

**elementenergy**

**V2GB – Vehicle to Grid  
Britain**

**Requirements for market  
scale-up (WP4)**

**PUBLIC REPORT**

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## Executive Summary

The V2GB – Vehicle to Grid Britain project 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. Building on and extending work by other partners on the V2GB project, this report identifies the conditions required for successful scale-up of V2G in the UK and for the technology to make a significant contribution to economic grid decarbonisation.

### V2G revenue projections to 2030

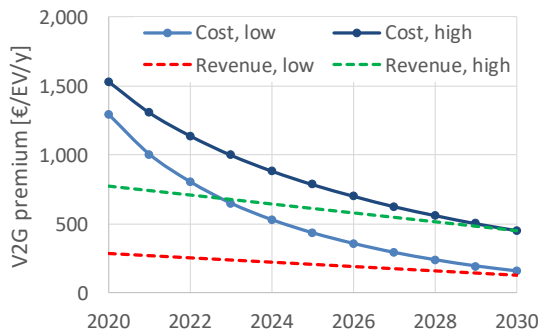
- There could be an opportunity for Smart and V2G charging to generate significant revenues where it is in a Distribution Network Operator (DNO) **congestion management zone**. Using estimates of revenue from this nascent market, where **congestion is acute and sustained**, the value per EV could be £250/EV.year or more. The average value across all zones may be much lower. The opportunity will be geographically restricted and the most valuable opportunities are expected to be time limited as they will compete with network upgrades.
- Erosion in the specific value of Frequency Response (FR) seen in recent years can be expected to continue, and by 2030 other revenue streams will be expected to dominate residential V2G viability.
- Opportunities for import savings/arbitrage will increase, but as these services require larger energy throughput compared to FR, their viability will be dependent on any degradation impacts.
- 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 System Operator (SO) requirements, increase liquidity in Balancing Services markets and drive value for the end consumers.

### V2G cost projections to 2030

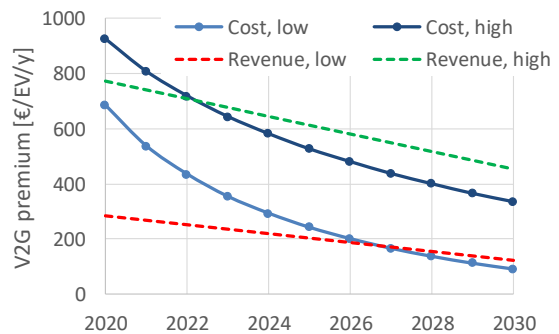
- A combination of top-down (learning rate) and bottom-up (component based) cost analyses aligned on projections of 2030 on-costs of a 7kW V2G charger of between £660-£1160. This hardware investment dominates annualised V2G costs if the hardware is depreciated over 5 years and remains a major component of the cost stack if depreciated over 10 years.
- Should it emerge that V2G operation increases battery degradation, this could dominate the cost stack for V2G. Careful consideration of cycling, and V2G based dispatch is required to minimise this.

Cost benefit of V2G to 2030

Cost vs revenues of V2G 5y lifetime

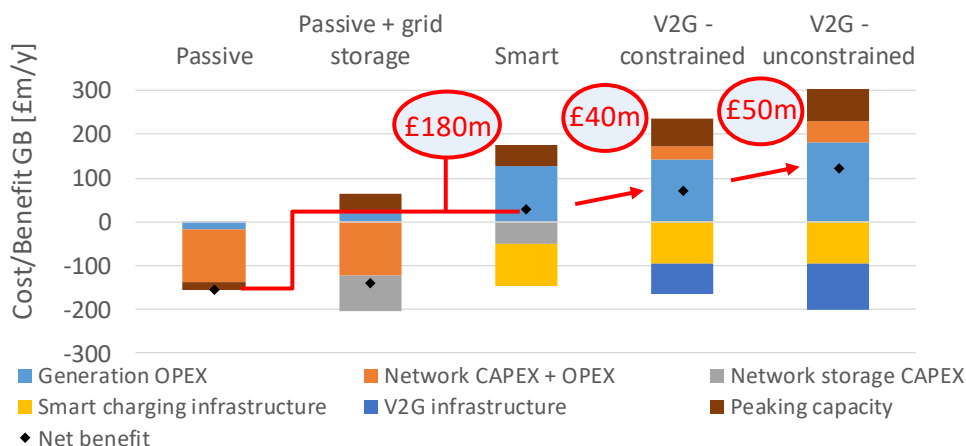


Cost vs revenues 10y lifetime



- 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. This is expected to come via technology change and volume production.
- As hardware costs are paramount, it is 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.
- 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.

**System benefit of V2G to the GB power system**



- 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 Variable Renewable Energy Sources (VRES) deployment which can simultaneously support high VRES deployment and sustain economically viable revenues for flexibility assets such as smart charging and V2G.
- 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.

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## Acknowledgements

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## Glossary

Term	Explanation
<b>Arbitrage</b>	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.
<b>Commercial EV</b>	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.
<b>Customer</b>	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.
<b>DNO services</b>	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.
<b>DTU</b>	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 ( <a href="https://www.nationalgrideso.com/balancing-services/reserve-services/demand-turn?market-information">https://www.nationalgrideso.com/balancing-services/reserve-services/demand-turn?market-information</a> ).
<b>ENTSO-E</b>	European Network of Transmission System Operators - electricity
<b>FFR</b>	Firm Frequency Response is the monthly tendered market used by National Grid ESO to commercially procure frequency response services
<b>Import savings</b>	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.
<b>Peak day</b>	The day which has the highest electricity demand of the year. Usually this day is in the winter months.
<b>Plug-in rate</b>	The percentage of hours per day for which the EV is connected to the EV charger.
<b>Residential EV</b>	An EV connected to a residential charger and used by the household..
<b>Smart Charging</b>	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.
<b>STOR</b>	Short Term Operating Reserve is a service procured through tendered markets by National Grid ESO to help manage short duration energy imbalances.

<b>System Operator</b>	The operator of the electricity transmission system. In Britain, The System Operator is National Grid ESO.
<b>System Operator services</b>	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.
<b>TRIAD</b>	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.
<b>TRIAD Avoidance</b>	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.
<b>Unmanaged charging</b>	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.
<b>V2G</b>	In addition to Smart Charging Capabilities, EVs can export electricity from their batteries back to the grid.

## 1 Introduction to Vehicle to Grid Britain

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. The 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.

This report summarises the work undertaken by Element Energy under work package 4 of the V2GB project. The task evaluates the development of V2G costs and revenues over the next decade, to determine 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. It also evaluates how flexible EV charging and V2G technology can support a rapidly decarbonising electricity system.

The report first evaluates the evolution of V2G cost over the next decade, using a scenario approach to reflect a range of feasible technology developments and a comparison of top-down and bottom-up approaches to estimate impact on technology cost. Revenue stacks are then estimated drawing on V2GB WP2 report as well as additional insights to reflect revenue estimates out to 2040. Reflecting inherent uncertainty as well as locational variability of revenues, high and low estimates are used to represent the range in revenue opportunities for V2G that is expected to emerge. Finally, a comparison of annualised costs and revenues identifies the conditions under which economic viability may be achieved.

A GB power system dispatch model is used in chapter 4 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. Chapter 5 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.



## 2 Development of V2G costs

### 2.1 Hardware cost reduction up to 2030

Hardware costs – meaning the cost of the bidirectional charger - were identified as an essential barrier to making V2G business models viable in V2GB WP3. As a result, hardware cost projections have been a key focus of work package 4.

While hardware costs today appear to be high and present a challenging business case for V2G, it should be acknowledged that V2G is a nascent technology and significant cost reductions can be expected with standardisation and mass production.

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](#)).

#### 2.1.1 Drivers of cost reduction

Main drivers of future cost reduction of bidirectional chargers can be summarised under the three following categories:

- Standardisation and volume production -leading to production efficiencies and cost reductions as a function of volume and proceed down cost-volume curves
- Technology change – allowing the technology to jump onto a lower cost-volume curve
- System architecture changes – finding synergies with other systems (such as residential PV) so that key components can be shared

#### Volume production

The low numbers in which bidirectional chargers are produced today mean that unit costs are high. Producing larger volumes of the chargers would allow to switch to mass production using standardised components and automated processes which would enable economies of scale and reduce the costs per charger.

The largest cost component of the bidirectional charger is the grid-tied inverter. Grid tied inverters are produced in mass quantities for the residential and commercial PV market today. The fundamental technical capabilities required in this application are very similar to the those required for bidirectional EV charging<sup>1</sup>. Costs of PV inverters have been reduced substantially in the last ten years during the global growth of PV deployment and the emergence of an international market for PV system components.

The sharing of key technology components suggests it is reasonable to assume that volume production of V2G chargers would allow the cost to reduce significantly from currently high levels. Similar developments are expected in the market for inverters for grid scale battery storage systems<sup>2</sup>.

