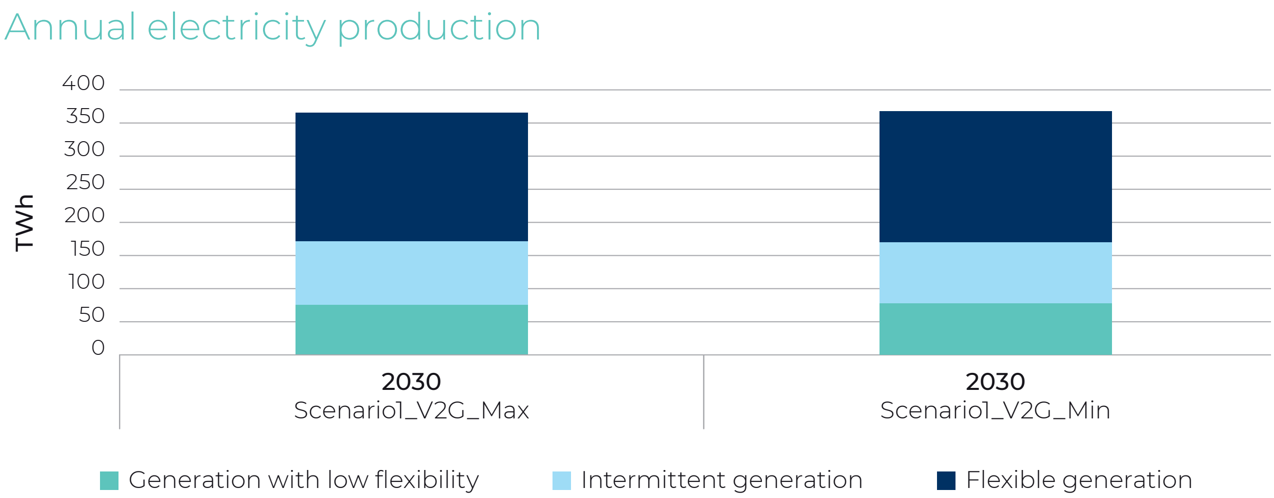


Figure 9: Installed electricity generation capacity (top) and annual electricity production (bottom) – Baseline scenario: V2G Max and Min cases

Based on this assessment, it suggests that there will be an enduring value from variable/smart charging and V2G to offer services to the electricity supply chain and that EVs are technically suited to do so, provided they are connected to the electricity system. However, there are important considerations to be made on how this value is enabled, from the inducements that may be offered, through to the market mechanisms and information exchanges that will be needed.

2.4 V2G market potential

2.4.1 Market Arrangements

The viability, and potentially the necessity of, flexibility adopted by EVs will be influenced by the way energy and network costs are billed to consumers, the way services to the energy supply chain are rewarded and the market arrangements that accompany them.

There are many developments that are underway now by Ofgem, the industry regulator, network companies and the System Operator that may allow EVs to better engage with the electricity system including the definition of services, network charging arrangements and market frameworks.

2.4.2 Market opportunity for smart/variable charging and V2G

There is undoubtedly value in charging flexibly and offering flexibility in the short term, which is likely to be sustained for a period of time. As the number of EVs grows, some relatively low volume services could reach saturation. The point at which this might happen is uncertain and will be based on the number of EVs available, participating and importantly competition from other flexibility providers. This is particularly the case for many System Operator services that are less locational specific, such as frequency response and reserve.

Ultimately, smart/variable charging and V2G can offer similar services and large numbers of EVs in smart/variable charging mode, aggregated together, are equivalent to V2G. A key determinant is therefore the number of vehicles participating and whether they are both connected to the electricity system and are able to be flexible. As an estimate of the relative size of markets, the table below shows some indicative volumes of particular services broadly based on current volumes and an expectation that, although service volumes will change, their relative size and how they compare with each other are likely to remain more stable.

	Despatch			Indicative service volumes			Despatch		
Service	Price Signal	Automatic	Instructed	Service equivalent Power (MW)	Service equivalent Power (MW)	Typical Frequency of call	Price Signal	Automatic	Instructed
Frequency Modulation		Yes		500	small	Continuas	small	small	small
Primary/ High Response		Yes		2,200	13.10	Assuming 5 events / week	2.20	0.013	4.8
Reserve (10 minutes)			Yes	3,000	1,000	Assuming 2 reserve call / day	3.00	1.00	365.0
Reserve (15 minutes)			Yes	3,000	1,500	Assuming 2 reserve call / day	3.00	1.50	547.5
Reserve (30 minutes)			Yes	3,000	3,000	Assuming 2 reserve call / day	3.00	3.00	1095.0
Time of Use / Arbitrage	Yes		Yes	10,000	2,500	Daily/ habitual	10.00	2.50	912.5
Gen Peak avoidance	Yes		Yes	1,000	2,000	Seasonal - 30dys year	1.00	2.00	730.0
Network congestion (e.g. avoiding evening peak)	Yes		Yes	3,000	3,000	Daily / habitual	2.20	3.00	1095.0

Table 1: Summary of value areas that EVs could access and indicative volumes of service

2.4 V2G market potential cont...

Note that the services Reserve (10 minutes), Reserve (15 minutes), Reserve (30 minutes) described in the table above are different ways that a reserve service could be defined. For example, 3 successive uses of Reserve (10 minutes) would provide an equivalent Reserve (30 minutes) service.

An important observation is that, during periods of time when many vehicles are charging, small variations in individual EV charging will deliver the service volumes needed and therefore there is less opportunity for V2G to differentiate from Smart/Variable Charging. Conversely, when there are fewer EVs charging, those EVs that are connected have a greater opportunity to differentiate V2G capability.

V2G can however differentiate from variable charging where they can reduce the underlying demand on the electricity system at peaks that would otherwise drive generation and network capacity investment.

2.4.3 Service requirements and alignment with EV charging

EVs present a tremendous and sizeable resource to provide flexibility resources however they also represent a significant impact.

Some costs could be substantial and unnecessary, for example mass responses to half hourly time of use price signals. Currently, the way the System Operator manages rapid changes in demand and uncertainty is by procuring additional reserve or imposing restrictions on rates of change. EV charging has the potential to introduce rapid changes in electricity demand if their charging behaviour is not co-ordinated to some degree and therefore affect the reserve volume requirement adversely.

Equally, service definitions could be designed to exploit EV capability as opposed to EV charging fitting around the services. For example, reserve service definitions and the way services are aggregated could be tailored to capitalise on the opportunity.

If the majority of charging is non-rapid (i.e. <7kW), the greatest opportunities for EVs to provide value to the electricity supply chain are overnight and during the working day when a large population of vehicles are stationary. 'Away from home' charging inducements and facilities will be essential in capitalising on this opportunity (cp. Figure 9 showing the available V2G capacity in various time slices in the baseline scenario). The calculated available capacity of V2G in each time slice, is presented in Figure 9. It is a result of the charging profile of the vehicles and the aggregate available capacity.

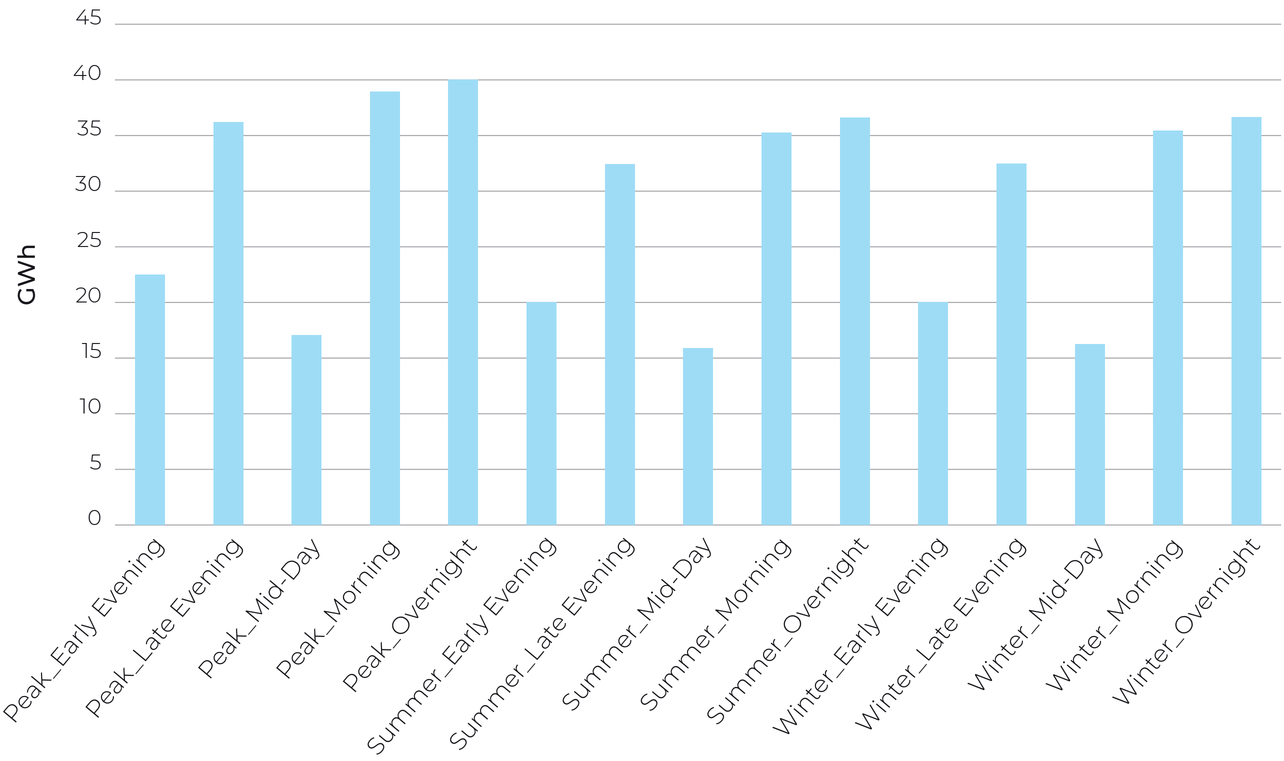


Figure 10: 2030 – Available V2G capacity in each time slice – Baseline scenario

2.4.4 Natural behaviour and inducements to adapt behaviour

The value obtained from EV storage capability and costs incurred by charging can be presented to EV users as a combination of benefits, charging costs, or reduced charging costs. It is unclear though, what the best way of combining the offerings to EV users is. Careful design of EV charging tariffs and levels of control will be key to achieve the right blend of incentives to deliver the EV amenity efficiently. Developing business models, ownership models and EV supply contracts terms will all play a role in building on and expanding knowledge in this area. A significant element of this is the way EV charging, and the services that they could offer, are aggregated and how information is exchanged between supply chain actors. Aggregation has multiple aspects including; market rules, roles and responsibilities, forecasting, despatching and paying for services.

2.4.5 Competition from other flexibility assets

Static storage, second life batteries and other flexible assets are likely to pursue the most attractive periods for flexibility service provision, which currently coincide with the times when the greatest proportion of EVs are mobile. Once investment in flexible assets has been made, there is likely to be competition to provide service at all times, which may depress service prices when EVs can contribute. It is likely, however, that local services, e.g. local network congestion management, will experience less competition and be confined to flexible assets at the residential level such as EVs and heat pumps.

2.5 Further work

During the course of WP1 whole energy system modelling and assessment, further areas were identified where more detailed analysis could derive additional insights. Findings and recommendations from WP1 were used in WP4. In summary these are:

- Use of more temporally detailed analysis of energy system operation (e.g. hourly resolution) over extended time periods to provide further insight in harnessing the flexibility that V2G can offer.
- Use of dynamic network modelling to investigate the energy flow between V2G and the network
- Sensitivity analysis around the level of intermittent generation and electrification of non-EV loads
- Sensitivity analysis around the available capacity of V2G, the impact of varying vehicle battery size on V2G opportunity
- Incorporating learnings about mainstream consumer EV usage and charging behaviour and the potential impact on V2G availability
- More granular analysis of fleet utilisation, vehicle battery sizes, battery degradation impacts and charging strategies to inform understanding of the opportunity for V2G amongst different types of fleet.
- Accounting for risk and uncertainty in key supply factors (e.g. short-term wind availability) and vehicle availability factors (e.g. due to journey variations)
- Enhanced modelling with data on V2G technology costs to inform business model feasibility assessments

Aggregation approaches and service definitions are critical in exploiting EV potential fully. For the former, understanding the risk reduction potential of pooling EV V2G storage capability during the day and year, at a national and local level will be invaluable. In the latter case, removing market barriers to Frequency Response and Reserve services could allow greater value to be extracted.

26

Near term revenues & target opportunities

3.1 Introduction

This chapter contains a summary of some of the work performed by Cenex in WP2 under the Innovate UK funded project V2G-Britain.

The work seeks to provide an evidence-based assessment of the realistic annual revenue of reasonably representative groups of people for V2G in the GB within the next five years.

The work also aimed to identify the early opportunities for V2G (in terms of both customers and markets) and derive revenue values for the most promising cases.

To this end, the work undertaken sought to:

- Use actual GB based data of EV charging and driving behaviour
- Provide some assessment of all possible revenue streams for V2G in GB
- Develop archetypal customers for V2G and provide a full assessment of the most promising cases
- Model the key archetypes against revenue streams using a half-hourly simulation of charging and discharging against market prices
- Obtain 'best case' revenue for the V2G proposition given varying sets of conditions

One of the challenges of evaluating the potential revenue for V2G in GB is that in order to derive accurate and justifiable results, the operation of the V2G unit within the given market needs to be modelled with a reasonably high granularity (e.g. half-hourly). This is because value in many of the relevant markets and services are highly time dependent. This, coupled with the fact that V2G provision using an EV is intermittent, means that detailed data sets giving EV availability and state of charge are required to do the best assessment. Every effort has been made to obtain the most suitable data sets, and appropriate modelling assumptions have been applied to support the analysis of the data.

3.2 EV Driver Archetypes

3.2.1 Introduction to EV Driver Archetypes

When developing a business model for a product or service, it is important to first consider two aspects:

1. The target customer(s).
2. The value proposition(s).

For development of existing products, it is possible to consider the existing customers, however where a product or service is entirely new or constitutes a significant change away from similar products, it is necessary to start from scratch and hypothesise on the likely customer groupings who would be interested in the product.

EV driver archetypes are fictional character groupings created to represent customers within a specific demographic. Typically, when developing an archetype, the following questions would be considered:

- Who are they?
- What do their lives look like?
- Where are they located?
- How do their behaviours impact your product?
- What are their aims, drivers and values?
- How and when do they make purchasing decisions?
- Where, when and how would they use the product?

By creating EV driver archetypes, it is then possible to analyse their behaviours in order to gain insight into the features or value propositions which would appeal to different groupings. It also enables us to make an initial assessment of the suitability of the archetype for the provision of services via V2G.

When thinking of archetypes, it is most intuitive to think of the EV drivers themselves. However, in the case of V2G it is the V2G charge point which is the asset that will provide services and earn revenue. How this revenue is then shared between various stakeholders is down to the business case and contractual arrangements. For this reason, each archetype is from the perspective of the charge point but making strong reference to the usage of the charge point by the EV driver. This approach enables us to include public charge points that may have multiple users or other complex arrangements.

