Independent, not-for-profit,
low carbon technology experts

Understanding the True Value of V2G

An analysis of the customers and value streams for V2G in the UK

Prepared for:

Prepared by:

Greg Payne
Senior Technical Specialist, Energy Systems & Infrastructure, Cenex

Approved by:

Chris Cox
Head of Energy Systems & Infrastructure, Cenex

Company Details

Cenex
Holywell Building
Holywell Park
Ashby Road
Loughborough
Leicestershire
LE11 3UZ

Registered in England No. 5371158

Tel: +44 (0) 1509 642 500
Email: info@cenex.co.uk

Twitter: @CenexLCFC
Website: www.cenex.co.uk

Document Revisions

No.	Details	Date
V0.1	First Draft	19/12/18
V0.2	Initial edits	08/01/19
V0.3	CC edits	18/01/19
V0.4	Version to distribute	22/01/19
V0.5	Updated for standard tariff	28/01/19
V0.6	Correction to figure 33	12/03/19
V0.7	Updates from IUK feedback	01/04/19
V1.0	Published Version	07/05/19

Contents

Abbreviations

BM	Balancing Mechanism
BRP	Balance Responsible Partner
CM	Capacity Market
DTU	Demand Turn Up
DSR	Demand Side Response
DSO	Distribution System Operator
DUoS	Distribution Use of System charges
EFA	Electricity Forwards Agreement. Commonly refers to the 6 four-hour blocks that wholesale energy is traded in the prompt market.
EFES	Ebbs and Flows of Energy Systems, an Innovate funded V2G demonstrator project
ENA	Electricity Networks Association
EV	Electric Vehicle, specifically a Plug-in Vehicle, whether a Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV) or Range Extender Electric Vehicle (REEV)
FFR	Firm Frequency Response
HV	High Voltage
LV	Low Voltage
MFR	Mandatory Frequency Response
MW	Mega Watts ($1x10^6$ Watts)
NG	National Grid
NPV	Net Present Value
PV	Solar Photovoltaic Electricity Generation
ROI	Return on Investment
STOR	Short Term Operating Reserve
TNUoS	Transmission Network Use of System charges
TSO	Transmission System Operator
TOU	Time-of-use
ULCVD	Ultra Low Carbon Vehicle Demonstrator, an Innovate funded demonstrator project
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant

Definitions

Business Model: In its basic form, a business model sets out a specific product or service, the target customer(s) and the mechanism for making money. Typically, a business model will also include details around the relationship with the customer, sales channels, key activities, resources and partners required to deliver the business. At this point the focus is on understanding what the business is and how it operates, rather than on the detailed financials. It is likely that a new product or services could lead to multiple potential business models, with the 'preferred' business model then being selected.

Business Case: Once business models have been developed for a product or service and the preferred model has been selected, it is possible to carry out a detailed financial analysis of the business model. This is called the 'Business Case'. In a business case the focus is on forecasting costs and income models in order to develop key criteria such as the return on investment (ROI) and net present value (NPV).

1 Executive Summary

One of the biggest challenges limiting the wide-spread adoption Vehicle-to-Grid (V2G) is the availability of clear data on the costs and opportunities for V2G, as required to build an effective business case. Cenex has performed work within the Innovate UK funded projects **V2G-Britain**, **Sciurus** and **EV-elocity** to tackle this gap by defining and assessing potential customer archetypes for V2G, along with possible V2G revenue streams.

Customer Archetypes

Every customer is different, and each customer’s behaviour will impact their ability to access certain value streams. While it isn’t practical to profile every potential customer, it is possible to group customers into ‘archetypes’ which more generally define their behaviour. Cenex has identified a list of 16 domestic customer archetypes and 18 commercial archetypes which are believed to be representative of current and future customers for V2G. Each archetype was assessed for their applicability for V2G, resulting in the following short list of archetypes that provide high applicability to V2G and significant potential scale in the UK:

- Council fleet - Pool cars
- EV Car clubs
- Company car park
- The Retired Professional
- The Eco-Professional
- The Run-around (EV as 2nd Car)

Revenue Streams

24 potential revenue streams were also identified and assessed for their suitability for V2G. The following shortlist gives the most suited revenue streams along with their outlook over the next five years:

Revenue Stream	5 Year Outlook
LV and HV DUoS	Good
Demand Turn Up (DTU)	Good
Imbalance	Stable
FFR (Dynamic and Static)	Poor
Short Term Operating Reserve (STOR) Flexible	Stable
Arbitrage	Stable

Data

Vehicle journey data was collected for each of the archetypes to identify ‘plug-in’ behaviour and charging times which can then be used to evaluate the value streams which can be accessed by each archetype. However, the data available to the project was of insufficient size, quality and quantity to assess archetypes individually, so a combined data set was created representing an aggregation of the shortlisted archetypes. This was used to build up the use cases. A perfect foresight optimisation modelling approach was taken to assess use cases. Within each use cases, charging and discharging was optimised based on potential income with a portfolio of assets aggregated to perform a combination of grid services and behind-the-meter savings. Current market prices for tariffs and grid services were used.

Smart Charging Value Vs V2G

In the base case (with a plug-in rate of 28%), modelled without grid services, Smart Charging captured 80% of the value achieved by V2G. However, once grid services were included, Smart Charging captured only 40% of the value of V2G. The average annual import cost savings for V2G was £81 (versus unmanaged on a single rate tariff), with an additional £106 coming from grid services. However higher plug-in rates (75%) can lead to significantly higher revenue from grid services (£414).

Key Sensitivities

A number of key sensitivities were identified which dramatically impact the potential value of V2G revenue streams. In particular, FFR and other grid service values, actual EV plug-in rates, price forecast error and EV battery degradation costs will all have a significant impact on the business models and values which can be achieved. This report provides more detailed evidence for two of these areas:

1. *FFR & Grid Service Market Value*

For V2G the grid services revenue was highly dependent on FFR, with just under ¾ of the value coming from the 24/7 baseload FFR product and ¼ coming from EFA block FFR products.

It was found that halving the FFR price almost halves the grid services revenue for V2G, showing that there is significant downside risk to grid service revenue for V2G, with at least half the revenue at risk from falling FFR price.

When optimising against the imbalance price, V2G was able to make £82 per year.

Local PV generation increase annual earnings from V2G by a modest £23. While savings from using V2G against a half-hourly tariff were only slightly higher than when using Economy 7.

2. *Plug-in Rates*

The plug-in rate of the EVs is a strong driver for grid service revenue from V2G. In the high plug-in rate (75%) scenario V2G was able to earn four times the grid services revenue as the Base Case (28% plug-in rate). In the high plug-in rate scenario, the total annual revenue for V2G from grid services was £414.

From our combined archetype we can see that it would take a portfolio of around 780,000 chargepoints to provide an assumed requirement of 650MW of FFR.

Conclusions

If V2G is to provide significant value above savings provided by smart charging, then it is important that grid services are accessible as additional revenue streams. Without this any additional upfront cost of V2G will likely negate savings.

For V2G the key driver of this grid service revenue is the plug-in rate. With current EV plug-in rates at low levels (around 30%), it will be important to encourage behaviour change to increase these rates. There is significant risk to potential grid service revenue for V2G, with at least half the revenue at risk from falling FFR prices.

The innovative half-hourly tariff modelled offers little potential savings to V2G above what can be captured from existing E7 tariffs. This suggests that half-hourly tariffs may not unlock significant additional value.

Cenex experience of EV projects over the past decade suggests that V2G users increase their plug-in rate significantly compared to standard EV plug-in behaviour which is driven predominantly by need. Whilst these few V2G demonstration cases cannot be seen as representative of a wider market adoption, it does suggest that the high plug-in scenario is achievable for V2G and represents the top end of revenue for V2G.

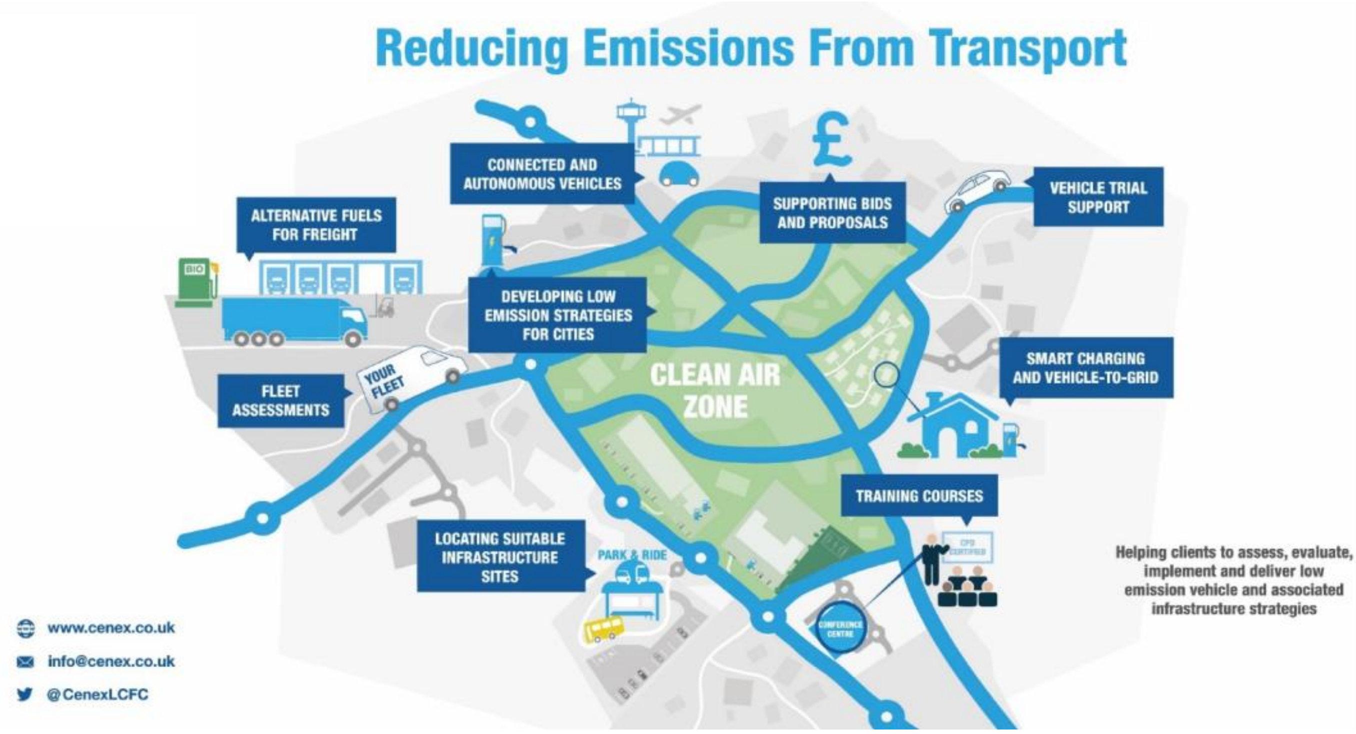
Next Steps

Each of the projects that contributed to this work, **V2G-Britain**, **Sciurus** and **EV-elocity**, will continue in evaluating V2G and will produce more results, some of which may be publicly available.

As well as assessing ‘Generic’ archetypes, by using simple data on driver behaviour, Cenex is able to provide detailed analysis of the likely value which could be achieved for specific use cases. This can be used to support the development of specific business cases for V2G applications and to identify the relative value of V2G and smart charging for any site. For more information on these services, contact Cenex at info@cenex.co.uk.

2 Introductions

2.1 Cenex



Cenex was established in 2005 as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies.

Today, Cenex operates as an independent, not-for-profit consultancy specialising in the delivery of projects, supporting innovation and market development, focused on low carbon vehicles and associated energy infrastructure.

Independent. Not-for-Profit. Consultants.

We highly value our independence as it allows us to provide impartial advice and helps us build trust with our customers.

Being a not-for-profit, Cenex isn't driven by doing the work which pays the most or builds our order book, but by what is right for our customers and for the industry. This is reflected in everything we do, from the work we do and the advice we give, even to the prices we charge.

Finally, as consultants our aim is to be trusted advisors with expert knowledge – the go-to source of help and support for public and private sector organisations. We want to be people you can trust to help where and when it is most needed as our customers progress along their journey to a zero-carbon future.

To find out more about us and the work that we do, visit our website:

www.cenex.co.uk

2.2 Background

This report contains a summary of some of the work performed by Cenex under the Innovate UK funded projects V2G-Britain, Sciurus and EV-elocity. At the time of writing, these projects have not yet finished, and each will continue to produce additional and wider results, some of which will be made public. V2G-Britian specifically will be producing a public report bringing together the findings from across the whole project.

Within each of these projects there was a need to:

- Understand the potential customers for V2G
- Evaluate possible V2G revenue streams
- Quantify earnings of parings between customers and revenue streams.

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

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

To this end, the work undertaken sought to:

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

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

2.3 V2G-Britain

V2G Britain is a one-year feasibility study project involving Element Energy, Cenex, Energy Systems Catapult, Moixa Technology, National Grid, Nissan and Western Power Distribution. The project is focused on increasing understanding of markets and revenue streams for V2G, the longer-term impact of V2G and potential business models. Cenex's role in the project was to assess and quantify the near-term revenue streams.

2.4 Project Sciurus

Project Sciurus is a two-year demonstrator project involving OVO Energy, Nissan, Indra Renewable Technologies and Cenex. The project is aimed at developing and trialling 1,000 V2G units in domestic homes. Cenex's role in the project is to develop the business models, including identification and evaluation of the current and future potential customer and values streams.

2.5 EV-elocity

The EV-elocity project is a three-year demonstrator with partners from the academic, public and private sectors including: A.T. Kearney, Cenex, Brixworth Technology, Honda, E-Car Club, Forward Utility, University of Nottingham, Warwick Manufacturing Group, Leeds City Council, Nottingham City Council and Peel Land & Property. The project aims to increase the uptake of electric vehicles by helping public, commercial and domestic consumers to use new technologies, encourage behaviour change and new business models to monetise their investment using V2G innovation. Cenex's role in the project is to: produce business models and analyse the business case for pilot sites; define the data specification and monitoring requirements; provide pilot management expertise and stakeholder engagement; and provide procurement management.

3 Customer Archetypes

3.1 Introduction to Customer Archetypes

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

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

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

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

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

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

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

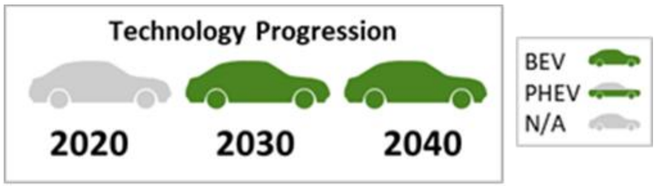
Cenex has been actively involved in V2G research activities since 2013. During this time Cenex has gained experience of a range of potential use cases for V2G. This knowledge was extracted through a workshop and used to form a list of potential customer archetypes. These archetypes were then given further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

A list of the 34 customer archetypes was created under the categories of Domestic and Commercial. These are listed in full in the Appendices. An example from both the Domestic and the Commercial customer archetypes is given in Figure 1 and Figure 2 respectively.

The Retired Professional

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

Key Information:	
V2G Location:	**Home**
No. of EVs using chargepoint:	**1**
V2G Availability:	**60-100%**
Potential no. in the UK:	**1M-10M**



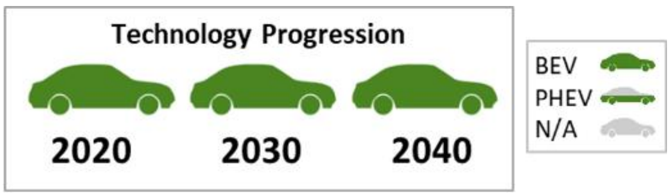
Primary User		**Usage**	
Age Range:	Over 60	Parking Pattern:	Predictable
Income Bracket:	Basic rate	Type of trips:	Short/Medium
Employment Status:	Retired	%age of plugged-in time used for charging:	20-40%
Vehicle Ownership Type:	Owned		
Battery Life Conservation:	High	Charging Location:	Mostly at this location
Primary Motivation:	Environmental	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Medium	On-site renewables:	Yes
Type of vehicle:	Midsize car	Parking Location:	Off-street

Figure 1: Domestic Archetype Example

Council fleet - Pool cars

`Council Fleet - Pool Cars' are based at council owned sites which has a variety of different size cars that can connect to the V2G chargers. The vehicles have unpredictable usage patterns during the day, but often have long dwell periods and are usually connected to the V2G charger overnight and during the day. The council has a range of renewables and onsite generation which they optimise the use of.

Key Information:	
V2G Location:	**Business**
No. of EVs using chargepoint:	**Many**
V2G Availability:	**60-100%**
Potential no. in the UK:	**10k-100k**



Primary User		**Usage**	
Age Range:	NA	Parking Pattern:	Predictable
Income Bracket:	NA	Type of trips:	Varied
Employment Status:	NA	%age of plugged-in time used for charging:	20-40%
Vehicle Ownership Type:	Fleet		
Battery Life Conservation:	Low	Charging Location:	Mostly at this location
Primary Motivation:	Varied	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Varied	On-site renewables:	Yes
Type of vehicle:	Midsize car	Parking Location:	Off-street

Figure 2: Commercial Archetype Example

3.2 Customer Archetype Assessment

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

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

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

The following charts show an assessment of the archetypes. The assessment is based on two things:

1. How applicable the archetype is for V2G applications
2. The potential quantity of the archetype

The first is represented by the vertical axis on the charts. For this measure the scoring from the twenty two data points has been used. The potential quantity is then represented by the horizontal axis.

Special consideration has been given to the percentage of the day that an EV is plugged in and not charging as this gives a strong indication of the flexibility that is available to a V2G unit within the archetype. On the charts this is represented by the bubble size, with larger bubbles representing archetypes where EVs are plugged in but not charging for longer periods.

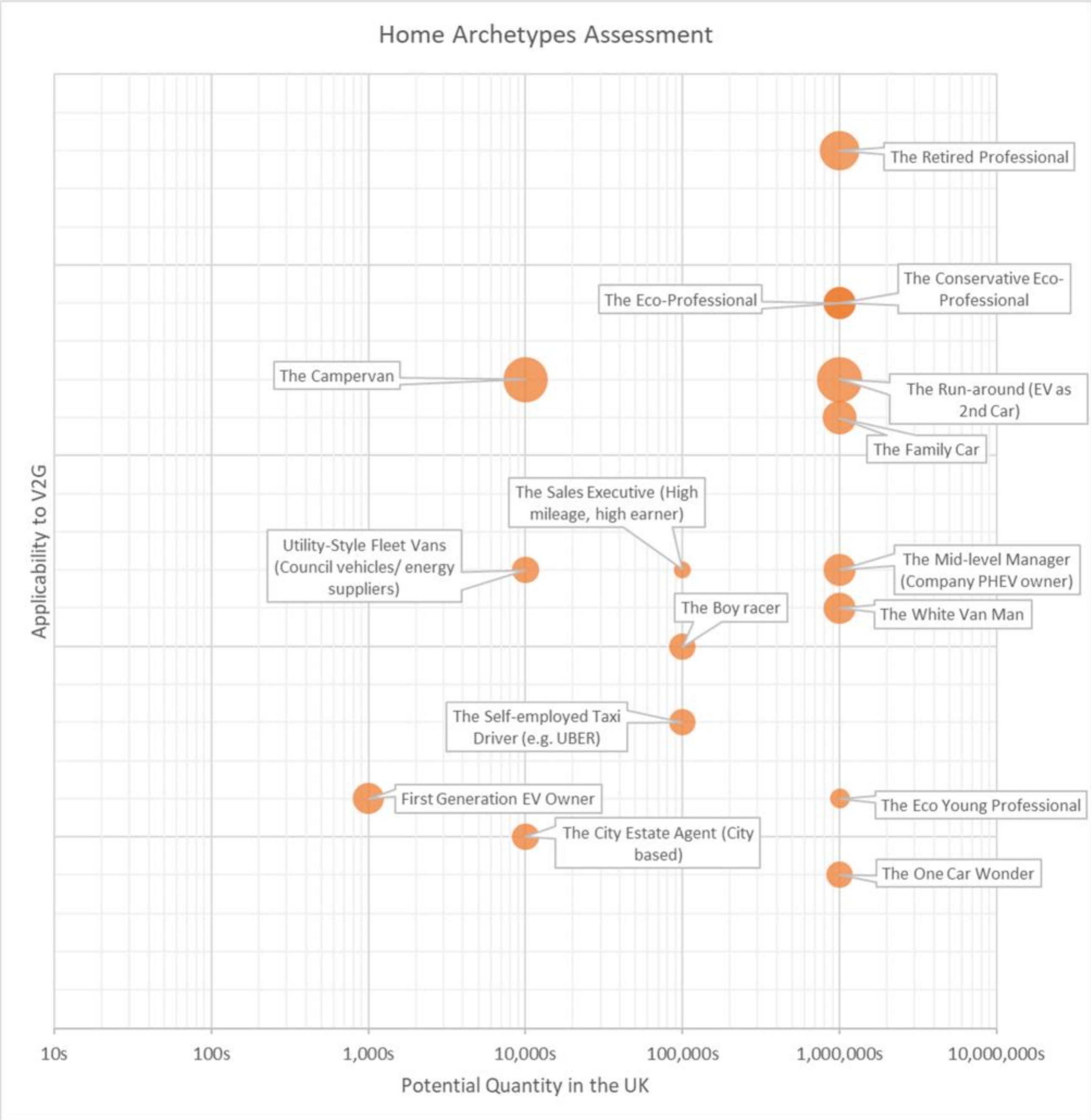


Figure 3: Assessment of domestic archetypes. Bubble size represents the percentage of time EV plugged in and not charging.