A technology learning rate (or “top-down”) approach is used to estimate how V2G costs can reduce with volume deployment, out to 2030. Observed cost-volume relationships in the residential inverter market are used as expected values for V2G, as shown below.

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<sup>1</sup> Communication with industry stakeholders

<sup>2</sup> Frankel et al, 2017, *The new rules of competition in energy storage*

## Technology change

While currently EV inverters use Insulated gate bipolar transistors (IGBTs), new types of inverters are being developed for applications in V2G and battery storage markets<sup>3</sup>. They are expected to enable significant reduction of size and weight due to their higher switching frequencies as well as better automation of the assembly of inverters<sup>4</sup>. They furthermore allow to reduce the energy losses in inverters significantly<sup>5</sup> which allows the product to be smaller in size and with less weight dedicated to component cooling. The most prominent semiconductor materials being used in newly developed inverters are Si-C and Ga-N. The introduction of these technologies would allow the cost of a high-volume production product to be reduced, in part due to reduction in cost of key components but also the overall reduction in weight and volume.

## System architecture

Cost reduction can also be achieved by sharing technology components of the V2G charger with other applications either within or outside the EV. One example of this is the use of one single inverter system to manage the power flows from a PV array and an EV to the grid. During the day, the inverter is used to feed electricity produced by the array to the grid, while during the evening it is used to feed electricity from the EV to the grid. Such multiport charging systems are already commercially available<sup>6</sup> and could be an attractive option for customers interested in the purchase of an EV as well as a PV system. At the same time car manufacturers are starting to offer energy services<sup>7</sup> in addition to selling EVs and could start to exploit such potential synergies.

A further example of reduction of costs by sharing technology components is the use of the inverter of the EV motor for the discharge to the grid. As EVs will only feed electricity to the grid when stationary, the motor inverter won't be used for propulsion and could therefore be used for discharging to the grid. While integrating the bidirectional charger into the EV in this way could provide one of the cheapest solutions and such integrated chargers have been developed and tested<sup>8</sup>, design challenges remain due to control complexity and extra hardware needed<sup>9</sup> as well as varying requirements to connect generation to the distribution grid internationally<sup>10</sup>.

The following subsections describe the top down and bottom up approaches taken to estimate future cost of V2G chargers and the corresponding estimates.

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<sup>3</sup> <https://www.siemens.com/innovation/en/home/pictures-of-the-future/industry-and-automation/the-future-of-manufacturing-software-defined-inverters.html>

<sup>4</sup> <https://automotive.electronicsspecifier.com/ev/will-evs-start-to-take-up-sic-and-drive-prices-to-parity-with-silicon-1>

<sup>5</sup> Alatawi et al. 2018, *Comparative Analysis of Si- and GaN-Based Single-Phase Transformer-Less PV Grid-Tied Inverter*

<sup>6</sup> Power Research Electronics, 2018, *World's first 'solar powered' bidirectional Vehicle to Grid (V2G) fast charger*

<sup>7</sup> Enkhardt, 2019, *Volkswagen is all set to become a green energy supplier*; Shahan, 2018, *Nissan Launches Nissan Energy Solar: All-In-One Energy Solution For UK Homes*

<sup>8</sup> Sharma & Sharma, 2018, *Review of power electronics in vehicle-to-grid systems*

<sup>9</sup> Monem, 2018, *Modelling, Analysis and Performance Evaluation of Power Conversion Unit in G2V/V2G Application—A Review*

<sup>10</sup> WPD, 2017, *Next Generation Networks – Vehicle to Grid, Electric Nation*

### 2.1.2 Top down approach

The top-down approach uses learning rates of a close proxy technology, which is residential solar PV inverters. A low-cost scenario uses a high learning rate of 15%<sup>11</sup> and assumes 10% of global EV fleet participates in V2G in 2030<sup>12</sup>. A high-cost scenario assumes a lower learning rate of 11%<sup>13</sup> and that 7.5% of global EV fleet participates in V2G in 2030. The projection of the global growth of EV markets is based on the IEA Global EV Outlook 2018<sup>14</sup>. This gives an on-cost range of £656-£1164 in 2030.

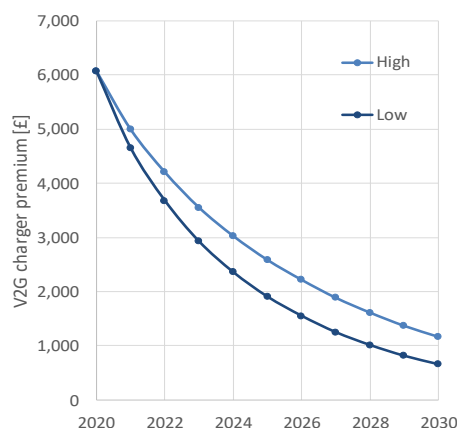


Figure 1: projected V2G charger premium

### 2.1.3 Bottom up approach

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. 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<sup>15</sup>. Using a low cost of £0.08/W<sub>p</sub> and a high cost of £0.12/W<sub>p</sub><sup>16</sup> for current (volume produced) solar inverters, scaling these down due to technology change, leads to a V2G charger cost prediction of £660 and £1150 respectively. This shows good agreement with the top down approach.

Note that Nichicon currently include a 5y warranty for their V2G charger<sup>17</sup>. A 5 year linear depreciation of the above 2030 cost figures, indicates an annualised hardware cost between £130 - £240 in 2030. These prices are halved with a simple 10-year depreciation which (despite warranties) may be more representative of what the residential market will accept (given deployment of residential PV).

The analysis indicates that the annualised cost of a 7kW V2G charger could range from £65/year (low hardware cost, 10 year depreciation), to £240/year (high hardware cost, 5 year depreciation).

## 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<sup>18</sup> showed that additional battery cycling due to V2G would shorten battery life; while Uddin et al, 2017<sup>19</sup> indicated that the use of prognostic battery

<sup>11</sup> Trancik et al., 2015, *Technology improvement and emissions reductions as mutually reinforcing efforts: Observations from the global development of solar and wind energy*

<sup>12</sup> Cenex, 2018, *V2G Market Study, Answering the preliminary questions for V2G: What, where and how much?*

<sup>13</sup> El Shurafa et al., 2018, *Estimating the learning curve of solar PV balance-of-system for over 20 countries: Implications and policy recommendations*

<sup>14</sup> IEA, 2018, *Global EV Outlook 2018*

<sup>15</sup> Personal communication with industry stakeholders

<sup>16</sup> Fraunhofer ISE, 2019, *Photovoltaics Report*

<sup>17</sup> Nichicon, 2018, *Development and Introduction of a Power Grid-Connected Vehicle to Home (V2H) System*

<sup>18</sup> Durbarry et al., 2017, *Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis*

<sup>19</sup> 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*

aging models, active communications between vehicle and grid, and restricting battery use could avoid degradation.

The authors of the two papers have since published another study which reconciles the two previous ones. They conclude that V2G can be deployed in a way that both provides benefits to the grid and the EV driver. However this requires the consideration of battery degradation in the V2G dispatch and operation as well as in the accompanying compensation and business models. More real-life testing and advances in understanding the causes, mechanisms and impacts of battery degradation are necessary to make V2G an attractive proposition to both the EV drivers and the electricity system. Improvement of battery degradation models and their integration into the control and dispatch of V2G are a focus of ongoing research<sup>20</sup>.

In order to reflect the wide range of uncertainty regarding impacts of V2G on battery degradation reported in research, 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 warranted, with a cap on annual V2G use of 4500kWh/year (roughly equivalent to annual mileage), which indicates a degradation cost of 3.2p/kWh or about £150/annum in 2030.

The detailed assumptions taken are provided in the table below. An increase of the guaranteed remaining capacity under the 8 year warranty from today 85% to 90% in 2030 has been assumed. The capacity loss per kWh discharge is derived from the lifetime (i.e. 8 years) capacity loss and lifetime discharge. This is then translated into a degradation cost per kWh of discharge.

**Table 1: Assumptions for modelling degradation cost in 2030**

Quantity	Unit	Value
EV battery cost	£/kWh	120
Battery size	kWh	80
Guaranteed remaining capacity under 8 years warranty	% of initial capacity	90%
Maximum of lost capacity after 8 years	kWh	8
Annual mileage	miles/annum	15,000
Electricity consumption per mile	kWh/mile	0.25
Electricity consumption in 8 years	kWh	30,000
kWh capacity degradation per kWh discharge	kWh/kWh	0.0003
Degradation cost per kWh discharge	£/kWh	0.032
Discharge for V2G per annum	kWh/annum	4,500
V2G degradation cost per annum	£/annum	144

An integral factor determining the degradation cost of V2G operation is the remaining value of the EV battery at the end of its lifetime. Mass roll out of electric vehicles will lead to increasing amounts of

<sup>20</sup> Grundy, 2019, *VIGIL launches new platform for managing vehicle-to-grid charging*; The Faraday Institution, 2018, *The Faraday Institution announces £42 million for energy storage research*

batteries at the end of their lifetime in vehicles whose remaining value can be captured either through recycling or reuse in second life applications<sup>21</sup>. Options for recycling and reuse have become a focus of research and a debate by car OEMs, policy and energy system stakeholders, as they could help to maximise the benefits that the roll out of EVs offers to the energy transition but also to reduce the costs of EVs further<sup>22</sup>. First examples of reuse of EV batteries have started to emerge<sup>23</sup> and car OEMs start to integrate reuse options into their business strategies<sup>24</sup>.