Cenex has been actively involved in V2G research activities since 2013. During this time Cenex has gained experience of a range of potential use cases for V2G. This knowledge was extracted through a workshop and used to form a list of potential EV driver archetypes. These archetypes were then given further detail based on hypothesised characteristics which were then validated, where possible, using a mixture of Cenex and public data.

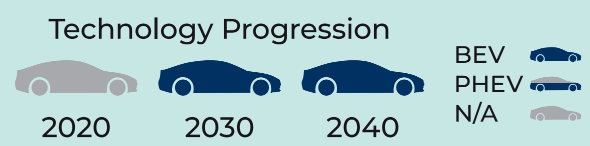
In total 35 EV driver archetypes were created under the categories of Residential and Commercial. An example of a Residential EV driver archetypes is given in Figure 10.

3.2.1 Introduction to EV Driver Archetypes cont...

The Retired Professional

The Retired Professional has a high-income background and is socially and environmentally conscious. They have PV on their home and are interested in the synergy with their midsized EV and off-street home V2G charger. The EV is used mostly for short or medium journeys during the day and is plugged in when not in use.

Key Information:	
V2G Location:	Home
No. of EVs using charge point:	1
V2G Availability:	60-100%
Potential no. in the UK:	0-1k



Primary User	
Age Range:	over 60
Income Bracket:	Basic Rate
Employment Status:	Retired
Vehicle Ownership Type:	Owned
Battery Life Conservation:	High
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Medium
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	20-40%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	Yes
Parking Location:	Off-street

Figure 11: Residential Archetype Example

3.2.2 EV Driver Archetype Assessment

As mentioned previously, the archetypes were constructed from the perspective of the V2G unit. However, other important factors for the archetype are:

- Users of the charge point
- Type of vehicles plugging in
- Usage pattern of the charge point and EVs
- Location of the charge point

These factors are important since they determine the characteristics (such as timing and volume) of flexibility available for the charge point. In total, twenty-two key data points were used in the assessment of each archetype. Each factor was scored on a simple scale and the sum used as a measure of the applicability of the EV driver archetype for V2G. Whilst this score has no real absolute meaning, it enables the relative value of each archetype to be determined. Figure 11 shows this assessment of the home archetypes against the applicability to V2G.

Home Archetypes Assessment

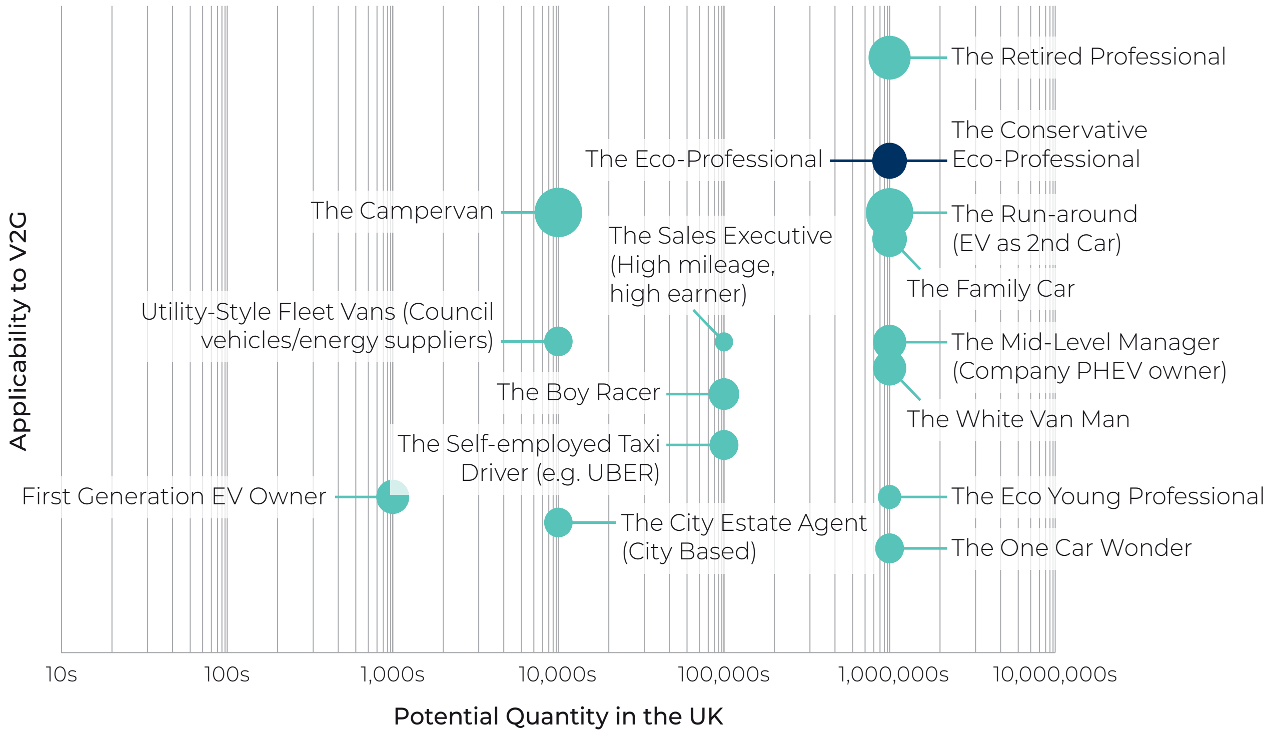


Figure 12: Assessment of residential archetypes. Bubble size represents the percentage of time EV plugged in and not charging.

From this analysis a short list of 'high value' EV driver archetypes was produced based on the following criteria:

- the potential quantity in GB by 2020,
- the applicability to V2G,
- the percentage of the day the EV is plugged in and not charging

These are presented in Table 2.

Archetype	Location of V2G charge point	Potential quantity of archetype in GB
Council fleet - Pool cars	Commercial	10k-100k
EV Car clubs	Commercial	10k-100k
Company car park	Commercial	>10M
The Retired Professional	Residential	1M-10M
The Eco-Professional	Residential	1M-10M
The Run-around (EV as 2nd Car)	Residential	1M-10M

Table 2: Archetypes Short Listed for Modelling

3.3 Revenue streams

3.3.1 Introduction to Types of Services V2G Can Provide

In order to provide flexibility services, V2G chargers can either be managed as stand-alone units or in local clusters. Distributed V2G units can also be aggregated to allow them to be managed and operated as groups for non-geographically sensitive energy services such as frequency response (see Figure 12 below).

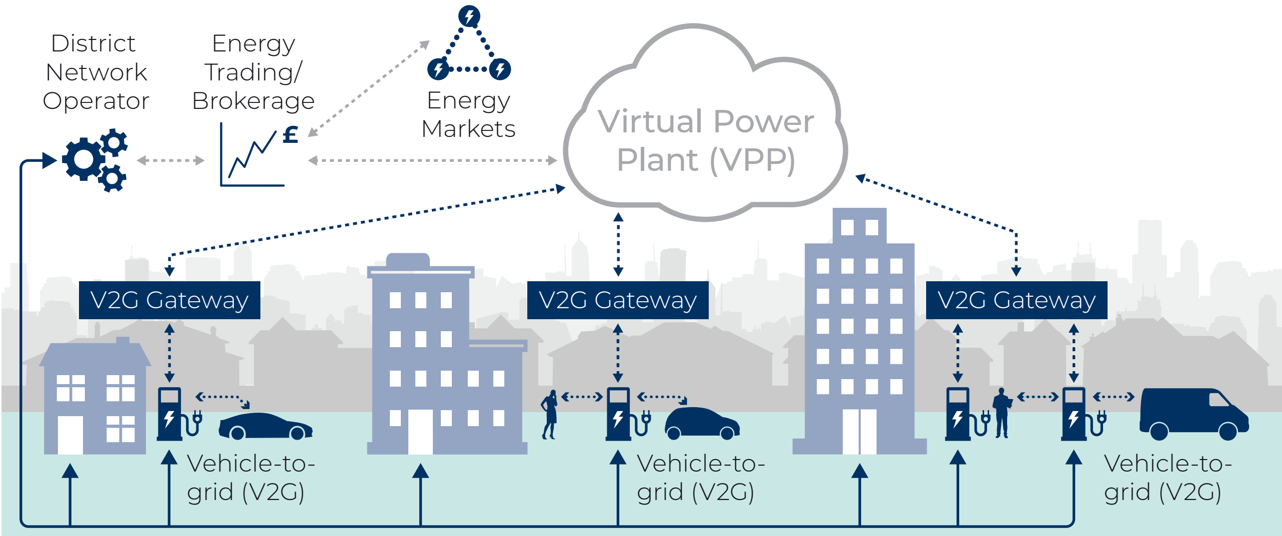


Figure 13: Aggregation of V2G units to trade electricity to energy markets via a VPP

V2G can therefore be used to provide a range of services at different levels in the energy system through demand shifting, exporting (discharging) or a combination of the two.

3.3.2 Core Services and Associated Financial Value

For the purposes of this analysis Cenex has identified 24 potential value streams for V2G. Each value stream was scored for suitability for V2G and ranked in order to provide an indication of the priority with which the service should be considered. The scoring criteria used for this assessment consisted of:

- Readiness for DSR.
- Technical Requirements.
- Minimum Capacity
- Service 'Stackability' (the ability to provide multiple services)
- Current Value
- Future Value

Each potential value stream was scored against the criteria. Figure 13 provides a graphical representation of the suitability for V2G of the top ten ranked revenue streams, versus a high-level estimation of the annual revenue.

Comparison of Suitability of V2G Revenue Streams

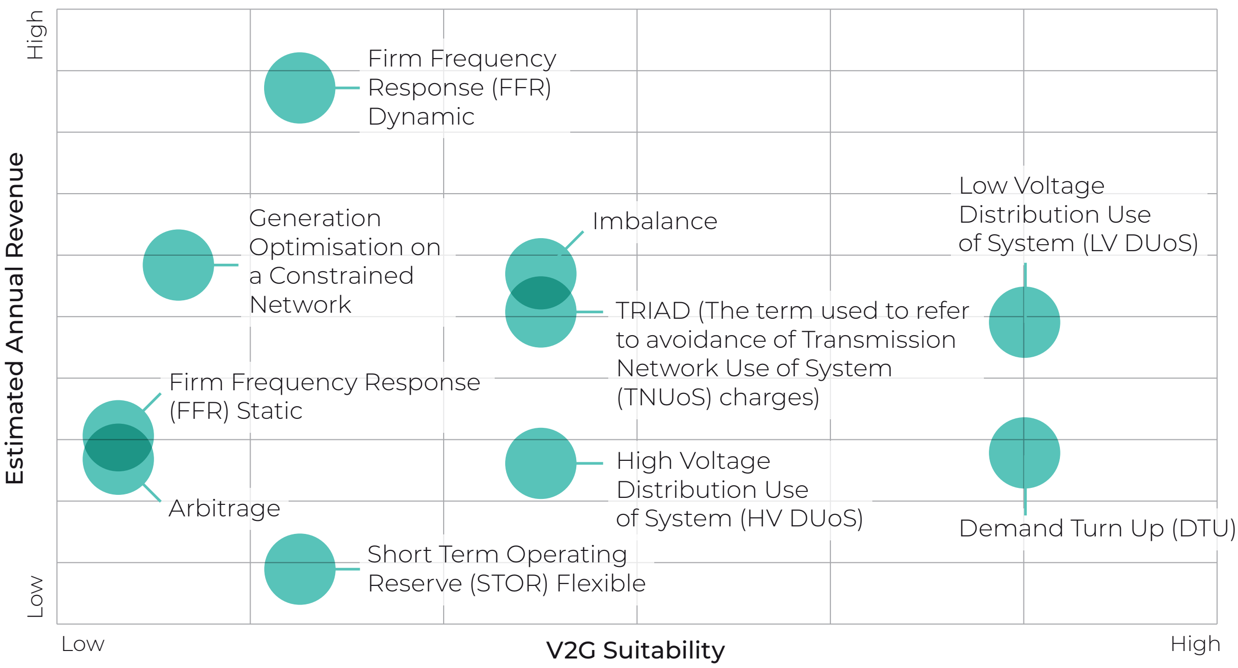


Figure 14: Comparison of Suitability of Top 10 V2G Revenue Streams

From this analysis, a short list of key revenue streams was produced that was taken forwards to the modelling work. DNO congestion management was excluded from the analysis since at the time very little information was available on this emerging market. It has however been subsequently included in WP3 and WP4. Further, given that our available data set for the customer archetypes are primarily residential focused, TRIAD avoidance was excluded, since residential customers are not currently exposed to this.

The short listed of key revenue streams are:

- Low Voltage (LV) and High Voltage (HV) Distribution Use of System (DUoS) charge avoidance
- Demand Turn Up (DTU) [1]
- Imbalance management
- FFR (both dynamic and static)
- Short Term Operating Reserve (STOR) – Flexible
- Energy price arbitrage

1 Despite the requirement for a negative reserve service, the volume procured and number of utilisations have fallen substantially since DTU was first procured in 2016. The offline dispatch process, long notice period for delivery and small volume procured were identified by National Grid ESO as the key barriers to increased utilisation of DTU in its current form: https://www.nationalgrideso.com/sites/eso/files/documents/EXT%20Demand%20Turn%20Up%202019.pdf

3.4 Modelling

The modelling for this work package has been performed using the Cenex REVOLVE model. REVOLVE is a perfect foresight optimisation model capable of simulating the charging/discharging behaviour of large numbers of EVs at half hourly granularity over a year.

Key Features:

- Simulates charging/discharging of up to a few hundred EVs
- Customisable constraints on max charging/discharging power to allow modelling of specific or generic V2G units
- Customisable constraints on max/min storage capacity of EVs to allow modelling of specific or generic vehicles
- Constraints on EV availability (plug-in times) and requirement to make journeys (energy demand)
- Modelling of:
    - charging/discharging losses
    - half-hourly varying import and export tariffs
    - flexibility of charging/discharging for the provision of grid services
- Simulation of local PV generation
- Optimises EV charging/discharging against behind-the-meter value streams and grid services
- Customisable warranty constraint modelling through optional limiting of maximum kWh of V2G provision per vehicle per day
- Evaluation of the impact of battery degradation costs on V2G revenue streams

Key data inputs for the REVOLVE model are:

- EV journey demand data sets
- EV availability data sets (a flag of plug-in status of each EV for each half hour)
- Half hourly demand data sets (for each charge point)
- Half hourly import and export tariff prices
- Grid service parameters and prices
- EV and charge point energy and power capacities and efficiencies

The model optimises the charging/discharging behaviour of individual EVs on a minimum cost basis using the import and export tariffs available to the EV. Whilst the model covers an entire year, it does this by optimising weekly blocks one at a time. Each EV in the model has an associated journey demand and plug-in availability data set for the year. It also includes the local electricity demand for the site or building(s) the charge point is connected to. The charge point is assumed to be behind-the-meter and so, by discharging the EV, the local demand can be offset.

The charge points in the model can also be aggregated up and offered to provide grid services. The model stacks the available flexibility inherent in the charge points to build up the grid service product window requirements. To provide a grid service, a minimum capacity (in MW) must be held in either an upwards or downwards (or both) direction, for the specified grid service periods. During the entire service periods, the model must also hold sufficient stored energy/demand reduction (or battery headroom) to meet a minimum length of call of the grid service product. Note that whilst this headroom/footroom is held, the model does not currently simulate the actual calls due to the additional modelling complication this adds.

