Independent, not-for-profit, low emission vehicle and energy for transport experts

V2G

Market Study

Answering the preliminary questions for V2G: What, where and how much?

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Abbreviations

AC	Alternating Current
BRP	Balance Response Partner
BTM	Behind the Meter
CCS	Combined Charging System
CO_2	Carbon Dioxide
DC	Direct Current
DLR	Demand Load Response
DNO	Distribution Network Operator
DSR	Demand Side Response
DSM	Demand Side Management
DSO	Distribution System Operator
DTU	Demand Turn Up
DUoS	Distribution Use of System
EMS	Energy Management System
EU28	28-member states of the European Union
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)
EVSE	Electric Vehicle Supply Equipment
FFR	Firm Frequency Response
HEMS	Home Energy Management System
ICE	Internal Combustion Engine
IEA	International Energy Agency
LEZ	Low Emission Zone
OLEV	Office for Low Emission Vehicles
PV	Solar Photovoltaic Electricity Generation
SO	System Operator
STOR	Short Term Operating Reserve
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use, generally relating to a tariff
TRIAD	The term used to refer to avoidance of TNUoS charges
TSO	Transmission System Operator
ULEV	Ultra-Low Emission Vehicle
V0G	Standard EV Charging systems
V1G	Managed EV Charging systems (for optimised load management)
V2G	Vehicle to Grid
VPP	Virtual Power Plant

Management Summary

- Vehicle-to-Grid (V2G) refers to the process whereby a plug-in Electric Vehicle (EV) can both import and export electrical power from and to the grid. V2G enables EVs to charge, have charging managed (time shifted or slowed), or export electrical energy stored in the EV battery, back to the local distribution network or a local load. V2G is therefore able to offer the customer 'Behind the Meter' (BTM) cost saving as well as having potential for revenue generation through electricity trading and third-party services through aggregation of V2G assets via a Virtual Power Plant.
- These services vary significantly in requirements and value and it is not always helpful to quantify their value without the wider context of a specific customer or application. Based on a 10kW V2G unit, potential income from these services can vary from a few pounds to almost a thousand pounds per year, however, this is based on an ideal, maximum value for each service.
- By considering the characteristics of a particular customer or customer group it is possible to identify the best value stream(s) for the customer, the proportion of this value which is achievable, and whether any value streams could be 'stacked' in order to achieve greater overall value.
- The market actors for V2G include the EV users (private motorists and fleet operators), the hosts for V2G assets (either the EV user or V2G owner\operators) and energy service providers who deliver the management interface between the V2G assets and electricity markets. The national and regulated nature of electricity markets means that the emerging opportunities for V2G will be shaped differently in individual national markets.
- The UK is one of the first markets to adopt V2G through technology demonstrations. This early activity offers UK companies a first-mover advantage which paves the way for UK exports.
- Rather than forecasting income generation potential for different actors in the supply chain between the EV and electricity markets, in order to quantify market potential this report forecasts hardware unit sales as a general proxy for the V2G market opportunity.
- As a new product offering, the approach underpinning the forecasting is that the market will develop initially through focused and differentiated 'supply-push' to prove value. First mover investors in V2G will target markets with the right conditions for early (higher unit cost) market introduction. Once the business case is understood there may be a 'demand-pull' across markets.
- The lead markets will have high EV uptake potential and they will be where Demand Side Response markets already exist, with the latter enabling V2G to deliver stacked services (both BTM and through third party services) that can enhance the revenue generating potential of V2G.
- The lead first mover markets for V2G have been identified as being Canada, France, Japan, South Korea and the UK. Important fast-follower markets include China, Germany and USA (particularly California and the West Coast states). Wider European markets (Benelux, Italy, Scandinavia and Spain) also offer key opportunities, although there are greater barriers to the development of the V2G markets in these areas compared to the fast-follower markets noted above. Some lead markets for EV adoption are secondary markets for V2G because of the energy market regulatory situation, most notably China.
- The market study estimates V2G potential unit sales by 2030 as follows:

Market	Canada	China	France	Germany	Japan	S. Korea	UK	USA
V2G Units by 2030	0.05m	1.78m	0.39m	0.58m	0.26m	0.09m	0.35m	0.53m

Table 1: Estimated V2G market potential by 2030

- Key sensitivities and business cases strongly influence the analysis around V2G unit sales. As a result, these figures are indicative only.
- If UK companies can take a lead in the development of V2G technology and viable business models, then the opportunity for export is significant. To export into these markets V2G hardware needs to be compatible with CCS as well as CHAdeMO connectors. This is particularly important as three of the eight leading markets are European, along with a high proportion of secondary

markets. Products will also need vehicle manufacturer approval (warranty for the car battery) and will need to comply with the relevant distribution grid codes (G98/G99 equivalent). Depending on the development of AC V2G vehicle systems, this may also need to be incorporated

- ISO 15118 and OCPP 2.0 are the key technical standards for V2G hardware, although additional standards and protocols are gaining prominence including OCPI. As the market moves from demonstrators towards commercial roll out, V2G hardware will need to comply with these standards, and consistency of standards or interoperability between competing standards, will be essential to support longevity of the V2G market.
- There are barriers facing the development of the V2G market. The most critical is to develop a clear understanding of the economics for V2G and the various potential revenue streams and as such to develop robust business models which enable clear identification and targeting of appropriate customer groups. This will enable hardware to be developed in line with the needs of these customers, therefore reducing costs and increasing the value to the customer.

1 Introduction

Cenex has been contracted by Innovate UK to investigate the potential opportunities for the UK to export Vehicle-to-Grid (V2G) products and services to global markets. This study investigates the potential export market potential for UK V2G equipment based on an analysis of EU and global markets identified as having the economic and regulatory conditions considered receptive for plug-in Electric Vehicle (EV) uptake and for the application of V2G to enable EV batteries to be better utilised in the wider energy system.

The scope of the study is split into four key areas as follows:

1. Current and proposed V2G standards at UK, EU and global levels
2. Hardware technical specification assessment
3. Identification and prioritisation of market locations by country
4. Export market potential forecasts for V2G by country

The study was conducted through the combination of desk research, interviews and a stakeholder workshop. The workshop, which was held on the 10th May 2018, attracted 60 attendees from more than 40 different organisations, and allowed key stakeholders to provide insights related to anticipated markets and market growth for V2G, along with insights as to barriers and concerns from the sector.

1.1 V2G Background

V2G as a concept has been around for a long time. The earliest recorded academic study of the topic was in 1997 by the University of Delaware. The study did not yet use the term 'V2G' but described the value of batteries to manage the peaks and troughs of electricity demand and hypothesised that battery electric vehicles could provide the bulk resource to make this possible on a large scale[1].

While further academic research continued in this area, it was not until the release of the first Nissan Leaf in 2010 that V2G began to seem feasible in the real-world. This was followed soon after by the 2011 Tohoku earthquake and subsequent Fukishima Daiichi Nuclear crisis, creating concerns around the Japanese energy system and prompting investigation into alternative ways to support the electrical network. By this time, Japan had the highest concentration of electric vehicle (EV) charging stations and plug-in EVs in the world. This led to investigations into using V2G to feed power back into homes to provide power during emergency situations. This has also prompted research into using second life batteries as stationary storage, as well as opportunities to use V2G to support the wider electrical network in routine operation as well as in emergency situations such as black outs.

Since 2011, organisations and consortia have been working to develop V2G units, with the first prototype believed to be developed by Docomo and Nichicon, supported by Nissan. This led to the commercial release of the 'Power Mover' in 2017; a 4.5kW portable unit which allows an EV to provide an AC power supply for multiple items.

Nissan has continued to play a key role in supporting the promotion and development of V2G and has been involved in early demonstration projects in Europe and North America. Nissan also partnered with Enel and Nuvee to launch the world's first commercial V2G units in Denmark in 2016.

In the UK, Cenex led with a number V2G studies and prototype demonstrators, supporting installation of the UK's first permanent V2G unit at Aston University (2016) and installing the first domestic V2G unit in Europe as part of the project 'Ebbs and Flows of Energy Systems (EFES)' in early 2017. Both were prototype systems, however the learnings from these projects are still being used now to support the development of new V2G units in the UK and wider Europe (through SEEV4-City – see appendix D).

While Fukishima pushed early development in the direction of emergency power, right from the initial studies by the University of Delaware the key interest in V2G has been in its potential to provide wider grid services. V2G could feasibly allow large aggregations of EVs, such as fleet vehicles, to provide a wide range of energy services – covering anything from peak shaving to frequency response, and in doing so to earn money for the drivers thereby improving the total cost of ownership proposition for EVs.

As V2G has developed, the term has been used to refer to a range of applications. As a result, for the purposes of this report, V2G is defined as follows:

Vehicle-to-grid (V2G):

A system whereby plug-in electric vehicles, when connected to electric vehicle supply equipment (EVSE) can provide bi-directional flows of energy.

For more details around EV charging or V2G technology, please refer to Appendix A and B respectively.

[1] "Electric Vehicles as a New Source of Power for Electric Utilities", Transportation Research 2(3): 157-175, W. Kempton & S. Letendre, 1997

1.2 Values Streams from DSR

As noted in Section 1.1, V2G chargers can either be managed as stand-alone units that export back to their electricity supply, or managed in local clusters. Additionally, distributed V2G units can be aggregated to allow them to be managed and operated as groups for non-geographically sensitive energy services such as frequency response (see Figure 1 below).

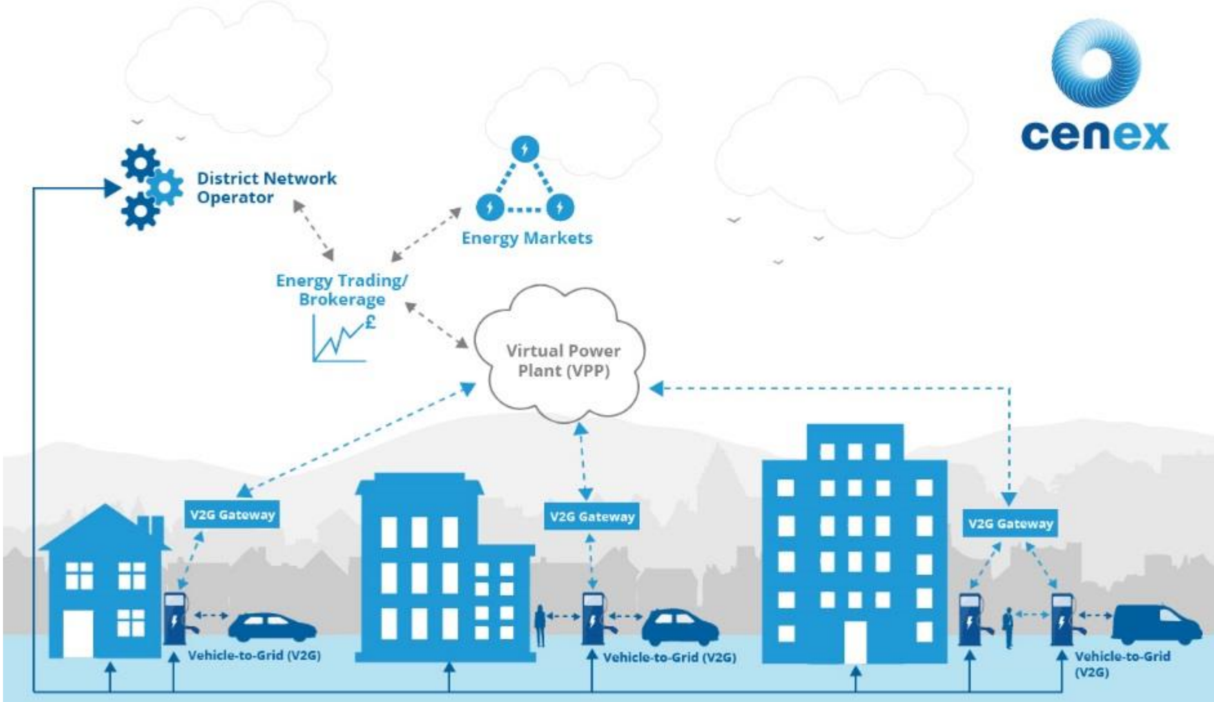

Figure 1: Aggregation of V2G units to trade electricity to energy markets via a VPP

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

- **Behind the Meter (BTM):** 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).
- **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. These services are usually geographically specific and relate to the needs of the network in that location. Unlike TSO services, the provision of these services from DSR assets is in its infancy in most countries, although some small-scale services are in commercial operation, most notably in Sweden.
- **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.