### 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. Current installation cost of chargers can be significant, in particular due to high costs of civil works because of large weight and dimensions of existing charger models. However recent charger models have already shown significant reductions in size and weight (cp. Table 2), so we do not add installation costs to the model<sup>25</sup>. 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 System Operator can be avoided<sup>26</sup>. 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 (Section 5).

**Table 2: Specifications of different V2G charger models**

Manufacturer	Dimensions	Output power	Weight
Magnum Cap	600 x 360 x 1620 mm	10kW	260kg
Nichicon	809 x 855 x 337mm	6kW	91kg
OVO	520 x 230 x 690mm	6kW	27kg

### 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.

<sup>21</sup> Element Energy, 2019, *Batteries on wheels: the role of battery electric cars in the EU power system and beyond, a report for Enel, Iberdrola, Transport & Environment, Groupe Renault*

<sup>22</sup> McKinsey, 2019, *Second-life EV batteries: The newest value pool in energy storage*

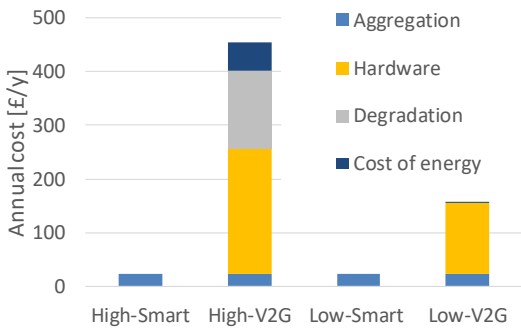
<sup>23</sup> Pratt, 2018, *Inside the Amsterdam ArenA, home to Europe's largest stadium battery*

<sup>24</sup> Kane, 2019, *BMW Group, Northvolt & Umicore Develop Life-Cycle Loop For Batteries*; Pratt, 2018, *EDF sets out to dominate European e-mobility by 2022*

<sup>25</sup> Communication with industry stakeholders

<sup>26</sup> Currently being assessed by National Grid ESO in the Residential Response Project.

Cost with simple 5 year capital depreciation



Cost with simple 10 year cap. depreciation

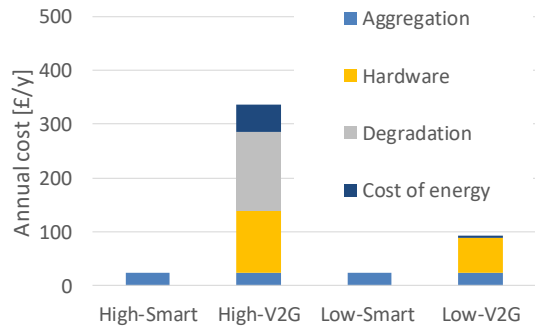


Figure 2: V2G costs in 2030 based on 5 year (left) and 10 year (right) depreciation

## 3 Development of markets for V2G services

### 3.1 Overview of revenue streams

Ancillary services markets are changing rapidly across Europe as the generation mix is changing from being dominated by thermal (mostly fossil fuel) generation to increasing shares of variable renewable energy sources (VRES). Furthermore new providers using novel technologies such as battery storage or demand side response enter ancillary services markets and challenge incumbent providers, mainly large thermal and hydro power plants.

The continuing change of requirements, commercial arrangements as well as competing technologies means that V2G business models will need to be flexible to cope with a set of revenue streams which might be changing over time. The relative importance of a particular revenue stream might decrease and new revenue streams might be added. A prominent example of revenue streams of potentially increasing importance are those from emerging markets for local flexibility run by distribution network operators (DNOs).

In this chapter we investigate the outlook for three revenue streams towards 2030: services to the DNO, services to the System Operator (SO) and import savings/arbitrage. As trials of markets for local flexibility have only started very recently, these revenue streams could not be covered in earlier work packages to the full extent due to lack of available data. Therefore they were a focus area of WP 4 and are treated in more detail in this chapter than the other revenue streams.

### 3.2 DNO services

#### 3.2.1 The DSO transition

Increasing amounts of renewable generation connecting at distribution grid level as well as the expected roll out of EVs and heat pumps represent new and unparalleled challenges to Distribution Network Operators (DNOs). At the same time, advances in control systems and power electronics are providing alternatives to conventional reinforcement when managing demand growth and providing new connections<sup>27</sup>. The new challenges as well as availability of new technology require DNOs to take new responsibilities and a more active approach to manage the grid than before. They are transitioning from DNOs to Distribution System Operators (DSOs).

DNOs are considering utilisation of demand side flexibility as an alternative to network reinforcement and are starting to develop markets for such flexibility services<sup>28</sup>. In the UK, this process is coordinated by the ENA Open Networks Project<sup>29</sup>. As such markets have not existed before, their design is still uncertain and various approaches are being discussed<sup>30</sup> including models led by the ESO, the DNO/DSO, or by third parties<sup>31</sup>. Examples of trials of markets for local flexibility include those by WPD and UKPN. Services offered in these markets include congestion management and voltage regulation (via reactive power)<sup>32</sup>.

#### 3.2.2 Uncertainties around DNO revenues

As pointed out in work package 1, the emerging local flexibility markets present an important opportunity for V2G technologies, as they are highly localised and therefore assets at the residential level such as EVs and heat pumps will experience less competition than in less localised markets such as those related to the total system balance (e.g. frequency response).

<sup>27</sup> WPD, 2018, *DSOF*; Ofgem, 2018, *Implications of the transition to Electric Vehicles*

<sup>28</sup> UKPN, 2018, *Electric Vehicles - Impacts & Opportunities*

<sup>29</sup> ENA, 2018, *Open Networks Project - Opening Markets for Network Flexibility: 2017 Achievements and Future Direction*

<sup>30</sup> Agora, 2017, *Smart-Market-Design in deutschen Verteilnetzen*; Bray et al., 2018, *Policy and Regulatory Barriers to Local Energy Markets in Great Britain*

<sup>31</sup> Stoker, 2019, *Future Worlds and the Internet of Energy: ENA unveils visions of the UK's future power landscape*

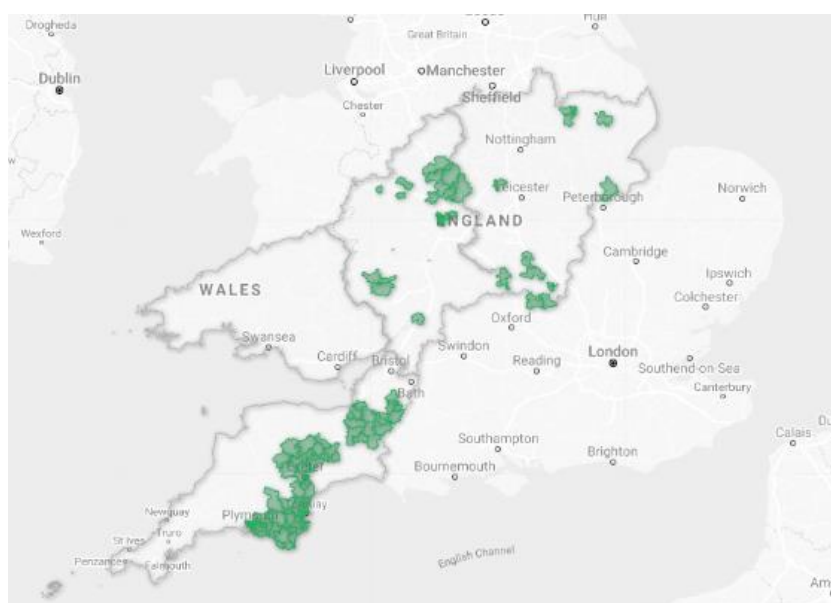
<sup>32</sup> CEER, 2018, *The role of DSOs in Flexibility in the context of the Clean Energy for All Europeans package*

However revenue streams through local flexibility services to the DNO face three key risks

1. They are highly location specific (responding to congestion)
2. They are highly time dependent (acute congestion could lead to reinforcement and flexibility value dropping as a result)
3. They are highly dependent on market structures and regulation.

### Location risk

The extent to which the demand for DNO services will be confined to very specific areas of the distribution grid can be seen in Figure 3, which shows the zones of the WPD licence area in which WPD expects congestion in 2024 based on the Gone Green scenario by National Grid ESO. It is apparent that congestion is only expected in a small share of the grid. The majority of zones have sufficient headroom of capacity available. Furthermore the degree of congestion varies significantly between those zones in which congestion is expected (see section 3.2.2).