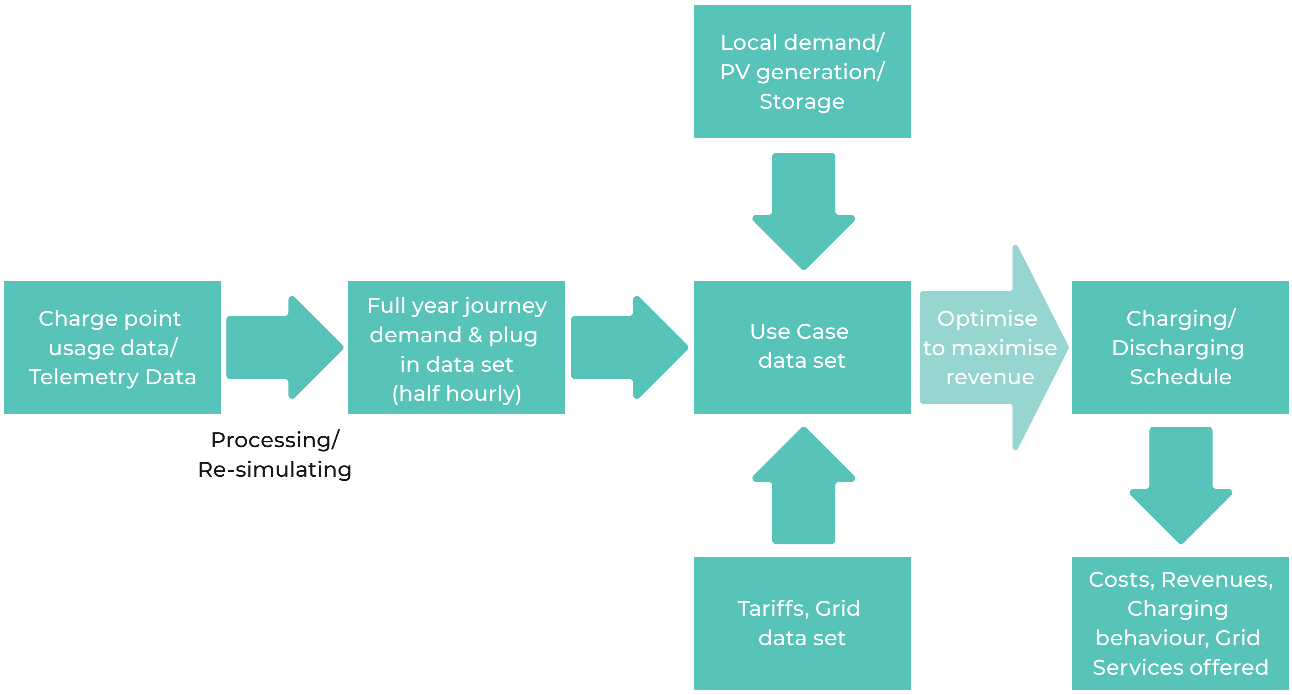


Figure 15: Cenex REVOLVE model diagram

Because the model is a perfect foresight model, it provides an upper bound on the revenue that can be earned through the V2G options modelled. In reality there will be deteriorations in the value through EV availability forecasting error.

In order to quantify the value provided by V2G, the model first performs an Unmanaged run. In this, all EVs charge up to full as soon as they are plugged in. This run is used to create an energy cost baseline. Subsequently, an Optimised run is performed. In this run the charging and discharging behaviour is optimised on the basis of minimum cost.

3.5 Use Cases

This section covers the different Use Cases that were used to define the model runs to be carried out. Each Use Case is made up of a combination of the following:

- Charge point data set (corresponding to a customer archetype)
- Local energy demand
- EV parameters
- Charge point parameters
- Import and export tariffs
- Grid services products and prices

3.5.1 Archetype Data Selection

Having identified the most promising archetypes, these were then matched to existing EV and charge point data sets. Data was obtained from the Electric Nation trial[2], the Ultra-Low Carbon Vehicle Demonstrator (ULCVD) (an Innovate UK trial capturing charging and journey data for EVs between 2011 and 2013) and from the 'Ebbs and Flows of the Energy System' (EFES) demonstrator (an early V2G demonstrator project).

After matching the data sets to archetypes, the data was cleaned and filtered. Charge point data sets were limited to only those with sufficient data quantity and quality. This led to such a small number of data set for each archetypal customer, that in order to produce a sufficient level of diversity in the portfolio (required for offering grid services) the data sets need to be combined into a single Combined Archetype.

The make-up of this resulting combined archetype is shown in the following chart.

Combined Archetype: 60 Charge Points

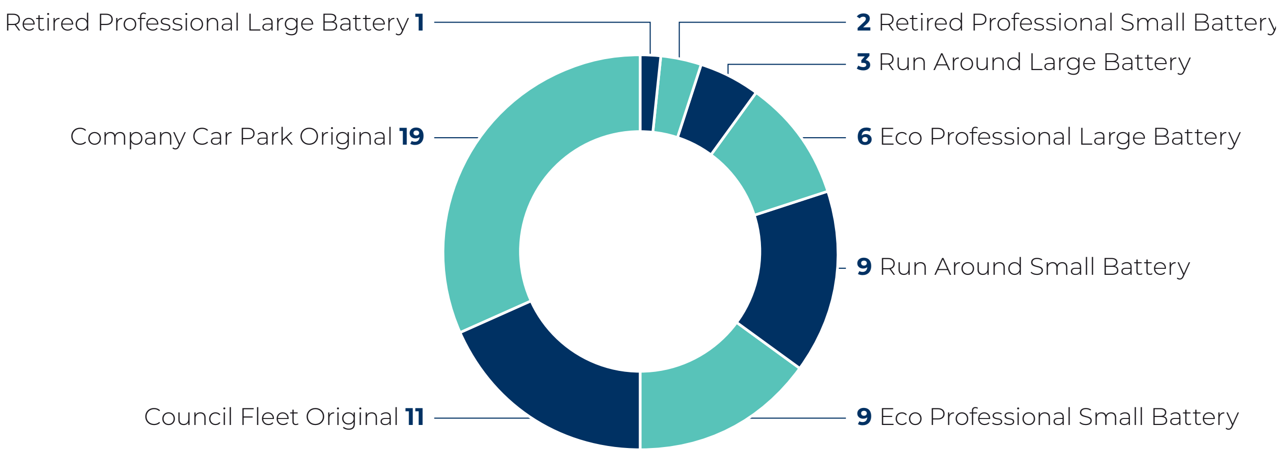


Figure 16: Components of Combined Archetype

2 www.electricnation.org.uk

3.6 Use Case evaluation

Several different use case configurations were run through the model and a few are presented in this section. Note that the modelling is based on current market arrangements of services. However, these are changing (i.e. National Grid ESO's reform of flexibility services as set out in the ESO's Forward Plans[3], changes to Balancing Mechanism access and connection regulation by Ofgem, as well as the emergence of DNO flexibility markets). These changes might lead to different assessments in the future.

3.6.1 Base Case Run

The base case run consisted of the combined archetype, FFR, STOR and DTU grid services and the Economy 7 tariff. Figure 16 shows the average annual cost and savings per charge point for Smart Charging and V2G. This is calculated from the results of the Unmanaged, Smart and V2G model runs. The import cost (red) in the figure represents the average annual energy cost across the 60 customers in the archetype. This includes the energy used in the building and for charging the EV. The import savings (black) show incremental savings made by employing first the Smart uni-directional charger and then the bi-directional V2G charger. The cost of transitioning from a single rate tariff (which is cheapest for most customers) to an E7 tariff (necessary for smart charging optimisation) is also shown. Savings from the Smart Charger are due to delaying charging of the EV to off-peak periods. It should be noted that in this case, all these savings could be realised by a simple timer charging solution. The additional import savings in the V2G case are due to a small amount of discharge from the EV to offset the building demand during peak rate periods. The value is small due to the combination of a relatively small (7p) tariff spread, round trip efficiency losses and the limitations from coincidence of EV availability and building demand. The chart shows that in this use case Smart charging can capture around 80% of the savings compared to V2G.

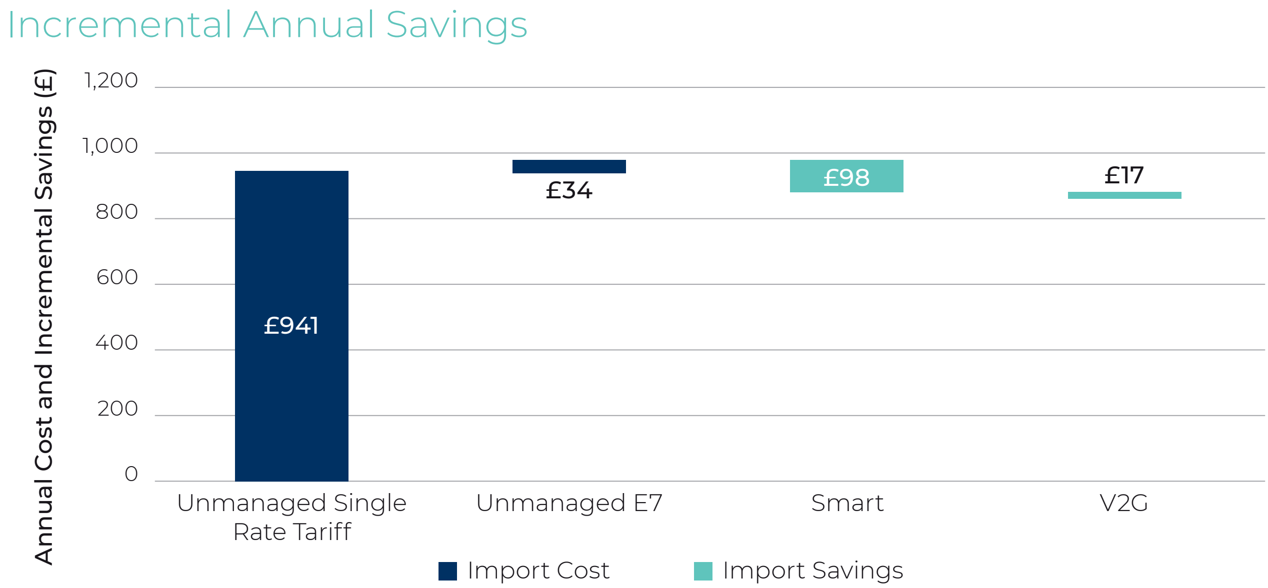


Figure 17: Base case incremental savings without grid services

3 https://www.nationalgrideso.com/news/our-forward-plan-2021

3.6.1 Base Case Run cont...

Once we include grid services, the picture changes somewhat. Results of the corresponding model runs, with grid services included, are given in Figure 17. This shows similar import savings to the previous case, however V2G can capture much more value in grid services than Smart Charging. This is due to the specifications of the individual services modelled. In this Use Case Smart charging is only able to capture 40% of the revenue that V2G can (netting off the cost of moving to an E7 tariff from any savings made).

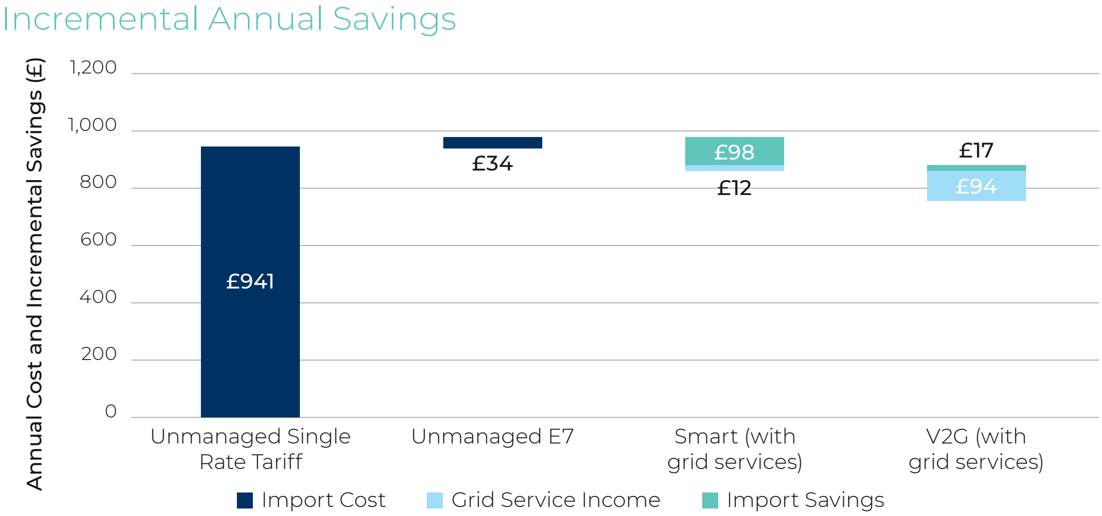


Figure 18: Base case incremental savings with grid services

It is useful to look in more detail at what grid services have been offered by both the Smart and V2G runs. The following two figures provide a breakdown of the revenue earnt in both runs. Note that the figures show the total (not incremental) revenue earned.

The make-up of this resulting combined archetype is shown in the following chart

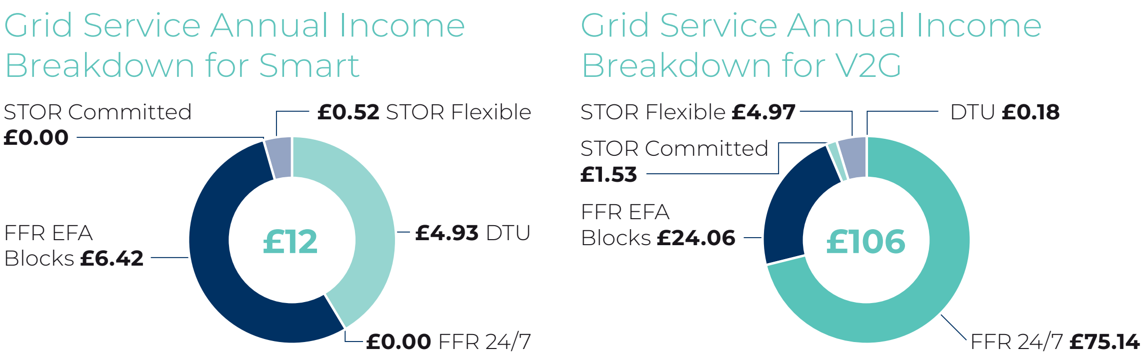


Figure 19: Grid service revenue breakdown Smart (left) and V2G (right)

3.6.2 Sensitivity 1: Low FFR Price Scenario

From the base case runs it was clear that FFR was the most lucrative market for V2G. However, the value of FFR has been in steady decline in recent years and the inclusion of V2G or other flexibility services in large volumes would be likely to further erode the value of the service. Therefore, a sensitivity analysis was performed where the FFR prices were halved, giving the sensitivity price of £5/MW/h for 24/7 service and £4/MW/h for EFA blocks.

In this run import savings are virtually unchanged, however, the grid service income is significantly reduced. For V2G the total grid services income is £59 compared to £106 in the Base Case. So, a halving of the FFR price results in an almost halving of the grid services revenue for V2G.