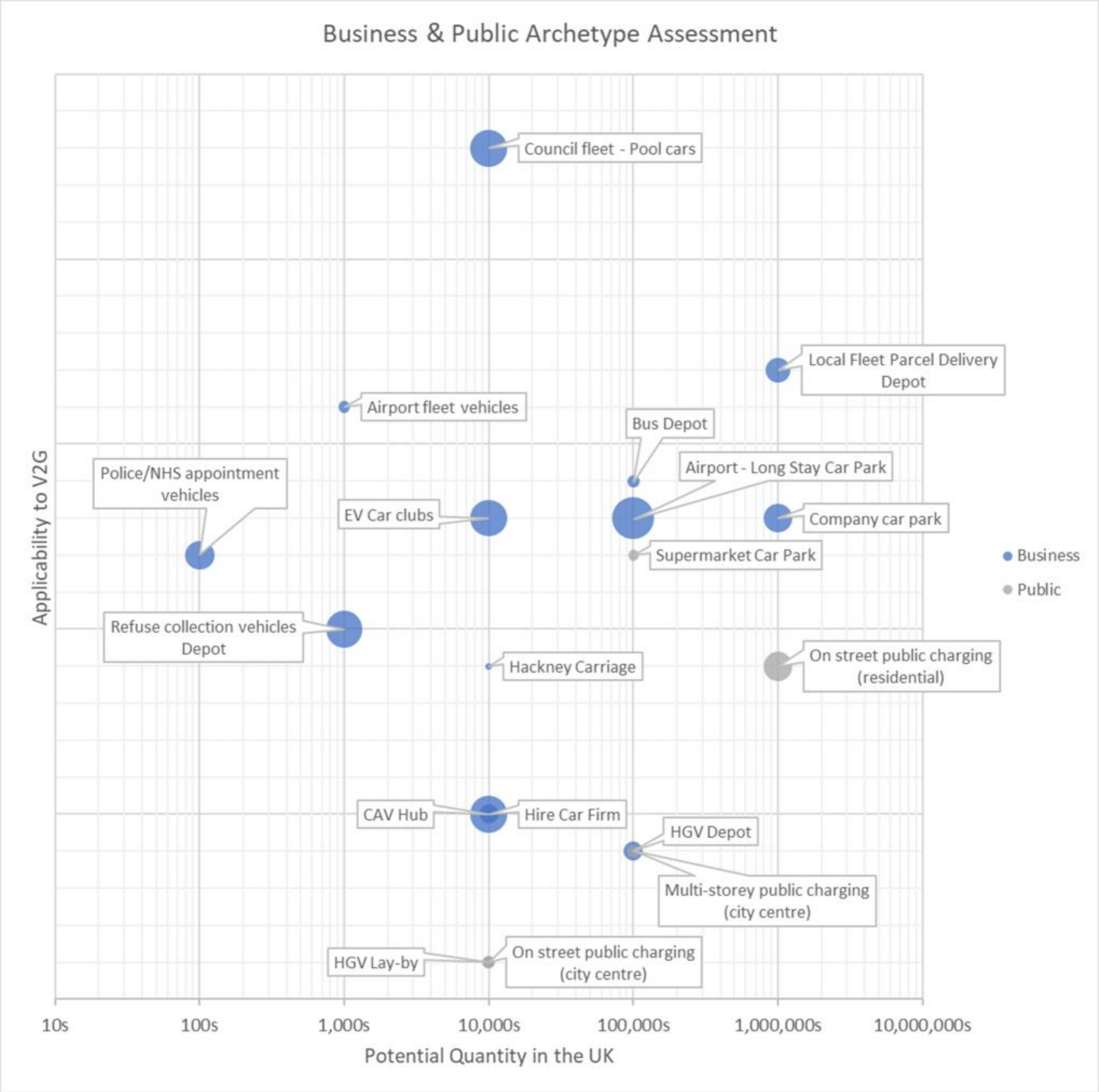


Figure 4: Assessment of business & public archetypes. Bubble size represents % of time EV plugged in and not charging.

A short list of 'high value' customer archetypes was produced based on the following criteria:

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

These are presented in Table 1.

Archetype	Location of V2G chargepoint	Potential quantity of archetype in the UK
Council fleet - Pool cars	Business	10k-100k
EV Car clubs	Business	10k-100k
Company car park	Business	>10M
The Retired Professional	Domestic	1M-10M
The Eco-Professional	Domestic	1M-10M
The Run-around (EV as 2nd Car)	Domestic	1M-10M

Table 1: Archetypes Short Listed for Modelling

4 Revenue Streams

4.1 Introduction to Types of Services V2G Can Provide

In order to provide flexibility services, V2G chargers can either be managed as stand-alone units or in local clusters. Distributed V2G units can also be aggregated to allow them to be managed and operated as groups for non-geographically sensitive energy services such as frequency response (see Figure 5 below).

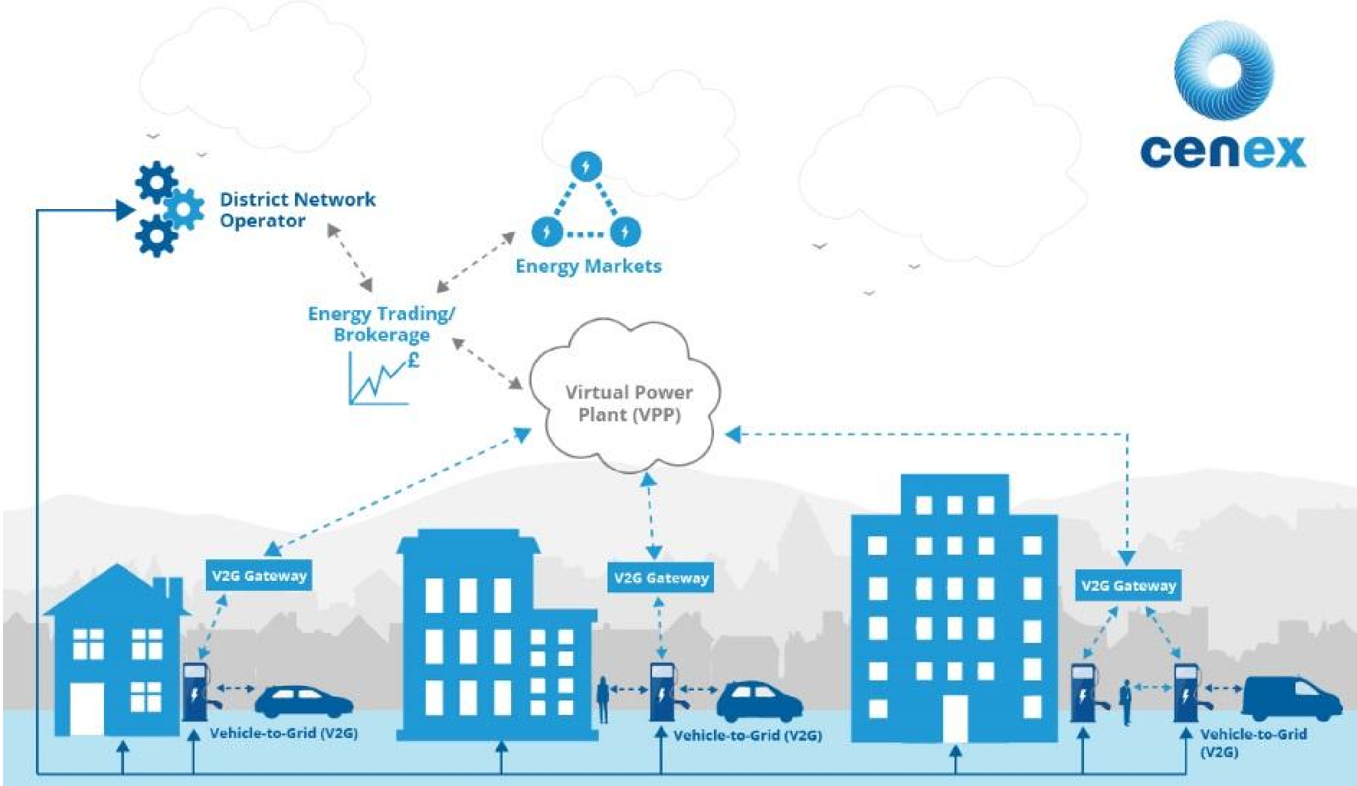


Figure 5: Aggregation of V2G units to trade electricity to energy markets via a VPP

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

- **Behind the Meter:** These are benefits such as peak charge avoidance or increasing utilisation of renewable generation which can be monetised directly by the customer.
- **Transmission System Services:** These are services such as capacity markets and balancing services which can be contracted through the Transmission System Operator (TSO). TSO procure these services to balance the demand and supply in the transmission system to ensure the security and quality of the national electricity supply. Services are broken down into:
  - Contingency - for restarting the network following a total loss of power,
  - Frequency response - used to manage fluctuations in system frequency in the near term (up to 30mins post fault),
  - Reactive power - to manage voltage within the required range,
  - Reserve - used to manage unforeseen demand increases or generation unavailability in the mid-to-long term (15mins+ post fault).
- **Distribution System Services:** Similar to TSO services, these are contracted through the Distribution System Operator (DSO) for provision of services at the distribution network level. Unlike TSO services, the provision of these services from Demand Side Response (DSR) assets

is in its infancy in most countries, although some small-scale services are in commercial operation, most notably in Sweden. These services in future are expected to provide network stability, security and resilience by providing capacity and competitive energy markets in an economic and coordinated manner to achieve whole system optimisation at the distributed level.

- **Wholesale Energy Market:** Energy is traded ahead of time, meaning that traders must predict the demand and generation requirement for any time period. Within this period, the trader must control their assets/contracts to manage any variance or ‘imbalance’. Traders gain financially through trades but are financially penalised for any imbalance. DSR gives traders increased flexibility in their portfolio, which enables these imbalance costs to be reduced. Wholesale energy trading is limited to energy suppliers in many countries, although some utilise ‘Balance Responsible Partners’ (BRPs) which enables non-energy suppliers who manage an energy portfolio, such as aggregators, to access this market.
- **Peer-to-Peer Services:** This is a relatively new concept. Where customers have a direct connection or sit under a single network node such as in a micro-grid, it may be possible to ‘trade’ energy locally at a better rate than could be achieved externally or to enable a non-financial benefit such as reduced dependence on the grid.
- **Battery Management to Improve Life:** One of the greatest concerns for electric vehicle manufacturers and EV owners alike is managing and minimising the degradation of the battery. Recent research by Warwick Manufacturing Group (WMG, part of the University of Warwick) indicated that managing the charge of a vehicle battery within a set of parameters can increase the life of the battery. V2G could therefore be used to provide this ‘intelligent battery management’, ensuring that the battery remains within ‘optimum’ parameters. Extending the battery life using V2G is likely to be favourable in encouraging EVs to participate in V2G services and will be reflected in the vehicle resell price which will be an added advantage.

Whilst the value of V2G extends beyond the economics (for example there is potential for V2G to offer social, environmental and political benefits) this work will focus on the economic benefits alone.

4.2 Core Services and Associated Financial Value

For the purposes of this analysis Cenex has identified 24 potential value streams for V2G. Each value stream was scored for suitability for V2G and ranked in order to provide an indication of the priority with which the service should be considered. The results of this scoring can be seen in Figure 6 (overleaf).

The scoring criteria used for this assessment consisted of:

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

Each potential value stream was scored against the criteria. An overall suitability score was also derived by combining the individual scores.

	Criteria						Overall Suitability
	1. Readiness for DSR	2. Technical Requirements	3. Minimum capacity	4. Service Stackability	5. Current Value	6. Future Value	
Mandatory Frequency Response (MFR)	Red	Red	Red	Amber	Green	Green	Red
Firm Frequency Response (FFR) Dynamic	Green	Amber	Green	Amber	Green	Green	Amber
Firm Frequency Response (FFR) Static	Green	Amber	Green	Amber	Amber	Amber	Amber
Fast Reserve	Amber	Amber	Red	Red	Green	Green	Red
Short Term Operating Reserve (STOR) Committed	Green	Amber	Green	Red	Green	Green	Amber
Short Term Operating Reserve (STOR) Flexible	Green	Green	Green	Green	Amber	Amber	Amber
Demand Turn Up (DTU)	Green	Green	Green	Green	Green	Green	Green
Obligatory Reactive Power Service (ORPS)	Red	Red	Red	Red	Red	Red	Red
Enhanced Reactive Power Service (ERPS)	Amber	Amber	Amber	Red	Amber	Amber	Red
Black Start	Amber	Amber	Red	Green	Green	Green	Red
Capacity Market (CM)	Green	Green	Amber	Amber	Amber	Amber	Amber
Behind-the-Meter Generation Optimisation	Green	Green	Green	Amber	Red	Red	Red
Generation Optimisation on a Constrained Network	Green	Green	Green	Amber	Amber	Amber	Amber
Islanded Energy System Support	Green	Green	Amber	Amber	Amber	Amber	Amber
Network Constraint Management	Green	Green	Green	Red	Amber	Amber	Red
TRIAD (The term used to refer to avoidance of Transmission Network Use of System (TNUoS) charges)	Green	Green	Green	Green	Green	Amber	Green
Low Voltage Distribution Use of System (LV DUoS)	Green	Green	Green	Green	Green	Green	Green
High Voltage Distribution Use of System (HV DUoS)	Green	Amber	Green	Green	Green	Green	Green
Imbalance	Green	Amber	Green	Green	Green	Green	Green
Battery Management	Green	Green	Green	Amber	Red	Red	Red
Arbitrage	Green	Amber	Green	Amber	Amber	Amber	Amber
EU Emissions Trading Scheme	Amber	Amber	Amber	Amber	Amber	Amber	Red
Carbon Reduction Commitment (CRC) Energy Efficiency Scheme	Amber	Amber	Green	Amber	Amber	Amber	Amber
Balancing Mechanism (BM)	Amber	Amber	Amber	Green	Amber	Amber	Amber

Readiness for DSR

- Green: DSR is already participating or is able to provide this service.
- Amber: Active steps are being taken to encourage DSR uptake or no significant barrier exists to DSR participation.
- Red: DSR cannot participate in providing this service.

Technical Requirements

- Green: V2G has no technical barriers to provide this service.
- Amber: V2G will require additional hardware, testing or tools to provide this service.
- Red: V2G is unable to meet the technical requirements of this service.

Minimum Capacity

- Green: A single V2G unit or small number of distributed V2G units can provide this service.
- Amber: A large number of V2G units required to meet min capacity or units cannot be distributed.
- Red: A large number of V2G units (>100) can provide this service AND units cannot be distributed.

Service Stackability

- Green: Service can be stacked with other services with minimal impact on value.
- Amber: Service can be stacked with other services but potentially with high impact on value.
- Red: Service cannot be stacked with other services.

Current / Future Value

- Green: V2G value stream has a good net profitability (>£500/Unit per annum).
- Amber: V2G value stream has a moderate net profitability.
- Red: V2G value stream has low or no net profitability (<£100/Unit per annum).

Figure 6: V2G value stream scoring

4.3 Evaluation of V2G Revenue Streams

Figure 7 provides a graphical representation of the suitability for V2G of the top ten ranked revenue streams, versus a high-level estimation of the annual revenue.

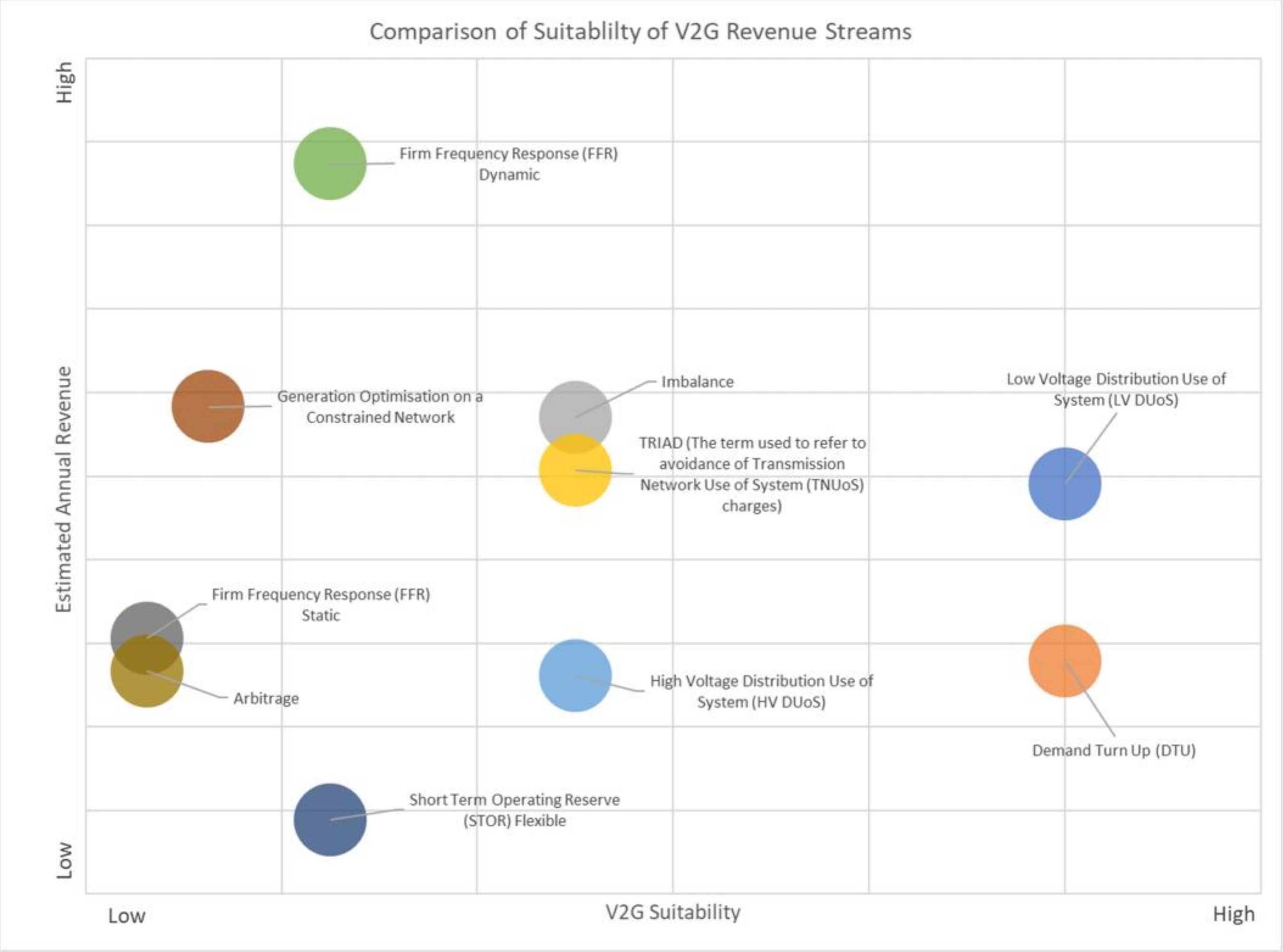


Figure 7: Comparison of Suitability of Top 10 V2G Revenue Streams

From this analysis, a short list of key revenue streams was produced. Revenue streams that were very site dependent (such as ‘Generation Optimisation on a constrained network’), were excluded. Further, given that the available data set for the customer archetypes was primarily domestic focused, TRIAD was excluded, since domestic customers are not currently exposed to this.