**Figure 3: Grid zones in which WPD expects congestion<sup>33</sup>; projection for 2024 based on Gone Green scenario by National Grid ESO**

### Temporal risk

Demand for DNO services will not grow indefinitely but is limited and of cyclic nature, since at a high level of constraint, it might become more cost effective to reinforce the grid than expand flexibility markets further. After the grid reinforcement, the demand for local flexibility will be very much reduced or eliminated in the corresponding area.

It is difficult to predict the timescales for flexibility markets and grid reinforcements. Depending on the scale of the reinforcement, a demand for flexibility might remain for several years even after the reinforcement decision has been taken, due to a long lead and construction times. Furthermore the decision on reinforcement will depend on various techno economic assumptions for the cost benefit assessment such as the most cost effective kind of reinforcement, the cost of capital, the lifetime of grid assets<sup>34</sup>

While reinforcement might eliminate demand for services in one area, the demand might increase in other areas such that the demand over a wider set of areas will stay constant. Aggregation over wider

<sup>33</sup> <https://www.westernpower.co.uk/network-flexibility-map/>

<sup>34</sup> WPD, 2019, personal communication



areas of the grid might thus help aggregators to manage the risk of lost revenue streams due to grid reinforcement.

### Regulation and market risk

A further risk to revenues from DNO services is that they depend to a very high degree on regulation, in particular regulation on grid access, grid charges, grid connections and grid reinforcement. All these areas of regulation are currently changing in response to technology and consumer driven changes of electricity grids which increases uncertainty around these revenues.

**Grid access:** Ofgem is currently reviewing regulation on grid access<sup>35</sup> and grid charges<sup>36</sup> with a view to implement changes by 2023. Currently the cost of grid reinforcement due to an EV connection are socialised. However in their consultation on grid access reform, Ofgem have suggested that apart from a connection capacity required for consumers’ basic needs, they would need to pay charges which reflect the costs their connection causes<sup>37</sup>. This could lead to smart charging of EVs becoming the standard and penalising of uncontrolled EV charging. Revenues from smart charging would thus turn into avoided costs, whereas V2G revenues would remain unchanged.

**Grid charges:** In their ongoing review of grid charges, Ofgem have proposed to charge grid fees as fixed charges from each consumer<sup>38</sup>. This is supposed to help distribute the costs of the grid more fairly but would lead to an end of revenue streams for flexibility providers (such as storage assets) from helping consumers to avoid high grid charges by shifting their demand outside of peak hours<sup>39</sup>.

**Grid reinforcement:** Regulation on distribution grid reinforcement as well as on grid connections in the UK is governed by various grid codes, which DNOs have to comply with. These codes are maintained by the Distribution Code Review Panel and approved by Ofgem<sup>40</sup>. The UK grid codes in turn have to comply with European regulations and guidelines such as the Requirements for Generators or the Demand Connection Code<sup>41</sup>.

Particularly relevant documents regarding grid reinforcement are the Engineering Recommendation (EREC) P2 standard and the related guidance document Engineering Report (EREP) 130. P2 is a planning standard which governs how DNOs plan their networks to provide security of supply<sup>42</sup>. It specifies the methodology by which DNOs assess the network demand that needs to be secured and the most cost-efficient combination of network reinforcement and flexibility solutions to secure this demand. The code specifies to an extent how to assess the contribution of DSR to security of supply but leaves DNOs some freedom in this assessment. This assessment crucially affects the potential size of flexibility markets as it determines the necessary reinforcements and thus counterfactuals to which flexibility markets are compared with. P2 has been revised and modified in 2018<sup>43</sup>. A common approach by DNOs how to assess the contribution of DSR to security of supply is currently being discussed through the Energy Networks Association (ENA) forum<sup>44</sup>.

**Grid connection:** Regulation regarding connections of generators to the distribution grid have been revised in 2018, when the GB Distribution Code was adjusted to comply with the European Network Code Requirement for Generators<sup>40</sup>. Since May 2019, generators connecting to the distribution grid

<sup>35</sup> <https://www.ofgem.gov.uk/electricity/transmission-networks/charging/reform-network-access-and-forward-looking-charges>

<sup>36</sup> <https://www.ofgem.gov.uk/electricity/transmission-networks/charging/targeted-charging-review-significant-code-review>

<sup>37</sup> [https://www.ofgem.gov.uk/system/files/docs/2018/07/network\\_access\\_consultation\\_july\\_2018\\_-\\_final.pdf](https://www.ofgem.gov.uk/system/files/docs/2018/07/network_access_consultation_july_2018_-_final.pdf)

<sup>38</sup> Pratt, 2018, *Ofgem proposes fixed residual charges and an end to Embedded Benefits*

<sup>39</sup> Stoker, 2019, *Flexibility industry rounds on TCR ‘conflict’ with BEIS storage ambitions*

<sup>40</sup> Cenex, 2019, *V2G Market Study - Answering the preliminary questions for V2G: What, where and how much?*

<sup>41</sup> ENA, 2018, *Distributed Generation Connection Guide*

<sup>42</sup> DNV GL, 2016, *Engineering Recommendation P2 Review (Phase1) - WS8: Summary Report*

<sup>43</sup> DCRP, 2018, *DCRP/18/03 - Final Modification Report*

<sup>44</sup> WPD, 2019, *Personal communication*

have to comply with the technical standards G98 and G99, which replace G83 and G59 respectively. Due to the typical power rating of V2G chargers at 6-10kW, they would need to comply with G99 (for export above 3.7kW). The complexity of the standard G99 is significantly higher than the one of G59, leading to longer planning and testing procedures. The standard requires generators to operate under a wider range of system conditions and contribute to system stability<sup>45</sup>. While this reflects the growing system relevance of distribution grid connected generation, administrative burdens should not deter the transition of consumers to prosumers. Rather, for small generators, “simplified and less burdensome authorisation procedures” should be in place, as required by the Renewable Energy Directive<sup>46</sup>. Currently, V2G chargers connecting to the distribution grid, would need to follow the same procedures as generators of size up to 1 MW<sup>41</sup>.

### 3.2.3 Revenue estimates

As mentioned in the previous section, under current regulation, residential 7kW chargers can be connected to distribution network and any reinforcement 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 of the service are unchanged out to 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 expected to have zero market value for congestion (cp. Figure 3). 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 additionally for V2G 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.

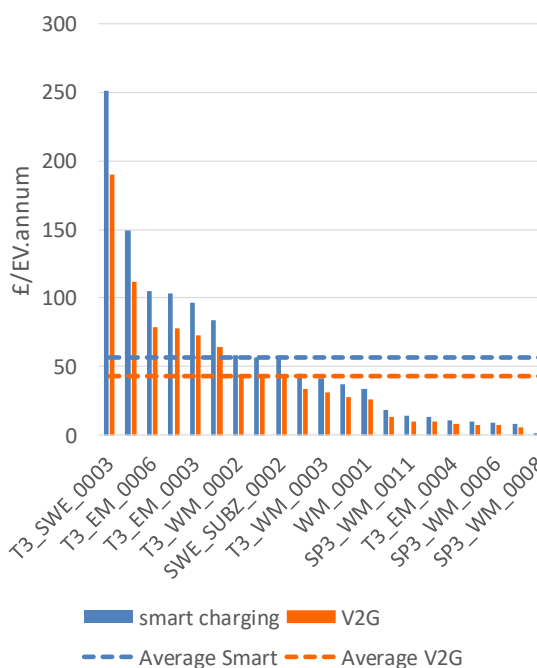


Figure 4: annual DSO revenues in WPD congestion zones in 2030

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.

### 3.3 SO 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 led to 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

<sup>45</sup> 33kV Ltd., 2018, *The Impact of Moving from G59 to G99*

<sup>46</sup> EU Parliament, 2016, *Electricity 'Prosumers'*

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<sup>47</sup>. However many factors determine the size of the market and value of services<sup>48</sup>. Expected higher service volume requirements (due to VRES uptake) are balanced by price downward pressure through SO cooperation and increasing number of technologies and suppliers in balancing markets.

As part of the creation of the Internal Energy Market for Electricity, regulators and SOs are harmonising balancing services across EU member states, a process coordinated by the Agency for Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators for Electricity (ENTSO-E). The key legislation outlining this process is the Electricity Balancing Guideline, Commission Regulation (EU) 2017/2195, which entered into force in November 2017<sup>49</sup>. Definitions of balancing products and requirements for providers as well as procurement processes are being aligned and SOs are establishing European platforms for balancing products, among them the following:

- A platform for Frequency Containment Reserve (FCR), already in operation and currently involving the Austrian, Belgian, Dutch, French, German and Swiss SOs;
- PICASSO, a platform for automatic Frequency Restoration Reserve (aFRR) involving SOs from 13 countries, expected to be operational in 2020
- MARI, a platform for manual Frequency Restoration Reserve (mFRR) involving 25 SOs, expected to be operational by 2022
- TERRE, a platform for Replacement Reserve (RR) involving 9 SOs, expected to be operational by the end of 2019<sup>50</sup>.