From the two figures above, we can see the FFR remains to be an important component of the revenue even at these lower prices. Although the transition to other grid services has started (notably with STOR in the V2G case) the point where other grid services become the more lucrative option has not yet been reached, suggesting significant risk in potential revenue earned from grid services.

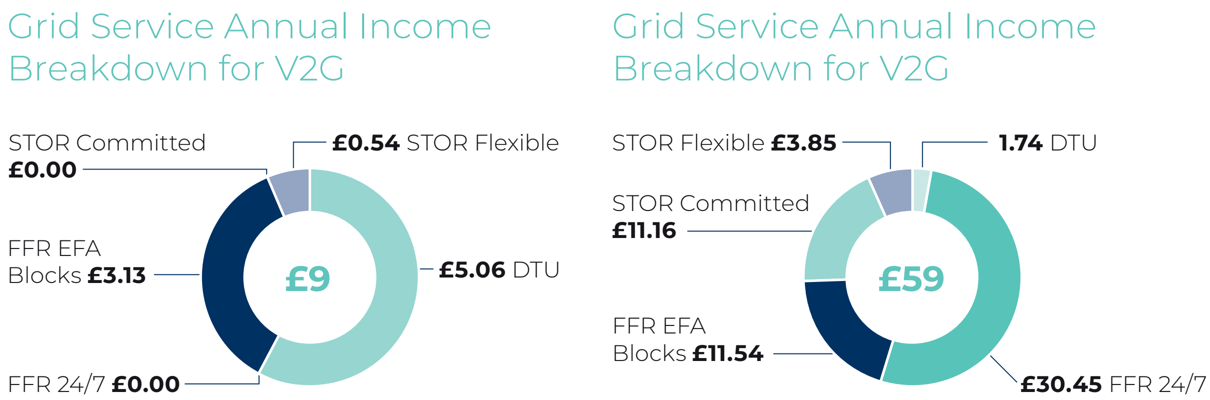


Figure 20: Grid service breakdown Low FFR price: Smart (left) and V2G (right)

3.6.3 Sensitivity 4: High Plug-in Rate Scenario

One limitation of the Combined Archetype that has been used in all the model runs so far is that it has an average plug-in rate of around 30%. . It is reasonable to assume that if encouraged, V2G users could achieve much higher plug in rates. Whilst the data from the EFES trial (that matched the Run-Around archetype) was for only one car, it had a very high plug-in rate of 75%. Because of the quality of the data set, with plug-in events on virtually every day, the simulation module in the model was able to be used effectively to simulate clones of the data set that exhibited similar statistical properties in terms of journey timings and durations.

3.6.3 Sensitivity 4: High Plug-in Rate Scenario cont...

The value of this simulated data set is that it gives us sufficient diversity to offer into grid services and it provides a 'best case' example from a V2G perspective of a vehicle that is regularly plugged in and available.

Figure 20 shows the incremental savings for both smart and V2G. Smart charging can achieve less import savings than in the Base Case. This is perhaps due to a much lower mean annual journey demand for the EV (637kWh compared to 1,842kWh in the Base Case). Whereas V2G can gain additional savings. V2G is also able to capture a total of £414 in annual revenue from grid services (almost all of which comes from FFR). This is around four times the equivalent value from the Base Case.

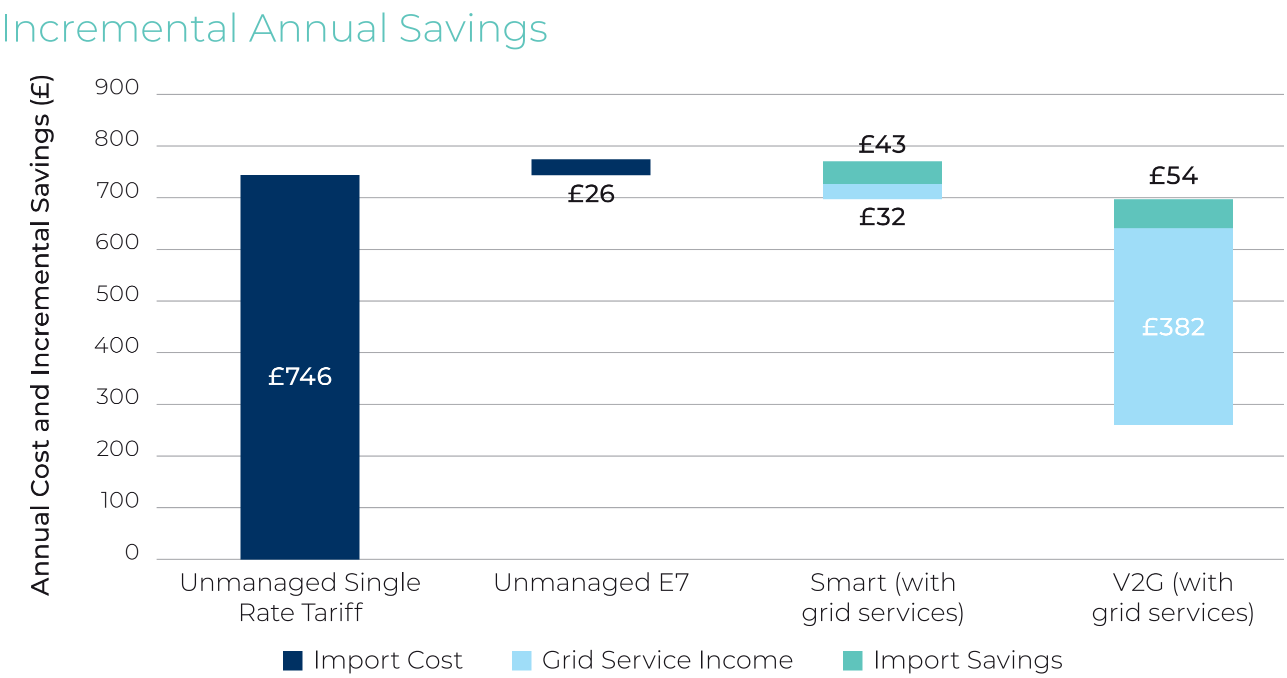


Figure 21: High Plug-in rate incremental savings with grid services

The V2G demonstration projects that Cenex has been involved with suggest that these users plug the vehicle in more regularly than conventionally charged EVs. Indeed, this high plug-in rate data set is based on a V2G demonstration. Whilst it is clear that these very early adopters are unlikely to be representative of most users of a wider V2G uptake, it does show that some change in plug-in behaviour is likely. This high plug-in rate scenario shows the potential of V2G if this behaviour change takes hold.

3.7 What is the potential impact of V2G

Out of the cases run through the model, the one that had the most potential for V2G was the high plug-in rate case, including grid services. This was able to capture an annual value of £436 under current market conditions. The high plug-in rate data sets matched the "Run-around" archetype. Assuming there are one million of these archetypal customers in GB, then this archetype alone has the potential to generate an annual revenue of £436m through the use of V2G (excluding any related costs).

Revenues for the Combined Archetype were lower. However, it should be noted that this was based on current plug-in behaviour with standard charge points. With V2G charge points users would likely plug in more regularly, and so it could be expected that revenues across most archetypes would increase, but not exceed that of the high plug-in rate case.

Due to limitations in the available data there was little value in making estimates of the total value available across all the archetypes. However, it is possible to quantify the impact which the combined archetype would have on the FFR market.

From our Combined Archetype of 60 charge points we can see that they provided on average 0.05MW of 24/7 FFR. Assuming that National Grid ESO had a dynamic response requirement of 650MW, it would take 780,000 charge points to fulfil this.

3.7.1 Interpretation of Results

There are of course limitations to any assumptions made in modelling and these will cause differences between the values quoted and what is attainable in the real world.

Differing plugging in behaviour will be a key driver in the differences. The behaviour of the users of EVs in the data used, appeared primarily to be plugging in on a need basis. i.e. they plugged in to charge the EV for a journey, rather than always charge to full after every journey. This resulted in a low plug-in rate. Our sensitivities showed that plug-in rate is a key driver for value for V2G, and results in the real world will depend a lot on actual plug-in behaviour of EV users.

The model applied used a perfect foresight approach. This means it could see in advance exactly when EVs would be plugged in, how long the journeys would be and what the prices of energy and grid services would be. In reality, all these things would need to be forecast in order to take a similar approach. The errors in such a forecast would result in a reduction in captured value relative to what was modelled here. This error will be different for the different components. For example, most residential electricity tariffs are known accurately for months ahead. However, imbalance prices are never known in advance and are hard to forecast.
User behaviour also varies in how hard it is to forecast depending on the type of user. There is significant uncertainty as to how much lower the value captured by V2G in the real world would be when compared with the values presented in this report, but the results can be used to give a strong indication of the scale of the value and the service combinations to target to maximise this value.

3.7.1 Interpretation of Results cont...

In modelling the use of the EVs for V2G it was assumed that there was no inherent cost associated with degrading the battery through discharging to the grid. It is clear that this is not the case in reality. However, the consideration of degradation effects and costs need a very careful treatment, since the effect is not a simple one. This is potentially a risk to the value of V2G services, as demonstrated by this example. Using assumptions by Cenex of a battery lasting 2,000 full cycles before incurring a replacement cost of 179£/kWh we assume a cost of 8.95p per kWh discharge. If this cost were applied to the model runs that used the Economy 7 tariff, then any gains that V2G made by charging during the cheap rate period in order to discharge at peak rate (offsetting local demand) would be negated. This is because the Economy 7 price spread is only 7p, so the revenue earned would be less than the cost of battery degradation. This example is imperfect, yet it demonstrates the need for the effect of V2G on battery degradation to be clearly understood and quantified. A wide range of impacts of V2G on the vehicle battery has been suggested in recent studies, from a significant acceleration of degradation to a reduction of degradation[4].

All the runs performed in the modelling were with just 60 charge points. Whilst this offers an acceptable level of diversity, results would improve with a larger portfolio. The greater the diversity, the higher the revenue will be from grid services offered by the portfolio. This effect hasn't been quantified in this work, however it will be a lesser effect than that of increasing the plug-in rates.

The Combined Archetype used represents a combination of both Commercial and Residential archetypes. There is likely value in combining these in a portfolio, as the plug-in times could be complementary, helping to provide a greater proportion of time with at least some vehicles plugged in. A portfolio made up of just Commercial or Residential is likely to earn lower revenues.

3.7.2 Stackability

Whilst not discussed in depth in this report, the stackability of the different revenue streams was considered during the revenue stream selection process. Hence the final set of revenue streams used are amenable to stacking. As a result of the modelling approach used, stacking wherever possible is inherent in the process. For example, all the grid services included (FFR, STOR, DTU) can be stacked provided the same capacity is not used to provide more than one of the services at the same time. The results of the model runs also suggest that these grid services stack well with import savings (as adding the option to provide grid services barely reduces import savings). For some customers archetypes there are additional revenue streams that can be stacked with revenues stated in this report. One example of this is TRIAD avoidance. However, this opportunity only exists for larger commercial (not residential) customers and due to regulation changes the revenues available are in steep decline.

4 Uddin et al., 2018, The viability of vehicle-to-grid operations from a battery technology and policy perspective

3.8 Conclusions

The aims of this chapter can be summarised by three key questions:

1. Is there additional value which can be achieved by V2G compared to Smart charging?
2. What are the key factors which influence this value?
3. What are the key services which V2G would need to provide to achieve maximum economic value?

This chapter indicates that there is added economic value which can be accessed by using V2G chargers compared to Smart Charging. However, it is also clear that the scale of this value is extremely variable and is impacted by a wide range of factors relating to the usage of the charge point and the behaviours of the user(s). In the case of a high plug-in rate archetype (75%) a 7kW V2G charger could be capable of achieving annual revenues of around £436 above Smart Charging.

By assessing the different EV driver archetypes and revenue streams we can see that one of the most influential factors impacting achievable economic value is the plug-in rate, especially when considering the provision of grid services such as frequency response. However, the relationship is not linear, as demonstrated by the 'high plug-in' case where archetypes with 75% plug-in availability attracted around 4 times the revenue of those with 30% plug-in availability. This is a key result, given that the average plug-in rate for the data sets used in this study was just below 30%. This represents typical plug-in behaviour of current EV drivers who are not incentivised to plug-in beyond the immediate benefit of charging the vehicle. It is therefore suggested that providing additional incentives to plug in would likely increase this value significantly. This was supported by data from existing V2G trials.

Much of the current value of V2G comes from provision of grid services and in particular FFR, while innovative half-hourly tariff modelled was also found to offer little additional opportunity for saving with V2G when compared to the existing E7 tariffs. However, there is significant risk to grid service revenue for V2G, with at least half the revenue at risk from falling FFR prices. After FFR, additional grid services offer diminishing returns due not only to lower prices, but also because they are only required during certain windows throughout the year.

If grid services are excluded, then Smart Charging can capture 80% of the value of V2G for low plug-in scenarios, or 24% for high plug-in cases. Therefore, if V2G incurs much cost additional to that of Smart Charging then it would likely counteract the value added by V2G. When including grid services, Smart Charging captures 40% of the total value of V2G for low plug-in scenarios, or merely 10% for high plug-in cases.

44

Business models and value chains

4.1 Introduction

Since the launch of the first generation Nissan Leaf in 2010, Nissan has been studying the impact of deploying Battery Electric Vehicles (BEVs) on electricity supply networks.

This WP3 report aims to inform stakeholders of how the application of smart integrated BEV charging technologies (Vehicle to Grid "V2G" or Vehicle Grid Integration "VGI"), can create sustainable business models that can:

- Provide services that enable greater penetration of renewable energy into electricity grids
- Accelerate the adoption of zero emission BEVs by delivering net benefits to customers

Nissan have sold c.28,000 zero emission Leaf in the UK between 2010-18, equivalent to c.825MWh of battery storage capacity. As manufacturers will have to deploy BEVs to meet stricter CAFE targets, by 2025 BEVs could add some 8GWh[5] of battery storage capacity to GB every year. Integrating BEVs into the energy system in a flexible way could bring holistic benefits to energy users, increasing the efficiency of renewable generation and reduce the cost of owning a BEV.

4.2 Objectives

This chapter covers the work undertaken during the FY'18 V2GB Feasibility Study in WP 3. This work package had the following objectives:

- Develop a customer centric value propositions for V2G services
- Complete business models using the Business Model Canvas tool
  - To reveal the best possible business models for V2G services
  - To identify which stakeholder is best placed to perform the function of the aggregator.
- Conduct quantified analysis

5 8GWh is over 20% of the 35GWh of storage currently serving the GB system.
The requirement for storage is expected to increase in future years in proportion to an expected increase in renewable generation capacity.

4.3 Value propositions arising from V2G

Much like a grid connected stationary battery storage, a BEV that can be charged and discharged to and from an electricity network can act as either a load or a supply. Aggregating a number of residential BEVs and coordinating their cumulative charging behaviour is believed to deliver benefits for V2G customers. It is important to clarify that when terms such as "the customer" are used in this chapter, this term is referring to the company or individual who is willing to pay for electricity flexibility services and not necessarily the owner or operator of a BEV or the consumer of electricity.