Figure 2 shows the core groupings of flexibility markets, along with the characteristics required of the assets and indicators of the potential scale of financial value of the service.

			Typical Response Times	Typical Duration of Service	Typical Revenue
Frequency Services	Including Frequency Regulation, Restoration and Containment i.e. FFR	+ −	0 – 30 seconds	30 seconds – 30 mins	£££££
Reserve Services	Typically separate positive and negative services i.e. STOR & DTU	+ / −	5 – 240 mins (faster response = higher value)	30 mins to 4 hours	££
Capacity Markets	Used to ensure sufficient capacity is available to meet system need	+	Up to 4 hours	Potentially unlimited (risk to DSR)	£££
Behind the Meter	Peak shaving services to avoid high price periods i.e. TRIAD, DUoS, TOU Tariffs	+	N/A	15 – 120 mins	££££
Behind the Meter	Increased utilisation of generation	+ −	N/A	15 mins – 4 hours	££

Figure 2: Characteristics of core flexibility markets

As can be seen from Figure 2, there is a lot of variation in these services, both in terms of requirements and value. According to Cenex analysis of current markets and value trends, the potential income from these services, based on a 10kW V2G unit, can vary from a few pounds per year to c.£500 per unit. However, this gives an ideal, maximum value for the service and once the customer and asset characteristics are considered, it may only be possible to achieve a percentage of this value.

By considering the characteristics of a particular asset and customer or customer group it is also possible to identify the best value stream(s) for the customer, the proportion of this value which is achievable, and whether any value streams could be 'stacked' in order to achieve greater overall value. The characteristics of Vehicle-to-Grid (V2G) are somewhat dependent on the specific use case (i.e. V2G units fitted in a car park will have different flexibility characteristics compared to a domestic unit). However, in general V2G has the following characteristics:

- Ability to provide a fast response time (<30 seconds);
- Duration of response is limited by the power of response and the capacity of the vehicle's battery. Therefore, continuous response is preferred for short periods (i.e. up to 30 mins) as sustained responses for more than a few hours at full power would be likely to drain the battery, requiring subsequent charging prior to use;
- Symmetrical response patterns (cycling between increasing demand and generating back to the grid) are preferred as they are more sustainable and minimise the impact of battery degradation.

As shown in Figure 2 above, in current markets, the highest value services for V2G to provide are typically frequency and behind the meter services. However, the value of frequency services is often based on low numbers of providers who are technically able to deliver the strict requirements of the service. If 1 million vehicles were all able to provide V2G services at the same time, this could result in 10GW of flexibility. By contrast, the entire frequency market in the UK requires less than 2GW of flexibility. Therefore, as the number of potential providers increases, this saturates the market and the value of these services will reduce. This has already been seen in recent years with other services such as STOR. This is not the case however for distribution system and behind the meter services where there is more room for growth without impacting the value of the services. It is therefore expected that V2G services will shift in the future from TSO services to DSO services. However, BTM services are expected to continue to be a core value stream for V2G.

1.3 Barriers to V2G

In terms of downsides to V2G, public experience of Lithium Ion batteries in devices such as phones and laptops demonstrates that batteries degrade with time and there is a concern with V2G that the constant cycling of the state of charge of the vehicle could accelerate the degradation of EV batteries. Despite some studies in this area, primarily conducted by Warwick Manufacturing Group (WMG)[2], this continues to be the key barrier to commercialising V2G as EV manufacturers are currently reluctant to warrant EVs for something which may reduce battery life. The V2G community recognises that further investigation into the effects of V2G on battery performance degradation is therefore needed before V2G is likely to be widely supported by EV manufacturers.

In addition to the minimal number of V2G compatible EV's, there is a lack of commercially ready V2G EVSE. As much of the V2G development so far has been focused around the Nissan Leaf, the CHAdeMO standard has become the predominant connector type for V2G. Consequently, these is a significant gap in the market around the European EV connector standard 'CCS'. The development of a wider range of V2G-ready EVs and EVSE is therefore critical to the development of the V2G market.

Key Points:

Section 1. Introduction to V2G

- V2G chargers are able to provide bi-directional flows of energy, which means the EV can be charged but can also export its stored energy back to the local electricity supply.
- V2G is an emerging technology that is entering the market predominantly through demonstration projects.
- The value of that exported energy depends on the economic value which can be achieved from a combination of behind the meter or third party traded services. The value depends on the service provided and is highly variable.
- Barriers to the use of V2G include the absence of V2G units that are compatible with common European EV connectors, and a concern that V2G operation could accelerate battery degradation and lead to a shorter useful battery life. Academic studies are ongoing to assess if battery degradation is accelerated by V2G or not.

2 "On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system", Energy 133 (2017) 710-722, K. Uddin et al, 2017

2 Vehicle to Grid Standards

This section of the study focuses on the regulatory requirements for V2G in the UK, EU and global markets. In most cases, standards that apply to EV Supply Equipment (EVSE) are also applicable to V1G and V2G applications. However, additional standards also apply to V1G and V2G respectively. Therefore, this section includes both the relevant EV/EVSE standards as well as additional standards and requirements applicable for V1G and V2G.

There are a number of standards applicable to EVs, charging and V2G derived from European and national regulations and legislation. Due to the volume, these are set out in Appendix C and divided into sub-sections based on the part of the EV system to which they apply. Section C3 of this appendix sets out the standards which specifically apply to V2G.

2.1 Charge Point to Vehicle Interface

2.1.1 ISO 15118

ISO 15118 'Road Vehicles – Vehicle to Grid communication interface' is an international standard defining the V2G communication for bi-direction charging/discharging of EVs and is concerned with the communication between the EV and the EVSE. The key communication elements concerned are the electric vehicle communication controller (EVCC) and the supply equipment communication controller (SECC). This standard covers both AC and DC charging modes and comes with two core focuses:

- **'Plug and Charge'** – This supports the move away from RFID cards or smart phone apps for authentication and billing and enables this process to be delivered using digital authentication from the vehicle. This is intended to support the transition to wireless charging and autonomous vehicles, where user interface through an RFID card or similar would be impractical.

- **Vehicle-to-Grid** – ISO 15118 breaks V2G down into two categories – Optimised load management (V1G) and reverse power flows (V2G). However, the standard considers communications only, with a focus on the communications between the EV and the EVSE only and does not consider the communications from third parties such as TSO signals received by the EVSE. As ISO 15118 focuses on communications only, it is agnostic when it comes to current flow, making it applicable to all V2G solutions, regardless of whether they are AC or DC.

2.2 Charge Point to Network Interface

2.2.1 OSCP 1.0

Open Smart Charging Protocol describes the protocol for smart charging of EVs, with primary focus on the communication between the DNO and charge service provider (CSP).

2.2.2 Distribution Network Interface

This section focuses on UK standards, however similar regional limitations will also apply in other countries.

From the point of view of the electricity network, an EV exporting power is a generator connected in parallel to the network. For that generator to be connected, it will have to meet a set of technical requirements. These technical requirements consider aspects around the installation requirements for the generator, but also ensure that the generator behaves as expected on aspects such as:

- Detecting and responding correctly in the event of a loss-of-mains power,
- Synchronising to the grid,
- Preventing unintended islanding (disconnecting when mains power is lost),
- Disconnecting and reconnecting correctly for over- or under-frequency and voltage events,
- Ensuring power quality aspects are met.

In the UK, all distribution network operators are required to comply with the GB Distribution Code, which is maintained by the Distribution Code Review Panel and approved by Ofgem. In May 2018 the code was revised to Issue 32 to ensure compliance with the European Network Code Requirements for Generators. This included the introduction of two new Engineering Recommendations (EREC) G98 and G99. From 17th May 2019, EREC G98 and EREC G99 will be applicable for all new installations, effectively replacing EREC G83 and EREC G59. Between May 2018 and May 2019, new installations can comply with the requirements of either EREC G83/G98 or EREC G59/G99 (as applicable).

The definition of micro-generators within these documents includes electricity storage devices. As V2G systems are in essence, energy storage systems, it is expected that V2G would fit within the definition of micro-generators and would therefore need to comply with these engineering recommendations. Where the micro-generator includes an inverter, its capacity is deemed to be the inverter's continuous steady state rating. In addition, installations will be considered as a single micro-generating plant where they comprise more than one inverter under a single connection point and have an aggregate registered capacity of less than 16A per phase (single or multi-phase, 230/400V AC).

All connection agreements are technology based. Therefore, even where there is already generation on the premises a separate application is required to connect a V2G unit. The specific connection procedure to follow is based on the total power of the technology. However, recent modifications to the code means that the installation date also impacts the connection procedure with which the installation must comply. Regardless of the engineering recommendation to be followed, all technologies must be type tested prior to installation. Type testing involves a range of tests relating to characteristics of a technology, such as harmonics, which may impact the operation of the local network. Type testing aims to ensure that connected technologies will not have an overly negative impact on the operation of the wider local network. Guidance on which engineering recommendation applies to a specific installation can be seen in Figure 3.