The short list of key revenue streams are:

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

5 Modelling

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

Key Features:

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

REVOLVE is designed to work with as much or as little data as is available for analysis. Possible model Inputs include:

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

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

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

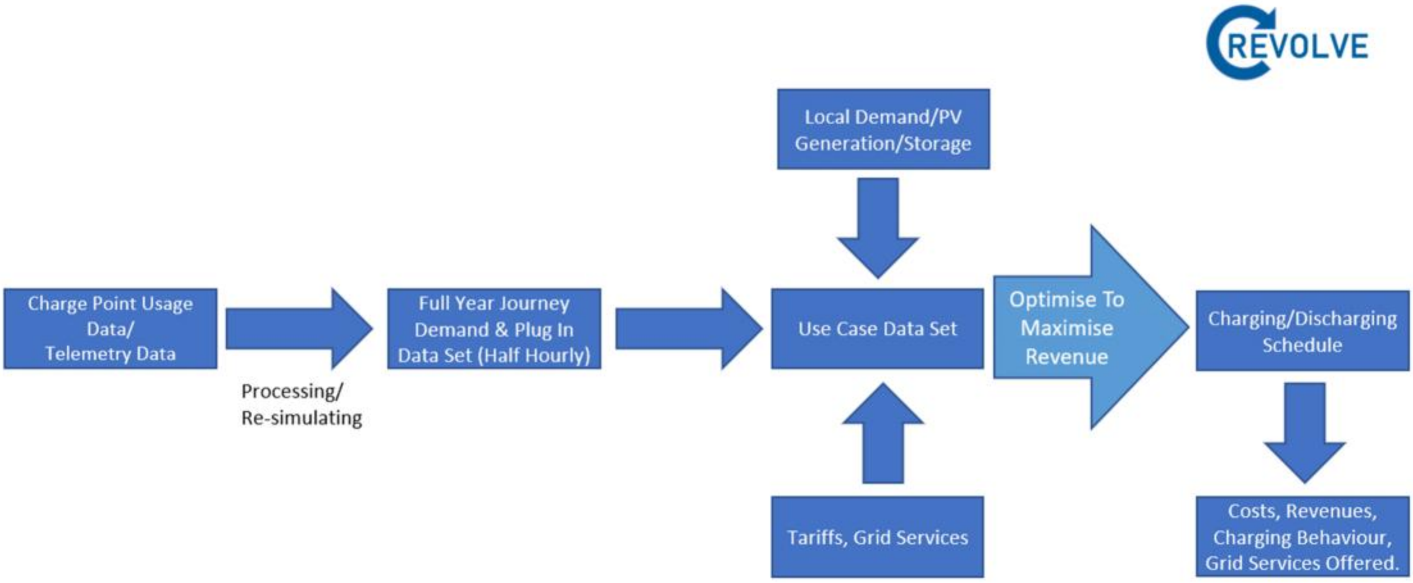


Figure 8: Cenex REVOLVE model diagram

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

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

6 Use Cases

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

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

Details of the assumptions made for the EV/Chargepoint parameters and the tariff and grid services prices are contained in Appendix C: Input Assumptions.

6.1 Archetype Data Selection

Having identified the most promising archetypes, these were then matched to existing data EV and chargepoint data sets.

Data was obtained from the Electric Nation trial[1], a trial that completed over six hundred Smart charger installations. The data included details of chargepoint charging events across the trial participants. This was linked to data on the specification of the EV connected to the chargepoint. Importantly data was also available on the demographic of the household where the chargepoint was installed. This data enabled the selection of only chargepoints that matched certain criteria that were in line with the identified short list of customer archetypes. Based on the answers to questionnaires given to participants in the Electric Nation trial, it was identified that there were participants that aligned with the characteristics of three of the short-listed archetypes, enabling data sets to be created for these archetypes.

Data was also obtained from the Ultra Low Carbon Vehicle Demonstrator (ULCVD), an Innovate UK trial capturing charging and journey data for EVs between 2011 and 2013. This was a more limited data set, however it did include classifications of the usage and user types which enabled cursory matches to the short-listed archetypes to be made.

Finally, over a year’s worth of data was obtained from the ‘Ebbs and Flows of Energy Systems’ (EFES) demonstrator. This was an early V2G demonstrator project. The data was for a single vehicle covering a period of over 12 months up to 2018. The vehicle had been used as a V2G demonstration, with the users plugging the vehicle in regularly in order to benefit from V2G optimisation of their local PV generation. After interviewing the user, it was clear that the usage had a good match to the “Run-around” archetype. The data set was also very detailed including journey, charging and location data.

6.2 Data Issues

After matching the data sets to archetypes, the data was cleaned and filtered. Chargepoint data sets were limited to only those that covered at least 350 days and contained at least 70 charging events. Consequently, the resulting data sets contained considerably less individual chargepoints, with the number of valid data sets for chargepoints per archetype ranging between 1 and 19.

The small number of chargepoints in the data sets cause an issue when it comes to modelling. In order to achieve a reasonable degree of diversity and provide grid services from a portfolio of assets at least 50 EVs/chargepoints were required (as suggested by information provided by Element Energy). So, these small sized data sets for each archetype were not large enough to provide results representative of a larger portfolio.

Two potential solutions to this problem were identified.

1) Simulated new data with similar statistical properties to the existing sets.

[1] www.electricnation.org.uk/

A simulation module in the model was written to achieve this. However, it was not possible to model sufficient diversity without reducing the integrity of the data.

2) Combine all the archetypes into a single data set.

Taking this approach created a combined archetype data set of 60 different chargepoints. As previously mentioned, a threshold of 50 chargepoints was identified to give an acceptable level of diversity in order to start to provide grid services on a portfolio basis. However, for sets larger than 50, diversity continues to improve.

The second solution was selected, and the resulting Combined Archetype was used for most of the model runs.

6.3 The Combined Archetype

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

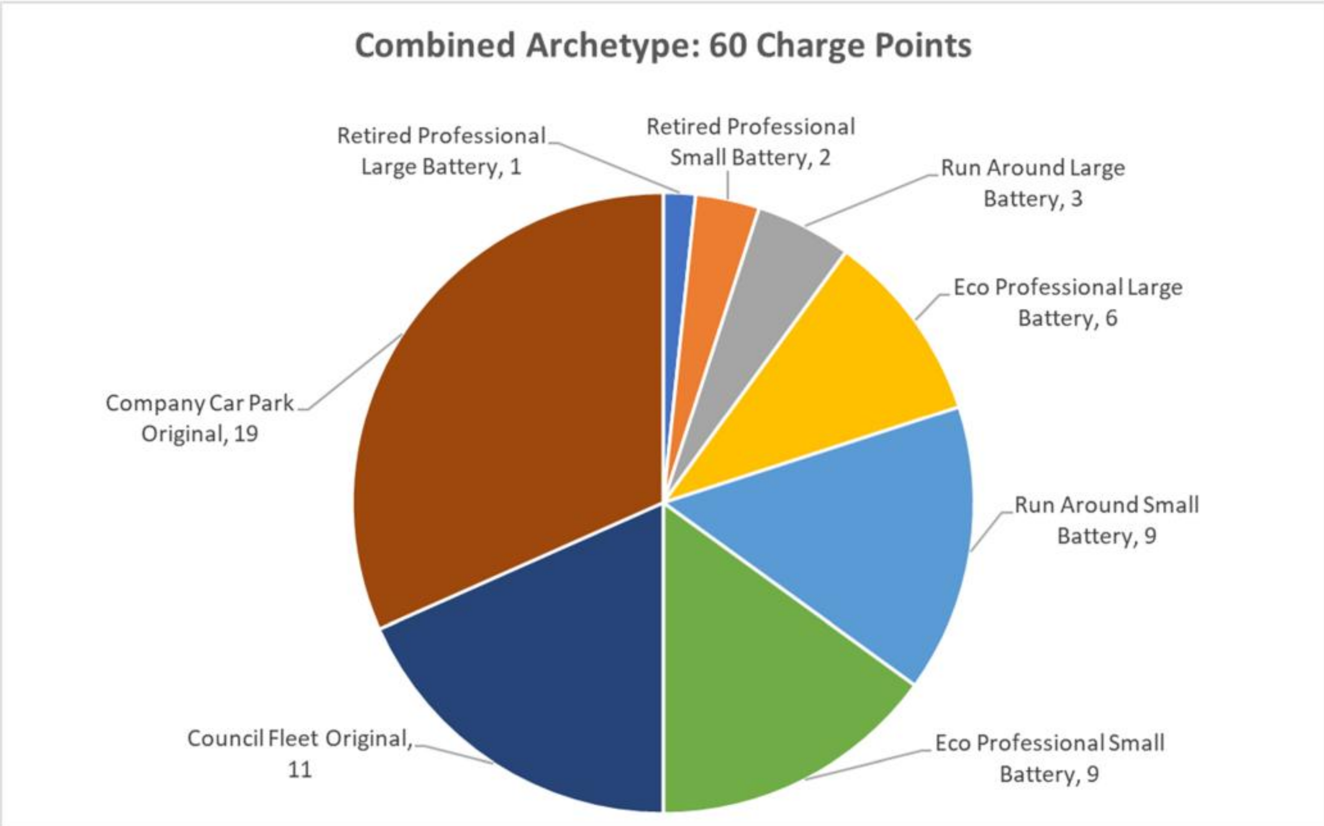


Figure 9: Combined Archetype make up

About half of the archetype is made up of domestic chargepoints, with the other half located at business premises.

A histogram of the annual journey energy demand reveals that modal energy demand lies between 1,000 and 1,500 kWh (equivalent to around 5,500 km to 8,500 km). However, a few have a demand of up to six times this.

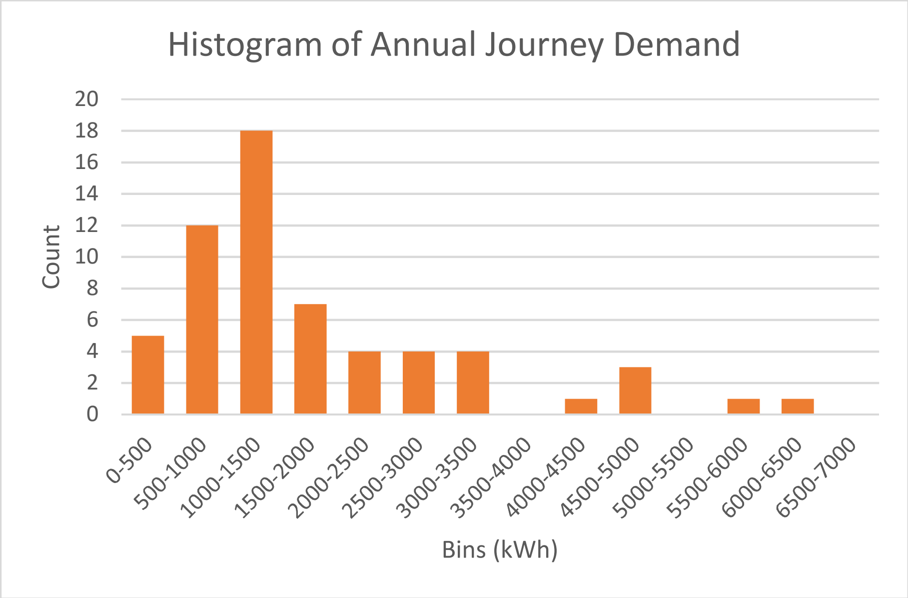


Figure 10: Annual Journey Demand

The two charts below show the EV plug-in availability across the year for each customer in the combined data set, split by weekdays and weekends. Each line represents the average availability across the day for a single EV. A clear pattern of EVs plugging in during the evening and unplugging in the morning can be seen. There are a few exceptional EVs that have a relatively flat profile across the whole day. The EV with the highest availability over the entire year has 80% availability. The lowest is 6%, and the mean of all EVs is 28%.

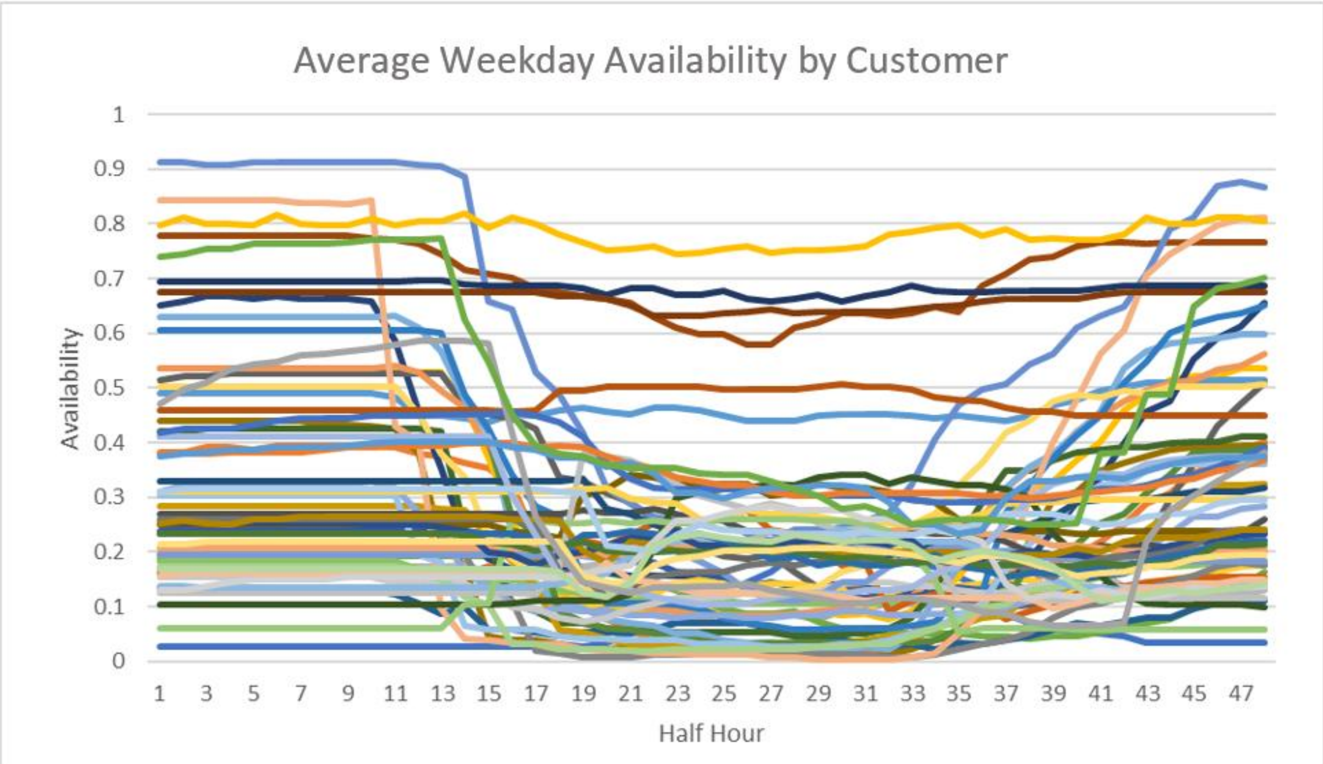


Figure 11:EV availability for Combined Archetype, weekdays.

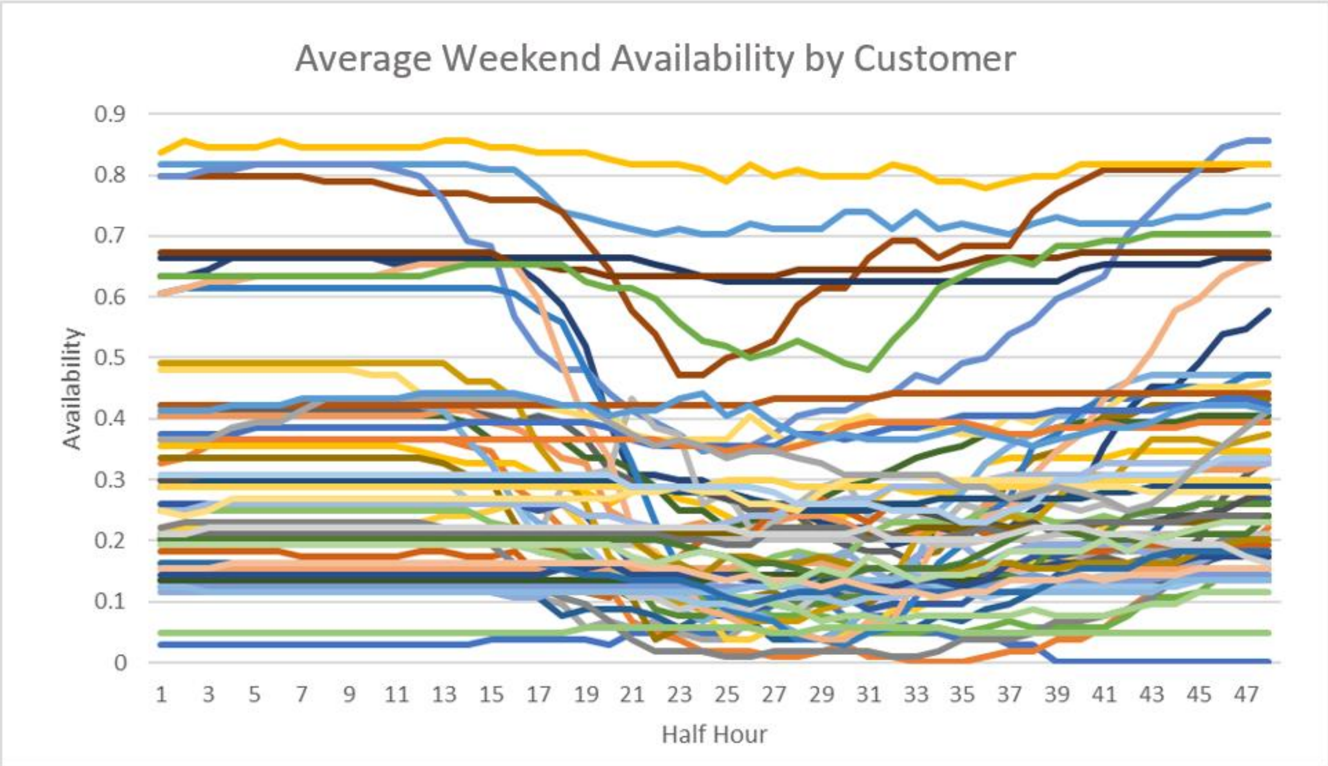


Figure 12: EV availability for Combined Archetype, weekend.