The Business Model Canvas (BMC) method which was used to identify and test exploratory business models aided this clarification: The BEV users are key partners in the provision of these services; they are required to offer the use of their resources in a flexible manner and as a result will likely require some form of incentive to do so.

4.4 The customers

Through developing an intimate understanding of each customer segment, each stakeholder's long term goals and ambitions were identified. Through bilateral stakeholder discussions it was possible to reveal the benefits that could be delivered when providing targeted services to customers.

The following shortlist of businesses were identified as the most likely candidates to benefit from flexible V2G services provided by an aggregation company:

Proposed Customer	Summary of Value Proposition to Customer
Transmission System Operator (System Operator/ESO)	**Value Proposition 1** (VP.1): Frequency response and other ancillary services (FFR, STOR, DTU)
Distribution Network Operator (DNO)	**Value Proposition 2** (VP.2): Deferral services to avoid the cost of reinforcement
Electricity Retailer/ Supplier	**Value Proposition 3** (VP.3): Optimise gains from volatile imbalance prices
Residential Solar Generator	**Value Proposition 4** (VP.4): Optimise Home Solar PV generation and self-consumption

Table 3: Value Propositions

4.5 Transaction channels

Aggregators can supply Demand Side Flexibility (DSF) services by changing the charging behaviour of a given group of BEVs. How this behaviour can be modified relies greatly on the hardware used to connect to each BEV, essentially what functionality the BEV charge point has.

Various BEV charging management devices are compatible with acting as a channel for providing dispatchable V2G services. These channels* are critically important, as they not only link the user of the BEV through the charging experience to the service provider, they also dictate the level of functionality a service can offer and this can affect the revenues that can be earned.

The channels can be categorised into four distinct types:

	Type	Supply	Variation in Method of Control
Uni-Directional Smart Charging	Level 1	7kW AC	Behaves in an on/ off binary manner. Turning on or off in response to signals or a preprogramed timer
	Level 2	7kW AC	Incrementally changes the rate of electricity supply to the BEV, ramping up and down
	Level 3	7kW AC	The BEV itself in response to a signal can incrementally reduce or increase the rate of charge requested
Bi-Directional Smart Charging	Level 4	10kW DC	In addition to smart functionality the charge point is given permission to release energy stored in an EV's battery to supply electricity

Table 4: Transaction channels

It is important to understand the functional benefits and disadvantages of each charger type as some chargers have a greater capacity to supply services whilst carrying very different cost premiums.

Type	Benefits	Disadvantages
Level 1	• Less high tech hardware required: Longer warranties may be available • Conveniently allows for simple tariff arbitrage	• Durability of rapid switching is a concern so considered unsuitable for FFR • Third party application to confirm availability • Flexibility is only available during charging • Cannot access vehicle data from the vehicle
Level 2	• By running at 50% of rated power capacity this charger can achieve an operating headroom that allows for an increase and decrease of load taken	• Third party application to confirm availability • Does not communicate with the vehicle • Flexibility is only available during charging • Cannot access vehicle data from the vehicle
Level 3	• No additional charging hardware required, any "dumb" charger is sufficient • A third party app is not necessary, the user interface can be onboard the vehicle • Can collect user behaviour data	• Requires BEV manufacturer collaboration • Requires BEV with on-board connectivity • Flexibility is only available during charging
Level 4	• Vehicle can act as a distributed generator • Communication is direct to the vehicle • Can Collect user behaviour data • As the vehicle can charge and partially discharge multiple times each session, flexibility is available for longer periods • DC chargers are available with higher power capacity	• Requires compatible DC charging standard (such as CHAdeMO) and manufacturer collaboration • Battery is at risk of accelerated degradation when acting as a generator • Most expensive option

Table 5: Advantages and disadvantages of transaction channels

4.6 Costs of different charger types

In this study the four variant chargers identified were costed on a relative basis to the installed cost of a non-smart "Dumb" 7kW AC residential charger (estimated to cost £500).

The costs below are indicative of the future (c.2023) premium that would have to be paid above the price of the benchmark charger; it reflects the cost of a single new residential installation rather than an upgrade to an existing connection or new public/commercial connection. As of today the actual premiums paid for prototype and early market smart/ V2G charging hardware are significantly higher than those used in this report; however, in an effort to reveal future potential of the business cases, premiums indicative of a more mature market were used.

4.6 Costs of different charger types cont..

Type	Power (kW)	Current	Smart	Bidirectional	Total premium to install Smart charger above the cost of a "Dumb" charger	Premium depreciated over a useful 5 Year period	Premium depreciated over a useful 10 Year period (Straight Line Method)
Level 1	7	AC	★	-	+£100	+£20	+£10
Level 2	7	AC	★	-	+£400	+£80	+£40
Level 3	7	AC	★	-	+£150	+£30	+£15
Level 4	10	DC	★	★	+£3,000	+£600	+£300

Table 6: Cost of different charger types

The depreciation rate is based on a 5 and 10 year straight line depreciation; in this report the 10 year model will be used. A 0% Interest rate has been applied and a 0% replacement/ warranty rate has been considered, in today's embryonic market there is little evidence of warranty periods of this length. This report therefore presents an illustratively optimistic annualisation of the cost premium.

All other costs relating to the provision, installation and maintenance of the charging hardware can be considered to be covered by the premium paid above the cost of the benchmark. The exception to this, is the fee paid for the existence of an aggregation service which is considered separately.

4.7 Aggregation costs

Aggregation services are commonly tendered on the basis of the aggregator taking a share of revenues generated by the demand side flexibility services offered to the aggregator's customers. The following assumptions were applies to aggregator cost modelling:

- 20% share of revenues from grid services
- Minimum return from services revenues of £30 per BEV per year to enter market. Thus service revenues need to exceed £150 per BEV per year (£150 x 20% = £30)
- The aggregator takes no share of import savings. Due to the nature of import savings the aggregator is not required, it may be, that by their own efficiency and activity, the aggregators start to generate additional income from this source but at this point no share of import savings has been allocated for aggregators.

These cost are then compared against potential revenues and savings for each of the suggested value propositions.

4.8 Revenues and savings

Work carried out by Cenex in support of Work Package 2 (WP2) of the V2GB study has helped to quantify both the revenues from services and the potential import savings arising from the optimisation of charging behaviour. Element Energy and Nissan have collaborated with Western Power Distribution (WPD) to estimate potential revenues from DNO services.

4.8.1 Revenues and Savings: VP1 Services to the System Operator

VP1 presents a traditional approach to offering balancing services, by bidding into pre-existing markets provided by the System Operator. Typically a battery asset can generate revenues by providing demand management services, as WP2 have shown there are several key high value services which can be delivered, these include: Dynamic and Non-dynamic Frequency Response (FFR), Short Term Operating Reserve (STOR) and Demand Turn-Up (DTU). A BEV that is charging can also behave in much the same way, turning demand up or down at a customer's request. BEVs connected via bidirectional chargers have the added advantage of being able to actively provide services before the vehicle begins charging or after it has finished so long as they are plugged in, thus increasing both the utilisation of the BEV/ charge point as services can be offered over a much longer period.

WP2 modelling intrinsically favoured offering the highest value services like FFR, with revenues generated being proportionate to the time the charge point is active. This led to the examination of two specific scenarios an average case (Base Case) and a best case (high plug in rate sensitivity):

1.0 Base Case: **Average Plug-In Rate**	**FFR 24/7 price: £5/MW/h** **FFR EFA blocks price: £4/MW/h**	**Plugged in availability:** **6 hours per day**

Due to the reliance of this value proposition on generating revenues from FFR the price (£) per MW/h has been set to reflect a future expected value for FFR. Revenues reflect the mean amongst a population of users as set out in WP2.

1.1 Sensitivity: **High Plug in Rate**	**FFR 24/7: £5/MW/h** **EFA EFA: £4/MW/h**	**Plugged in availability:** **18 hours per day**

This sensitivity looks to examine the potential to generate revenues if an extreme plug in rate can be guaranteed, therefore maximising revenue generation specifically when providing services utilising bidirectional chargers. Using a vehicle's battery can increase the risk of accelerated battery degradation, strict monitoring and management of the energy throughput in all use cases (including driving) are required.

4.8.2 Revenues and Savings: VP2 Services to a DNO

VP2 explores a relatively new business opportunity in the local flexibility services market. Distribution Network Operators (DNOs) face the biggest impact of GB's energy transition; without countermeasures, increasing network loads from EVs and heat pumps and distributed energy generation creating regional constraints, will result in considerable new infrastructure investments running into multiple millions of pounds (£GBP). DNOs more exposed to these constraints are taking progressive early steps to become Distribution System Operators (DNO); becoming customers of flexible load service providers[6].

If a fleet of BEVs exist in a region whose network is approaching a network constraint, then useful services like demand deferral or local generation can be purchased to counteract any urgency for upgrading the network. However if no local constraint exists, there will be no opportunity to access these revenues at all so opportunities are restricted by the circumstances in the local distribution network. The large majority of local substations are not under constraints and have sufficient headroom capacity (according to WPD's Network Capacity Map).

In these scenarios the BEV is called to defer its charging or to provide distributed generation to avoid peak constraints. Constraints generally occur during winter months, but how many times each month a DNO might utilise flexibility services is still unknown. A sensitivity has been modelled to examine the effect of a high utilisation of BEVs to provide the service.

2.0 Base Case: Average Call Rate	**WPD's Secure Service**
It is assumed that BEVs are utilised at the average utilisation rate of the service. BEVs cannot provide all of the services requirement (in MW). If the service is utilised on only a few days but at high power capacity only a small share of the overall utilisation of the service will be provided by the BEVs.	
2.1 Sensitivity: High Call Rate	**WPD's Secure Service**
In this sensitivity to the Base Case, the DNO is anticipated to utilise the service during more regular weekly events but at relatively low power capacities and call upon BEVs preferentially in these periods. Providing services more frequently allows an aggregated set of BEVs to maximise the revenue they can generate.	

This analysis looked at publicly available guidance data provided by Wester Power Distribution as part of their exploration into purchasing DNO flexibility services. The services revenues currently include an arming/ availability payment as well as an additional utilisation payment, these are both included in the estimated values.

6 http://www.energynetworks.org/electricity/futures/open-networks-project/

4.8.3 Revenues and Savings: VP3 Imbalance Optimisation

VP3 attempts to maximise returns through optimising a supplier's position in the balancing market. This case requires advanced forecasting methods and having near perfect foresight of imbalance pricing - an exceptional level of aggregation not evident today. Despite being an interesting orthogonal revenue stream for aggregators and suppliers, the spread of system pricing was insufficient to illustrate any competitive revenues. Further dedicated study is required to seek more credible revenues.

4.8.4 Revenues and Savings: VP4 Home PV Optimisation

The charge point selectively chooses to optimise the charging of the BEV instead of exporting electricity back to the grid. In this case the consumer is able to make additional import savings, beyond those considered for other cases. In this scenario it is assumed that the solar panels are a pre-existing asset and that the device is not included as an additional cost to the model.

4.8.5 Import Savings

Import savings have been estimated based on the optimisation of the price paid for imported electricity. This was calculated in WP2 as being the difference between a flat rate tariff and an Economy7 tariff which offers a lower tariff per kWh between the night-time hours of 22:00 and 08:30. In the case of VP 1,2, and 4, these revenues are available in addition to the revenues from providing grid services and increasing PV self consumption respectively.

4.8.6 Revenues and Savings: Results

Value Proposition	Type	Potential Barriers to Market	Services Revenue	Import Savings	Agg. Fees @20% Revenues	Total Net Income
VP1.1 Average Plug-In	Level 1	Hardware durability	N/A			£70
	Level 2	Insufficient Agg. Rev	£9	£64	£2	£31
	Level 3	Insufficient Agg. Rev			£2	£56
	Level 4	Charger cost too high	£84	£79	£17	-£154
VP1.1 High Rate Plug-In	Level 1	Hardware durability	N/A			£70
	Level 2	Insufficient Agg. Rev	£43	£17	£9	£12
	Level 3	Insufficient Agg. Rev			£9	£36
	Level 4	Charger cost too high	£313	£71	£62	£22
VP2.0 Low Call Rate	Level 1	Insufficient Agg. Rev	£102	£64	£20	£136
	Level 2	Insufficient Agg. Rev			£20	£106
	Level 3	Insufficient Agg. Rev			£20	£131
	Level 4	Charger cost too high	£178	£80	£36	-£78
VP2.1 High Call Rate	Level 1	Extreme case	£168	£64	£34	£188
	Level 2	Extreme case			£34	£158
	Level 3	Extreme case			£34	£183
	Level 4	Low revenues	£294	£80	£59	£15
VP4. Home PV Optim	Level 1	Good	£-	£80	N/A	£70
	Level 2	Good				£40
	Level 3	Good				£65
	Level 4	Charger cost too high	£1	£102	N/A	-£197

Table 7: Revenues and Savings: results

The largest revenues are provided using bi-directional charging, but these are offset due to the exceptionally high costs of the hardware even though a future hardware cost and an optimistic 10 year depreciation were chosen. Other than VP2.1, uni-directional smart charging cases are held back by their inability to offer services when not charging. This limits revenues from being sufficient to cover the cost of an aggregator.

4.9 Further optimisation of business models

Due to high costs and low net income challenging the initial business models, further work was undertaken to find workable opportunities. One common method of increasing revenue generation through aggregation is to stack services and optimise the utilisation of assets. However today's flexibility markets are often restricted by exclusivity clauses, requiring an asset to be dedicated to a particular service. There is speculation around the feasibility of stacking FFR with DNO deferral services when using bi-directional chargers. However if proven feasible, combining these streams could provide attractive revenues.

5.0 Optimisation 1:
Average Call Rate
Average Plug-In

VP 1.0, VP 2.0 & VP 4 Stacked

System OperatorServices, WPD's Secure Service & Home Solar Optimisation

This value proposition takes the average plug in rate from VP1.0 and combines it with revenues from VP2.0 offering DNO services at an average call rate, whilst optimising residential solar PV generation. Providing FFR and energy generation in support of DNO services can increase the risk of battery degradation.

5.1 Sensitivity:
High Call Rate
High Plug-In

VP 1.1, VP.2.1 & VP 4 Stacked

System OperatorServices, WPD's Secure Service & Home Solar Optimisation

This sensitivity takes the most extreme cases from VP1.1 and VP2.1 and combines them with import savings arising from the residential solar optimisation case. There are less solar savings available in this case due to the lower energy consumption of VP1.0. Combined energy storage and transfer can increase the risk of accelerated battery degradation.

Value Proposition	Type	Potential Barriers to Market	Services Revenue	Import Savings	Agg. Fees @20% Revenues	Total Net Income
VP5.0 Stacked Revenue	Level 4	Battery degradation risk, Customer with solar in constrained area	£263 [BC]	£91 [B]	£53	£1
VP5.1 Stacked Revenue	Level 4	Battery degradation risk, Customers with solar & high Plug-in Rates in constrained area	£608 [BC]	£91 [B]	£121	£278

These users must also exist in a sufficient population as to contribute a reasonable level of flexibility to an aggregator's portfolio. Further study is required to understand the potential size of this segment and the feasibility of stacking these services.

4.10 Further optimisation of business models

V2GB has focussed on opportunities for residential consumers to generate positive net income, however further opportunities are believed to exist for commercial fleet operators.