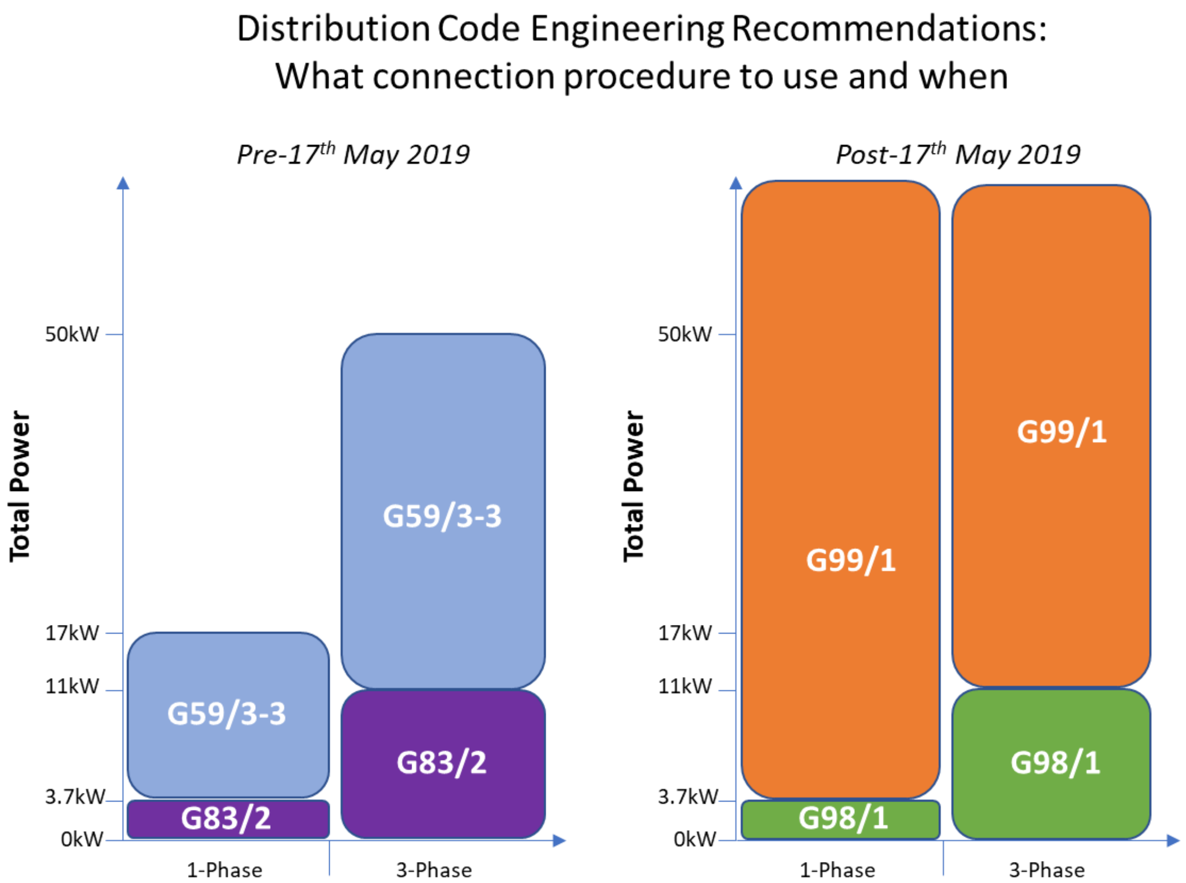

Figure 3: Graph demonstrating the evolution of distribution network connection procedures

Summary of connection agreements

- *Engineering Recommendation G59 Issue 3 Amendment 4 (EREC G59/3-4)* - EREC G59 sets out the connection procedure for micro-generation connecting to the LV distribution network where the aggregated rating of all micro-generators exceeds 16A per phase but is less than 50kW or 17kW per phase.
- *Engineering Recommendation G83 Issue 2 Amendment 1 (EREC G83/2-1)* - On 4th August 2008, the Health & Safety Executive (HSE) issued a certificate of exemption that effectively relaxes the timescales for notifying a DNO when commissioning a micro-generator rated less than 16A per phase. The DNO must still be notified but this no longer needs to be before or at the time of commissioning. Instead notification must now be made within 28 days. This was implemented into the distribution code through EREC G83.
- *Engineering Recommendation G98 Issue 1 (EREC G98/1)* - EREC G98/1 sets out two connection procedures. The first covers the requirements for connection of fully type tested micro-generators (up to and including 16A per phase) in public LV distribution networks on a single site. The second connection procedure covers the connection of multiple micro-generators in a close geographic region and under a single programme of works. In effect this document supersedes EREC G83, coming into force from 17th May 2019. Micro-generators that conform to EREC G98 can also be connected in advance of this date as G98 exceeds the pre-existing EREC G83.
- *Engineering Recommendation G99 Issue 1 (EREC G99/1)* - Whereas EREC G59 covered Micro-generators between 16A per phase and less than 50kW (3-phase) or 17kW (1-phase), G99 has an extended remit. G99 replaces the term 'Micro-generator' with 'Power Generating Module' (PGM) which aligns with transmission network definitions. PGMs come in 4 types, depending on their registered capacity and connection point. These are set out in Table 2. EREC G99 applies to all PGMs which are not in the scope of, or are not compliant with, EREC G98 requirements.

	Type A	Type B	Type C	Type D_1	Type D_2
Connection Point	Below 110kV	Below 110kV	Below 110kV	Below 110kV	110kV+
Registered Capacity	0.8kW - 1MW	1MW - 10MW	10MW - 50MW	50MW+	Any

Table 2: Power generation module types[3]

EREC G99 applies only where PGMs are connected to the LV distribution network and also comes into force from 17th May 2019. However, PGMs should comply with EREC G59 where they have:

- connected to the distribution network prior to 17th May 2019;
- completed the purchase of the plant prior to 17th May 2018; or
- been granted a derogation by the Authority.

- *Engineering Recommendation G100 Issue 1 Amendment 1 (EREC G100/1-1)* - EREC G100/1-1 operates in conjunction with EREC G59/3-4 and EREC G83/2-1 (and is expected to operate in conjunction with EREC G98 and EREC G99) to provide guidance on the connection of customer Export Limitation Schemes (ELS) on the distribution network. Export limitation schemes can be used where the customer is attempting to:
  - Over-size the generation on a site beyond the maximum generation limit;
  - Guarantee a defined export limit.

[3] "Engineering Recommendation G99 Issue 1", ENA, 2018

Even where a V2G unit is acting as, or is controlled by an ELS, the response will not be immediate, meaning that export above the limit may occur for a brief period before the ELS kicks in. To prevent mal-operation of the distribution network protection systems, the maximum installed capacity of the generation (including V2G) at any site is not allowed to exceed 1.25 x agreed import capacity or 1.25 x agreed export capacity; whichever is higher. As no diversity is applied to either solar PV, energy storage or V2G, an ELS therefore only allows a 25% increase in onsite generation to be installed beyond the standard maximum generation limit for the fuse.

Where a G100 compliant ELS is installed and the total aggregated capacity of all generating units is below 16A per phase, an EREC G83 application can be made. Where the total aggregated capacity of all generating units is between 16A per phase and 32A per phase and the installation also meets the following criteria, an EREC G59 application can be fast-tracked and given approval to connect within 10 working days:

- The application is a single premise application (not applicable for multiple premises applications);
- The total aggregated capacity of the generating units (excluding V2G and storage) is ≤ 16A per phase and the total aggregated capacity of the V2G (and/or storage) is ≤ 16A per phase;
- All generating units are EREC G83 type tested units;
- An ELS is present that limits export capacity to 16A per phase (3.68kW/phase) and which complies with EREC G100;
- The generating units will not operate in island mode; and
- The customer submits an ELS Enquiry form (Appendix A of EREC G100) which includes a single line schematic diagram of the proposed scheme.

What does this mean for V2G?

Due to the typical export power rating of existing domestic V2G units of 6-10kW, V2G is likely to come under EREC G59 up until 17th May 2019, after which it will count as a 'Type A' Power Generating Module under EREG G99. However, based on the likely timescales for V2G installations to reach commercial scale, it would be advisable that V2G units be designed to comply with EREC G99 from the outset.

AC V2G falls into a grey area as far as the distribution code is concerned. The distribution code is written predominantly for stationary generation and as AC V2G locates the inverter within the EV rather than the EVSE, this causes some difficulties around type testing procedures. For AC V2G to develop in the UK would therefore require some clarification, and potentially modification, to the distribution code and/or connection agreements.

It should also be noted that no diversity is applied when connecting stationary batteries, generation (e.g. PV) or V2G. This means that, despite potential for positive interactions between the technologies resulting in lower overall peak export, power ratings are summed when installed at a single site. Based on the EREC G59 limit of 17kW per phase, this could limit the combination and size of technologies which could be installed. While the move to G99 removes this top limit, costs relating to increasing a sites connection capacity would currently to be passed on to the installer, meaning that while combined installations may be possible, they may not be economically feasible. This can be mitigated to some degree by setting up the system with an ELS as per G100, however this would only allow the installation capacity behind the ELS to be increased by 25%.

2.3 Charge Point to Operator Interface

2.3.1 Open Charge Point Protocol (OCPP) 2.0

OCPP is defined as a universal open communication standard which aims to solve the challenges put in place by proprietary networks. The OCPP enables communication to take place between the vehicle, the charge points and the charge point network operator. This standard ensures an open platform that gathered great support from industry and consumers. OCPP 1.6 was updated in 2017 to include extended security measures, including encryption methods, security logging and certificate handling. In addition, OCPP 2.0 develops the support for smart charging systems, incorporating Vehicle-to-Grid. OCPP 2.0 also incorporates many of the aspects of ISO 15118, supporting future 'plug and charge' functionality, making this a complimentary protocol for ISO 15118, although not a direct alternative.

2.3.2 Open Charge Point Interface (OCPI) 2.11

OCPI 2.11 is a similar standard to that of OCPP 1.6 with the main sections of the standard describing in detail methods by which to implement a fully scalable automated system that allows a roaming service to be implemented, with a focus on communication between charge point operators and their counter parts in the e-mobility services companies.

This standard also supports the authorisation and charge point information exchange whereby data from the charging event is stored, including the status of the charge point, information about the charging event itself and the exchange of commands to initiate or stop smart charging between different parties. This standard incentivises market participants in EV by showing a scalable solution for an inter-network roaming service, aiming to reduce expenditure and increase innovative solutions by negating the need for the traditional central roaming hubs or non-automated solutions that are in use presently. The aim is that EV users will be able to charge anywhere utilising the systems to do so in an informed manner, allowing the market to expand rapidly whilst aiding market participants to efficiently go about their business.

2.4 Installation and General Standards

2.4.1 OLEV Minimum Technical Specifications

To support the development of the EV industry, in the UK the Office for Low Emission Vehicles (OLEV) produced minimum technical standard documents for EV charging which can be found through their website[4]. While these are not regulations or standards in themselves, these documents set out the applicable UK standards for domestic and workplace charging installations. Further specifications have been developed for smart charging including V2G. In the UK, all electrical installations are required to comply with IET Wiring Regulations (BS7671), and these underpin the OLEV documents.

2.4.2 IET Code of Practice for Electric Vehicle Charging Equipment Installation

In 2012 the Institution of Engineering and Technology (IET) created a 'Code of Practice' (COP) for EV charging equipment installations. The 3rd edition which is published in August 2018 incorporates 18th edition of the IET wiring regulations as well as other updates. Although not legally binding, any installation not following this document would need to demonstrate that the safety of the installation exceeds those set out in the IET COP. Currently this document does not cover bi-directional EVSE and as such, does not directly apply to V2G; however, where possible installation of V2G equipment would need to comply with the code of practice or be able to establish which sections are is not applicable for V2G and demonstrate that the installation method meets or exceeds the safety standards set out in the COP.

IET has also published a technical briefing on EV infrastructure for fleet operators (available through the IET website[5]), providing additional guidance to support public and private sector organisations looking to incorporate EVs into their fleets.