6.4 Use Cases Modelled

As detailed in Table 2 below, the following Use Cases were performed as model runs. Across the runs, the assumptions on EV and chargepoint parameters were kept fixed. The associated building electricity demand data was also kept fixed across the runs. For each use case (i.e. row in the table) the model was run in Unmanaged mode (dumb charging), Optimised mode with a uni-directional charger (Smart Charging), and Optimised mode with a bi-directional charger (V2G)

No.	Archetype	Grid Services[2]	Tariffs[3]
1	Combined	FFR, STOR, DTU	E7
2	Combined	FFR, STOR, DTU	HH Octopus Agile
3	Combined	FFR (sensitivity price), STOR, DTU	E7
4	Combined	None	Imbalance
5	Combined + 2.8 kW PV	FFR, STOR, DTU	E7
6	Run Around (Simulated from EFES data)	FFR, STOR, DTU	E7
7	Run Around (Simulated from EFES data)	None	Imbalance
8	Run Around (Simulated from EFES data)	FFR (sensitivity price), STOR, DTU	E7

Table 2: Use Cases performed as model runs

[2] FFR – Firm Frequency Response; STOR – Short Term Operating Reserve; DTU – Demand Turn Up

[3] E7 – Economy 7; HH – Half Hourly

7 Use Case Evaluation

Results from the model runs are presented in this section. The model was run for all 60 EVs in the archetype, so for clarity averages across the archetype are presented in the charts.

It is worth noting that the Base Case modelled (section 7.1) has a low (albeit currently realistic) plug-in availability rate of 28%. Results for an archetype with a higher plug-in availability rate of 75% are presented in section 8.4. The reader should note that since the plug-in rate is a key driver of value for V2G, both these sections should be considered.

Note that the modelling is based on current market arrangements of services. However, these are changing (i.e. National Grid's reform of flexibility services through power responsive; changes to Balancing Mechanism access and connection regulation by Ofgem). These changes might lead to different assessments in the future.

In all the runs the maximum power of the charge point is set at 7kW.

7.1 Base Case Run

The base case run consisted of the combined archetype, FFR, STOR and DTU grid services and the Economy 7 tariff (No. 1 in Table 2). Figure 13 shows the average[4] annual cost and savings per chargepoint for Smart Charging and V2G. This is calculated from the results of the Unmanaged, Smart and V2G model runs. The import cost (red) in the figure represents the average annual energy cost across the 60 customers in the archetype. This includes the energy used in the building and for charging the EV. Consequently, the first column in Figure 13 shows that the across the archetype average total cost of electricity (for both EV charging and use in the home) over the year was £941. The cost of transitioning from a single rate tariff (which is cheapest for most customers) to an E7 tariff (necessary for smart charging optimisation) is also shown (£34). The import savings (black) show incremental savings made by employing first the Smart uni-directional charger (£98) and then the bi-directional V2G charger (£17). Savings from the Smart Charger are due to delaying charging of the EV to off-peak periods. It should be noted that in this case, all these savings could be realised by a simple timer charging solution. The additional import savings in the V2G case are due to a small amount of discharge from the EV to offset the building demand during peak rate periods. The value is small due to the combination of a relatively small (7p) tariff spread, round trip efficiency losses and the limitations from coincidence of EV availability and building demand. The chart shows that in this use case Smart Charging can capture around 80% of the net savings compared to V2G. The total savings due to V2G being £115 or £85 if we subtract the cost of first moving to an E7 tariff.

[4] Averaged across the portfolio of the 60 vehicles in the Combined archetype.

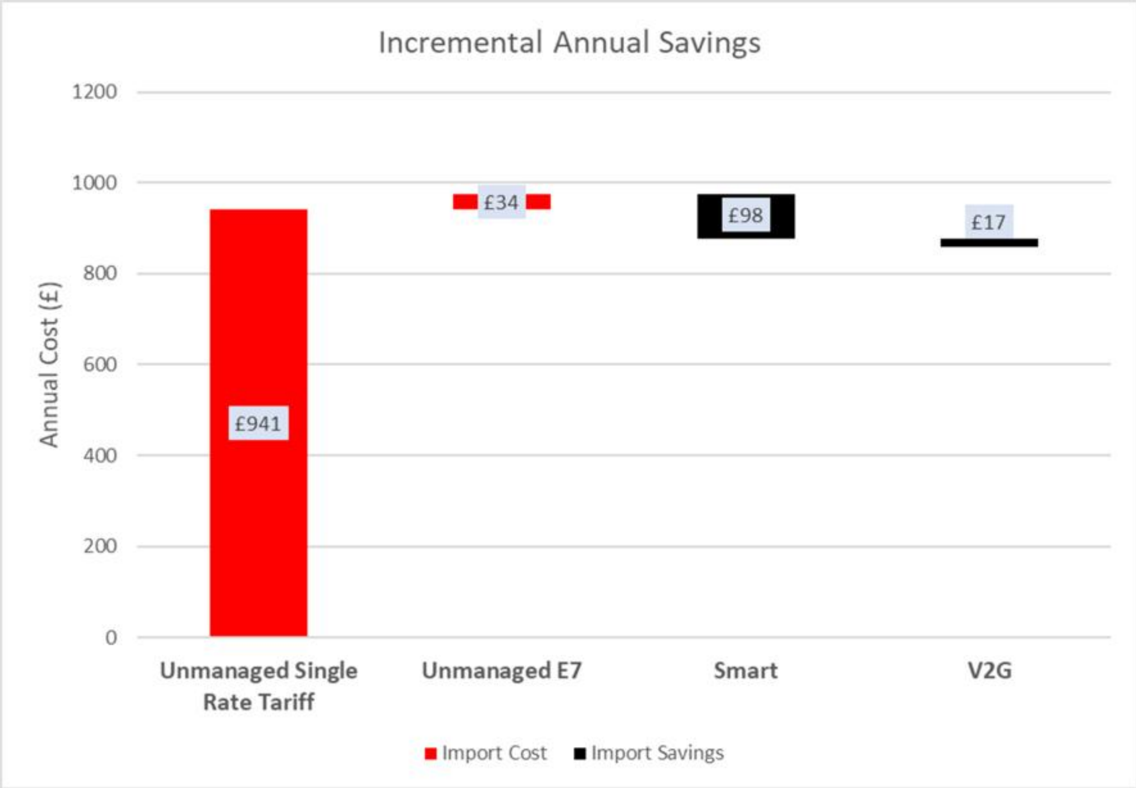


Figure 13: Base case average incremental savings without grid services

Once we include grid services, the picture changes somewhat. Results of the corresponding model runs, with grid services included, are given in Figure 14. This shows similar import savings to the previous case, however V2G can capture much more value in grid services than Smart Charging. This is due to the specifications of the individual services modelled. In this Use Case Smart Charging is only able to capture 40% of the revenue that V2G can.

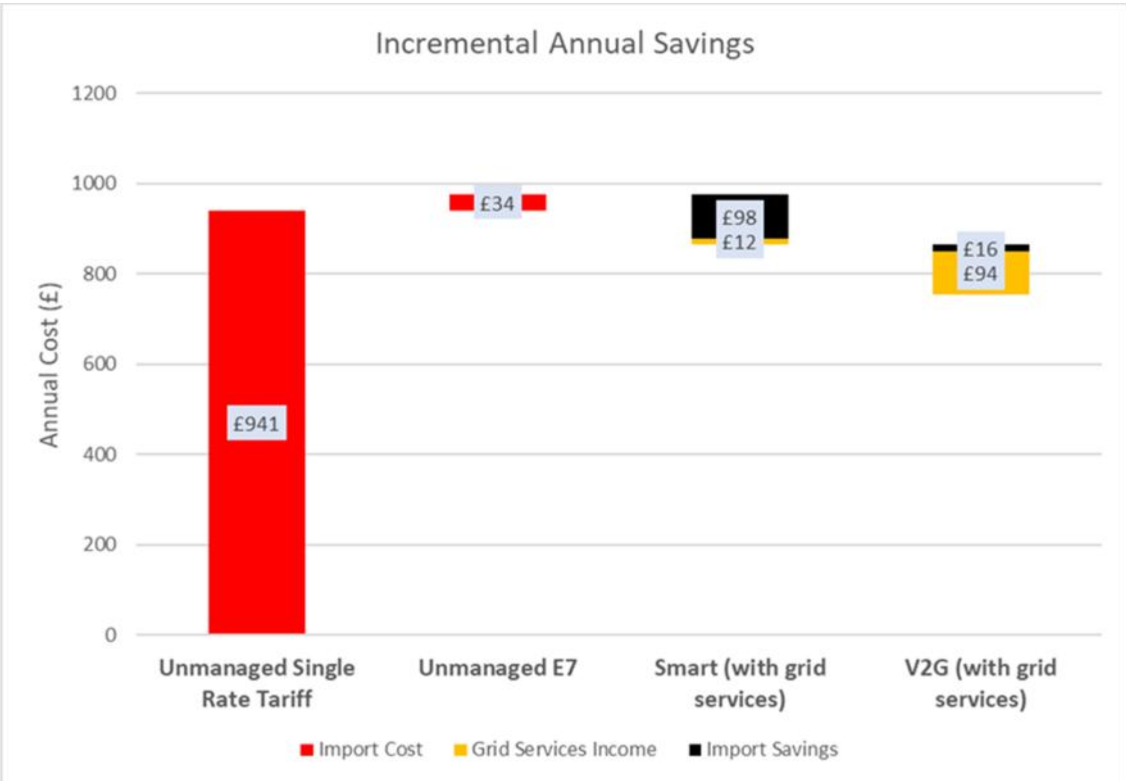


Figure 14: Base case average incremental savings with grid services

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

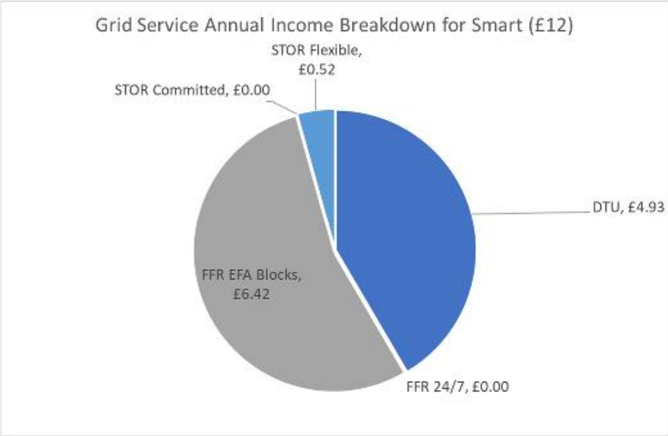


Figure 15: Average grid service revenue breakdown Smart

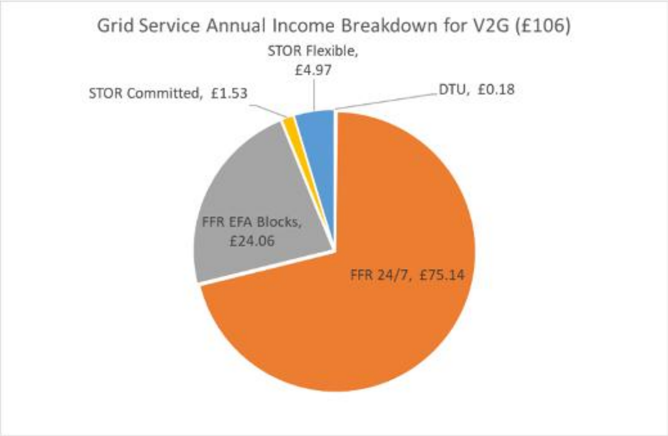


Figure 16: Average grid services revenue breakdown V2G

It can be seen that V2G is able to earn most of its revenue through the FFR 24/7 product. This is supplemented by offering additional FFR EFA blocks.

Smart Charging however is unable to offer the 24/7 FFR product. This is due to the product requiring flexibility both up and down. The only time that Smart can offer this is if it were charging at part load. However, the model is unable to find sufficient coverage from its portfolio of 60 EVs to cover charging at part load for an entire week. So Smart Charging relies on providing some FFR EFA blocks and DTU.

Breaking down the results further for the V2G case, in Figure 17 we can see the grid services offered across the entire portfolio of 60 EVs. This figure shows the “baseload” offering of the 24/7 FFR (grey block) and the additional FFR EFA blocks (green blocks) offered. No STOR or DTU has been offered in this particular week.

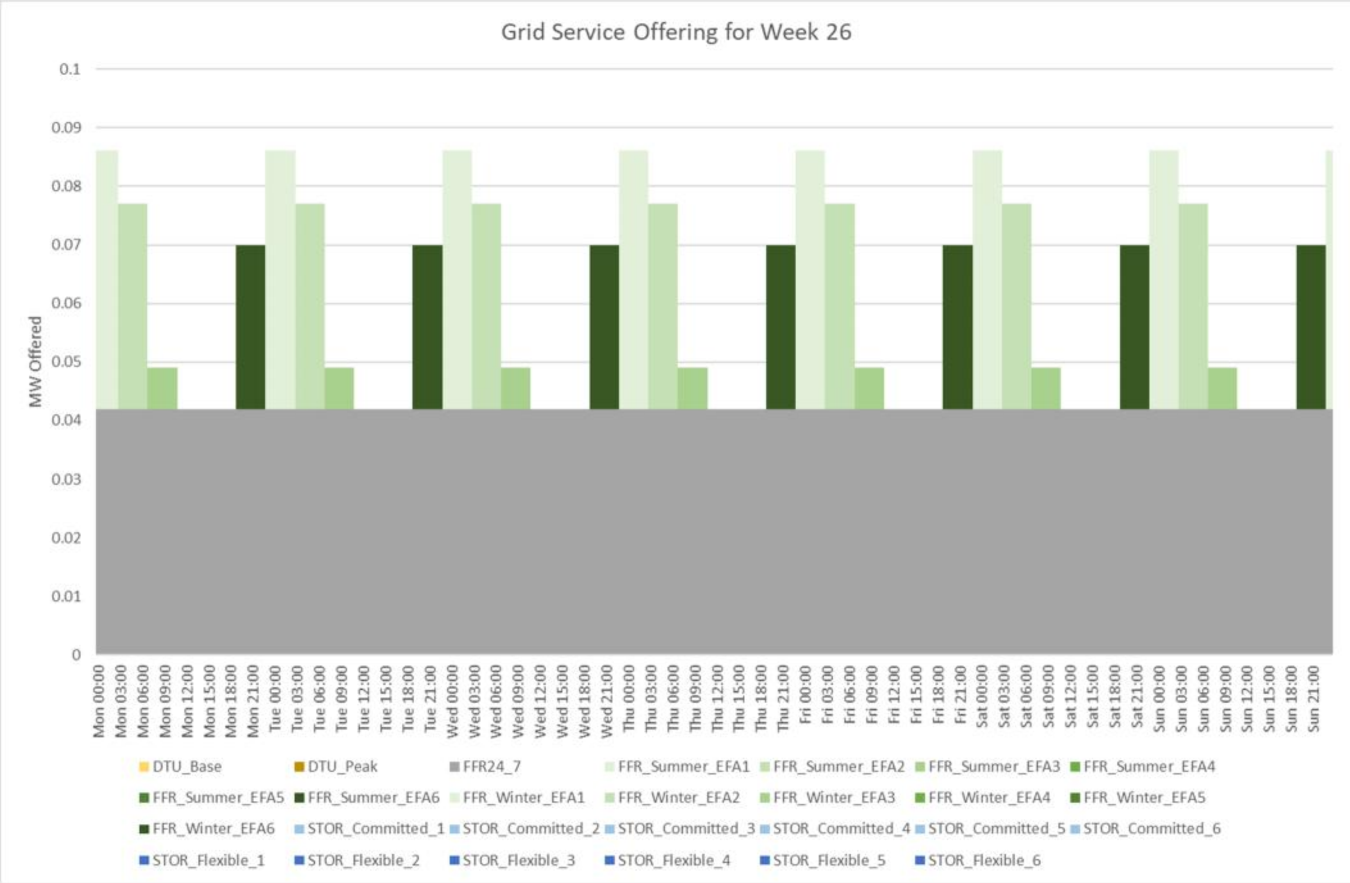


Figure 17: Total grid services offered by V2G in typical summer week

For comparison, the equivalent chart in the Smart Charging case is shown below. This show that the DTU Peak product is offered along with one FFR EFA block.

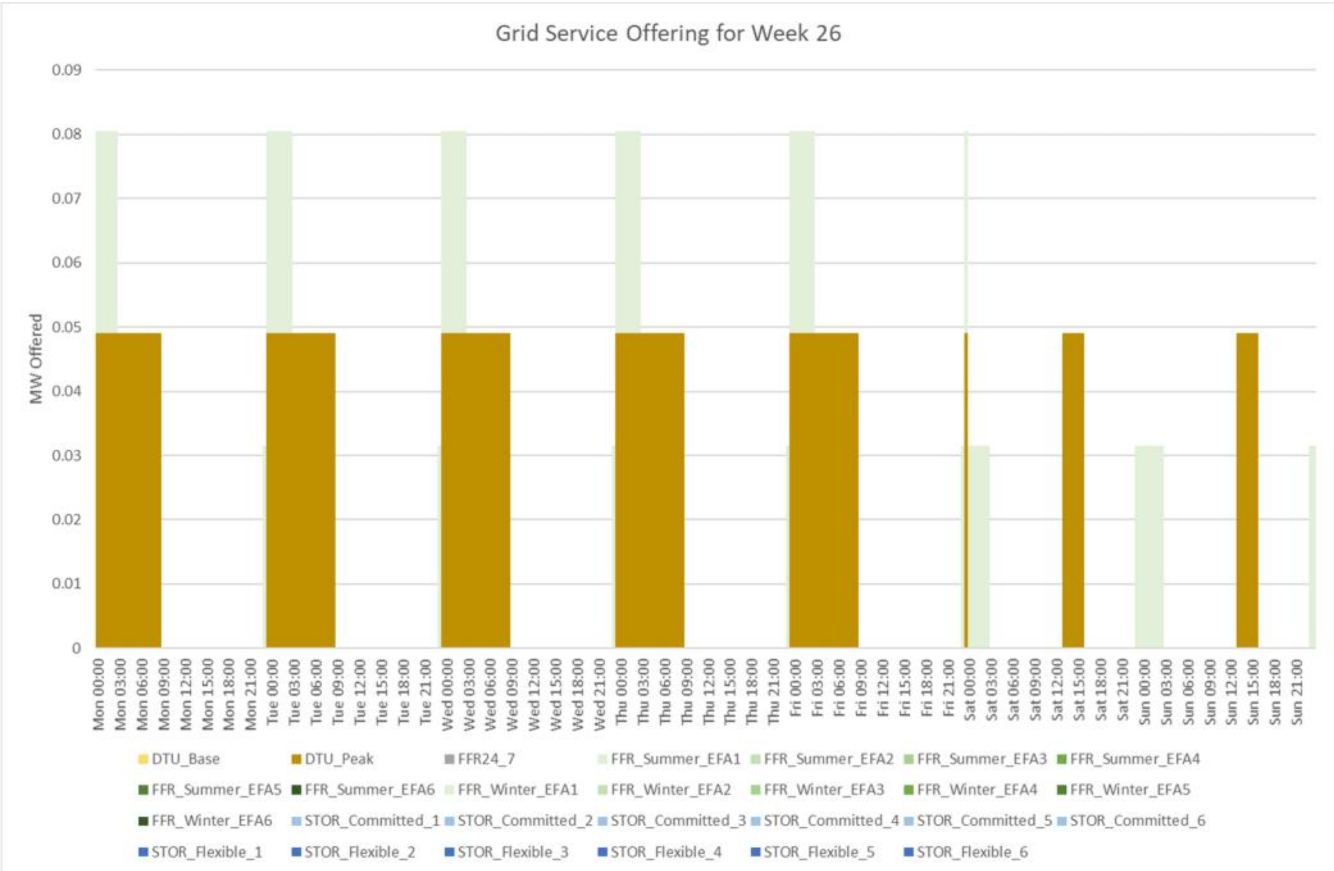


Figure 18: Total grid services offered by Smart Charging in typical summer week

7.2 Base Case and Imbalance

To model the revenue potential of the Imbalance market, additional runs were performed. In these runs, the tariff that charging points were exposed to were replaced with a tariff consisting of the last 12 months of imbalance prices (at half hourly granularity). The model implicitly assumes that all imbalance prices are known in advance, and so schedules the charging and discharging with perfect foresight. This of course is not the case in reality, since imbalance prices are not determined until after the fact. The approach taken is a necessary simplification and provides an upper bound on the revenue available.