If a business is a large consumer of electricity it may be exposed to expensive demand TNUoS (Transmission Network Use of System) charges, (calculated through the TRIAD process). In such situations it could be possible to create opportunities for further savings of between £200 and £700.

However, many businesses already manage their exposure to TNUoS charges, meaning that relative savings might not be as lucrative. In fact TNUoS charges are being so widely well managed that it has been proven to be a poor deterrent against heavy consumption and is expected to be restructured in the very near future, which will likely eliminate the opportunity for these benefits.

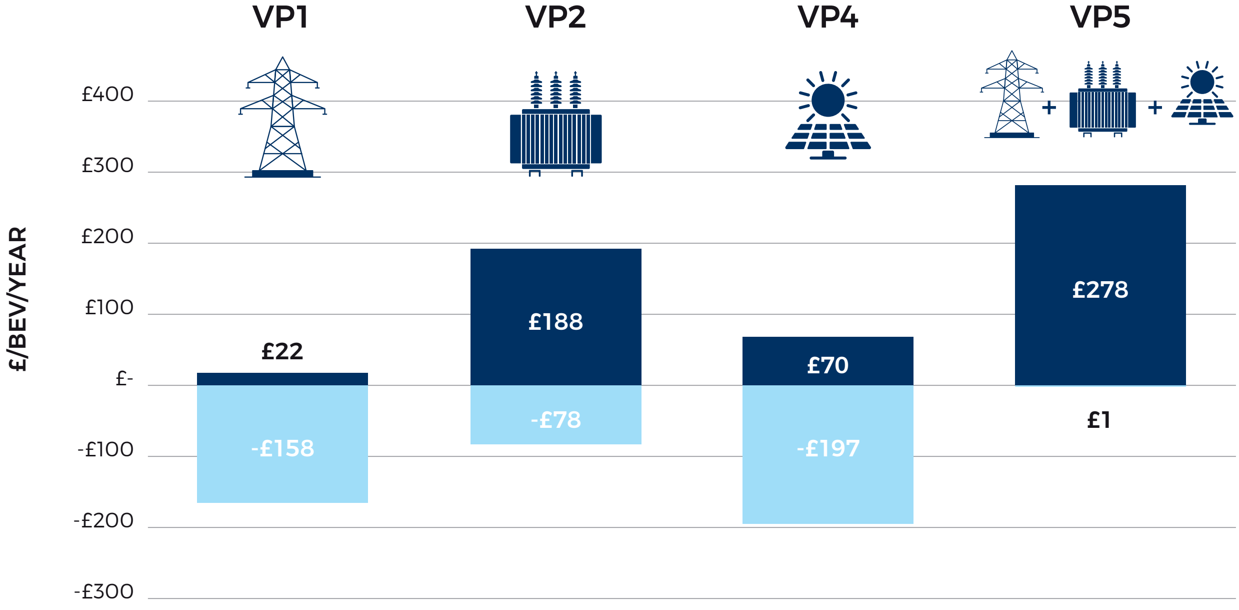
4.11 Revenues and savings: Conclusions

Analysis of the value propositions 1 through 5 shows that revenues can be created through the intelligent management of charging behaviour; revenues can also come from the provision of services and through savings on imported electricity. However, the high costs of providing V2G bi-directionally make it prohibitive and restrict the best revenues to very narrow types of BEV users (e.g. High plug-in, home solar exists, residing within a constrained network).

The requirement for the services of an aggregator also places restrictions on which business models can provide returns on investment, especially in the case of Smart uni-directional charging.

Net positive returns do look possible to achieve in providing DNO services; but further work is needed to evaluate this developing market to better understand their requirements and whether they can sustainably be met through the aggregation of a BEV fleet.

Range of net revenues from V2G value propositions



Range of estimated net revenues from proposed V2G value propositions

Requirements for market scale-up

5.1 Introduction

This chapter summarises the work undertaken by Element Energy under WP4. The task evaluates the development of V2G costs and revenues over the next decade, to determine whether and how the technology can transition out of niche applications and towards a scale which would have tangible and positive impacts on GB grid operation and decarbonisation.

The chapter first evaluates the evolution of V2G cost over the next decade, using a scenario approach to reflect a range of feasible technology developments and resulting costs. Revenue stacks are generated, drawing on WP2 as well as additional insights, again with high and low estimates to represent the variation in revenue opportunities that is expected to emerge. A comparison of annualised costs and revenues identifies the conditions under which economic viability may be achieved, and the drivers for this.

A GB power system dispatch model is used to determine the relative impact and benefit of passive, smart and V2G charging scenarios, and explores the dynamics of competition between various sources of flexibility, as identified in WP1. The chapter also evaluates consumer issues that can accelerate or delay adoption of V2G, and customer targeting and commercial models that may overcome these barriers as the market grows.

5.2 Development of V2G costs

5.2.1 Hardware cost reduction to 2030

We have projected the cost premium for a 7kW V2G charger out to 2030 using top-down and bottom-up methods and reconciled the results. Current costs are scaled from a Nichicon 6kW charger, excluding tax (Nichicon, 2018).

The top-down approach uses learning rates of a proxy technology, which is residential solar PV inverters. A low cost scenario uses a high learning rate of 15% (Trancik et al., 2015) and assumes 10% of global EV fleet participates in V2G in 2030 (Cenex, 2018). A high-cost scenario assumes a lower learning rate of 11% (El Shurafa et al., 2018) and that 7.5% of global EV fleet participates in V2G in 2030. In both scenarios it is assumed that Si-C and Ga-N will replace IGBTs to provide multiple benefits including size and weight reduction, efficiency improvement and leading to a 31% reduction of costs relative to IGBT alone. This gives an on-cost range of £656-£1164 in 2030.

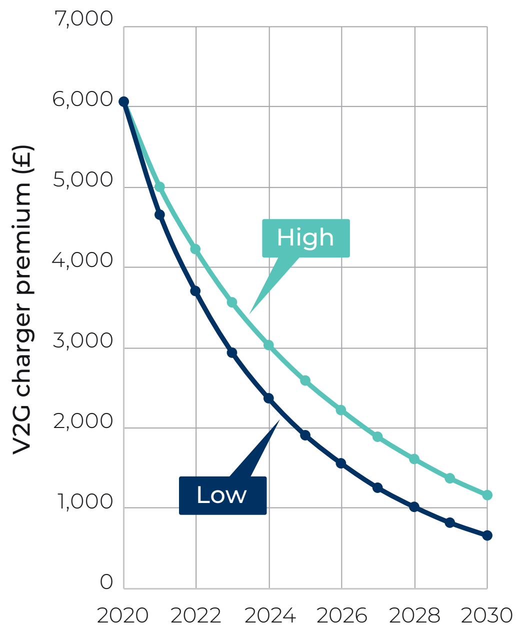


Figure 22: projected V2G charger premium

The bottom up approach identified the most costly components in the V2G charger and the expected change in costs of these out to 2030. Si-C and Ga-N technologies are assumed to enable the same cost savings as in the top-down approach. Furthermore the main cost components of the V2G charger are assumed to be the DC charger and the grid tied inverter. As both components use power electronics similar to those used in PV inverters, the cost of both is estimated using current costs of PV inverters. The DC charger is assumed to come at 70% of the cost of the power inverter[7]. Using a low cost of £0.08/Wp and a high cost of £0.12/Wp (Fraunhofer ISE, 2019) for solar inverters leads to a V2G charger cost of £660 and £1150 respectively, which shows good agreement with the top down approach.

Note that Nichicon currently include a 5y warranty for their V2G charger (Nichicon, 2018). A 5 year linear depreciation indicates an annualised hardware cost between £130 - £240. These prices are halved with a 10 year depreciation, which (despite warranties) may be more representative of what the residential market will accept (given deployment of residential PV).

5.2.2 Degradation

Proper accounting for lithium-ion battery degradation is important in determining the viability of V2G business models, but determination of impact is still at the research stage with recent papers providing apparently contradictory conclusions. Durbarry et al, 2017 showed that additional battery cycling due to V2G would shorten battery life; while Uddin et al, 2017 indicated that the use of prognostic battery aging models, active communications between vehicle and grid, and restricting battery use could avoid degradation. In response, our low-cost scenario assumes there is no cost associated with V2G degradation. For our high cost scenario, we use a simple degradation model based on publicly available information on Tesla batteries, and limited annual V2G use of 4500kWh/year, which indicates a degradation cost of 3.2p/kWh[8] or £150/annum in 2030.

5.2.3 Other costs

We also include the impact of efficiency losses (85% roundtrip) in terms of additional energy required. No installation costs are included. No grid connection cost (such as related to G99/1 or equivalent) is included. We further assume the high cost of unit testing and participation for residential assets providing balancing services to the SO can be avoided[9]. We have used a 2030 aggregation cost of £24/EV per annum proposed by Moixa. Perceived cost barriers are also excluded from the cost model, but are addressed subsequently.

5.2.4 Cost summary 2030

A summary of annual costs per EV is shown below. Five-year and 10-year linear depreciation is shown separately to demonstrate the impact expected lifetime will have on costs. We note that the residential PV sector expanded significantly, even when generous feed-in tariffs still required over 10-year payback for cost-effectiveness. For smart charging, costs are limited to aggregator control and dispatch. For V2G, the charger hardware-on cost dominates. Should battery degradation be exacerbated by V2G operation, it would have a profound effect on annual costs.

7 Personal communication with industry stakeholders

8 See full WP4 report for calculation.

9 Currently being assessed by National Grid ESO in the Residential Response Project.

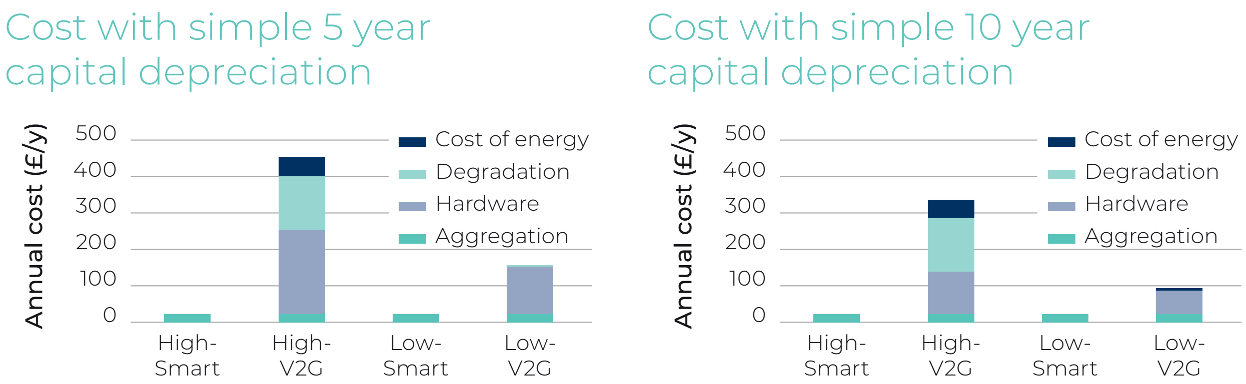


Figure 23: V2G costs in 2030 based on 5 year (left) and 10 year (right) depreciation)

5.3 Development of markets for V2G services

5.3.1 DNO services

Under current regulation, residential 7kW chargers can be connected to distribution network and any cost associated with this will be socialised. For V2G, a connection agreement (G99/1 for export above 3.7kW) would be required. Currently some UK DNOs (WPD and UKPN) are trialling and testing active congestion management zones, which could provide a revenue stream for actively managed and V2G chargers. DNO revenues are based on WPD published data on their active congestion management zones, (Gone Green 2024 scenario). As agreed with WPD, prices are unchanged out to 2030.

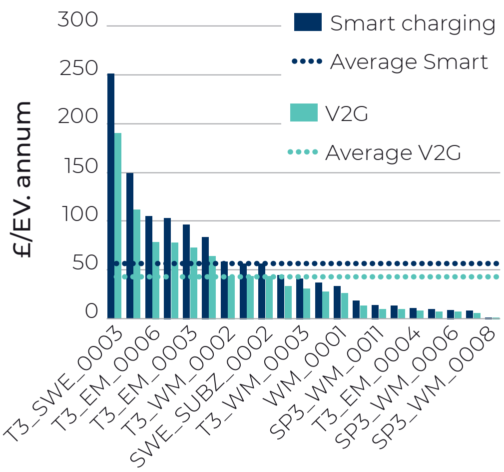


Figure 24: annual DNO revenues in WPD congestion zones in 2030

The graph shows the predicted annual revenue per EV, for smart charging and additionally for V2G, across the 21 zones that WPD expect to manage. Note that these 21 zones represent a small fraction of all WPD areas i.e. these are only zones where congested is expected. Most zones are expected to have zero market value for congestion. The reason for a difference in revenue between regions is due to the expected call rate (number of hours per day, seasonality of calls etc). The average value for Smart is £57/EV.annum, and for V2G it is £43/EV.annum. Revenues for V2G are incremental, i.e. in addition to those for smart charging. The daily charging requirement is 6.6kWh/day; while the degradation throughput limit is equivalent to 5kWh/day.

From this the high scenario takes the average of the five most highly utilized zones, while the low takes the average of 5 least utilized zones. Note that most areas have value of zero – no congestion expected.

5.3.2 System Operator services

WP2 indicates that frequency regulation could be a significant component of revenues currently. However it is a small fraction of the overall electricity market and the emergence of battery storage in this market has significant reduction in the specific value of services in recent years. Our estimate for 2030 revenues for frequency response are based on CENEX WP 2 data (using the lower FFR specific value of £5/MW/h accounting for significant competition for service provision), extrapolated to 2030 by estimating future FFR demand and diluting per EV value as appropriate. Our high scenario assumes high plug-in rates, and low assumes low plug-in rates, as per the WP2 report.

Balancing markets with products requiring response times on the order of several minutes to one hour are of significantly larger size than frequency regulation markets. Demand for balancing products is expected to grow with higher VRE penetration as forecasting errors of intermittent renewable generation lead to an increased need for reserves in the system (Hirth & Ziegenhagen, 2015). However many factors determine the size of the market and value of services[10]. Expected higher service volume requirements (due to VRES uptake) are balanced by price downward pressure through System Operator cooperation and increasing number of technologies and suppliers in balancing markets.

5.3.3 Import savings/arbitrage

Arbitrage opportunities in wholesale electricity markets were identified as an enduring value point for V2G in the long term in WP1. With increasing penetration of Variable Renewable Energy (VRE) sources like wind and solar in electricity, prices are expected to become more volatile. Such fluctuating prices offer an opportunity for flexible assets such as storage and DSR, they are in fact seen as a central signal to incentivise flexibility of demand as well as generation in electricity markets for systems with high penetration of fluctuating energy sources. We use the Element Energy Whole System Dispatch model to generate estimates of 2030 arbitrage revenues/savings.

5.3.4 Revenue stack 2030

Figure 25 shows the estimated revenue stack for 2030, with low and high revenue estimate for each of smart charging and V2G. In contrast to WP2 near term revenues, in 2030 the revenue stack is more reliant on DNO services and on import savings. DNO revenues will only be available in congested areas with an appropriate market mechanism, and so are time and location sensitive. V2G-based arbitrage revenues will be more exposed to issues related to degradation than frequency response, given the larger volumes of energy required to generate these revenues.