[4] www.gov.uk/government/collections/government-grants-for-low-emission-vehicles

[5] www.theiet.org

Key Points:

Section 2. Vehicle-to-Grid Standards

- There are a wide range of standards which apply to EVs and charge points more generally, but very few currently which apply specifically to V2G.
- Many existing standards which impact V2G, such as the GB Distribution Code, were not developed with V2G in mind and as a result they are impractical and create potential barriers to the development of V2G as a market.
- The standards for the operational management of smart charging, including V1G (demand load balancing) and V2G are not yet fully defined. For V2G ISO 15118 is the key standard for charger operation.
- As the V2G unit is the conduit through which the EV exports electricity back to the grid, the V2G charger needs to comply to the distribution network interface regulations (currently G59 and G83, however new developments will need to comply with G98 and G99, which can now be considered as the relevant applicable regulations).

3 Hardware Technical Specifications

The main concept behind V2G is to utilise the large battery packs on board electric vehicles as energy storage, allowing electrical energy to be charged into the vehicles during times (often when electricity prices are low, for example during night time hours, or when there is high availability of renewable generation) and stored, with the option or intention of selling the energy back to the grid when prices are higher (e.g. during the day and early evening peaks in electricity demand).

Different modes of operation are anticipated for V2G, but it is likely that in most cases management systems would be put in place to ensure that a minimum (back stop) state of charge is maintained for the vehicles' battery and the timing of V2G operations are controlled, to ensure the vehicle is always able to deliver a reasonable range to allow the driver to use the vehicle should they need to.

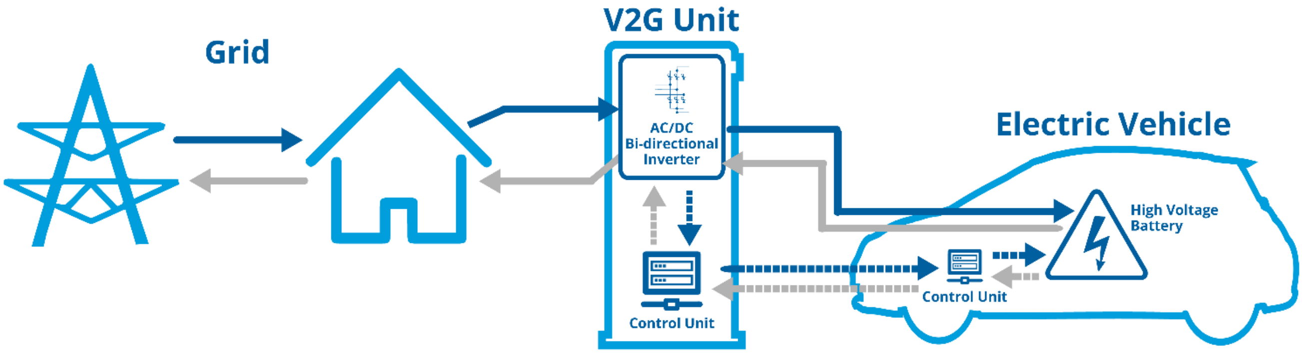

Figure 4: Vehicle-to-Grid system Diagram

Figure 4 shows that there are two different flows for each direction of travel, the solid arrows indicate energy flow and the dashed lines indicate communication or control flows.

In export mode, the EV operates as a small-scale source of distributed generation. EV battery storage capacity typically ranges between 15 to 60 kWh with only a few vehicles (Tesla EVs, Jaguar I-PACE, Hyundai Kona) having a higher battery capacity. The level of export depends on the power electronics within the V2G charger as well as the EV. Units deployed to-date are capable of exporting between 3 and 10 kW of power (see Figure 5) which positions the EV as a distributed generation asset comparable to a large domestic solar PV.

Figure 5: Early prototype V2G units in the UK - Commercial building (left) and domestic unit right)

For context, it is helpful to compare V2G chargers with the two other types of charging; standard and smart (or managed) charging.

3.1 Standard Charging

Conventional EV charging is provided by uni-directional chargers that transfer AC power from building power supplies (single or 3-phase) or from local distribution network power supplies (e.g. on-street or car park locations) to the EV.

The time to complete the charging process depends on the initial state-of-charge of the vehicle's battery when plugged in, the rated capacity of the onboard charger and the rated capacity of the charge point being used. A standard charger rated at 7 kW would charge a 30 kWh EV battery in just over 4 hours from empty. Timescales for charging can be reduced by utilising faster charging systems, where the charge point is rated 20-50 kW, with a typical 43 kW rapid charger being able to fully charge an EV in less than an hour.

Appendix A includes a summary table of electric vehicle connector types with indicative charge rates for each type.

For standard charging, electricity flows to the vehicle once the control handshake between the car and the charge point has been made and charging continues until the EV battery is at full capacity. Charging cannot be scheduled through the charge point; however, some EVs and PHEVs offer timers that can be set either from the dashboard or via an App to control when charging takes place.

3.2 Smart Charging (V1G)

The concept for Vehicle-to-Grid has been around since the early 1990's, however neither the vehicle, nor the energy system has been in a position to utilise this. As a result, EVSE developers have focused on V1G charging services which could be implemented immediately. The mechanism for V1G (often referred to as 'smart' or 'managed' charging) is like that of standard charging where electricity flows in one direction, via the charger to the EV battery. However, V1G chargers can be controlled so that power transfer to the vehicle can be managed both in terms of when charging occurs (scheduling) but also by controlling the power transfer rate at which charging takes place. V1G enables demand shifting which can then be utilised to provide energy services including:

- Time of use (TOU) tariff optimisation.
- Peak demand shaving.
- Network constraint management.
- Simple renewable optimisation.

V1G remains unidirectional (charging only) and does not support export of power from the EV to the grid. As demonstrated above, V1G can be used to provide a range of services. The definition of V1G charging is currently inconsistent in the market, resulting in products being labelled as 'Smart' while offering anything from simple scheduling of charging based on user inputs, to fully dynamic systems which monitor and respond to market signals.

V1G counts as a form of 'Export Limitation Scheme' (ELS) under the distribution code, and therefore can be utilised to enable large numbers of EVSE to be installed at a site while maintaining a set capacity limit. Key applications for this are public and workplace car parks, where the local distribution network may not be sufficient for large numbers of concurrently connected standard chargers without resulting in significant upgrade costs.

In domestic settings, V1G can be used to optimise charging around a time-of-use tariff or to increase utilisation of renewable generation.

3.3 V2G Compatibility

The first generation of V2G units have used a CHAdeMO connector for DC power supply (see Appendix A). This connector was developed in Japan and has become the industry and regulatory standard connector for rapid charging in the Japanese market, with wide adoption by Japanese vehicle manufacturers.

V2G compatible vehicles at present include the following:

- Commercially Available EVs
    - Nissan EVs (Nissan Leaf passenger car and the ENV-200 light commercial vehicle) with Nissan providing warranty on EVs for 'certified cycles' in current UK V2G projects.
    - Mitsubishi Outlander PHEV (without warranty provision).

- Small production run EVs modified for V2G operation
    - The REV 300 ACX vehicle.
    - Boulder Electric Vehicle 500 series and 1000 series trucks (in production: 2012–2014).
    - The AC Propulsion T-Zero.

In some cases, small numbers of other vehicles have also been modified for V2G as part of R&D trials.

European manufacturers have progressed with an alternative DC connector standard, called CCS. At the time of writing no CCS-based V2G equipment has been put into public trials and no announcements regarding the introduction of CCS-based V2G units were identified through desk research and by interviews and peer commentary at the hosted workshop.

AC V2G is generally seen as a theoretical concept as it requires additional hardware to be installed in the vehicle which many car manufacturers believe will lead to lower efficiencies and higher costs. However, while there are no commercial AC V2G warrantied vehicles currently in the UK market, Renault (with the Zoe) and BYD (with the e6) have been trialling AC V2G since 2015 and Hyundai Mobis announced in 2017 that it had developed a two-way on-board charger (OBC) for future electric and plug-in hybrid vehicles[6,7].

Key Points:

Section 3. Hardware Technical Specifications

- V2G is possible with both AC and DC systems, however they require different hardware configurations. The key difference is whether the export inverter is fitted in the vehicle or the charge point.
- Current V2G systems are typically limited to 3-10kW export rates.
- The range of commercially available V2G compliant vehicles is extremely limited at present and the major OEMs are not advertising their timescales for implementing V2G.

[6] www.mobis.co.kr/communityid/7/view.do?pageIndex=1&idx=4113 (Korean)

[7] "Smart Solar Charging: Bi-Directional AC Charging (V2G) in the Netherlands", Journal of Energy and Power Engineering 11 (2017) 483-490, B. de Brey, 2017

4 Market Size and Opportunities

This section explores the market potential for V2G, considering the growth potential based on customer segments as well as market drivers, barriers and market trends in relation to EV uptake and trends within national and international energy markets.

EV uptake is increasing on a yearly basis, with estimates suggesting that the number of electric vehicles in the UK could be as high as 36 million by 2040[8]. The effect of this uptake is that far greater numbers of charge points will be needed to ensure these new EVs will be able to be charged when parked at residential, workplace and public parking locations. With this growth in EVSE comes a choice as to whether the equipment is V0G, V1G or V2G.

The critical factor for V2G is the dwell time (the time which an EV is plugged into a charging point) in relation to the required charging time. The longer the dwell time and the shorter the charging requirement, the greater the opportunity for provision of other services. The time at which EVs are plugged in can also have an influence on the services which the V2G unit can provide. As an example, an EV plugged in at night only will have limited ability to provide optimisation of solar generation. However, dwell time depends significantly upon the application/customer and can be extremely variable. Therefore, this report investigates the general opportunity rather than focusing on a specific application.