Since the imbalance price is symmetrical (i.e. the same for both buying and selling power), the effect of any local demand is negated and so is omitted from this analysis. Figure 19 shows annual average revenue per chargepoint value captured by both Smart Charging and V2G when exposed to the imbalance mechanism. It can be seen that Smart Charging is able to capture just over half the value of V2G.

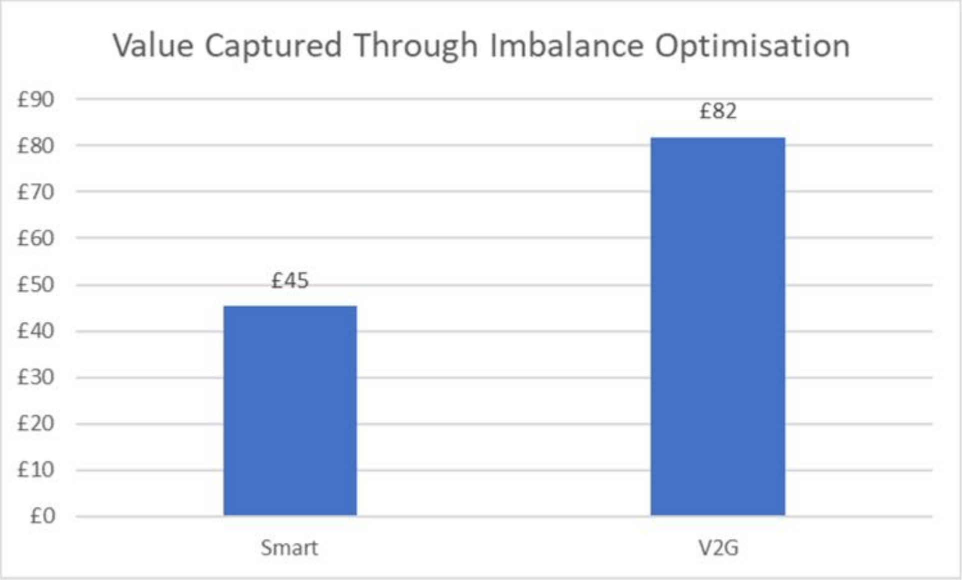


Figure 19: Average value captured through imbalance optimisation

8 Sensitivities

Several sensitivities to the base case runs were performed.

8.1 Sensitivity 1: Low FFR Price Scenario

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

Figure 20 shows the incremental average annual savings per chargepoint in this scenario. The import savings are virtually unchanged from the Base Case. However, the grid service income is significantly reduced. For V2G the total grid services income is £59 compared to £106 in the Base Case. So, a halving of the FFR price results in an almost halving of the grid services revenue for V2G.

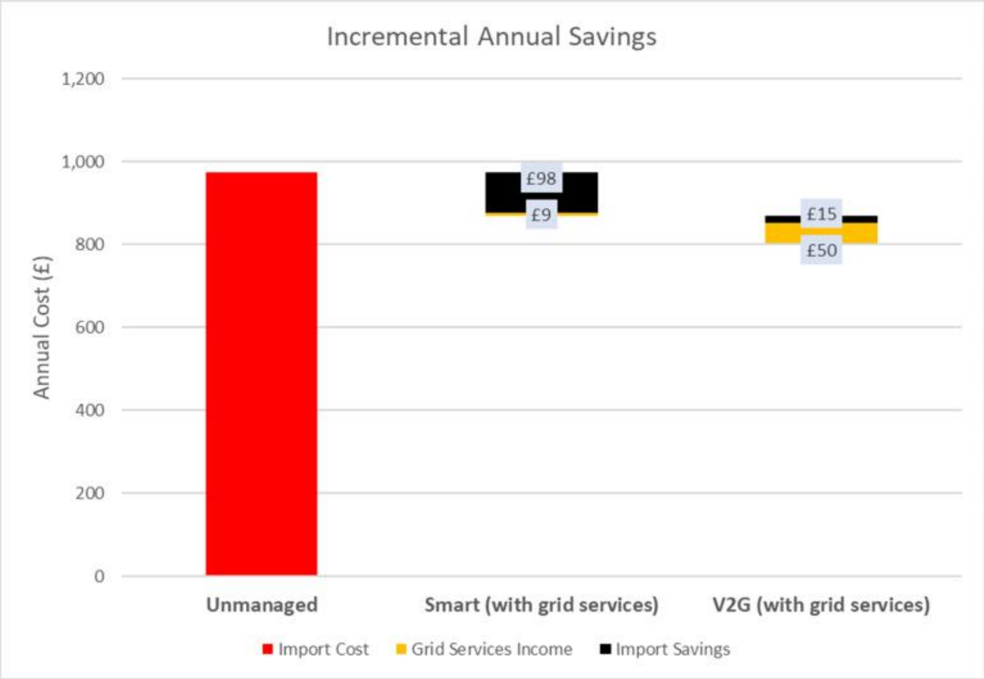


Figure 20: Low FFR price, average incremental savings

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

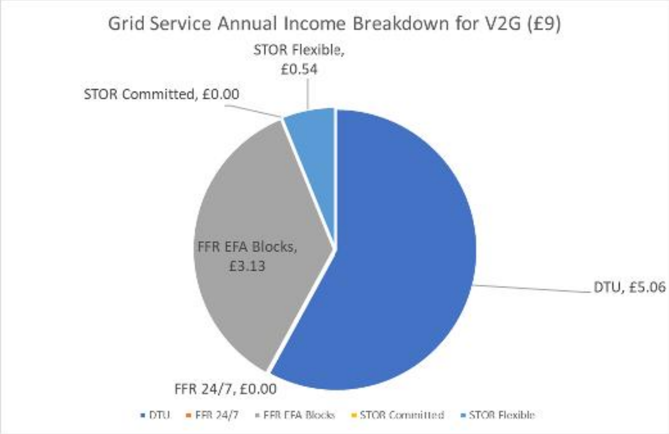


Figure 21: Average grid service breakdown Smart Low FFR price

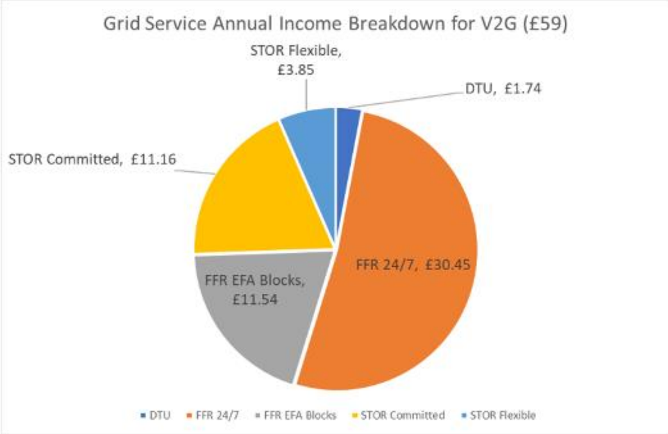


Figure 22: Average grid service revenue breakdown V2G Low FFR price

Looking at a summer week of grid service provision for V2G (Figure 23) we can see more of a mixed picture of revenue sources. DTU (orange) is provided as well as STOR (blue) and FFR (green and grey).

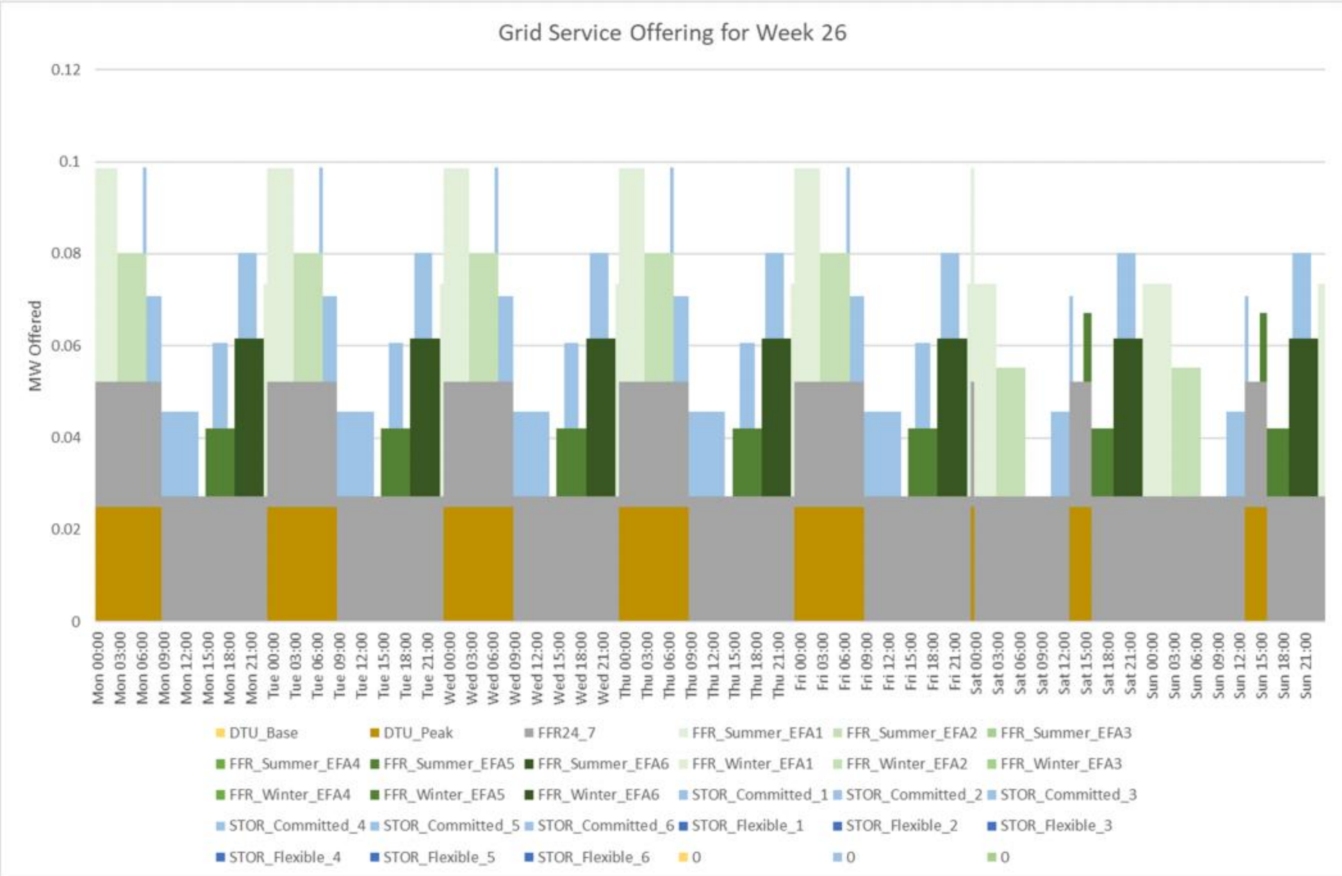


Figure 23: Total grid services offered by V2G in typical summer week in low FFR price scenario

8.2 Sensitivity 2: Local PV Generation

There is an obvious synergy with V2G and local PV generation, whereby the EV can charge using excess energy from the PV and then discharge the energy later to offset some of the local demand. In order to capture this effect, a scenario was run where each customer in the model was given 2.8 kW of PV generation (2.8 kW being the national average of domestic PV installations). Both the PV and charging point are assumed to be behind the meter and so the V2G unit can be used to offset the local demand. It is also assumed that export from the PV is unmetered and paid on a deemed basis. This means that if less PV is exported then there is no reduction in revenue paid. Whilst this is the current situation, from

April 2019 export arrangements for PV are set to change, although the full details of the changes have yet to be seen. It is reasonable to assume that in the future export from domestic properties may be metered, particularly if V2G becomes widespread.

Figure 24 shows that the import savings in this case are increased (from £98 in the Base Case) to £114 for the Smart charger. Total V2G import savings are increased to £138 (from £115 in the Base Case).

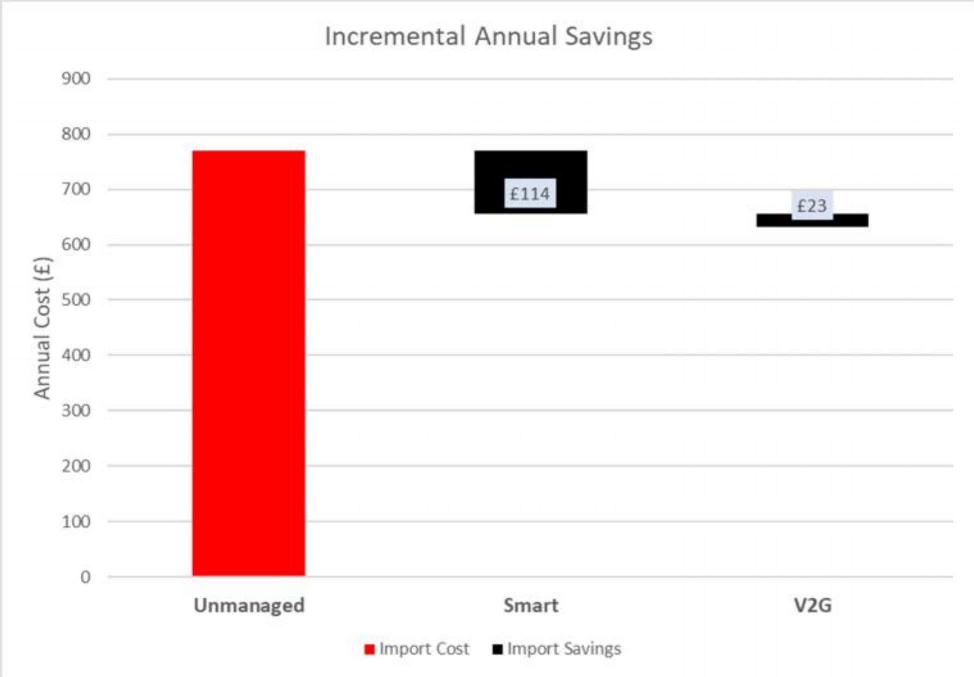


Figure 24: PV case, average incremental savings without grid services

Figure 25 indicates that the revenue from grid services in the PV scenario remains virtually unchanged from the Base Case.

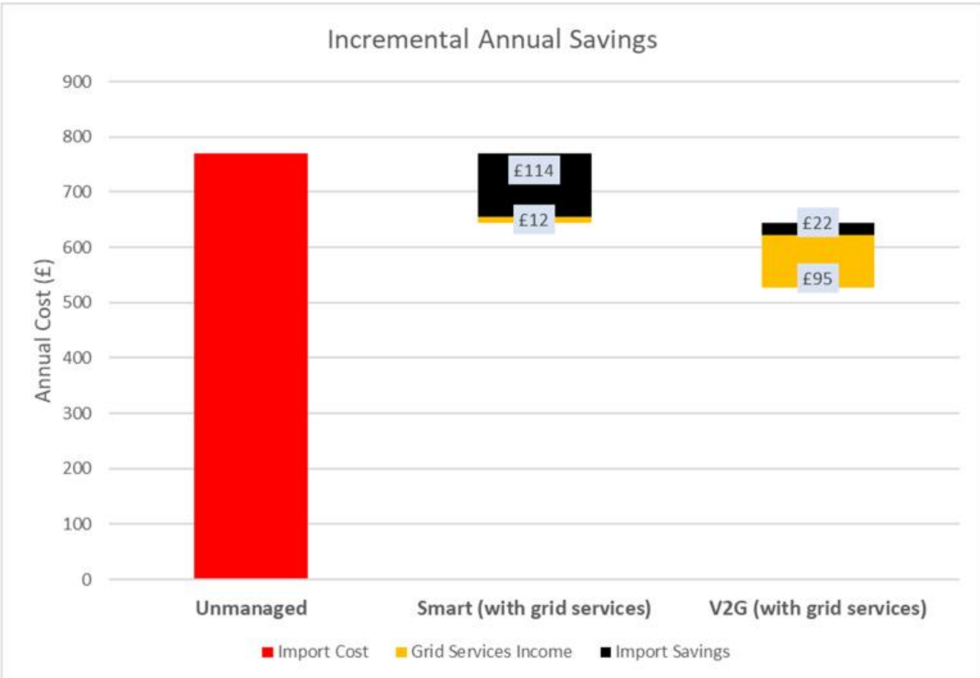


Figure 25: PV case, average incremental savings with grid services

8.3 Sensitivity 3: Half-Hourly Tariff Scenario

Time-of-use tariffs can potentially give further opportunities to optimise controllable demand and generation against price. Whilst Economy 7 is the only widespread domestic time-of-use tariff, it is limited in its components. More innovative tariffs are starting to emerge, and the Octopus Agile half hourly varying tariff is one example. Some runs were performed exposing the chargepoints to this half hourly tariff (using the last 12 months of half-hourly tariff data published by Octopus).

Figure 26 shows the incremental savings against the half hourly tariff. For Smart Charging this is marginally higher than the Base Case. For V2G the total import savings are £130, versus £115 in the Base Case.

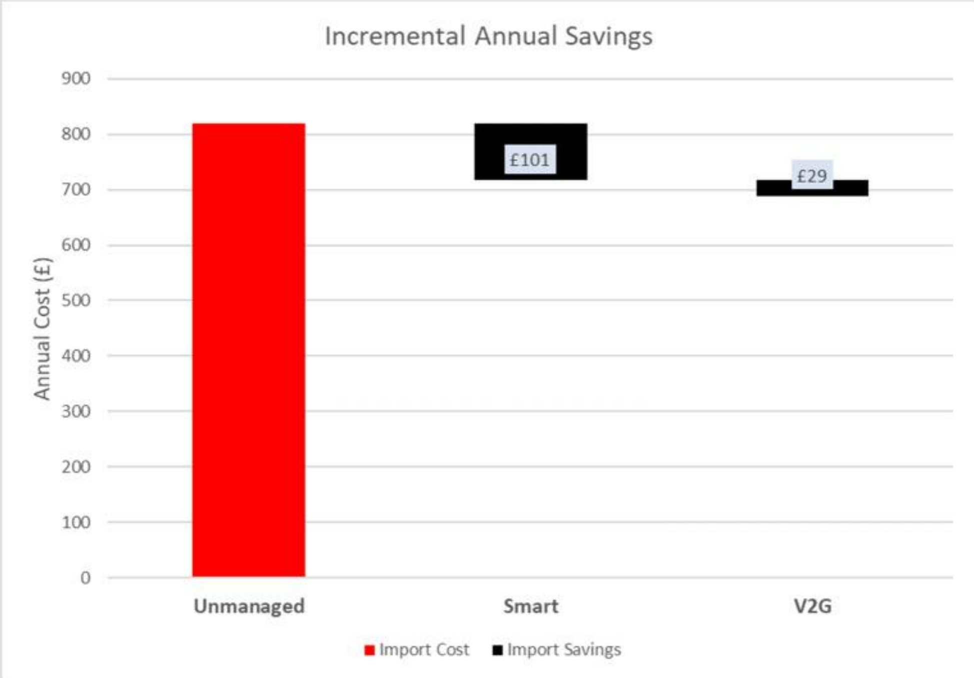


Figure 26: Average incremental savings against half hourly tariff

Figure 27 confirms that the revenue earned from grid services in this case are little changed from the Base Case. However, it does show that the provision of grid services comes at the cost of reduced savings from the import tariff. This should not come as a surprise as both tariffs and some grid services provide different means for tackling similar problems.