These platforms enable providers of balancing services such as V2G fleets to sell their services to connected markets. While this in principle increases the opportunity for such providers, it also increases competition and puts downward pressure on prices (as have been observed in markets which have been integrated through the establishment of a common procurement platform such as the German and French markets for FCR<sup>51</sup>). Whether the integration of European balancing markets increases the opportunity for GB V2G fleets to provide balancing services, will depend on whether V2G will be one of the cheapest technologies to provide such services.

The SO requires stringent testing to be successfully completed before an asset can be accepted into markets for provision of services such as frequency response. These tests have been designed around the assets which provided them, which were often many MW in power. The costs associated with testing on-boarding, and verifying such assets were small in relation to their expected revenues. However when applied to small, kW scale residential assets, these costs are prohibitive. Also, the individual availabilities of small assets such as EVs are low, and provision of a service can only be maintained through a portfolio, with each asset contributing dynamically to the (derated) portfolio capacity. National Grid ESO is working with industry stakeholders to understand how these markets can be opened up.

<sup>47</sup> Hirth & Ziegenhagen, 2015, *Balancing Power and Variable Renewables: Three Links*

<sup>48</sup> For example, revenues in Germany have eroded as four balancing areas were integrated into one, and increased international cooperation of TSOs.

<sup>49</sup> [https://www.entsoe.eu/network\\_codes/eb/](https://www.entsoe.eu/network_codes/eb/)

<sup>50</sup> Elxon, 2019, P344 'Project TERRE'

<sup>51</sup> ACER, 2018, *Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2017 – Electricity Wholesale Markets Volume*

### 3.4 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. While prices get very low in periods of high VRE output<sup>52</sup>, they can show spikes at times of low VRE output and high demand. 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<sup>53</sup>.

Wider fluctuation of power wholesale prices can already be observed today. Negative wholesale prices have started to emerge in a number of markets, among them the US, Australia, Germany and GB<sup>54</sup>. Figure 2 shows the system power price in GB on a recent day with high wind generation and low demand<sup>55</sup> resulting in 9 consecutive hours of negative prices. The share of hours of extremely high and low system prices are expected to increase with further growth of VRE capacity<sup>56</sup>.



**Figure 5: System Price of electricity in GB in the 48 half hourly settlement periods on 26/05/2019**

We use the Element Energy Whole System Dispatch model to generate estimates of 2030 arbitrage revenues/savings. Our estimates represent cost savings at the wholesale level in terms of capacity as well as generation. Thus they would be reflected in the wholesale electricity price as well as in costs of potential future capacity markets. Therefore these savings differ from the arbitrage revenues in WP 2, which are based on residential electricity tariffs (E7 or Octopus Agile tariff). These tariffs cover not only wholesale costs but all the supplier’s costs, including grid fees, levies, surcharges and taxes. Several of these costs are not dynamic, i.e. don’t vary with time. The arbitrage revenues based on a residential tariff whose only dynamic component is the wholesale price are identical to those based on the wholesale price alone. However, depending on the supplier’s tariff design, a dynamic residential tariff might expose consumers to further risk due to dynamic cost components (and also share the savings) such as grid fees, which do vary with time.

Arbitrage revenues based on a residential tariff are thus likely to reflect a wider set of savings than only wholesale cost savings. However in this report on WP4, we refer only to wholesale costs when using the term arbitrage savings. Electricity grid cost savings (on the grid operator or supplier side) are represented in the revenue stream from providing services to the DNO.

<sup>52</sup> Burger, 2018, *Power generation in Germany – assessment of 2017*  
<sup>53</sup> Federal Ministry for Economic Affairs and Energy, 2015, *An electricity market for Germany’s energy transition*  
<sup>54</sup> Starn, 2018, *Power Worth Less Than Zero Spreads as Green Energy Floods the Grid*  
<sup>55</sup> Stoker, 2019, *Negative pricing, flexibility and the power sector’s evolution*  
<sup>56</sup> Stoker, 2019, *Negative imbalance pricing periods could spiral by 2034*

Finally it should be noted that it was explicitly assumed in WP 2 that no arbitrage revenues could be realised by exporting to the grid, instead the EV battery was used to shift further electricity demand of the home to hours of lower prices. In the future, aggregators might sell the combined discharge of EV and domestic storage portfolios at power exchanges<sup>57</sup>. The discharge per EV in our unconstrained V2G scenario is about 3,400kWh per year, which corresponds to the typical annual consumption of a household<sup>58</sup>.

The arbitrage savings in WP 2 range between £20-100 per EV per year depending on whether smart charging or V2G is applied as well as on other assumptions such as the plug-in rate. Our values range between £50-130 per EV per year across smart charging and V2G scenarios.

### 3.5 Revenue stack 2030

Figure 6 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.

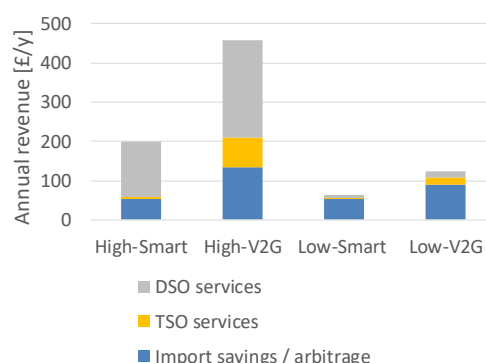


Figure 6: annual Smart and V2G revenues in 2030

### 3.6 Regulation and Standards

While the previous sections assessed future revenue streams mainly from a techno-economic perspective, this section investigates aspects of regulation and standardisation which will need to be addressed to enable a scale up of V2G markets. The first subsection investigates barriers and opportunities for revenue stacking in current energy markets while the second subsection focuses on technical standards for EV charging.

#### 3.6.1 Revenue stacking in energy markets

The UK and EU are reforming energy services to enable more distributed energy resources to participate. National Grid’s System Needs and Product Strategy (SNAPS) lays a plan for reforming the way it buys services to simplify and standardise products and increase the ease of participation. The European project TERRE (cp. Section 3.3) is creating a European balancing market with standardised services, shifting toward shorter term products and daily auctions (which the UK will enter into in December 2019). The UK SO service reform is following suit, with SNAPS aiming to shorten contract periods, lower capacity requirements and procure services in nearly real-time. National grid is also investigating how to ensure their contracting is fit-for-purpose for aggregators. Shifting contracting to be based on a minimum availability or statistical reliability could also allow more aggregated portfolios to enter the market.

The Balancing and Settlement Code (BSC) review opened the balancing mechanism and wholesale market to independent aggregators in February 2019. The first storage aggregator, Limejump, entered the balancing mechanism in 2018 by receiving a dispensation from licensing requirements to aggregate data at the grid supply point. Following this, the grid code has also been modified to allow aggregation of balancing mechanism data across a whole grid supply point group.

<sup>57</sup> Colthorpe, 2019, *Siemens’ Junelight launch: Not about making money from selling batteries*

<sup>58</sup> Ofgem, 2019, *Typical Domestic Consumption Values*

The compatibility of DSO and SO services is also under review. ENA's Open Networks Project (cp. section 3.2.1) is developing a framework for coordination of DSO & SO services to make processes simpler and better aligned. In 2018 they began consulting on removing the exclusivity clause to make it possible to offer multiple non-contradictory services to multiple parties, a critical step towards unlocking additional sources of flexibility<sup>59</sup>. This work package is expected to be delivered in 2019<sup>60</sup>.

### 3.6.2 Standardisation of charging

As the energy system is transitioning to a system of multiple distributed assets such as small-scale renewable generation as well as storage and DSR devices, interoperability has increasingly become a focus of industry, policy and research. Interoperability and standardisation of charging are of particular importance for V2G technologies for the following reasons:

- In order to play a substantial role in the decarbonisation of the electricity system, significant numbers of individual EVs will need to be aggregated to offer their combined flexibility potential. Interoperability of communication and control devices in EVs, charge points, and charge point management systems (CMS) increases the pool of EVs which can be aggregated<sup>61</sup> and will avoid EV driver inconvenience due to incompatibility of hardware.
- As the number of actors involved in the charging process – such as car OEMs, charge point operators, aggregators, DNOs, SOs – increases, the definition of standards for communication and control gets more urgent<sup>62</sup>. Such standards will also increase the confidence of the sectors involved in the supply chain, to move into areas which are outside their traditional business models<sup>63</sup>.
- As laid out in Section 2

We briefly discuss the status of development of standards for different parts of the V2G charging process.

#### Vehicle to charge point connection and communication

CHAdeMO and CCS have emerged as the main standards globally for DC charging of EVs. Currently only the CHAdeMO standard includes functionality for V2G, but CCS is expected to add such functionality as well, with showcases expected for 2019 but standard implementation perhaps not before 2025<sup>64</sup>. The number of charging standards should be reduced to avoid customer inconvenience and recent developments seem to suggest that the industry is taking steps to align and integrate standards. Tesla recently announced to fit European models with a CCS socket instead of instead of Tesla's own version of the Type 2 Mennekes connector. Furthermore CHAdeMO and the China Electricity Council have announced to develop a joint global DC charging standard.