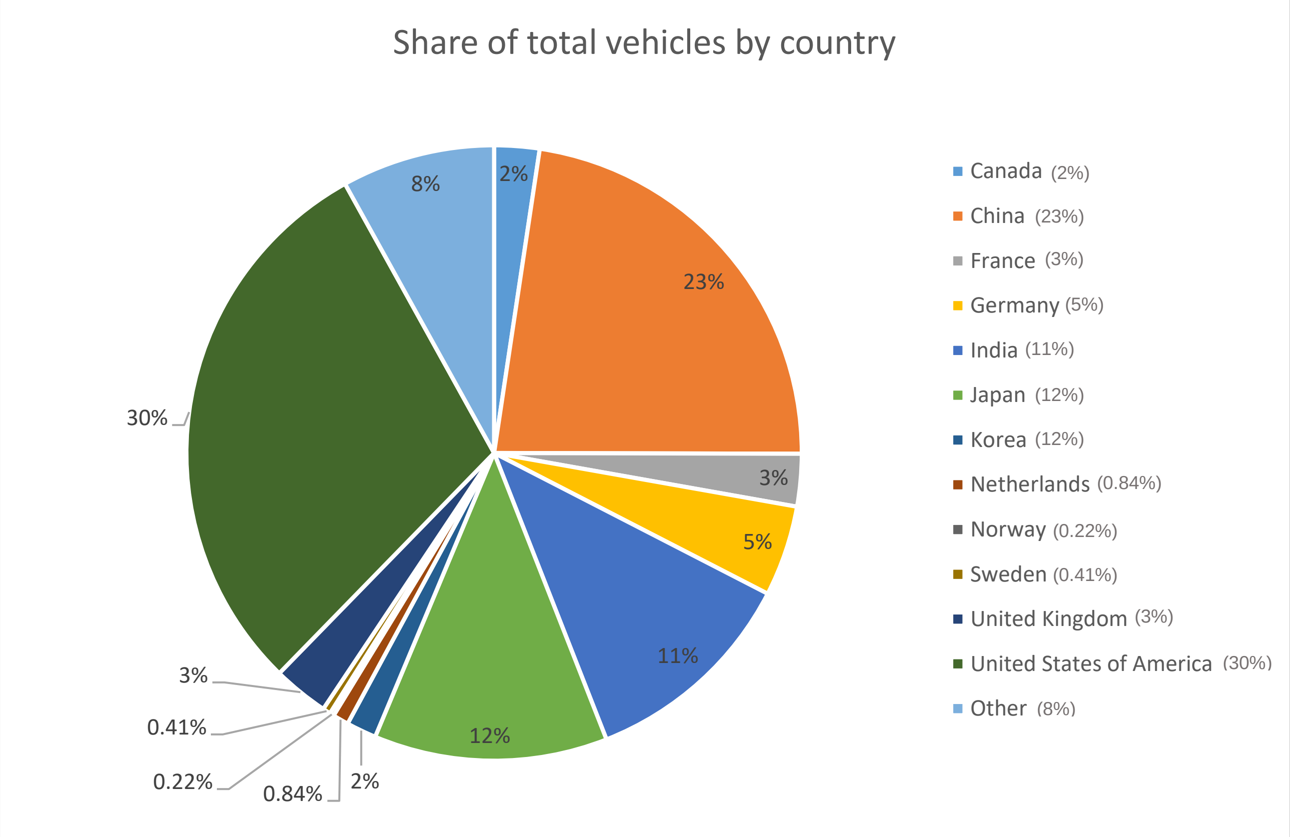

Figure 6: Chart demonstrating the share of personal transport vehicles across the world

The most likely growth area for EV, and consequently for V2G, is where petrol and diesel vehicles are transitioning to electric, most notably for personal transport (cars and vans). Figure 6 how these vehicles are distributed across the world. China, India, Japan and the USA make up about ¾ of the total vehicles. Figure 7 shows that the greatest growth rate in EV uptake has been in the Netherlands and Nordic regions (Norway and Sweden), while adoption across the rest of Europe has been quite consistent, with EVs

[8] "Future Energy Scenarios", National Grid, 2018

accounting on average for 1.4% of the total market share by 2016. Adoption of EVs across the rest of the world (Figure 8) has been less consistent with uptake in the USA and Japan seeing significant drops in 2015 and demonstrating a potential risk of levelling off. China however saw quite slow initial adoption but with significant increases since 2014. Comparing EV uptake with the total number of vehicles per country (vehicle parc) it can be assumed that while Europe and particularly the Nordic countries provide the greatest initial market for EV and V2G, the largest long-term opportunities lie in China and the USA.

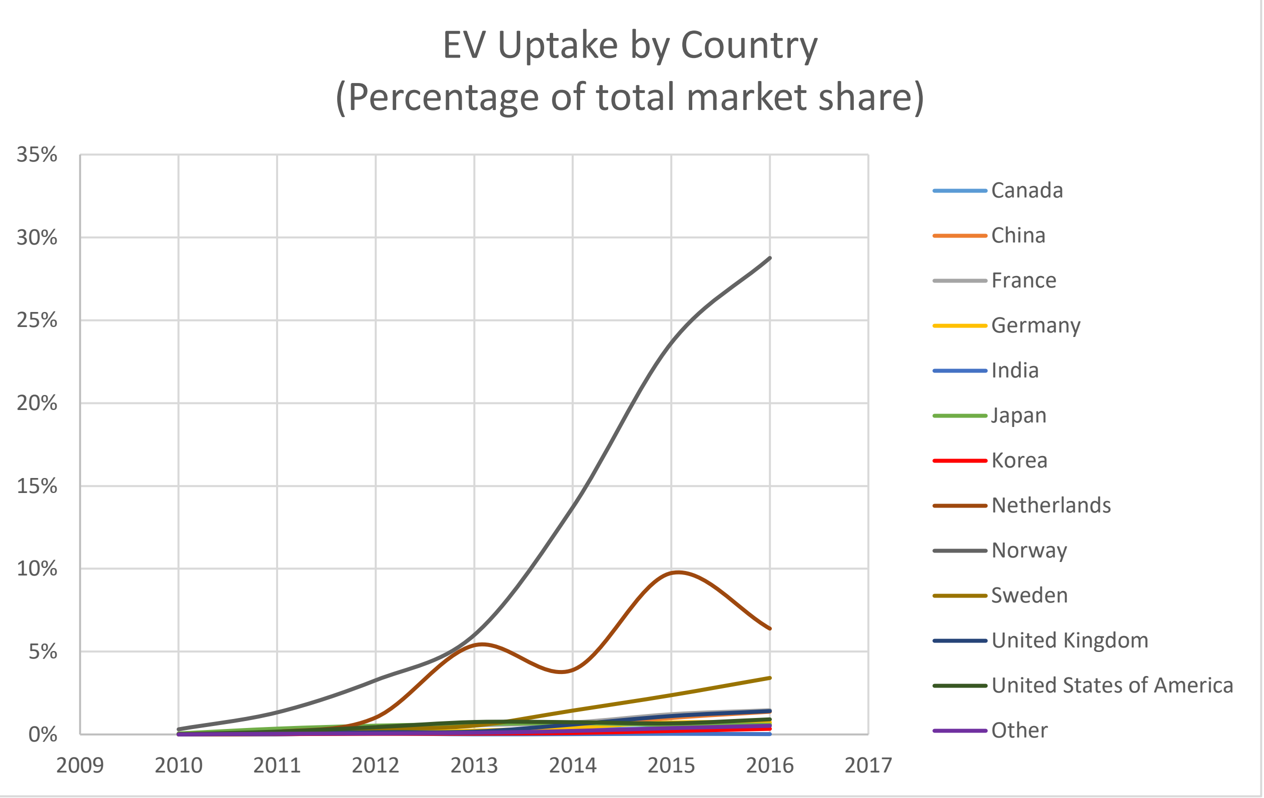

Figure 7: Growth of EV uptake by Country

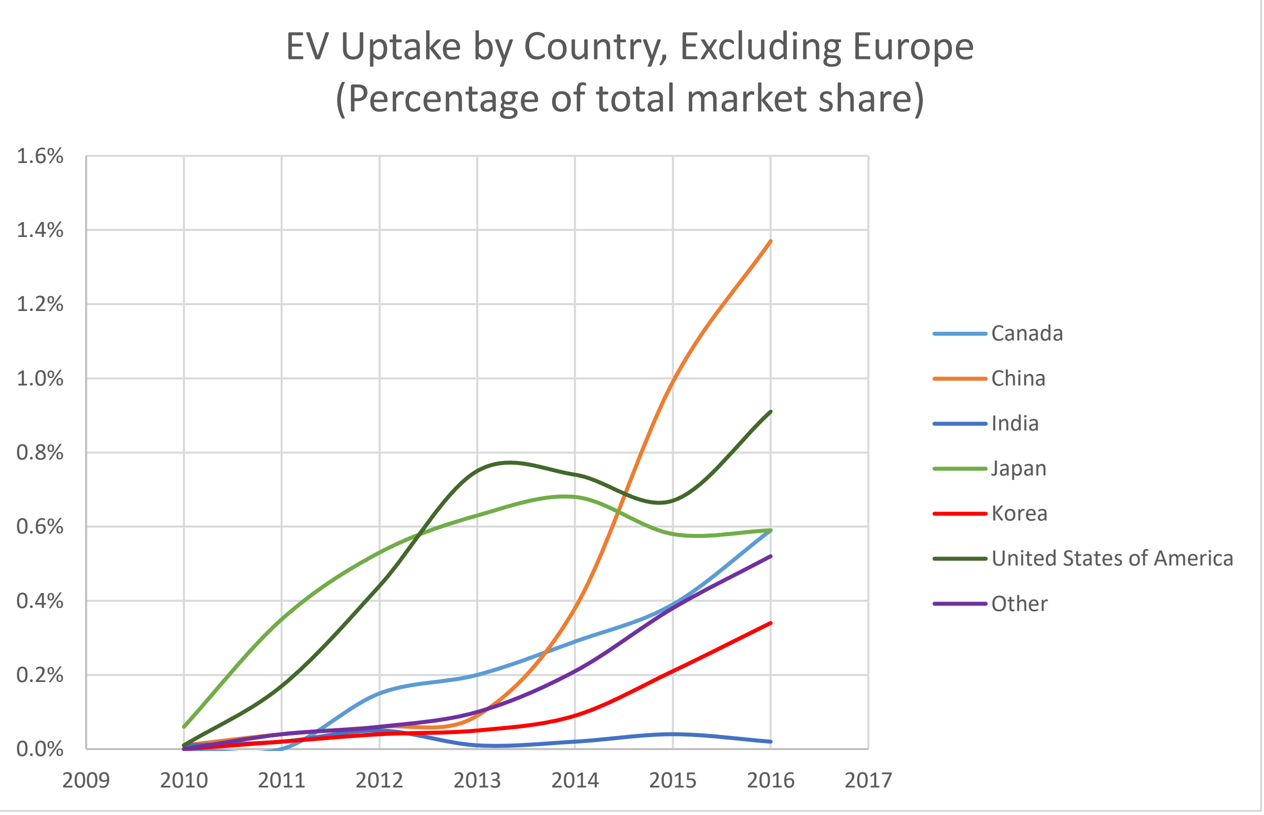

Figure 8: EV uptake outside Europe

4.1 Key Customers Segments

Finding the best market isn't just about finding the best country overall. It is also important to bear in mind the types of customers and business cases which the product will target.

Due to the potential impact of V2G services on battery life, for V2G to be adopted it is likely that the EV driver/operator should be considered ultimately as the customer for V2G. Typically this can be either:

- A private motorist whose EV can be connected to a V2G charger when parked at home, at the workplace, or at publicly accessible charge points (e.g. at train stations, airports, city centre public parking, etc)
- A fleet operator, who can arrange for their fleet EVs to plug in to V2G units when parked at workplace locations, for return-to-base fleet, or at dedicated charging bays (for car clubs or taxis) or at publicly accessible charge points

4.1.1 Private EV Users

Private EV motorists are key target customers for V2G services, whether via V2G hardware at the home (considered most likely) or when the motorist is at work or using publicly accessible chargers.

Private passenger cars are typically parked for long dwell times at home for night or day-time charging, as well as at the workplace, or at publicly accessible car parking, during the day. This long dwell time makes them good candidates to be recruited by a V2G service provider. Airport parking has been identified as a candidate location for V2G, due to the long (days and weeks) and predictable (based on flight information provided to the car park operator) nature of long-stay airport parking.

Where the private home or shared housing has on-site renewables, V2G, or to some degree V1G, can be used to direct excess generation (most commonly solar PV) to charge the EV. V2G can then discharge this energy back to the home later, in order to offset the demand from the dwelling or to provide third party services.

At the workplace, and with the permission of the EV owners, EVs connected to V2G units could be used to provide behind-the-meter energy services to the business, such as TRIAD-avoidance.