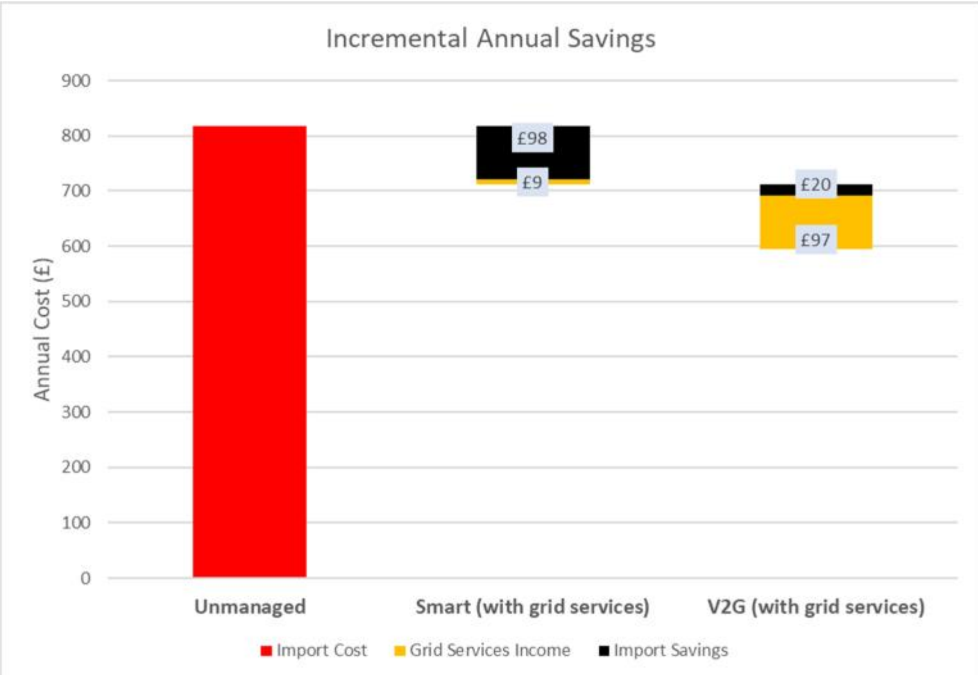


Figure 27: Average incremental savings against half hourly tariff with grid services

8.4 Sensitivity 4: High Plug-in Rate Scenario

One limitation of the Combined Archetype that has been used in all the model runs so far is that it has a low plug-in rate. Whilst the data from the EFES trial (that matched the Run-Around archetype) was for only one car, it had a very high plug-in rate of 75%. Because of the quality of the data set, with plug-in events on virtually every day, the simulation module in the model was able to be used effectively to simulate clones of the data set that exhibited similar statistical properties in terms of journey timings and durations. Figure 28 and Figure 29 shows the comparison of the average week day availability for both the original single EFES data set, and a simulation of 60 chargepoints with similar characteristics.

Figure 28: Average week day availability, original EFES data set

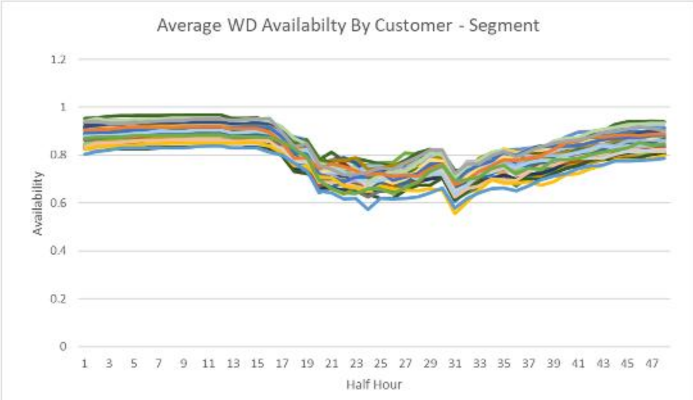


Figure 29: Average week day availability, simulated data set

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

Figure 30 shows that in this case the import savings that Smart Charging can achieve are less than in the Base Case. This is perhaps due to a much lower mean annual journey demand for the EV (637 kWh compared to 1,842 kWh in the Base Case). However, V2G is able to gain additional savings, taking total V2G import savings to £99, or £73 if we account for the cost of moving to the E7 tariff.

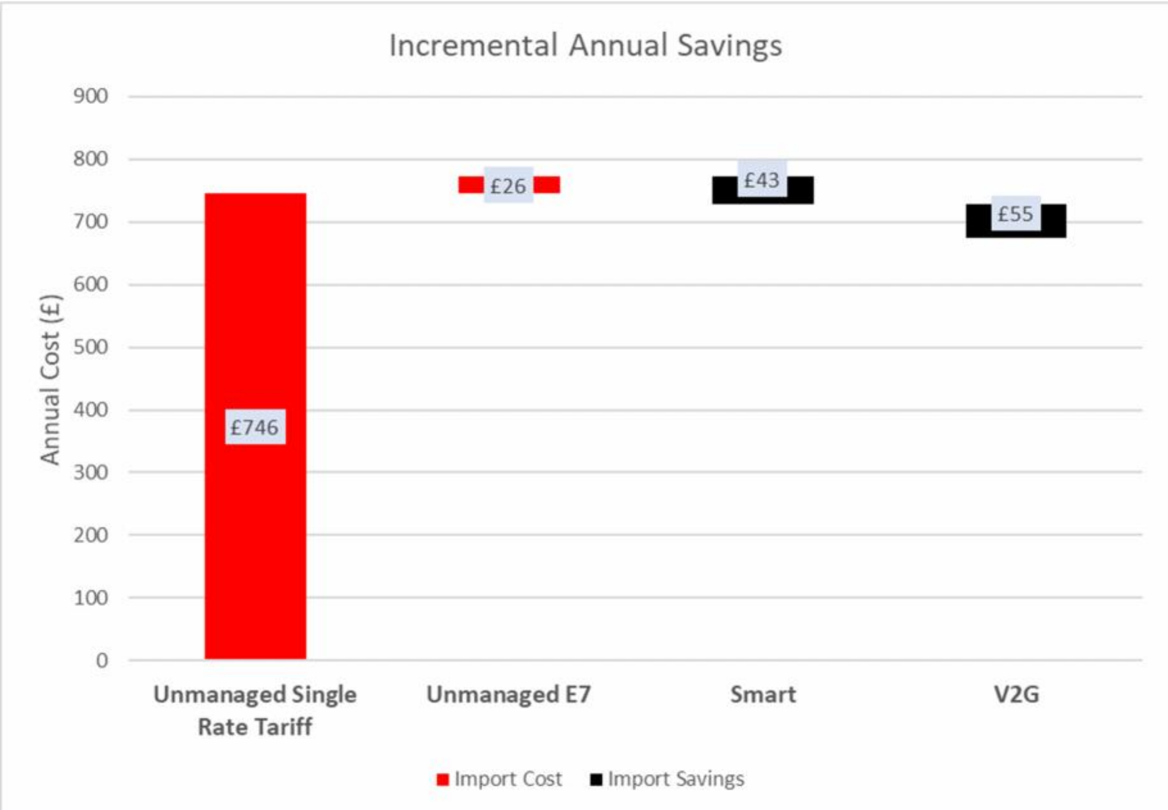


Figure 30:High Plug-in rate, average incremental savings without grid services

When grid services are included as shown in Figure 31 the picture is quite different. The import savings remain virtually unchanged, however the V2G is able to capture a total of £414 in annual revenue from grid services. This is around four times the equivalent value from the Base Case.

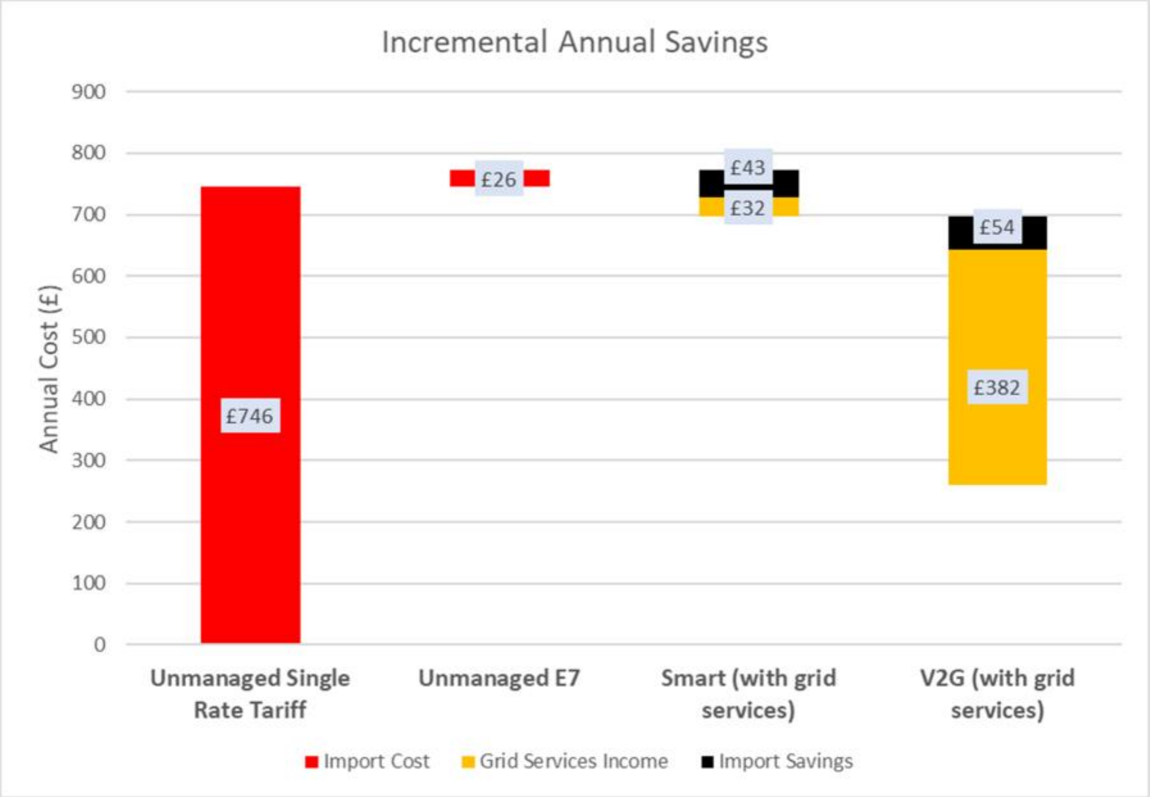


Figure 31: High Plug-in rate, average incremental savings with grid services

The breakdown of grid service revenue in Figure 32 reveals that the majority of the income comes from providing the FFR 24/7 services. This makes sense since the vehicles have a much higher availability for V2G.

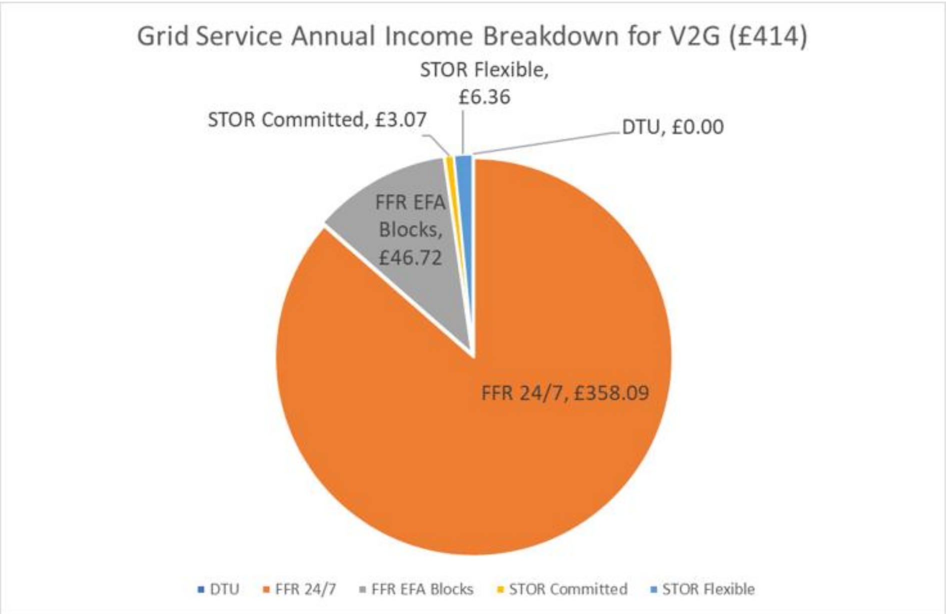


Figure 32: Average grid service revenue breakdown V2G, high Plug-in rate

Breaking the results down to the grid services offered within a typical summer week (in Figure 33), we can see an intricately shaped offering, where the model is able to offer into a variety of services due to the high availability of the V2G assets.

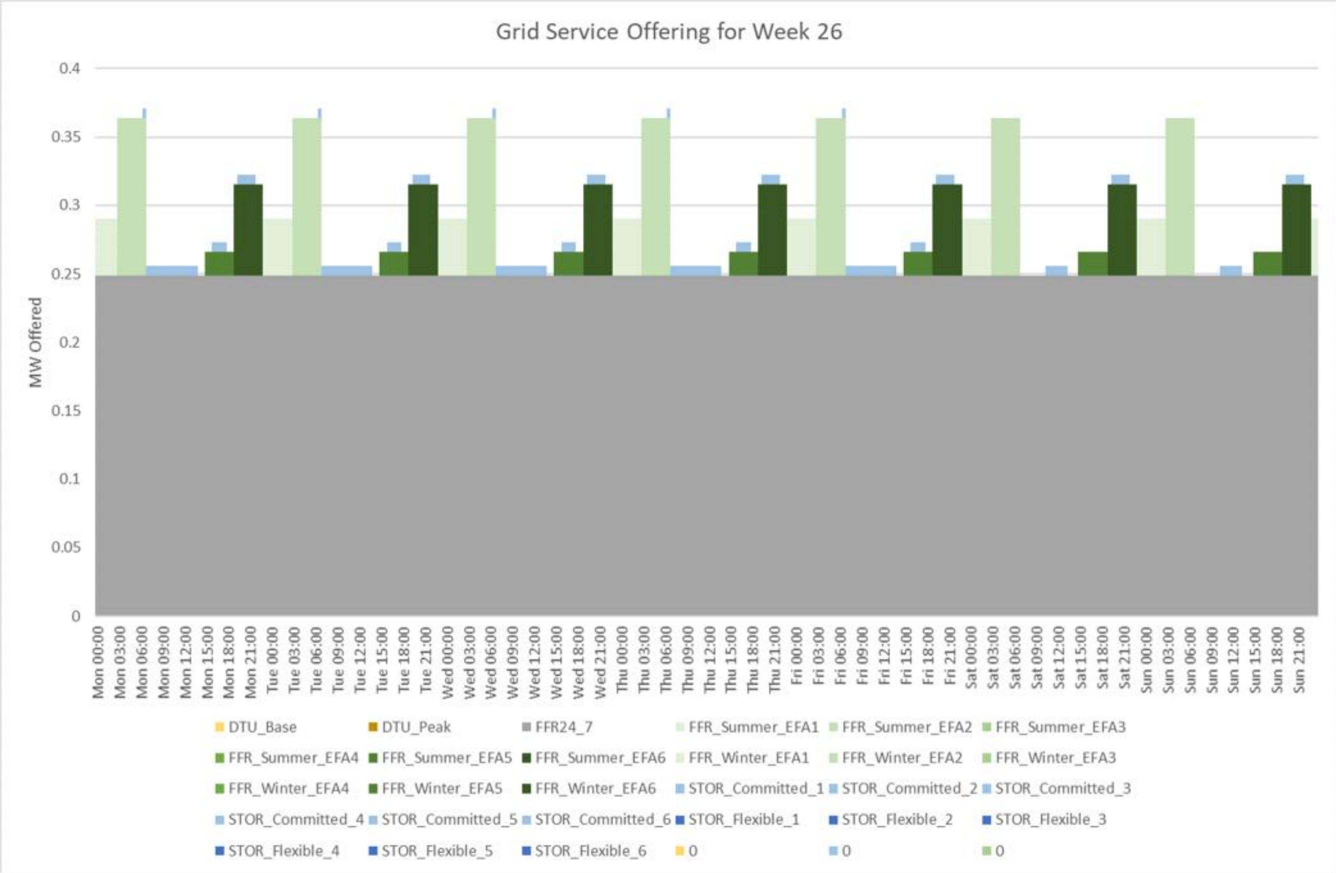


Figure 33: Total grid services offered by V2G high Plug-in scenario in typical summer week

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

9 What is the Potential

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

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

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

From the Combined Archetype of 60 chargepoints (rated at 7kW) can be seen that they provided on average 0.05 MW of 24/7 FFR. Assuming that National Grid had a dynamic response requirement of 650 MW, it would take 780,000 chargepoints to fulfil this.

9.1 Interpretation of Results

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

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

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

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

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

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

10 Conclusions

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

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

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

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

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

If grid services are excluded, then Smart Charging can capture 80% of the value of V2G for low plug-in scenarios, or 24% for high plug-in cases. Therefore, if V2G incurs significant additional capital and operational costs to that of Smart Charging then it would likely counteract the value added by V2G. When including grid services, Smart Charging captures 50% of the total value of V2G for low plug-in scenarios, or merely 10% for high plug-in cases.

10.1Next Steps

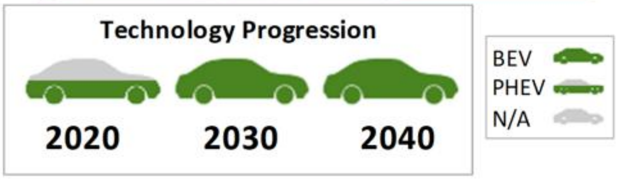
As Cenex continues its work within the V2G space, the next step will be to use data from the real-world demonstrator projects to evaluate the economic potential of these customers. This will be used to develop effective operational strategies for aggregation and trading of flexibility from V2G in the real world. Cenex will also be looking to work with the public and private sectors to help customers understand the impact that V2G and smart charging could have on their businesses and to support the uptake of low emission vehicles, helping us move one step closer to achieving our ambition of a zero-carbon future.

Appendices

Appendix A: Customer Archetypes Definitions (Domestic)

The Self-employed Taxi Driver (e.g. UBER)

This 'Self-employed Taxi Driver' does most of their charging at an off-street home charge point. Their vehicle is used regularly with unpredictable shift patterns. Their high mileage and frugal mindset drives them towards a low running cost EV option.



Key Information:

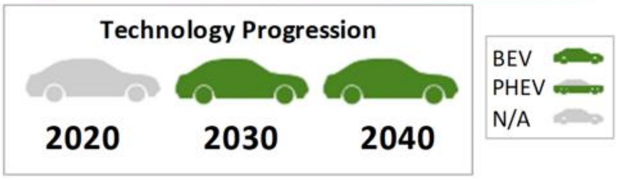
V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 40-60%
Potential no. in the UK: 100k-1M

Primary User	
Age Range:	Varied
Income Bracket:	Basic rate
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Medium
Primary Motivation:	Financial
Vehicle	
Battery Size:	Medium
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Unpredictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	40-60%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	Off-street

The City Estate Agent (City based)

The 'City Estate Agent' has their V2G charge point at home, to power their small EV optimised for urban use. The EV is used for regular short trips during the day and is always plugged in overnight. They rent their home, and likely have use of another car.