An important standard focusing solely on the communication (not the connection) between EV and charge point is the international standard ISO 15118 'Road Vehicles – Vehicle to Grid communication interface'. The standard supports smart charging as well as V2G and intends to support the transition to wireless charging and autonomous vehicles, particularly through avoiding the need for identification through RFID cards and phone apps and instead using digital authentication through the vehicle<sup>65</sup>.

<sup>59</sup> National Grid, 2018, *Future of Balancing Services*

<sup>60</sup> Energy Networks Association, 2017, *Open Networks Project: Opening Markets for Network Flexibility*

<sup>61</sup> Uddin et al., 2018, *The viability of vehicle-to-grid operations from a battery technology and policy perspective*

<sup>62</sup> REA, 2019, *The Interoperability of public EV charging networks in the UK*

<sup>63</sup> ICCT, 2017, *Literature Review on Power Utility Best Practices regarding Electric Vehicles*

<sup>64</sup> Kane, 2019, *CharIN: CCS Combo Standard To Offer V2G By 2025*

<sup>65</sup> Cenex, 2018, *V2G Market Study, Answering the preliminary questions for V2G: What, where and how much?*

### Charge point to charge point management system communication

The Open Charge Point Protocol (OCPP) is defined as a universal open communication standard enabling communication between the vehicle, the charge points and a central CMS. It has emerged as the main standard used by charge point operators, aggregators and suppliers. OCPP 2.0, released in April 2018<sup>66</sup>, develops the support for smart charging systems, incorporating Vehicle-to-Grid. OCPP 2.0 also incorporates many aspects of ISO 15118, making this a complimentary protocol for ISO 15118, although not a direct alternative<sup>65</sup>.

### Distribution network connection

The standard G99 regulating connection of generators to the distribution grid in GB has been mentioned in Section 3.2.2. This new standard is applied since May 2019 and places greater requirements on generators to contribute to system stability than its predecessor G59. V2G chargers currently fall within the same category as generation up to 1MW in this standard. Planning, application, and testing processes for V2G chargers should be streamlined to avoid deterring uptake of V2G due to disproportionate administrative burdens. It should also be noted that regulation of AC V2G chargers is not clearly defined currently and would need to be clarified<sup>65</sup>.

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<sup>66</sup> Open Charge Alliance, 2019, *Background Open Charge Alliance*

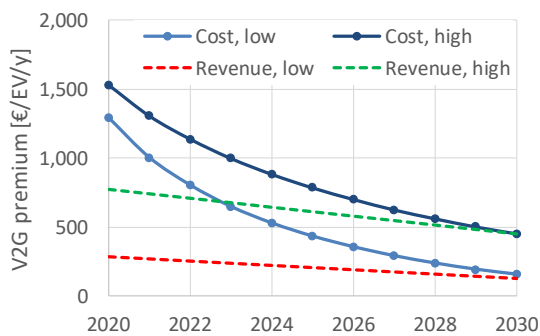
## 4 System impact, 2030

### 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 in the best circumstances. 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.

Cost vs revenues of V2G 5y lifetime



Cost vs revenues 10y lifetime

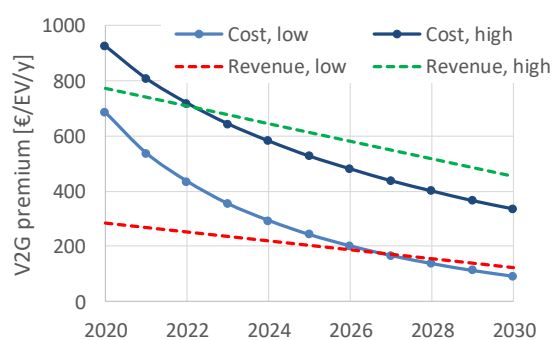


Figure 7: V2G cost and revenue projections for 5 year depreciation (left) and 10 year depreciation (right)

## 4.2 Whole system impact of charging scenarios

### 4.2.1 Element Energy Whole System Dispatch Model

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.



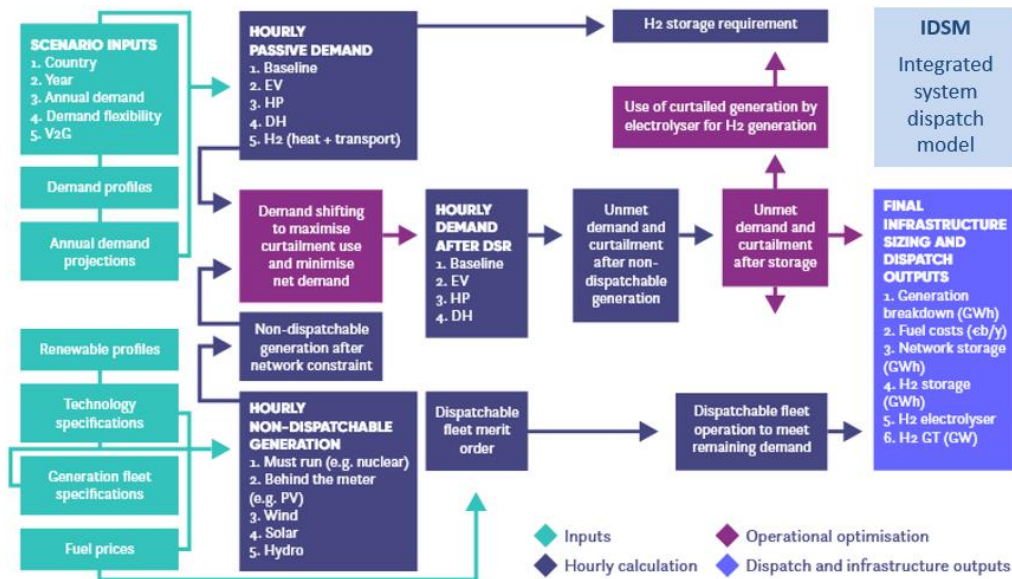


Figure 8: Element Energy Integrated Supply and Demand Dispatch model

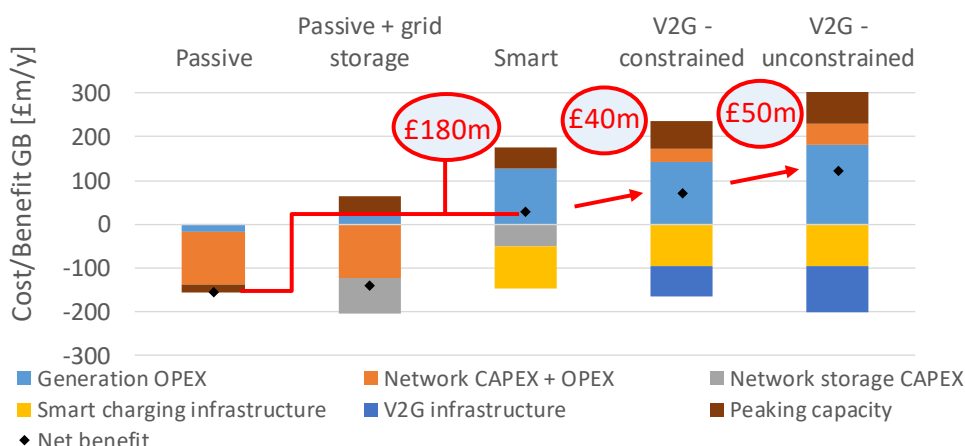
Transport demand is based on the stock of electric vehicles, their efficiency, the daily usage, and arrival/departure times from home and work to generate baseline electrified transport demand. Grid-responsive smart charging can schedule charging to times of most use to the grid, while still providing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

Once all hourly demands are met, annual system performance metrics are evaluated (CO<sub>2</sub>, limits on biomass use) and generation inputs adjusted to meet targets. Final outputs are generator capacities, network capacities, electrolyser, storage, and H2GT capacities, and associated costs.

### 4.2.2 Modelling results



**Figure 9: 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 GCA 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, and 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.

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 900k V2G chargers out of an EV fleet of 4M vehicles.