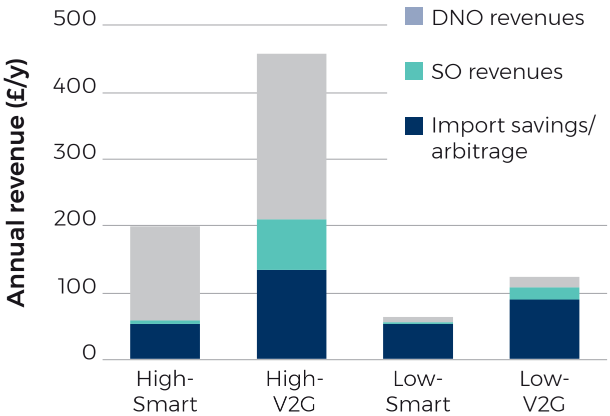


Figure 25: annual Smart and V2G revenues in 2030

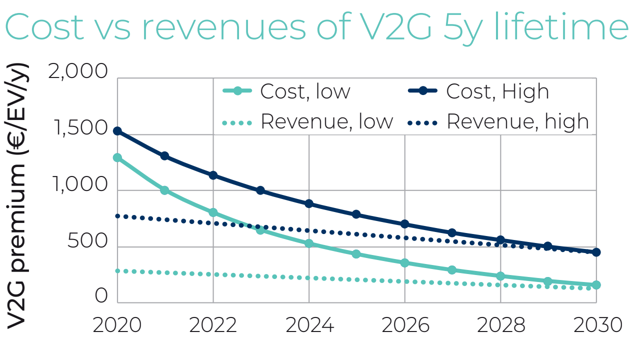
10 For example, revenues in Germany have eroded as four balancing areas were integrated into one, and increased international cooperation of System Operators.

5.4 System impact, 2030

5.4.1 V2G net costs, 2030

Estimates for annual 2030 costs and revenues per vehicle are shown below. The more challenging target of 5-year depreciation of hardware costs is shown on the left, and 10-year on the right.

With a 5-year lifetime, low costs and high revenue assumptions, net profitability could occur by the mid 2020's. With a 10-year lifetime, in a best-case scenario residential V2G could be profitable in the near future, with this being reliant on a combination of high plug-in rates (for FR), in a revenue generating congestion management zone (for DNO revenues), low hardware cost estimates and no degradation issues.



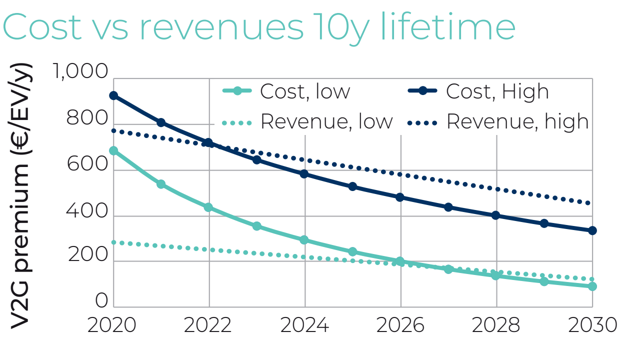


Figure 26: V2G cost and revenue projections for 5 year depreciation (left) and 10 year depreciation (right)

5.4.2 Whole system impact of charging scenarios

Element Energy used its whole system dispatch model to determine the net system cost/benefit of passive (uncontrolled) smart, and V2G based charging scenarios. The model also includes the impact of other flexible loads, such as utility battery energy storage.

The model is based on hourly profiles of demand (shiftable and non shiftable) and weather data to determine heating requirements and hourly VRES (wind and PV) output. 2030 UK power sector capacities are taken from ENTSO-E Distributed Energy scenario.

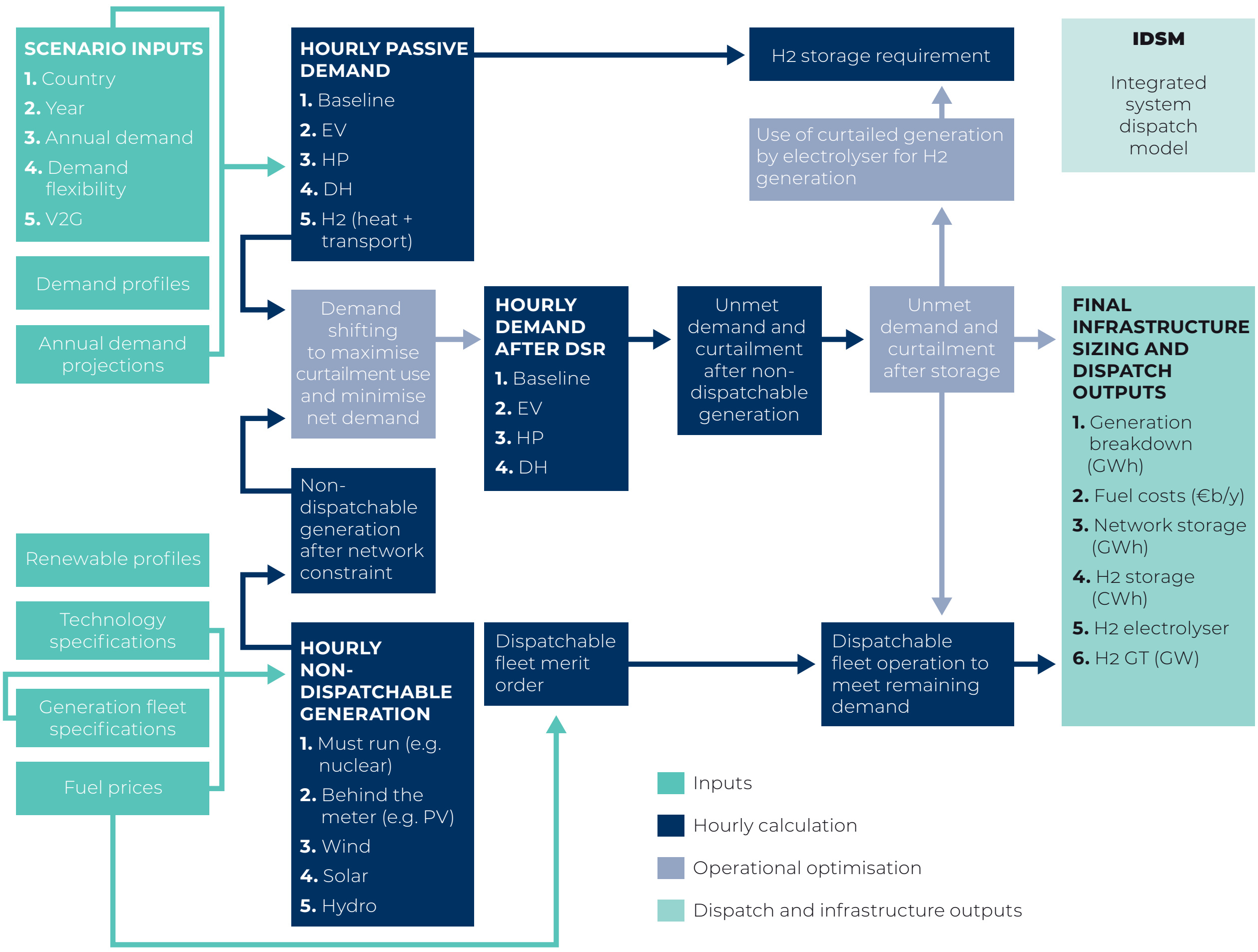


Figure 27: Element Energy Integrated Supply and Demand Dispatch model

Transport demand is based on the stock of electric vehicles, their efficiency, the daily usage, and arrival/departure times from home and work to generate baseline electrified transport demand. Grid-responsive smart charging can schedule charging to times of most use to the grid, while still providing vehicles have sufficient charge for transport.

Country-specific hourly weather data is also used to generate hourly load factors for wind and solar production. An initial specification of the VRES generation fleet is used and combined with the demand data to generate initial net load curves.

Demand shifting is deployed to minimise net demand and minimise generation curtailment. Network capacity is adjusted to optimise between demand driven and network curtailment. The dispatchable generation fleet is then deployed in merit order to fill in the supply gap. Remaining unmet demand is supplied by seasonal storage, and generation capacities are updated to reflect this.

5.4.2 Whole system impact of charging scenarios cont...

Once all hourly demands are met, annual system performance metrics are evaluated (CO2, limits on biomass use) and generation inputs adjusted to meet targets. Final outputs include generator capacities, network capacities, and storage capacities, and associated costs.

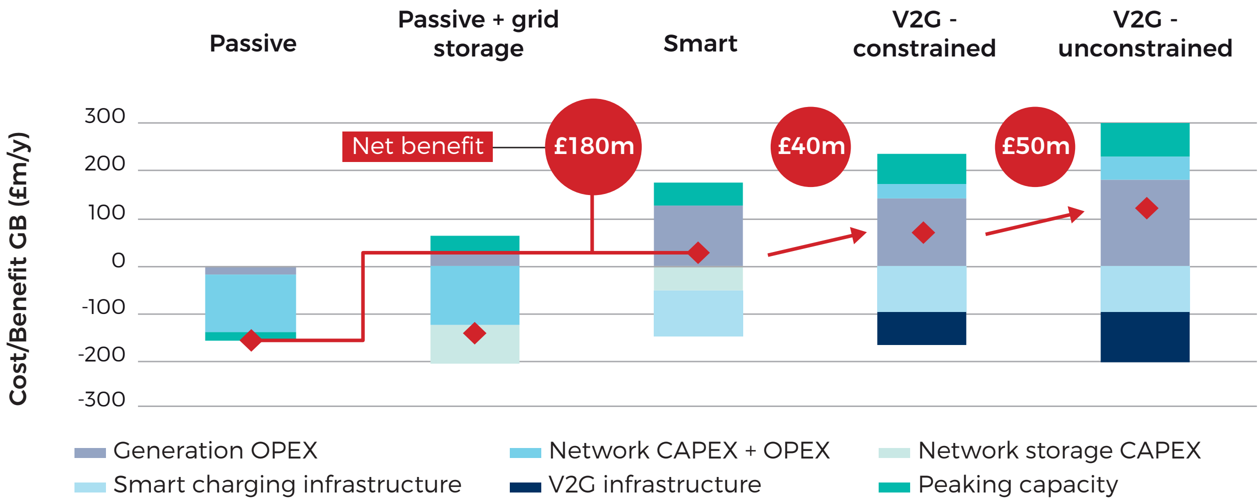


Figure 28: system cost and benefits of different charging scenarios

Generation opex refers to fuel use in thermal generation plant; this reduces when flexible demands help reduce VRES curtailment and when avoiding inefficient peaking plant. Peaking capex refers to generation peaker plant capacity required. Network capex/opex is the annualised cost of network capacity required in each scenario.

The reference case is the ENTSO-E Distributed Generation scenario where the additional EV energy requirement is constant for each hour of the year. Relative to this, passive charging results in an additional system cost; this is because the pattern of residential arrival/departure times means EV drivers are likely to begin charging on arrival at home. This increases peak loads on the system. Most of the cost is at distribution network level as EV charging uses up available network capacity. Network storage can be introduced to this system, which reduces peaking plant capacity, reduces peaking generation and results in a slight overall network benefit.

Deployment of smart charging eliminates additional network capacity investment; it also reduces peaking plant requirements and reduces thermal generator fuel use. Network storage requirements are also reduced. Overall, this scenario saves £180M/annum relative to a passive charging scenario.

5.4.2 Whole system impact of charging scenarios cont...

Two V2G scenarios are also evaluated. “Constrained” applies a V2G energy throughput limit of 2000kWh/annum, while this is not applied in “Unconstrained”. V2G is deployed up to an economic threshold- the point at which the marginal costs of V2G exceed marginal benefit – which is circa 800k V2G chargers out of an EV fleet of 4M vehicles.

Although V2G introduces additional hardware costs, it completely replaces network storage requirements, avoids even more peaking plant capacity, and could potentially generate some revenue from avoided network investments. Relative to smart charging, V2G (constrained) could generate a net saving of £40M/annum. Unconstrained charging allows each vehicle battery to do more, resulting in greater savings and economic deployment. Relative to constrained, this scenario could generate a net saving of £50M/annum to give an overall V2G saving of £90M/annum relative to smart charging.

5.4.3 Synergy between VRES and flexibility

Sources of flexibility, including smart charging, grid batteries, or V2G, work to reduce the mismatch between energy supply and demand (i.e. to flatten the net demand curve). The modelling shows that as deployment of flexibility assets increase, the average annual utilisation of each asset decreases[11]. This is shown in the left hand graph below.

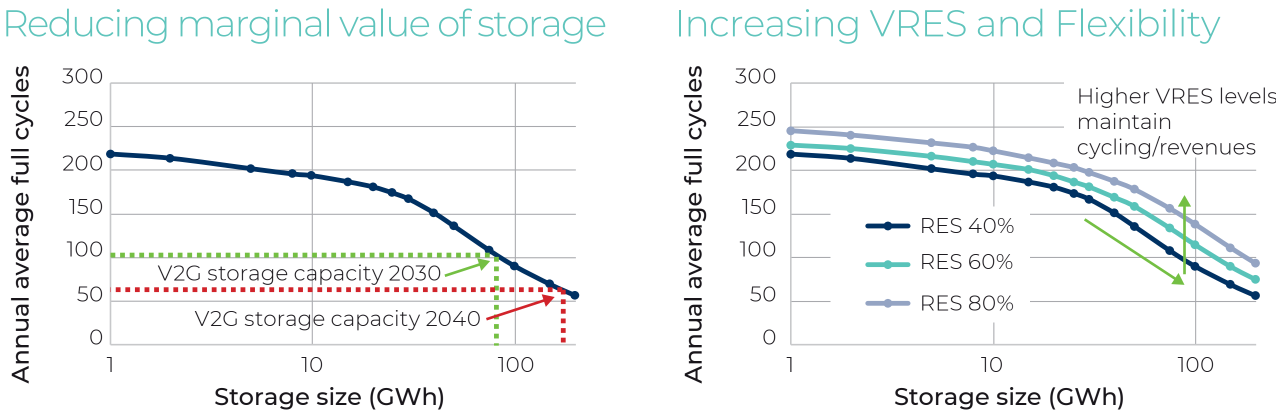


Figure 29: annual cycling vs cumulative storage capacity

11 Where all other aspects (such as VRES penetration) are held constant.

5.4.3 Synergy between VRES and flexibility cont...

As increasing storage volumes are deployed, the annual utilisation rate (in terms of full cycles per annum) decreases (blue line). This presents a challenge to sustained deployment of storage, because later deployments reduce the average annual cycling (revenues) of the whole battery fleet, until a threshold of economic viability is reached where revenues cannot sustain the investment. We note for reference the equivalent storage capacity of the V2G fleet in 2030 and 2040, assuming all EVs have V2G capability. This would provide storage capacities of national significance but would also erode annual cycling of storage assets to uneconomic levels. The impact between V2G and network storage assets will need careful consideration.