Key Information:

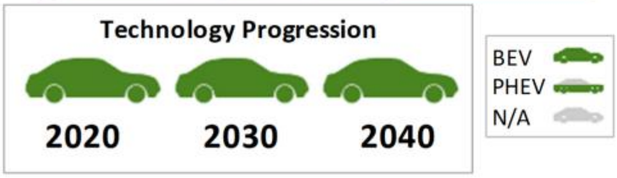
V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 40-60%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	Varied
Income Bracket:	Varied
Employment Status:	Employed
Vehicle Ownership Type:	Company vehicle
Battery Life Conservation:	Low
Primary Motivation:	Financial
Vehicle	
Battery Size:	Small
Type of vehicle:	Small car

Usage	
Parking Pattern:	Unpredictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	40-60%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	Varied

The Conservative Eco-Professional

The middle-aged 'Conservative Eco-Professional' is a higher rate tax payer with an off-street home V2G unit. They are strongly motivated by environmental benefits and likely have PV panels on their home. They own a midsize EV on which the battery is leased, so they will use it in accordance with the warranty conditions.



Key Information:

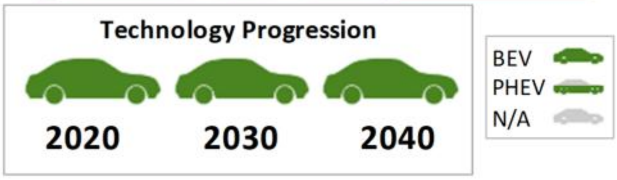
V2G Location:	**Home**
No. of EVs using charge point:	**Few**
V2G Availability:	**40-60%**
Potential no. in the UK:	**1M-10M**

Primary User	
Age Range:	40-60
Income Bracket:	Higher rate
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	High
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Medium
Type of vehicle:	Small car

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

The Retired Professional

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



Key Information:

V2G Location:	**Home**
No. of EVs using charge point:	**1**
V2G Availability:	**60-100%**
Potential no. in the UK:	**1M-10M**

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

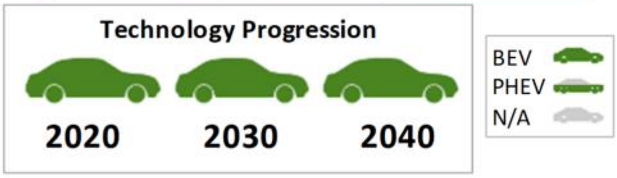
Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	20-40%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	Yes
Parking Location:	Off-street

The Eco-Professional

The middle-aged 'Eco-Professional' leases a new midsized EV which they plug in at the off-street home V2G charge point. They are an early adopter of new technology and may have PV on the home they own. They are a higher income earner and plug the car in overnight and mostly at weekends. They use their car mostly for commuting. They replace their car every 3-4 years. The core difference between the 'Eco-Professional' and the 'Conservative Eco-

Key Information:

V2G Location: Home
No. of EVs using charge point: Few
V2G Availability: 40-60%
Potential no. in the UK: 1M-10M



Primary User	
Age Range:	40-60
Income Bracket:	Higher rate
Employment Status:	Employed
Vehicle Ownership Type:	Leased
Battery Life Conservation:	Medium
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Varied
Type of vehicle:	Midsize car

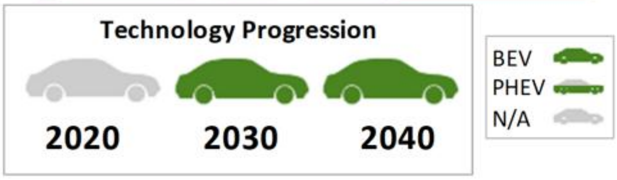
Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	20-40%
Charging Location:	Varied
Location	
Building ownership type:	Owner
On-site renewables:	Most likely
Parking Location:	Off-street

The Run-around (EV as 2nd Car)

This archetype has a home based V2G charge point serving a family's small second car. The user typically does short journeys only (such as school and shopping runs), with another car used for longer journeys. The EV therefore has a low annual mileage and spends much of its time plugged in at home. The user is driven by a balance of financial, social and environmental reasons.

Key Information:

V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 60-100%
Potential no. in the UK: 1M-10M



Primary User	
Age Range:	40-60
Income Bracket:	Varied
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Medium
Primary Motivation:	Varied
Vehicle	
Battery Size:	Small
Type of vehicle:	Small car

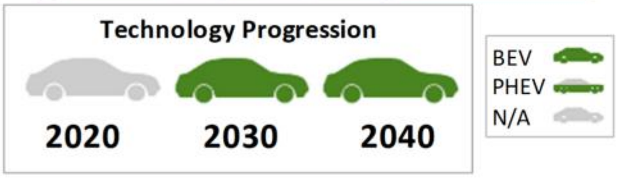
Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	0-20%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	Most likely
Parking Location:	Off-street

The Sales Executive (High mileage, high earner)

The 'Sales Executive' is a higher earner with a luxury EV that does a high annual mileage. They like branded products and new gadgets and are driven more by exclusivity than environmental benefits. They have an off-street V2G charge point. The EV is away most of the day but plugged in during evenings.

Key Information:

V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 0-40%
Potential no. in the UK: 100k-1M



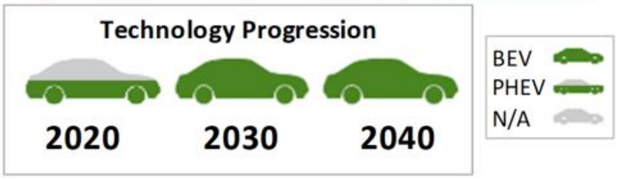
Primary User		Usage	
Age Range:	40-60	Parking Pattern:	Predictable
Income Bracket:	Higher rate	Type of trips:	Long
Employment Status:	Employed	%age of plugged-in time used for charging:	40-60%
Vehicle Ownership Type:	Owned		
Battery Life Conservation:	Low	Charging Location:	Mostly at other locations
Primary Motivation:	Status	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Large	On-site renewables:	Most likely
Type of vehicle:	Executive car	Parking Location:	Off-street

The Mid-level Manager (Company PHEV owner)

The 'Mid-level Manager' has an off-street V2G charge point used to charge a large vehicle. This is a company car and they are a high earner, motivated more by paying less tax than by environmental sustainability. The EV has an unpredictable parking/charging pattern but is mostly charged at home.

Key Information:

V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 40-60%
Potential no. in the UK: 1M-10M



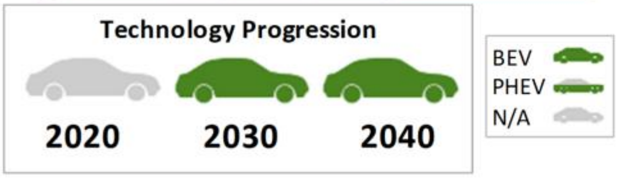
Primary User		Usage	
Age Range:	25-40	Parking Pattern:	Unpredictable
Income Bracket:	Higher rate	Type of trips:	Varied
Employment Status:	Employed	%age of plugged-in time used for charging:	20-40%
Vehicle Ownership Type:	Company vehicle		
Battery Life Conservation:	Medium	Charging Location:	Mostly at this location
Primary Motivation:	Financial	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Large	On-site renewables:	No
Type of vehicle:	Midsize car	Parking Location:	Off-street

The Eco Young Professional

The 'Eco Young Professional' has a V2G charger at home, but not necessarily off-street parking. They have strong environmental concerns but being only low/medium income have a second hand EV. This is used mostly for short and medium journeys, and they are interested in maximising the battery life.

Key Information:

V2G Location:	**Home**
No. of EVs using charge point:	**1**
V2G Availability:	**0-40%**
Potential no. in the UK:	**1M-10M**



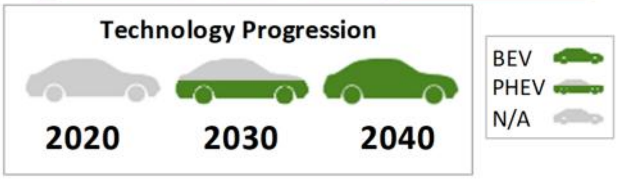
Primary User		Usage	
Age Range:	25-40	Parking Pattern:	Predictable
Income Bracket:	Basic rate	Type of trips:	Short/Medium
Employment Status:	Employed	%age of plugged-in time used for charging:	20-40%
Vehicle Ownership Type:	Owned		
Battery Life Conservation:	High	Charging Location:	Mostly at this location
Primary Motivation:	Environmental	**Location**	
Vehicle		Building ownership type:	Tenant
Battery Size:	Small	On-site renewables:	No
Type of vehicle:	Small car	Parking Location:	Varied

The One Car Wonder

The 'One Car Wonder' is owned by a family as their single workhorse vehicle, doing both school and commuter runs. The family are middle-to-low earners, hence having a single vehicle for the family and therefore the vehicle must be extremely versatile. The car is a large family vehicle (e.g. Ford S-Max) and it is likely to be second-hand. They have a V2G charge point at home, but not necessarily off-street parking. It is parked overnight, and the owners

Key Information:

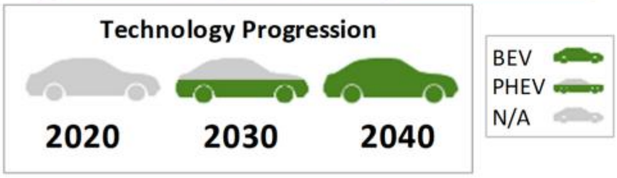
V2G Location:	**Home**
No. of EVs using charge point:	**1**
V2G Availability:	**40-60%**
Potential no. in the UK:	**1M-10M**



Primary User		Usage	
Age Range:	25-40	Parking Pattern:	Unpredictable
Income Bracket:	Basic rate	Type of trips:	Varied
Employment Status:	Employed	%age of plugged-in time used for charging:	40-60%
Vehicle Ownership Type:	Owned		
Battery Life Conservation:	High	Charging Location:	Mostly at this location
Primary Motivation:	Varied	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Large	On-site renewables:	No
Type of vehicle:	Midsize car	Parking Location:	Off-street

The Family Car

This large family car was bought motivated by practicality and value for money. It is the family workhorse used for many short journeys, and occasional family holidays. It is parked off-street at their V2G charge point overnight and between runs during the day. A second, smaller car is used for commuting.



Key Information:

V2G Location:	**Home**
No. of EVs using charge point:	**Few**
V2G Availability:	**60-100%**
Potential no. in the UK:	**1M-10M**

Primary User	
Age Range:	Varied
Income Bracket:	Higher rate
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Medium
Primary Motivation:	Financial

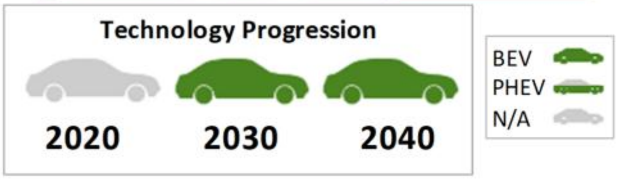
Vehicle	
Battery Size:	Large
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	40-60%
Charging Location:	Mostly at this location

Location	
Building ownership type:	Owner
On-site renewables:	Most likely
Parking Location:	Varied

The Boy Racer

The 'Boy Racer' plugs in their sporty EV to their home V2G charge point. The car is used for commuting and socialising so has low availability at the charge point. The EV is high performance with a large battery capacity. The owner is motivated more by status than environment or economics.



Key Information:

V2G Location:	**Home**
No. of EVs using charge point:	**1**
V2G Availability:	**40-60%**
Potential no. in the UK:	**100k-1M**

Primary User	
Age Range:	17-24
Income Bracket:	Varied
Employment Status:	Other non-working
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Low
Primary Motivation:	Status

Vehicle	
Battery Size:	Large
Type of vehicle:	Sports car

Usage	
Parking Pattern:	Unpredictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	40-60%
Charging Location:	Mostly at this location

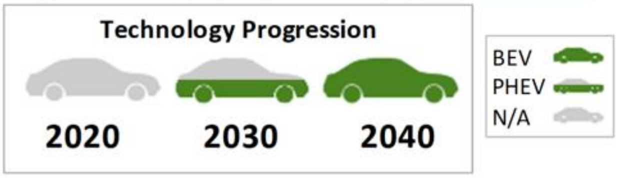
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	Varied

The White Van Man

The self-employed 'White Van Man' owns an electric van that is used throughout the day and sometimes at weekends. It has a large battery capacity and is plugged in every night at the home V2G charge point. They rent their home and may need to use on-street parking. They want reliability and low cost for their vehicle.

Key Information:

V2G Location: Home
No. of EVs using charge point: Few
V2G Availability: 40-60%
Potential no. in the UK: 1M-10M



Primary User	
Age Range:	Varied
Income Bracket:	Basic rate
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Medium
Primary Motivation:	Financial
Vehicle	
Battery Size:	Large
Type of vehicle:	Van

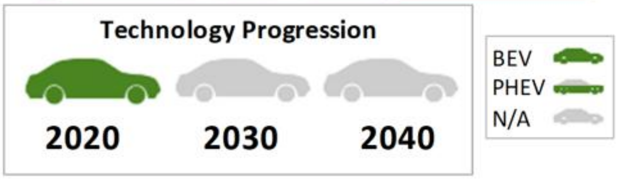
Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	20-40%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	On-street

First Generation EV Owner

This is someone in their 50's or 60's who is an early adopter of technology. They already have PV on their home, and now an off-street V2G charger. They are very energy conscious and would like to maximise battery life. The car is an early EV, used for commuting in the day but spends most of the rest of the time plugged in at home.

Key Information:

V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 40-60%
Potential no. in the UK: 1k-10k

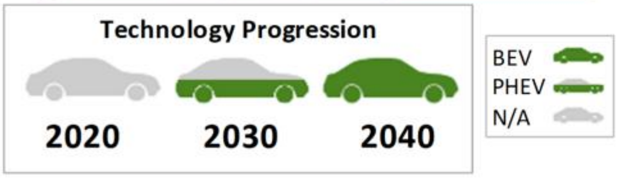


Primary User	
Age Range:	40-60
Income Bracket:	Varied
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	High
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Small
Type of vehicle:	Midsize car

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

Utility-Style Fleet Vans (Council vehicles/ energy suppliers)

This archetype works for a utility, council or similar and operate a fleet vehicle. These are small vans (often converted Ford Fiesta's or similar) used to carry small volume of tools and equipment between domestic appointments. The vehicle is owned by a company but kept by the driver and charged at home or on public networks. The home that the unit is connected to is not the property of the company and therefore it is unlikely that the company would



Key Information:

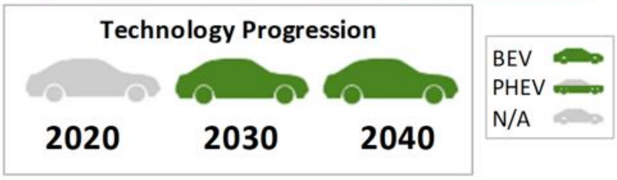
V2G Location: Home
No. of EVs using charge point: Few
V2G Availability: 40-60%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Fleet
Battery Life Conservation:	Low
Primary Motivation:	Financial
Vehicle	
Battery Size:	Medium
Type of vehicle:	Van

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	40-60%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Varied

The Campervan

This family owns a campervan for holidaying within the UK and a separate car for daily travel. During most of the year it is stored on the drive and use is mostly predictable, although good weather during the sprin/summer may result in last-minute weekends away. The owner is a medium to high earner (particularly for initial buyers of EV Campervans), but as a Campervan is a significant investment they would likely be financially motivated to reduce the cost of ownership.



Key Information:

V2G Location: Home
No. of EVs using charge point: 1
V2G Availability: 60-100%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	40-60
Income Bracket:	Higher rate
Employment Status:	Employed
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Medium
Primary Motivation:	Financial
Vehicle	
Battery Size:	Medium
Type of vehicle:	Van

Usage	
Parking Pattern:	Predictable
Type of trips:	Long
%age of plugged-in time used for charging:	0-20%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

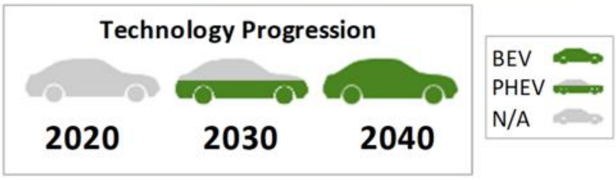
Appendix B: Customer Archetypes Definitions (Commercial)

Local Fleet Parcel Delivery Depot

The `Local Fleet Parcel Delivery Depot' has some V2G charging points that has many fleet vans using it. The vans are leased and perform continuous short journeys. The vans are driven during the days, evenings and weekends, but are always plugged in overnight.

Key Information:

V2G Location:	**Business**
No. of EVs using charge point:	**Many**
V2G Availability:	**40-60%**
Potential no. in the UK:	**1M-10M**



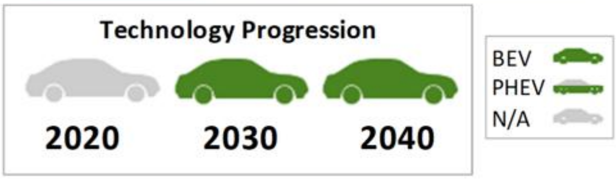
Primary User		Usage	
Age Range:	NA	Parking Pattern:	Predictable
Income Bracket:	NA	Type of trips:	Short/Medium
Employment Status:	NA	%age of plugged-in time used for charging:	40-60%
Vehicle Ownership Type:	Leased		
Battery Life Conservation:	Low	Charging Location:	Varied
Primary Motivation:	Financial	**Location**	
Vehicle		Building ownership type:	Tenant
Battery Size:	Large	On-site renewables:	No
Type of vehicle:	Van	Parking Location:	Off-street

Refuse collection vehicle Depot

The `Refuse Collection Vehicle' is based at a depot near the waste transfer and management facilities. It is used every working day on a defined route for each day of the week. The route for the vehicle invoves a modest distance from the depot and then large number of extremely short start/stop journeys, followed by return journey back to base. The vehicle usage is highly predictable and covers around 50 kM per day and is used from early morning until early afternoon. As a large fleet vehicle owned or leased by a local authority, it has its own dedicated high power V2G charge point at the depot to charge its large 150 kWh battery. The primary motivation is to meet urban environmental targets and achieve the best economic usage of the asset.

Key Information:

V2G Location:	**Business**
No. of EVs using charge point:	**Many**
V2G Availability:	**60-100%**
Potential no. in the UK:	**1k-10k**

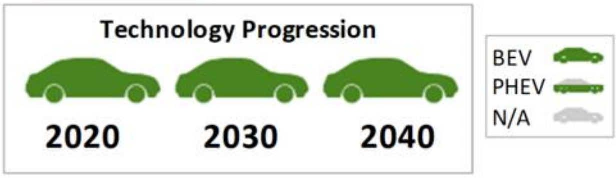


Primary User		Usage	
Age Range:	NA	Parking Pattern:	Predictable
Income Bracket:	NA	Type of trips:	Short/Medium
Employment Status:	NA	%age of plugged-in time used for charging:	20-40%
Vehicle Ownership Type:	Fleet		
Battery Life Conservation:	Low	Charging Location:	Only at this location
Primary Motivation:	Environmental	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Large	On-site renewables:	No
Type of vehicle:	Truck	Parking Location:	Off-street

cenex

Bus Depot

The `Bus Depot` has a number of V2G charging points whih are used every night to charge the busses so the batteries are full for the next day. The buses have a high duty cycle and are used Mon-Sat from early in the morning until the evening, with significant numbers of the vehicles used in the evening and on Sundays. The charging times for the buses overnight are predictable using a 40+ kW charger, but while the battery is large 180 - 300 kWh relative to the vehicle size and usage the batteries need to be fully charged in the morning and are supplemented with fast charging each time the bus completes its route during the day.