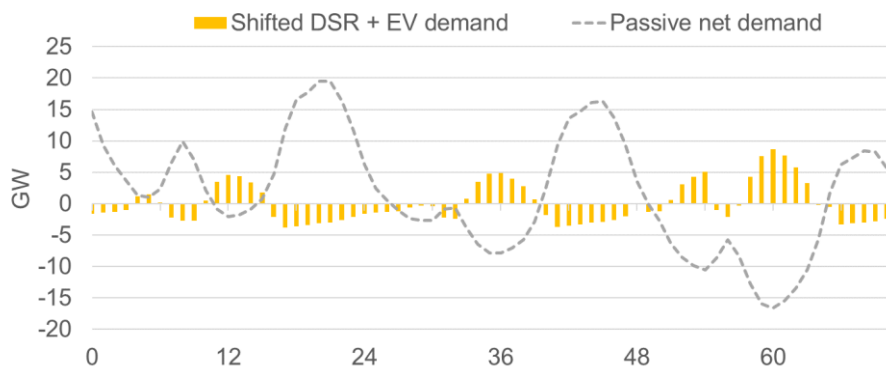
Although V2G introduces additional hardware costs, it completely replaces network storage requirements, avoids even more peaking plant capacity, and could potentially generate some revenue from avoided network investments. Relative to smart charging, V2G (constrained) could generate a net saving of £40M/annum in 2030. 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.

### 4.2.3 Hourly operation of V2G

While the previous section showed annual results of the dispatch modelling of the GB electricity system, this section covers results on an hourly level, which illustrate the daily operation of V2G and smart charging and its principles.

Figure 10 shows the passive net demand for each hour over a three-day period. This is the uncontrolled demand minus supply from variable renewable energy sources (VRES). The yellow bars represent the

shift in demand from the uncontrolled to the smart demand profile through smart EVs and further sources of demand side response (DSR). What can be seen is that smart charging reduces demand when the net demand is high, and increases demand when the net demand is negative (excess RES). In a thermally dominated power system, DSR may only act to lop peaks in demand; but in a future system with high RES penetration, DSR can decrease and increase loads on the system, responding to the net-load. It is clearly visible that the demand is increased in times of low net demand (i.e. high feed in from VRES) and reduced in times of high net demand.



**Figure 10: Passive net demand and demand shifted through smart charging and further DSR over a three day period**

The model applies V2G (or storage assets in general) after DSR technologies to further shift demand into times of high renewable feed in. Figure 11 shows the net demand after application of DSR technologies and the charging and discharging of EV batteries for V2G over a 7 day period. Figure 12 shows the corresponding storage status of the cumulative EV fleet participating in V2G. Important to note is the optimisation of the model over a longer period, illustrated on the right hand side of the figure: as net demand and thus energy costs are higher than the annual average, the storage is not charged. Instead the storage is discharged in the hours of highest value (i.e. highest net demand) within this multiday period.

Figure 13 shows the V2G discharge over the hours of the year, ranked by net demand. The graph illustrates like Figure 11 that cumulative storage capacity of the EVs is discharged in hours of high net demand (left hand side of the graph), whereas it is discharged in hours of low net demand (right hand side of the graph).

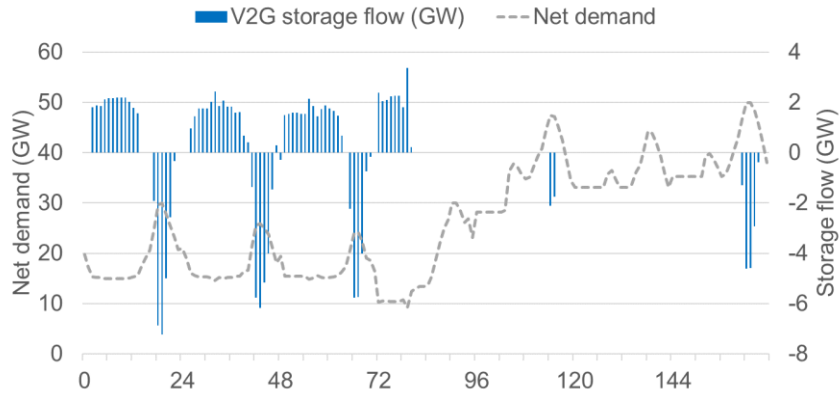


Figure 11: Net demand and V2G storage charge and discharge over a 7 day period

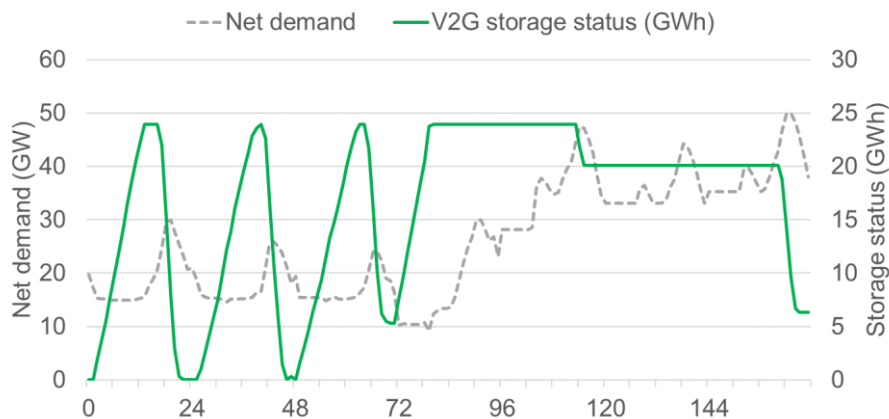


Figure 12: Net demand and storage status over a 7 day period

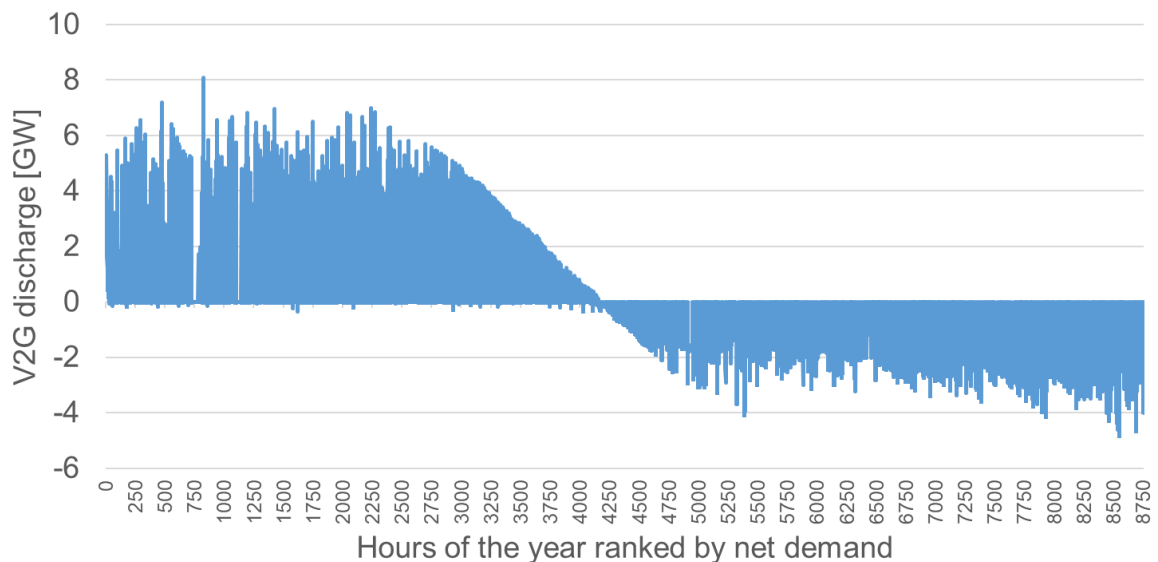
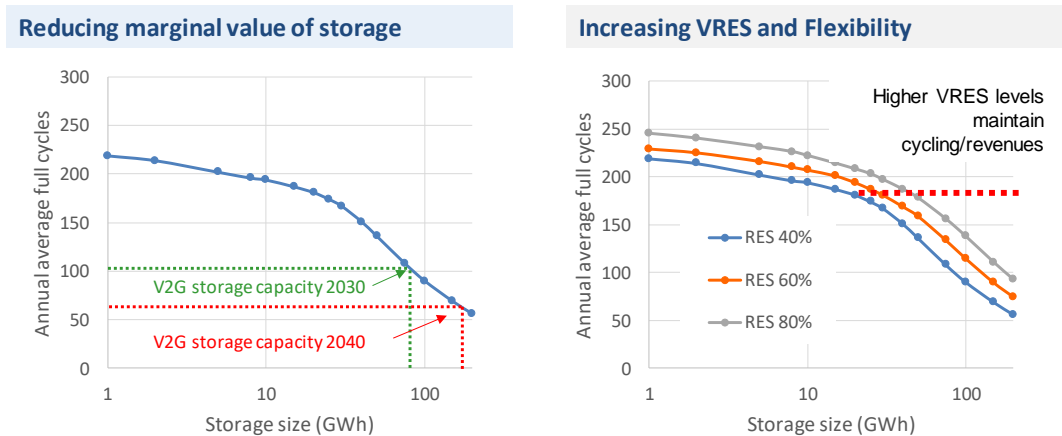


Figure 13: V2G discharge over the hours of the year ranked by net demand

### 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 storage assets decreases<sup>67</sup>. This is shown in the left hand graph below.



**Figure 14: annual cycling vs cumulative storage capacity**

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.

<sup>67</sup> Where all other aspects (such as VRES penetration) are held constant.