However, there is a positive synergy between the deployment of storage capacity and increased uptake of VRES to decarbonise energy systems (above graph on right). Higher VRES deployments tend to increase the mismatch between supply/demand, and so greater battery storage capacities can be economically deployed to flatten the net demand curve. Continued deployment of VRES in line with decarbonisation targets will support the sustained deployment of flexibility solution such as batteries. This is an essential part of the self-reinforcing dynamic between greening electricity and smartening demand flexibility.

5.5 Consumers and business models

5.5.1 Challenges

While the sections above deal with an economic evaluation of EV costs and revenues, they do not include a specific representation of customer concerns. Early adopters might be willing to overlook or ignore issues which would adversely impact economic viability, while the mass market may have concerns which translate into an excessively high estimate of costs. Understanding consumer concerns and values is critical to developing a viable V2G business model with a net positive value proposition. Both early adopters of EV and charging technology and the mass market currently have a range of perceived risks posing difficulties to V2G development. This section aims to identify and quantify the concerns associated with consumer participation of V2G and identify solutions or potential incentives to ensure the benefits of V2G outweigh the costs to targeted consumers.

Transferring control of charging
Some consumers may be concerned by giving up control of the charging and discharging of their EV battery, due to lost convenience or reduced certainty regarding vehicle state of charge. While giving up control is not specific to V2G it is expected to be more pronounced with V2G.

Range anxiety is one result of autonomously controlled charging as consumers may have little control over the level of discharge beyond setting a minimum threshold. Controlled discharging may also lead to data protection concerns. Distrust of the operator controlling charging may result in higher perceived costs of battery degradation.

5.5.1 Challenges cont...

Quantifying the value consumers place on control is difficult as it is tied to many other elements; however, a range of research reveals that the majority of EV drivers are open to allowing controlled charging. One study found 61% of EV drivers would consider allowing utilities to control their charging to support the greater good despite some lingering concerns about privacy and control[12], while recent work in GB by electric nation shows the majority of EV drivers are not aware of controlled charging events and are overall supportive of the concept[13]. About 25% of consumers can be swayed to participate in exchange for access to their vehicle data, but their willingness is sensitive to impacts to their data, flexibility and battery health. Research shows participation is reduced drastically with restrictive contractual arrangements[14] and nearly three quarters of participants would not sign up to controlled charging if the state of charge of their vehicle was not considered in the optimisation[15].

Minimising range anxiety

Due to a diversity of consumers values, there is no clear cut-off SoC that is acceptable or not to all consumers[16]. However, one study found that that consumers value their remaining range more as the guaranteed minimum state of charge drops[14]. In a combined choice experiment, the study showed consumers placed the same dis-benefit of reducing range from 175miles to 25 miles, as in tripling the initial price up to $84,000. Guaranteeing a minimum of 125 miles would require only $10 per mile or the equivalent of a $500 increase in the initial price). Considering the average BEV driving ranges are predicted to reach 275 miles by 2022, it is possible the minimum range could be limited to 100 miles in the future while still providing enough discharge for profitable V2G operations. Using that study's consumers' non-linear value function and ignoring discounting, this would equate to a monthly compensation requirement of approximately £18/month. It is possible this compensation could be reduced further as research shows EV owner's confidence in the driving range increases with time[17].

There are several ways to limit the range anxiety compensation for V2G participants. V2G could be initially targeted at those consumers who do not require compensation because they have other options. For example, a California study found no range anxiety for drivers who could rely on other transportation options or fuel sources like multi-car households or those consumers with PHEVs[18].

As EV battery capacity continues to grow, it will be easier to guarantee the acceptable minimum ranges to those groups identified as requiring least compensation and the customer base can expand. Consumer perceived value for higher driving ranges can be expected to simultaneously decrease as the expected distances between charging options decreases. The charging infrastructure development could allow lower compensation and further expansion of the target customers.

12 Bailey and Axsen, 2015, Anticipating PEV buyers' acceptance of utility controlled charging
13 Electric Nation, May 2018, Smart charging summary
14 Parsons et a., 2014, Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms
15 Bauman et al., 2016, Residential Smart-Charging Pilot Program in Toronto: Results of a Utility Controlled Charging Pilot
16 Innovate UK
17 Burgess et al., 2013, Assessing the Viability of Electric Vehicles in Daily Life: A Longitudinal Assessment (2008-2012)
18 Sovacool et al. 2017, Tempering the Promise of Electric Mobility? A Sociotechnical Review and Research Agenda for Vehicle-Grid Integration (VGI) and Vehicle-to-Grid (V2G)

5.5.1 Challenges cont...

Protecting data security

Privacy and data security are key concerns involved with the collection and aggregation of vehicle driving and charging data for many V2G consumers. One study found nearly a quarter of respondents believed V2G to be an invasion of privacy[18,19]. For the majority of consumers, the perceived risk that the data may also be used for other purposes and shared with other stakeholders may be larger than the real risk because consumers tend to distrust traditional electricity companies. Ofgem reports a third of consumers do not trust their supplier to treat them fairly, particularly for younger and wealthier customer segments[20]. With the recent and rapid development of V2G and smart charging technology, fit-for-purpose regulation protecting consumer data has not yet been put in place. Without a regulatory delineation of where information is used and shared, this distrust and concern about misuse of their data remains a real concern for consumers.

The development of clear regulation surrounding ownership and use of data for smart charging and V2G will reduce much of the real data security risks. Transport data security is a top priority of the current regulatory review being conducted by the Department of transportation[21]. The new data and privacy regulation being developed will be focused on the role of smart charging but could be created with sufficient flexibility to adapt to V2G capabilities.

Consumers may trust V2G providers more if they can easily see the personal and social benefit of their data on the service provision to ensure it is being used as expected. As EVs are increasingly connected to the internet and supported by digital capabilities, the perception of their data use may become more like that of the mobile phones.

Increasing plug-in time

Maximising plug-in time is critical to maximise the revenues from V2G, yet data shows that consumers tend to minimise plug in events. While private cars are parked over 90% of the time[22], research shows consumers prefer to plug in their car for an average of 5 hrs/day[17] and tend to charge every other day[23]. EV drivers perceive the action of plugging in their vehicle to be a hassle. EV drivers minimise this transaction cost similarly to how they would have refuelled a traditional car by typically plugging in when they believe the car is in a low state of charge or to prepare for a trip. Research for UKPN[24] revealed that EV owners tend to charge when they need to: on weekdays; if they are commuters without workplace charging; and if they have smaller batteries.

19 Bailey and Axsen, 2015, Anticipating PEV buyers' acceptance of utility controlled charging
20 Ofgem, 2017, Consumer Engagement Survey 2017
21 Stoker, 2019, DfT unveils mobility regulatory revolution to capitalise on 'unprecedented' shift in transport
22 Parsons et a., 2014, Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms
23 Irish, 2017, V2G: The role for EVs in future energy supply and demand
24 Element Energy, UKPN, 2019, Recharge the Future-Charger Use study

The impact of requiring higher plug-in rates varies widely showing how sensitive different customer segments may be to plug-in requirements. One study found increasing plug in times from 5 hours to 10, 15 and 20 hours was the equivalent of increasing the price of the EV by $1,400, $4,500, or $8,504 respectively[25]. Incentivising for ca 10 hours per day would require a monthly compensation £11/month. However, in a different study when participants were contractually required to plug in for just their normal 5 hours, they required £150/month compensation[26]. This disparity reflects the perceived negative impact on consumers by the use contracts and large impact of consumer preferences.

Financial rewards or electricity cost savings could be used to compensate for the remaining transaction costs. Plug-in rates increased by 12% for every dollar savings in a UC Davis trial, so V2G offerings could include special tariff structures to incentivise particular plug-in times with reduced prices or free charging on the weekends or for specific customer segments like non-commuters. Consumers prefer upfront payments/ discounts and short-term pay-as-you-go rewards from supply companies over annual cash-back payments[26].

Minimising perceived costs of degradation

As well as the true value of degradation, successful V2G businesses will have to address the perceived disutility of V2G exacerbating battery degradation. In early trials, consumer costs may also be higher due to the uncertainty that remains on V2G battery degradation. One study found early EV adopters require 2-3x more compensation than the mass market to enrol in V2G because of their increased understanding of the true costs of battery degradation and their concerns about this risk[27].

As the cost of EV batteries continues to steadily fall, the cost of replacing the battery will fall as well. In addition, studies indicate that the levels of battery degradation may be manageable by controlling the depth and state of charge and temperature of the battery, with some even proposing that battery life could be extended with adequate infrastructure to monitor battery health[28]. V2G algorithms could focus on ensuring minimum battery degradation by controlling the SoC while future arrangements for extending the life of the battery should continue to be examined including any additional infrastructure required to monitor the 'health' of the battery[29]. For early adopters, businesses may still need to pay some consumers for perceived battery degradation and the resulting reduction in range while risks are unknown. To reduce the costs to the V2G provider to as little as possible, alternative business models could be considered that absorb the cost of battery replacement to minimise the cost paid to consumers for their perceived risk.

25 Parsons et a., 2014, Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms

26 Steward, 2017, Critical Elements of Vehicle-toGrid (V2G) Economics

27 Sovacool et al. 2017, Tempering the Promise of Electric Mobility? A Sociotechnical Review and Research Agenda for Vehicle-Grid Integration (VGI) and Vehicle-to-Grid (V2G)

28 Uddin et al, 2017, On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system

29 Landi and Gross, 2014, Battery Management in V2G-based Aggregations

5.5.2 Solutions

Targeting customer segments

A viable business model must deliver a net positive value (of sensible and perceived costs) to the end-user. Research suggest certain customers will place higher value on the non-economic V2G benefits than others. For example, a study of the Nordic countries Willingness to Pay (WTP) found most regions wouldn't pay anything for the benefits of V2G as they did not place any value in them; however, in Norway they were willing to pay €4000 to participate in V2G because of an awareness of the electrification impacts of the mature EV market[30]. Different values can be seen amongst early adopters of EVs vs. the mass market.

Successful business models could tailor value propositions to target specific customer segments who highly value the social and environmental benefits as they may require the least monetary compensation. Gaining a better understanding of which customers value what costs and benefits and by how much may enable cost reduction methods and targeted business models.

Alternative value chains

One solution to increase consumer trust may be to have automotive OEMs rather than energy utilities take responsibility for the V2G value chain. Unlike with energy suppliers, OEMs have a strong brand loyalty. If consumers trust the OEM to ensure their EV is protected, it may lower their perceived risks of the V2G provider putting energy system needs over the health of the battery. OEM's will also have a stake in ensuring efficiency of the supply chain because V2G services will provide them with an ongoing revenue that will be necessary to replace the (expected) reduction in revenues from EV maintenance and part manufacturing. Since the OEM may not have expertise in the energy sector, they could partner with an energy supplier and aggregator to receive energy services at low costs under their branding as a white label supplier to ensure the participation of the energy supplier is trusted in the same way as the OEM.

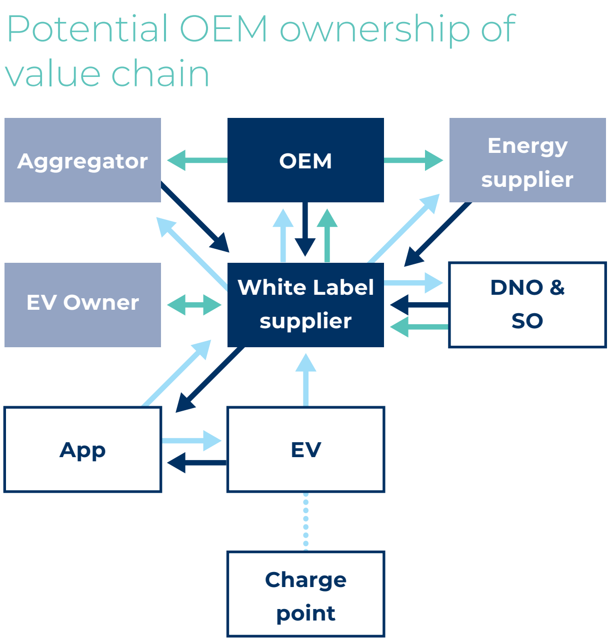


Figure 30: potential OEM ownership of value chain

30 Kester et al., 2018, Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion. 2018.

Leasing models
Battery warranty or leasing models are both potential commercial methods of transferring the risk of degradation of a battery from an EV owner onto the OEM or leasing company.

As the vehicle sector moves away from ownership toward leasing and integrated mobility services, V2G may be provided as a combined offering with battery and EV leasing models to take the risk of battery degradation away from the consumer. It can be expected that EV and battery leasing will grow as GB has the largest leasing market in Europe with over 85% of new private cars bought using finance[31] and 5% growth in automotive leasing[32]. Battery leasing is also becoming increasingly popular in the EV sector as it allows EVs to be cost competitive and negates battery replacement anxieties. Battery leasing costs are nearly half that of leasing an entire car (£60-70/month), thus any options to reduce these leasing price could substantially boost EV sales for OEMS.

5.6 Conclusions for market scale-up

- A combination of top-down (learning rate) and bottom-up (component based) cost analyses aligned on projections of 2030 on-costs of a 7kW V2G charger of between £660-£1160. This hardware investment dominates annualised V2G costs if the hardware is depreciated over 5 years, and remains a major component of the cost stack if depreciated over 10 years.
- The cost of degradation would be large enough to drive the economic case for V2G, should it emerge that V2G operation increases battery degradation. Careful consideration of cycling, and V2G based dispatch is required to minimise this.
- Erosion in the specific value of Frequency Response seen in recent years can be expected to continue, and by 2030 other revenue streams will drive residential V2G viability.
- Emerging markets for distribution constraint management could become the dominant revenue stream for V2G, but only in areas where acute congestion is expected. This revenue stream is also subject to policy risk should regulation move away from socialisation of residential charging costs. Work is required to streamline grid connections such as G99/1 or equivalent and limit the cost.
- Opportunities for import savings/arbitrage will increase, but as these services require larger energy throughput compared to FR, their viability will be dependent on degradation.

31 Reuters, 2017, More UK cars bought on credit - data
32 Lease Europe, 2017, Key Facts and Figures 2017

5.6 Conclusions for market scale-up cont...

- With a 10-year lifetime, in a best-case scenario residential V2G could be profitable in the near future. However this is reliant on a combination of: high plug-in rates (for FR), in a revenue generating congestion management zone (for DNO revenues), low hardware cost estimates and no degradation issues.
- Hardware costs must come down aggressively to allow economic viability beyond unusual edge cases.
- As hardware costs are paramount, it is critical that critical that commercial models are able to annualise cost over long life (10 years +) and with low discount rate.
- Trials are required to determine the true impact of V2G operation on battery degradation.
- Relative to unmanaged charging, smart charging could generate system savings of £180M/annum, with benefits throughout the GB power system.
- Additionally, V2G operation could save between £40M-90M/annum, with the variation due to the application of an annual constraint on V2G-based energy throughput.
- Competition between flexibility sources means that the marginal value of flexibility reduces as its deployment increases.
- However there is a positive synergy between flexibility and VRES deployment which can simultaneously support high VRES deployment and sustain economically viable revenues for flexibility assets such as smart charging and V2G.
- To be viable, introduction of V2G into the residential market will need to identify consumer groups with high plug-in rates, high range EVs with ample rapid charging availability.
- In addition, novel business models will need to be developed to remove any customer concern about V2G based degradation (whether actual or perceived risk).

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