4.1.2 Fleet Operators

Fleet operators may also be key customers for V2G technology manufacturers. Fleet operation offers features that can assist the V2G business case, as follows:

- Long dwell times: Many fleet vehicles are parked at a depot either overnight, or for operational downtime during the day.
- Predictable usage patterns: Where fleet vehicles are used for fixed duties, the usage can be quite predictable. Alternatively, vehicles that are booked out may give a good forecast of usage.
- High charge point utilisation: Where fleets exist, there is the possibility of multiple vehicles plugging in to a single charge point, thus increasing the utilisation of the charge point. Although this may prove detrimental if EVs are only connected for the duration it takes to charge.
- Concentration of charge points: Having many charge points at a single location makes them easier and cheaper to aggregate for potential grid services. This is because they could exist behind a single meter, and all utilise the same monitoring and dispatch hardware.

Fleet operators tend to be very cost conscious and make fleet renewal decisions based on changes in Total Cost of Ownership (TCO). Therefore, where an opportunity for revenue through V2G services exists they are likely to be early adopters, as long as the value of providing these services outweighs any risks around battery degradation and EV availability for useful work.

There are several possible markets that may be appropriate for fleet based V2G. Key ones are given in the table below.

Market	Comment
Frequency Response	When aggregated in sufficient numbers, V2G charge points could be used to provide frequency response at the 1MW entry capacity.
Tariff Optimisation	Fleet charging at a depot location would almost certainly be subject to a half-hourly tariff. This provides opportunity to optimise energy consumption for not just the EVs but any associated on-site energy demand against the tariff. Tariff components include wholesale energy price, DUoS, TNUoS and Capacity Market Charges.
On-site Renewable Optimisation	Where on-site renewables exist, V2G charging can utilise excess on-site renewable energy and later use it to meet on-site demand, avoiding the import of additional energy from the network.

Table 3: Markets for V2G fleet operators

There are many types of fleets in the UK, recent studies by Cenex has identified the following as possible early opportunities for V2G.

- Council pool cars fleets: These may benefit from being plugged-in outside of standard office hours, and possibly on-site PV giving an additional optimisation opportunity.
- Refuse collection vehicles: There are some estimated 10,000 refuse collection vehicles in the UK. Typically, they can be parked up between 2pm and 6:30am giving a long period of charging optimisation, including the valuable evening peak (5pm-7pm) for electricity demand. While historically these vehicles would be diesel powered, due to high demand from local authorities, the major manufacturers are already trialling hybrid and fully electric options. Overcoming the weight of the vehicles would require large on-board batteries. However, when connected for V2G this would provide much greater capacity per unit compared to a standard EV and therefore greater opportunity for optimisation.
- EV car clubs: Having many charge points at a single site will help with aggregation. The car club business model requires a high availability of vehicles to allow for potential bookings. This means a certain number of vehicles sat available (rather than booked). It will assist the car club business model if the EVs can earn money through V2G services during these times.
    - UK car club operator e-car club is investigating this business model through the latest round of Innovate UK funding.
- City buses: Electric city buses have large onboard batteries, giving scope for V2G services. Daily operating hours tend to be longer than for refuse collection vehicles, but the vehicles operate on fixed routes and can have dwell time at the end of routes before recommencing operations. UK Power Networks and Cenex have both separately investigated city bus V2G potential in R&D projects, and this topic is being investigated further through the Innovate UK funded project 'Bus2Grid'.

A key success factor for fleet V2G would be predictable dwell times when parked and plugged-in to the V2G unit, ideally with a proportion of fleet vehicles being parked during the early evening peak in electricity demand.

For fleets, business models for V2G hardware include either hardware sale to the fleet operator, hardware leasing, or a service where the hardware is installed, operated and maintained by a V2G specialist who receives the greater proportion of the earned income but shares a portion with the fleet operator.

Depending on the revenue streams being accessed, there may be a requirement for another party to act as an aggregator to offer grid services. If the revenue streams are purely local (such as tariff or on-site renewables optimisation) then the V2G units could be controlled by systems on-site, however there may still be a need for specialist software to run the optimisation of the V2G units.

4.2 V2G Market Drivers

4.2.1 Changes to the Energy System

Over the past 20 years, energy systems around the world have followed a number of key trends:

- Deregulation of energy markets,
- Shifting away from centralised generation, towards smaller decentralised generation,
- Increased focus on improving energy efficiency and emissions reductions,
- Moving away from 'conventional' sources such a coal and gas, towards the use of renewables, especially wind and solar PV,
- Increased use of demand management to align demand with supply.

The combination of the above trends has led to the development of a new actor in the energy system, typically referred to as the Aggregator or Virtual Power Plant (VPP). Virtual Power Plants bring together large numbers of individual assets, both generation and demand, which due to their size would not normally be able to provide services to the energy system. However, by aggregating these assets they can be operated and traded as a single unit. This enables system operators to have greater control over supply and demand as well as providing the aggregated assets with access to additional revenue streams such as TSO balancing services.

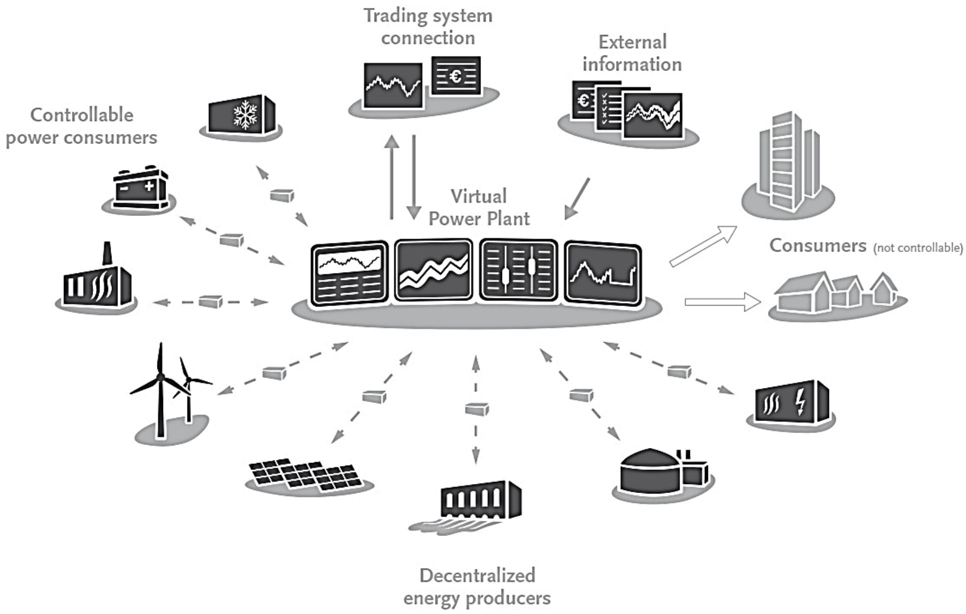

Figure 9: Virtual Power Plant system layout (Ulrich Focken, 2018)

Aggregators are a relatively new role within European electricity markets. They were initially introduced in the USA to enable greater demand side participation by supporting smaller power, more distributed, assets. Following their success in the USA and as the market became saturated, many aggregators moved their focus to Europe. VPPs are now able to operate commercially in a number of countries across the world and many system operators are adapting their services to allow participation by demand management (termed demand side response or DSR) and aggregation. However, this is not the case in all countries and the level of progress varies significantly from country to country.

One of the leading voices in this area has been the Smart Energy Demand Coalition (SEDC, recently renamed 'smarten') whose 2017 report 'Explicit Demand Response in Europe' sets out the regulatory and commercial readiness of all European states in relation to DSR[9].

Rather than replicate their effort, the results of the study are shown in Figure 10 and Figure 11. SEDC used 4 key criteria for assessing the potential opportunity with a country, scoring each out of 5 (where 5 is the best possible score). These were perceived as having equal weighting and as a result, the overall rating is the sum of these scores. High overall scores indicate a high level of readiness for DSR, while low overall scores indicate the presence of significant barriers or a low general readiness for DSR.

2017					
	Demand Response Access to Markets	Service Provider Access	Product Requirements	Measurement and Verification, Payments and Penalties	Overall
Austria	3	1	5	3	**12**
Belgium	3	3	5	3	**14**
Denmark	3	1	3	3	**10**
Estonia	1	0	1	0	**2**
Finland	5	1	3	5	**14**
France	5	5	5	3	**18**
Germany	3	1	3	3	**10**
Great Britain	5	3	3	3	**14**
Ireland	5	5	3	1	**14**
Italy	1	0	1	1	**3**
Netherlands	3	1	3	3	**10**
Norway	3	1	3	3	**10**
Poland	1	1	1	1	**4**
Portugal	0	0	1	0	**1**
Slovenia	1	1	0	3	**5**
Spain	0	0	1	0	**1**
Sweden	3	1	3	3	**10**
Switzerland	3	5	3	5	**16**
Overall	**48**	**30**	**47**	**43**	**168**
Max score	**90**	**90**	**90**	**90**	**360**

Scale: 0 – Non-existent, 1 – Significant barriers exist, 5 – Ideal conditions

Figure 10: Detailed grading of countries for DSR readiness (Smart Energy Demand Coalition (SEDC), 2017)

[9] "Explicit Demand Response in Europe – Mapping the Markets", SEDC, 2017

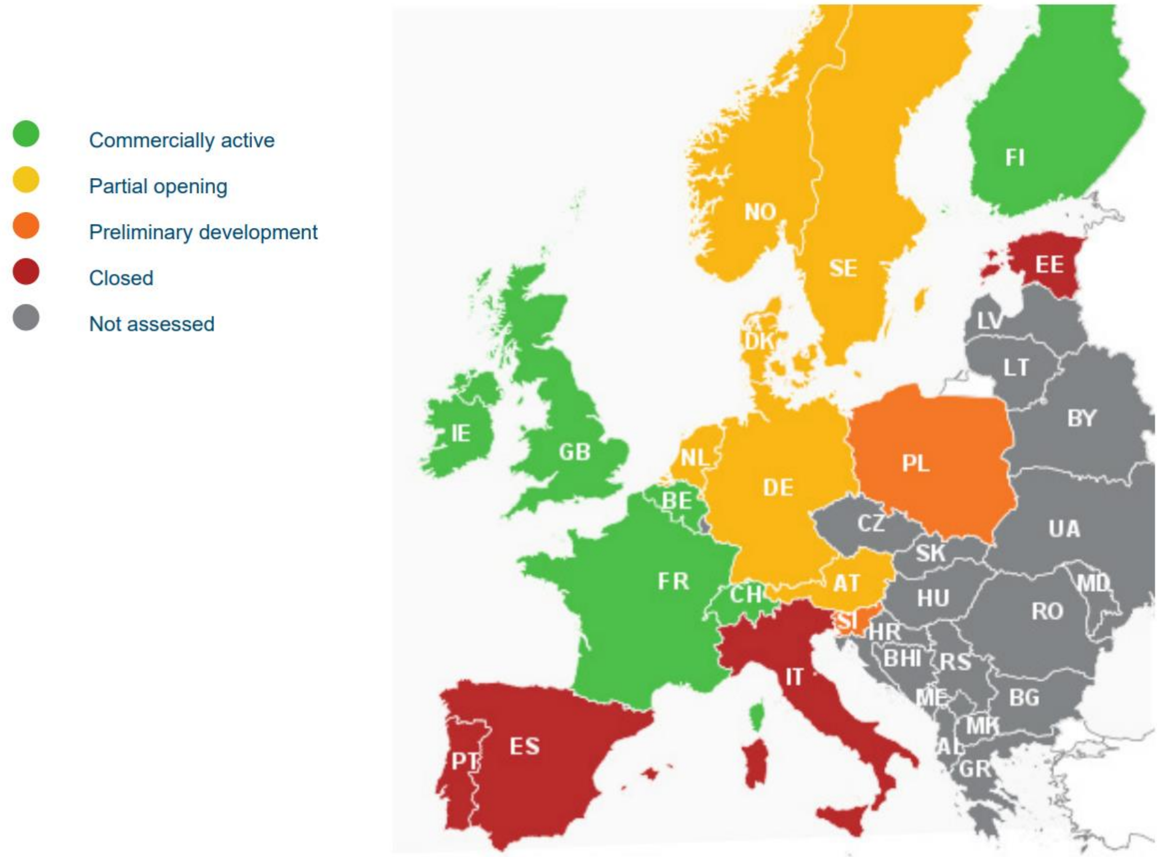

Figure 11: Map of DSR development in Europe (Smart Energy Demand Coalition (SEDC), 2017)

Aggregated flexibility can come from a broad range of assets and customers. Some examples can be found in Figure 12. In this context V2G would be counted as both DSR and generation, while V1G (smart charging) would be DSR only. As a result, the readiness of a country, in terms of both regulations and markets, to DSR and aggregation is critical to the development of V2G in that region.