## 5 Consumers and business models

### 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.

#### 5.1.1 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 could present a greater risk 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.

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<sup>68</sup>, 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<sup>69</sup>. 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<sup>70</sup> 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.<sup>71</sup>

#### 5.1.2 Minimising range anxiety

Due to a diversity of consumers values, there is no clear cut-off minimum State of Charge (SoC) that is acceptable or not to all consumers<sup>72</sup>. However, one study found that that consumers value their remaining range more as the guaranteed minimum state of charge drops<sup>70</sup>. In a combined choice experiment, the study showed consumers placed the same dis-benefit of reducing range from 175 miles to 25 miles, as in tripling the initial vehicle 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 range is 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

<sup>68</sup> Bailey and Axsen, 2015, *Anticipating PEV buyers' acceptance of utility controlled charging*

<sup>69</sup> Electric Nation, May 2018, *Smart charging summary*

<sup>70</sup> Parsons et al., 2014, *Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms*

<sup>71</sup> Bauman et al., 2016, *Residential Smart-Charging Pilot Program in Toronto: Results of a Utility Controlled Charging Pilot*

<sup>72</sup> Innovate UK

compensation could be reduced further as research shows EV owner’s confidence in the driving range increases with time.<sup>73</sup>

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<sup>74</sup>.

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.

### 5.1.3 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<sup>74,75</sup>. 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<sup>76</sup>. 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 and standardisation 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<sup>77</sup>. 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. Apps integrating vehicle and charging data may support consumer awareness. 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. Evidence of this can already be seen with consumer’s perception of data shared by Tesla cars.

### 5.1.4 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,<sup>78</sup> research shows consumers prefer to plug in their car for an average of 5 hrs/day<sup>73</sup> and tend to charge every other day<sup>79</sup>.

<sup>73</sup> Burgess et al., 2013, *Assessing the Viability of Electric Vehicles in Daily Life: A Longitudinal Assessment (2008-2012)*

<sup>74</sup> 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)*

<sup>75</sup> Bailey and Axsen, 2015, *Anticipating PEV buyers’ acceptance of utility controlled charging*

<sup>76</sup> Ofgem, 2017, *Consumer Engagement Survey 2017*

<sup>77</sup> Stoker, 2019, *DfT unveils mobility regulatory revolution to capitalise on ‘unprecedented’ shift in transport*

<sup>78</sup> Parsons et a., 2014, *Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms*

<sup>79</sup> Irish, 2017, *V2G: The role for EVs in future energy supply and demand*

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<sup>80</sup> 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. Convenient charging locations also matter, as consumers would rather spend longer charging at home than use fast charging at a remote location<sup>81</sup>.

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 \$8,500 respectively<sup>82</sup>. This would mean that incentivising consumers to plug-in for ca 10 hours per day would require a monthly compensation of £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<sup>83</sup>. Free priority parking was sufficient to incentivise consumers to plug-in in one trial. This disparity reflects the perceived negative impact on consumers by the use of contracts, the benefit of convenient charging locations 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<sup>83</sup>.

### 5.1.5 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.<sup>84</sup> Lack of consumer trust in V2G operators to manage their battery degradation will amplify this risk.

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.<sup>85</sup> 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.<sup>86</sup>

Businesses may still need to pay some early V2G adopters 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.

<sup>80</sup> Element Energy, UKPN, 2019, *Recharge the Future- Charger Use study*

<sup>81</sup> Fleet Carma, 2018, *The key to increasing EV adoption is hidden in EV driving and charging data*

<sup>82</sup> Parsons et al., 2014, *Willingness to pay for vehicle-to-grid (V2G) electric vehicles and their contract terms*

<sup>83</sup> Steward, 2017, *Critical Elements of Vehicle-toGrid (V2G) Economics*

<sup>84</sup> 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)*

<sup>85</sup> 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*

<sup>86</sup> Landi and Gross, 2014, *Battery Management in V2G-based Aggregations*



## 5.2 Solutions

### 5.2.1 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 that customers in 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 the mature EV market had made consumers aware of the need to mitigate the negative impacts of electrification<sup>87</sup>. Different values can also be seen amongst early adopters of EVs vs. the mass market. Early EV adopters tend to highly value environmental benefits, with one study revealing they value charging to reduce renewable energy curtailment seven times more than 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. For example, in locations with surplus solar and high time of use or peaking tariffs, V2G could provide higher cost savings and environmental benefits for homes with PV. Early adopter PV-EV customers could be targeted with green management credentials and special tariff structure for self-consumption of PV like those used in the pilot project in the Netherlands, Germany and California (INVENT, redispatch, City-zen and Smart Solar). 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. Education about V2G benefits could support later mass market acceptance.

### 5.2.2 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. OEMs can also incorporate V2G hardware into a connected car to reduce cost and provide consumers access to their vehicle data. 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

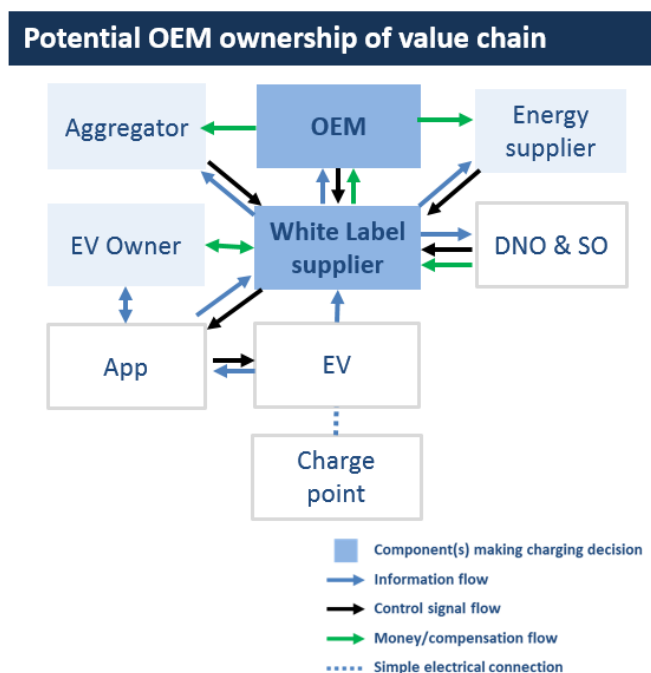


Figure 15: potential OEM ownership of value chain

<sup>87</sup> Kester et al., 2018, *Promoting Vehicle to Grid (V2G) in the Nordic region: Expert advice on policy mechanisms for accelerated diffusion*. 2018.

supplier to ensure the participation of the energy supplier is trusted in the same way as the OEM (See Figure 15).

### 5.2.3 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. 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<sup>88</sup> and 5% growth in automotive leasing<sup>89</sup>. Battery leasing is also becoming increasingly popular in the EV sector as it allows EVs to be cost competitive and negates battery replacement anxieties.

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. 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. Paired with the ongoing V2G service revenues, falling battery prices and EU requirements to recover EV batteries for disposal, this may offer an attractive option for OEMs.

### 5.2.4 Business-to-business models

Several business-to-business models that may pair well with V2G services including some for commercial EVs for fleet vehicles and Mobility as a Service (MaaS) which are expected to grow rapidly in the next few years.

MaaS will increase to 130 million vehicles globally by 2030. Ride-hailing businesses are growing rapidly and are looking to switch to EVs, with companies such as Uber promising to invest £200 million to have all their drivers in London using electric vehicles by 2025<sup>90</sup>. With increasing competition driving prices down, V2G could support the costs of this transition. Car sharing has grown to 250,000 vehicles in the UK<sup>91</sup>. Stationary car sharing businesses, with dedicated parking and infrastructure and low turnover, may also pair well with V2G services.

Fleet vehicles transitioning to EVs would similarly benefit from additional V2G revenues or decreased network connection costs. One study found 90% of UK fleet managers plan to switch to EVs by 2030, with upfront costs sited as the most common barrier<sup>92</sup>. Fleet vehicles' predictable duty cycles and higher number of vehicles per site may provide higher revenues for aggregated grid services. Fleet vehicles that are idle during evenings and weekends could capture greater value as well as depots looking to avoid paying for additional substation upgrades. For example, the Parker trial in Denmark is a commercially viable business-to-business V2G trial which provides the charger, maintenance and V2G management to a fleet of commercial vans used during working hours at a business headquarters<sup>93</sup>.

<sup>88</sup> Reuters, 2017, *More UK cars bought on credit - data*

<sup>89</sup> Lease Europe, 2017, *Key Facts and Figures 2017*

<sup>90</sup> Cnet, 2018, *Uber promises all London rides will be in electric cars by 2025*

<sup>91</sup> Ofgem, 2018, *Future Insights: Implications of the transition to Electric Vehicles*

<sup>92</sup> Edie, 2018, *Survey: 89% of UK fleet managers 'will switch to EVs before 2030'*

<sup>93</sup> Innovate U, 2018, *V2G Global Roadtrip: Around the World in 50 Projects*