Key Information:

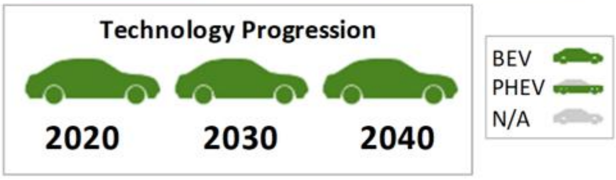
V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 0-40%
Potential no. in the UK: 100k-1M

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Fleet
Battery Life Conservation:	Low
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Large
Type of vehicle:	Bus

Usage	
Parking Pattern:	Predictable
Type of trips:	Long
%age of plugged-in time used for charging:	60-80%
Charging Location:	Only at this location
Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

Council fleet - Pool cars

`Council Fleet - Pool Cars' are based at council owned sites which has a variety of different size cars which can connect to the V2G chargers. The vehicles have unpredictable usage patterns during the day, but often have long dwell periods and are usually connected to the V2G charger overnight and during the day. The council has a range of renewables and onsite generation which they optimise the use of.



Key Information:

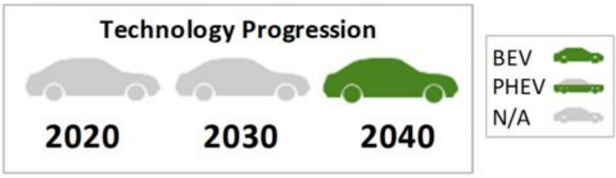
V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 60-100%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Fleet
Battery Life Conservation:	Low
Primary Motivation:	Varied
Vehicle	
Battery Size:	Varied
Type of vehicle:	Midsize car

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

HGV Depot

This is a V2G charger at an HGV depot. The vehicles travel long distances on a scheduled basis. Charging is done at depots on the regular routes.



Key Information:

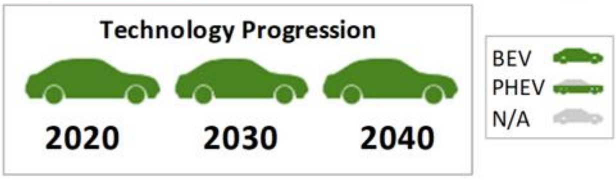
V2G Location: Business
No. of EVs using charge point: Few
V2G Availability: 40-60%
Potential no. in the UK: 100k-1M

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Fleet
Battery Life Conservation:	Medium
Primary Motivation:	Varied
Vehicle	
Battery Size:	Large
Type of vehicle:	Truck

Usage	
Parking Pattern:	Predictable
Type of trips:	Long
%age of plugged-in time used for charging:	60-80%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

Company car park

The `Company Car Park' are V2G units in a company car park. Leased company cars are plugged in during the weekdays (9am-5pm +/-1 hour) and absent overnight. Parking times are generally predictable. Network constraints at the site are likely.



Key Information:

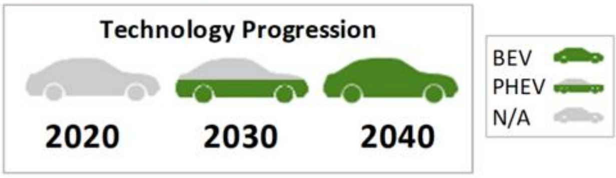
V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 40-60%
Potential no. in the UK: >10M

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Varied
Battery Life Conservation:	Low
Primary Motivation:	Financial
Vehicle	
Battery Size:	Varied
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	20-40%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Varied
On-site renewables:	No
Parking Location:	Off-street

Airport - Long Stay Car Park

The `Airport - Long Stay Car Park' is a commercial business offering visitors an opportunity to park their car for multiple days while they undertake air based travel. Car parking is booked days in advance by customers looking for the best deal, so when the car will be parked and for how long is hihgly predictable. The motivation is that the car park operator is able to realise a lower cost customer offering, optimise use of onsite generation, while generating alternative revenue via V2G. The users want their car charged when the collect it, but can offer significant flexibility while they are away in return for cheaper parking costs.



Key Information:

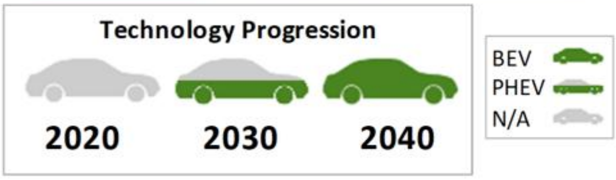
V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 60-100%
Potential no. in the UK: 100k-1M

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Varied
Primary Motivation:	Financial
Vehicle	
Battery Size:	Varied
Type of vehicle:	Varied

Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	0-20%
Charging Location:	Mostly at this location
Location	
Building ownership type:	Tenant
On-site renewables:	Yes
Parking Location:	Off-street

Hire Car Firm

The `Hire Car Firm' is based at strategic locations close to where customers need vehicles: airports, stations, central city. The company keeps a large fleet of vehicles for a short duration of time, to ensure they have a modern fleet of vehicle to suit a wide range of size and budget requirements. There is some predictability to when vehicles are hired, but bookings are often made last minute, and the use of V2G charging facilities is unpredictable, except for when the office is closed out of hours, when there is usually a few vehicles which are not out on hire that can be plugged in. The motivation of the hire car company is financial and ensuring that there is the highest utilisation of hire vehicles possible which are fully charged when a customer hires them.



Key Information:

V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 60-100%
Potential no. in the UK: 10k-100k

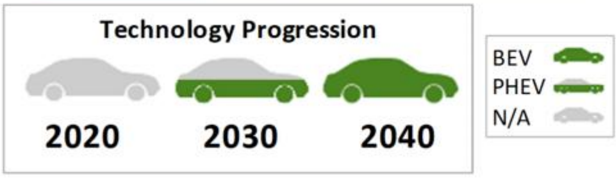
Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Low
Primary Motivation:	Financial
Vehicle	
Battery Size:	Varied
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Unpredictable
Type of trips:	Varied
%age of plugged-in time used for charging:	20-40%
Charging Location:	Varied
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	Varied

cenex

Hackney Carriage

This is a V2G unit at a Taxi Rank. The unit is highly utilised with many different vehicles connecting to it, that perform many short and medium journeys.



Key Information:

V2G Location: Business
No. of EVs using charge point: 1
V2G Availability: 0-40%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Owned
Battery Life Conservation:	High
Primary Motivation:	Financial

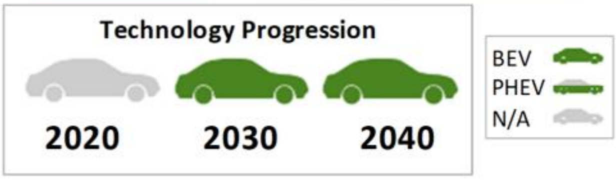
Vehicle	
Battery Size:	Large
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	80-100%
Charging Location:	Mostly at this location

Location	
Building ownership type:	Owner
On-site renewables:	Yes
Parking Location:	Off-street

Police/NHS appointment vehicles

`Police/NHS Appointment Vehicles' are based at sites and are used for non-response activities. Vehicles are usually parked at the site overnight and intermittently during the day. The vehicles are purchased and operated with achieving the best economic solution in mind.



Key Information:

V2G Location: Business
No. of EVs using charge point: Many
V2G Availability: 40-60%
Potential no. in the UK: 0-1k

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Fleet
Battery Life Conservation:	Low
Primary Motivation:	Financial

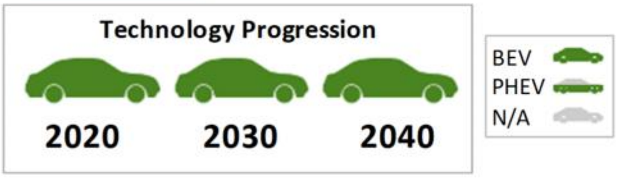
Vehicle	
Battery Size:	Medium
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	20-40%
Charging Location:	Mostly at this location

Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

EV Car club

The V2G unit at the Car Club base has a high utilisation, with cars being parked for fairly long periods. The charge point may see many different vehicles and users.



Key Information:

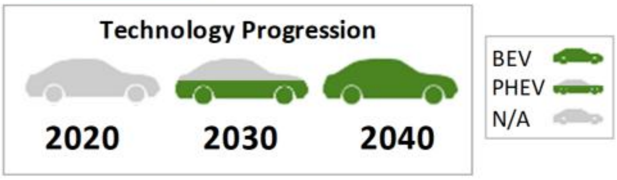
V2G Location: Business
No. of EVs using charge point: Few
V2G Availability: 60-100%
Potential no. in the UK: 10k-100k

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Leased
Battery Life Conservation:	High
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Medium
Type of vehicle:	Midsize car

Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	20-40%
Charging Location:	Only at this location
Location	
Building ownership type:	Tenant
On-site renewables:	No
Parking Location:	Off-street

On street public charging (residential)

This is an on-street charging post in a residential area. It has a small pool of regular users, but utilisation can be variable. Most utilisation is overnight.



Key Information:

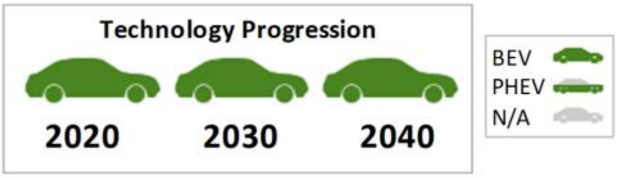
V2G Location: Public
No. of EVs using charge point: Few
V2G Availability: 40-60%
Potential no. in the UK: 1M-10M

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Varied
Battery Life Conservation:	Varied
Primary Motivation:	Environmental
Vehicle	
Battery Size:	Varied
Type of vehicle:	Varied

Usage	
Parking Pattern:	Predictable
Type of trips:	Varied
%age of plugged-in time used for charging:	20-40%
Charging Location:	Varied
Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	On-street

Airport fleet vehicles

`Airport Fleet Vehicles' have a relatively long usage cycle each day, but with only short journey distances. The vehicles are parked at the charge points between 10pm and 4am.



Key Information:

V2G Location:	**Business**
No. of EVs using charge point:	**Few**
V2G Availability:	**0-40%**
Potential no. in the UK:	**1k-10k**

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Owned
Battery Life Conservation:	Low
Primary Motivation:	Environmental

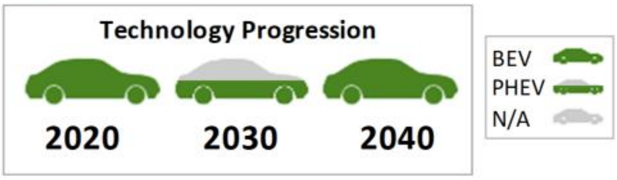
Vehicle	
Battery Size:	Small
Type of vehicle:	Small car

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	60-80%
Charging Location:	Only at this location

Location	
Building ownership type:	Owner
On-site renewables:	Yes
Parking Location:	Off-street

Supermarket Car Park

Many different vehicles are parked at this charge point between 8am and 8pm. However they need charging during their relatively short dwell times or up to an hour.



Key Information:

V2G Location:	**Public**
No. of EVs using charge point:	**Many**
V2G Availability:	**40-60%**
Potential no. in the UK:	**100k-1M**

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Varied
Battery Life Conservation:	Varied
Primary Motivation:	Varied

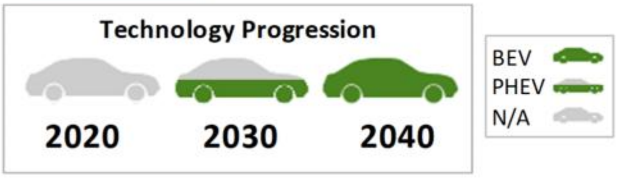
Vehicle	
Battery Size:	Varied
Type of vehicle:	Varied

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	80-100%
Charging Location:	Varied

Location	
Building ownership type:	Owner
On-site renewables:	Most likely
Parking Location:	Off-street

On-Street Public Charging (city centre)

`On-Street Public Charing' in the city centre is typically for short and medium stay car parking typically averaging around 2 hours and the vehicles will usually need charging as much as possible. Utilisation of the charger is low overnight.



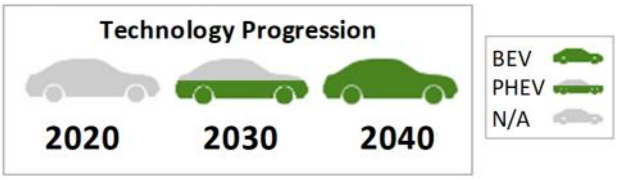
Key Information:

V2G Location: Public
No. of EVs using charge point: Many
V2G Availability: 0-40%
Potential no. in the UK: 10k-100k

Primary User		Usage	
Age Range:	NA	Parking Pattern:	Unpredictable
Income Bracket:	NA	Type of trips:	Short/Medium
Employment Status:	NA	%age of plugged-in time used for charging:	60-80%
Vehicle Ownership Type:	Varied		
Battery Life Conservation:	Varied	Charging Location:	Varied
Primary Motivation:	Varied	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Varied	On-site renewables:	No
Type of vehicle:	Varied	Parking Location:	On-street

Multi-storey public charging (city centre)

Large, citycentre multi-storey car park. Either local authority owned or private, but used predominantly by commuters working in the city or shoppers visiting for a couple of hours. Generally maintenance and refurbishments are few and far between and the site is unlikely to have a large electrical feed.



Key Information:

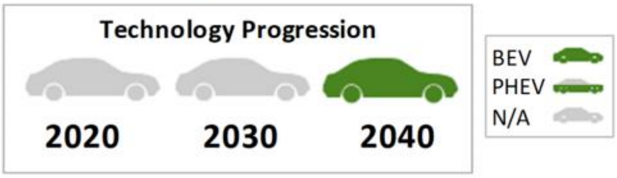
V2G Location: Public
No. of EVs using charge point: Many
V2G Availability: 0-40%
Potential no. in the UK: 100k-1M

Primary User		Usage	
Age Range:	NA	Parking Pattern:	Predictable
Income Bracket:	NA	Type of trips:	Varied
Employment Status:	NA	%age of plugged-in time used for charging:	60-80%
Vehicle Ownership Type:	Varied		
Battery Life Conservation:	Varied	Charging Location:	Varied
Primary Motivation:	Varied	**Location**	
Vehicle		Building ownership type:	Owner
Battery Size:	Varied	On-site renewables:	No
Type of vehicle:	Varied	Parking Location:	Off-street

cenex

CAV Hub

This is a dedicated Connected Autonomous Vehicle (CAV) charging hub. Vehicles return here for charging once they are low on charge and can stay connected until either they are required for another trip, or the charge point is need by another CAV.



Key Information:

V2G Location:	**Business**
No. of EVs using charge point:	**Many**
V2G Availability:	**40-60%**
Potential no. in the UK:	**10k-100k**

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Varied
Battery Life Conservation:	Varied
Primary Motivation:	Varied

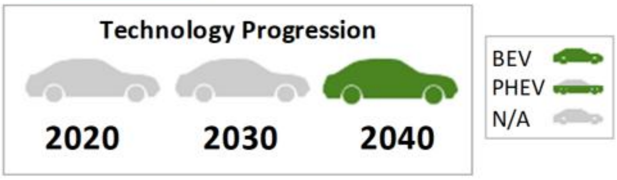
Vehicle	
Battery Size:	Medium
Type of vehicle:	Small car

Usage	
Parking Pattern:	Predictable
Type of trips:	Short/Medium
%age of plugged-in time used for charging:	60-80%
Charging Location:	Only at this location

Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

HGV Lay-by

This is a V2G charge point positioned in an overnight HGV parking lay-by. It is designed exclusively for use by HGVs. They mostly plug in at the end of the day and spend the night charging.



Key Information:

V2G Location:	**Public**
No. of EVs using charge point:	**Many**
V2G Availability:	**0-40%**
Potential no. in the UK:	**10k-100k**

Primary User	
Age Range:	NA
Income Bracket:	NA
Employment Status:	NA
Vehicle Ownership Type:	Varied
Battery Life Conservation:	Varied
Primary Motivation:	Varied

Vehicle	
Battery Size:	Large
Type of vehicle:	Truck

Usage	
Parking Pattern:	Predictable
Type of trips:	Long
%age of plugged-in time used for charging:	60-80%
Charging Location:	Mostly at other locations

Location	
Building ownership type:	Owner
On-site renewables:	No
Parking Location:	Off-street

cenex

Appendix C: Input Assumptions

1 Inputs Prices for Key Revenue Streams

Input prices for all the Use Cases modelled have been based on current market values. However, simplifications to the price structure or shape have been made where necessary to enable the services to be modelled.

1.1 FFR

FFR prices used are shown below. Two types of products have been used in the model. The first is a 24/7 product that must be provided continually for a whole week at a time. The second is a selection of six four-hour long products. Each of which corresponds to one of the six EFA blocks.[5]

Product	Base Price	Sensitivity Price
24/7 service	£10/MW/h	£5/MW/h
EFA Blocks	£8/MW/h	£4/MW/h

Table 3: FFR prices

An additional price shape was applied to the EFA blocks, in line with previous price shape analysis published by National Grid[6].

1.2 STOR

Because STOR prices are made up of both an availability and utilisation price, in order to input to the model these were combined. This was done by increasing availability prices by average utilisation rates, using prices from the most recent STOR year (2017/18).

Season	Single price (with utilisation uplift) Committed (£/MW/h)	Single price (with utilisation uplift) Flexible (£/MW/h)
12.1	7.01	1.09
12.2	6.86	1
12.3	8.72	1.4
12.4	8.79	1.43
12.5	8.88	3.91
12.6	9.22	4.10

Table 4: STOR prices

1.3 Imbalance

Market prices for the last 12 months from the imbalance market were used.

1.4 DTU

A single price of £4.072/MW/h was used based on 2018 prices and the utilisation rate from 2017, as the utilisation rate for 2018 has not yet been published.

[5] EFA blocks are used in energy wholesale trading. The blocks are four hours each. EFA1 runs from 23:00 to 03:00, subsequent blocks follow on consecutively.

[6] National Grid Firm Frequency Response (FFR) Market Information Report for Oct-18

1.5 Tariffs

A representative residential supply “Economy 7” tariff rate was used. This was selected so that the V2G could optimise against the multiple tariff rates. Additionally, the “Octopus Agile” half-hourly shaped tariff was used in some runs to simulate a more complex time-of-use tariff arrangement.[7]

The export tariff was set at zero, since without bespoke arrangements V2G does not currently get paid for exporting to the grid.

Economy 7	
Peak	17p/kWh
Off Peak	10p/kWh

Table 5: Tariff prices

2 Other Inputs

The following assumptions on chargepoints and EV parameters were made.

EV useable battery capacity:	37.25 kWh
Minimum SOC permitted by V2G:	12.5%
Maximum V2G discharge per day:	5 kWh
Charging point maximum power:	7 kW
Charging/discharging efficiency:	87%

Table 6: Chargepoint and EV assumptions

Additionally, in the model with each chargepoint there is an associated building electricity demand. Data for this was taken from the UKPN project Low Carbon London[8]. This provided half hourly electricity demand data for over one hundred residential customers in London. The mean electricity demand for the data used was 4.25 MWh.

[7] https://octopus.energy/agile/#what-does-it-cost

[8] http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/

Independent, not-for-profit,
low carbon technology experts

Cenex
Holywell Building
Holywell Park
Ashby Road
Loughborough
Leicestershire
LE11 3UZ

Tel: 01509 635 750
Email: info@cenex.co.uk
Website: www.cenex.co.uk
Twitter: @CenexLCFC