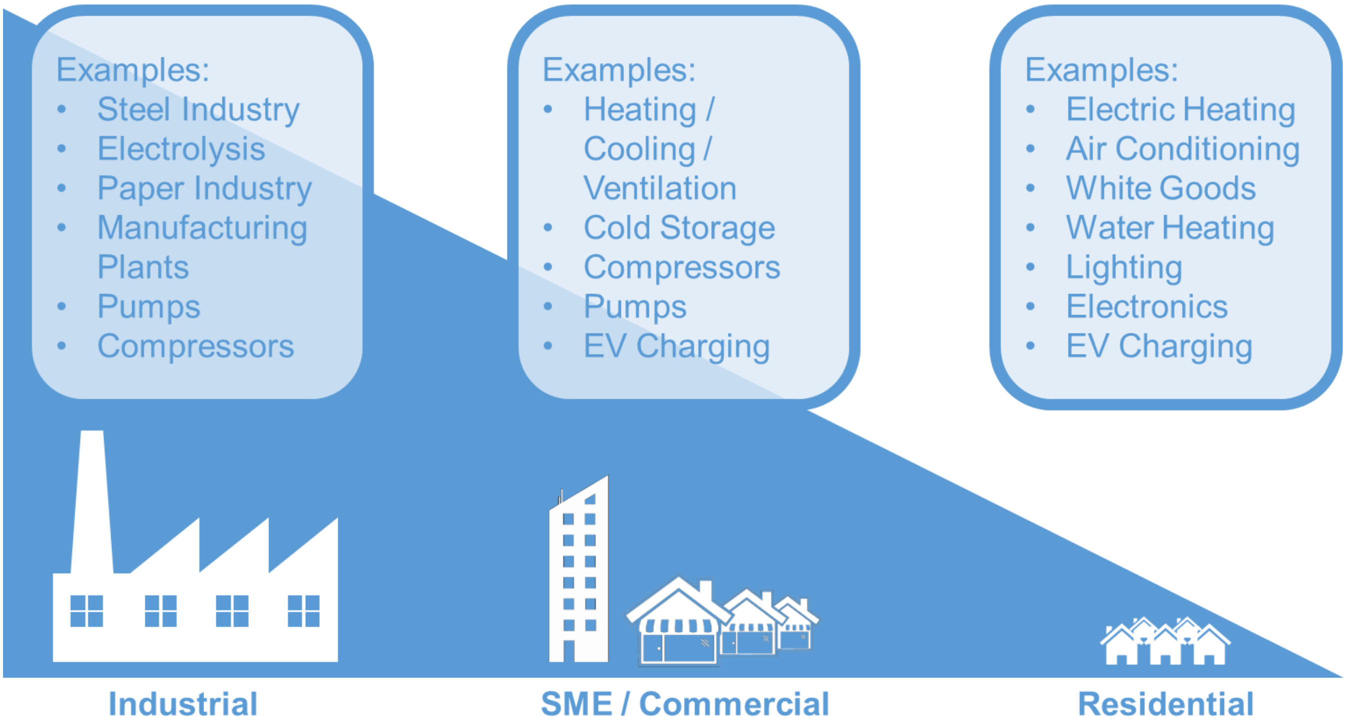

Figure 12: Examples of sources of flexibility

Aggregators often employ a range of assets with different characteristics within a single pool to create the 'ideal' unit characteristics. This can be used to increase reliability, provide backup, reduce risk and to compensate for the characteristics of specific assets. For example, combining flexibility from air conditioning units (most flexibility during hot weather) and heat pumps or heaters (most flexibility during low temperature periods) could enable an aggregator to provide flexibility all year round. This portfolio approach could similarly help overcome some of characteristic based barriers to V2G, such as unpredictability of when a vehicle will be plugged-in and the state of charge.

4.2.2 Impact of Projected Growth in EVs

In 2017 the impact of EVs on the energy system made national headlines in the UK, as newspapers reported that uptake of EVs would result in the need for 30GW of additional generation by 2050. While the calculations to reach this figure were found to be flawed, National Grid later confirmed that this figure would likely be between 6-18GW. By contrast, National Grid's 'Future Energy Scenarios' stated that this impact could be limited to 6GW through the widespread utilisation of smart charging (V1G) and V2G[10].

Figure 13 (below) shows a forecast of the global energy outlook for increased energy demand by sector. EV energy demand growth is shown to be relatively minor compared to other growth areas, such as industry and buildings. In fact, IEA predict that EV demand may account for as little as 1.5% of the total global energy demand by 2030. This illustrates that the impact of EV's on the energy system as a whole may not be as significant as often thought and the increased electricity generation required to meet demand may not be the key energy issue connected with EV roll out. Rather, it is likely that the impact of charging on capacity constrained local distribution networks and the alignment of EV charging with periods of peak demand may be the greater challenge.

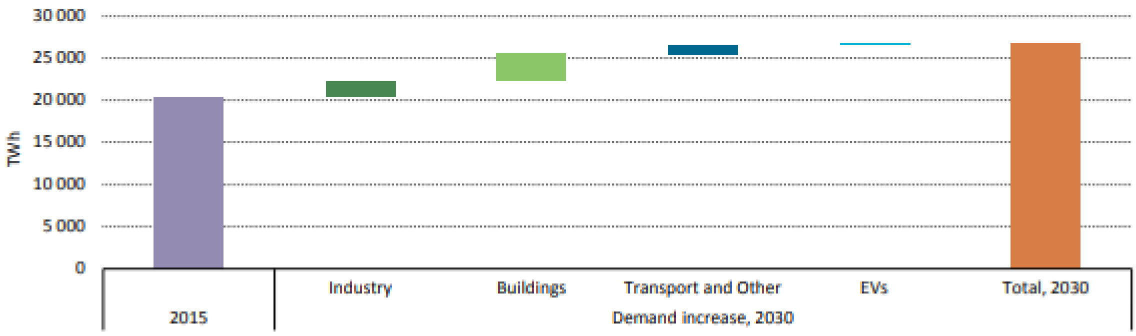

Figure 13: Impact of EV deployment on global electricity demand (OECD / IEA, 2017)

As the shift from ICE vehicles to EVs gains traction, the ability of the distribution network to meet local demand will prove pivotal in the market for V2G services. The application of V1G, and potentially V2G, is seen as critical to enabling the charging of EVs within local grid constraints. The deployment of V1G is likely to become the market norm across international markets (as all will face local distribution constraints, to varying degrees, for the same reasons as identified for the UK), with V2G chargers being utilised in specific applications where trading-based grid services are used to manage charging, alongside traditional upgrades to the local distribution networks.

[10] "Future Energy Scenarios", National Grid, July 2017

4.3 Key Barriers to V2G Uptake

The development of V2G has faced barriers and challenges. While some of these have been resolved as the EV market has developed, many still apply. These can be broken down into four main areas:

- User/Social,
- Hardware,
- Regulatory and Market Access,
- Business case.

4.3.1 User/Social

Despite the growth of the EV market, V2G as a technology has maintained a relatively low public profile, often seen as too complex for the general public's interest. Therefore, during a commercialisation phase for V2G, public awareness will need to be raised. This will require setting out a clear and targeted benefits case for users. Users will likely be driven firstly by economics, but also by sustainability or a desire to be more energy independent.

There is also a perceived risk in allowing autonomous control of a user's EV battery from an external source. To allay these concerns, retailers will need to demonstrate a customer-centric proposition where the primary purpose of the EV cannot be compromised. Clear and concise user controls may also help by enabling customers to put limits on how and when the V2G unit will be operated.

Potential Enablers:

- Public communication of a clear, customer-centric benefit case (e.g. "Let your EV work for you overnight with V2G", or "Why waste clean, free energy from the sun, when you can store it in your car with V2G?")
- User retention of overall control of the V2G unit (or override option for a controlled unit) so as to avoid compromise to primary EV use.

4.3.2 Hardware

There have been a limited number of demonstrators of the hardware required to perform V2G in the UK (for example the Innovate UK projects 'Ebbs and Flows of Energy Systems' and 'Intelligent Transport, Heating & Electrical Control Agents') and Europe (see Appendix D for examples). These examples of V2G charging fall into the following categories:

1. Proof of concept devices
2. Products designed for overseas markets (e.g. Japan) requiring modification for local markets
3. Announcements of the details and specifications for future products.

Several manufacturers are reported to be working on V2G products or have products which claim to be "V2G ready", however there is a notable absence of products commercially available on the market.

The 'ENA Type Test Verification Report Register' contains details of generating units of all types which are compliant to EREC G83. Having a product that is 'type tested' and listed in the register means that product can be readily installed and connected in parallel to the UK LV electricity network (subject to overall plant size limitations and meeting other requirements). To date the register does not list any V2G EVSE. This provides a strong indicator of the lack of market readiness of V2G chargers.

It is possible to connect generators to the electricity network which are not G83 compliant (type tested), but this requires a more significant application process via the local DNO and could require associated facilitating works, which is not ideal for widespread commercial rollout of products.

With increasing interest in V2G, the commencement of demonstrators involving larger numbers of charging points, and standardisation and adoption of common V2G and EV protocols it is expected that the range of choices and availability of V2G EVSE will rapidly expand.

Given the current market readiness of the hardware, prices are prohibitively high for any economic business case, likely costing in the region of £5,000. Technavio[11] has forecast prices of residential V2G chargers in the period 2017-2021 at $2,000-$3,000 which gives an indication of some cost reduction. Additionally, V2G hardware is excluded from the current OLEV grant, meaning that in the UK the relative cost of V2G compared to standard or V1G charging is even higher.

Finally, there are currently very few models of EV available in the UK that support V2G (Nissan Leaf, Mitsubishi Outlander) and it is also unclear what V2G activities are covered under battery warranty. EV owners are unlikely to want to jeopardise or invalidate battery warranties and therefore uptake of V2G is likely to be limited until this is made clear. It is believed that in Japan, Nissan warranties 5kWh of V2G 'approved cycles' of discharge per day. However, Nissan and other EV manufacturers' positions on warranty provision for V2G long term and outside of Japan is currently unclear. This is driven by the understandable concern from vehicle manufacturers that excessive cycling of the battery through V2G operation will prematurely degrade the battery.

Potential Enablers:

- Standardisation and adoption of common protocols, supporting standardisation of V2G EVSE,
- Inclusion of V2G in EV/smart charging incentives
- Clarity on EV/battery warranty cover for V2G activities.

4.3.3 Regulatory and Market Access

V2G can potentially provide value in many different markets. However, access to some of these markets is currently difficult or unclear. TSO markets were not previously developed for distributed intermittent storage assets such as V2G, meaning that technically prohibitive requirements are common. In the UK, the current changes by National Grid to the balancing services provide the opportunity to improve market access for V2G.

It is likely that V2G will be able to provide value to a Distribution System Operator in resolving local constraints. However, such markets do not yet exist and understanding of how these could operate is lacking. V2G would be uniquely positioned to provide services in such a market given its distributed nature and being primarily connected at the distribution network level.

To access some markets, including System Operator (SO) balancing services, V2G units require aggregation both to meet minimum capacity requirements, but also minimum provision window coverage. Aggregation provides a potential solution to this challenge; however fundamental challenges currently exist where the energy supplier and the aggregator are different bodies. Fair mechanisms need to be put in place so that energy supplier's costs, such as imbalance charges, occurring as a result of aggregators actions can be fairly recovered or accounted for.

There are also issues around the connection of V2G to distribution networks. Depending on the power and number of V2G units being installed, different types of connection applications have to be put in to the DNO and different charges apply. In many cases, the cost of these charges could destroy the business case for V2G. This situation is currently evolving; however, this is another area where the

[11] Technavio - Global Vehicle to Grid Chargers Market by End-user 2017-2022 (2018)

original regulations and process were not designed with V2G in mind. Changes to the distribution connection procedures could enable V2G to connect more readily and at lower cost.

Potential Enablers:

- Reformed SO balancing services,
- Introduction of DSO constraint markets,
- Mechanisms for aggregators to instruct distributed V2G units without adversely affecting energy suppliers,
- Streamlined distribution connection procedures.

4.3.4 Business Case

The business case for V2G has a number of challenges. The first, which is currently being tackled by some of the current Innovate UK V2G projects, is the quantification of the revenue and identification of the services which can technically and practically be provided within the characteristics of V2G usage.

Another of the challenges of V2G is that it includes both the transport and energy sectors, existing at the intersection of them. This introduces complexity in understanding the potential business cases that could include actors in fleet management, energy management, asset aggregation and central market participation.

Due to the wide number of potential value streams for V2G (such as on-site energy optimisation, time of use charging, charge avoidance, balancing market participation) it is not trivial to determine the best usage for any given V2G unit.

The large number of actors and value streams involved creates a complexity that is off putting for many potential adopters. The results from current Innovate UK projects should provide specific use cases and value streams that can simplify this complex picture.

Potential Enablers:

- Innovate UK V2G projects providing clarity on V2G revenue.
- Innovate UK V2G projects providing specific use cases and value streams

4.4 Market Analysis by Region

4.4.1 Methodology

The aim of this analysis was to identify countries which were strongly placed for growing a V2G market. The modelling methodology is based on projections from early market growth driven by four factors as follows:

- Total size of automotive market
- Current EV uptake
- Existing levels of EVSE
- DSR enabled energy markets

Countries where each of these factors can be ranked 'High' are identified as 'Lead' markets.

Total size of automotive market

V2G hardware and service suppliers are likely to target areas with large car markets (by sales and total car parc) and high vehicle turnover (ratio of new sales versus total parc), as high vehicle turnover will create sales opportunities for EV and will see accelerated EV growth when a wider range of EV makes and models become available. This, combined with supportive policies, will help accelerate the uptake of EVs. However, significant changes to national policy in linked areas, such as air quality, could drastically impact the rate of growth within a market, resulting in some markets never reaching their potential, while others get there more quickly than forecast.

Current EV uptake

V2G technology depends on the uptake of EVs almost exclusively. Should the market either not move from Internal Combustion Engine (ICE) vehicles to EVs or should EVs give way to fuel cell vehicles in some markets, then the potential for V2G will be reduced dramatically (although some of the latest models of fuel cell vehicle do include plug-in capability).

Existing levels of EVSE

The levels of EVSE can be defined as the EV charging infrastructure available at public, as well as domestic, locations at present and in the future. EV uptake will be dependent on public perception that there are charging facilities available nationwide. As EV uptake increases, the number of users that do not have private driveways will increase, increasing the requirement for public and workplace charging facilities. Figure 14 shows figures around the total number of charging points and new install rates per country for 2017.

Demand Side Response enabled energy markets

This looks at the energy markets layout at each country involved in the study. Where the national energy market allows for aggregation of distributed generation assets, then there is a part for V2G technology to play in the larger DSR mix. Whilst there is still scope for V2G to be used in areas where there is no local aggregation enabled, the levels of additional income that can be gained by leveraging V2G assets for DSR markets will not be available. Therefore, the business case for V2G will be less attractive and the export of UK technologies to these markets may not be as lucrative, resulting in a reduction in the interest and uptake of V2G in these markets.

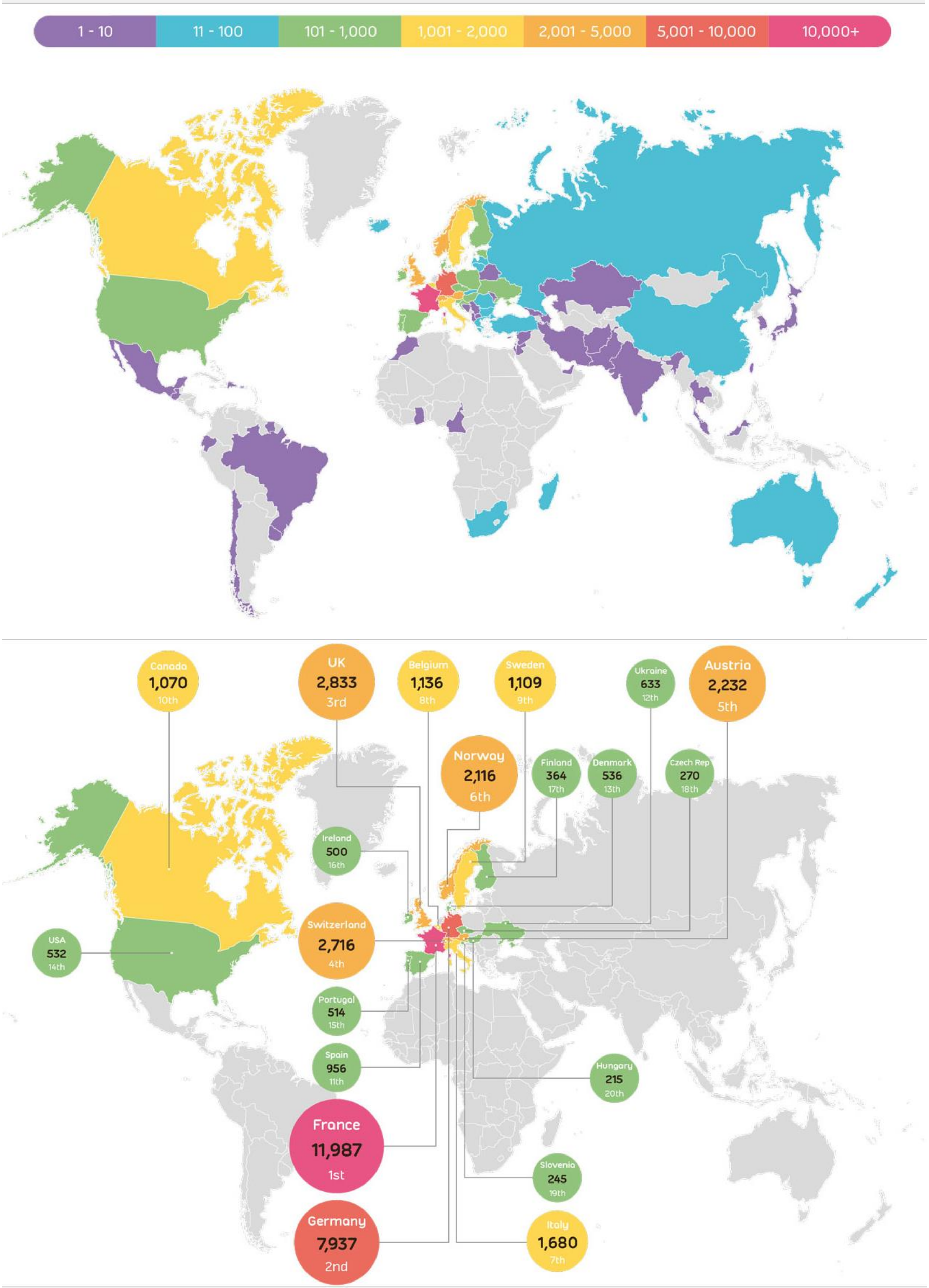

Figure 14: Top: Number of EV charging points created in past 12 months; Bottom: Top 20 countries with most EV charging points (INDIGO, 2017)

4.4.2 Lead Market Identification

Once countries have been ranked by the criteria described above this has allowed lead and secondary markets for V2G to be identified. Lead markets are those where minimal barriers exist, combined with greatest opportunity, whereas secondary markets are those where one or two small barriers or a single significant barrier exists which currently limits the opportunity for V2G, but once removed would result in a large and accessible market. Where significant barriers are identified in more than two criteria, this results in a low rating for both lead and secondary markets the country.

	Total size of automotive market	Current EV uptake	Existing levels of EVSE	DSR enabled energy markets
Australia	Low	Low	Low	Medium
Benelux	Medium	Low	High	High
Canada	Medium	Medium	Medium	High
Central & South America	Medium	Low	Low	Low
China	High	High	High	Low
Former Eastern Bloc	Low	Low	Low	Medium
France	High	Medium	High	High
Germany	High	Medium	High	Medium
India	High	Low	Low	Low
Italy	Medium	Low	High	Low
Japan	High	Medium	High	Medium
Russia	Low	Low	Low	Low
Scandinavia	Low	High	High	Low
South Korea	Medium	Medium	Medium	High
Spain	Medium	Low	High	Low
UK	High	Medium	High	High
USA	High	Medium	Medium	Medium

	Lead Markets	Secondary Markets	Export Potential for UK V2G services
Australia	Low	Low	Low
Benelux	Low	Medium	High
Canada	High	N/A	Medium
Central & South America	Low	Low	Low
China	Medium	High	High
Former Eastern Bloc	Low	Low	Medium
France	High	N/A	High
Germany	Medium	High	High
India	Low	Low	Medium
Italy	Low	Medium	High
Japan	High	N/A	Medium
Russia	Low	Low	Low
Scandinavia	Low	Medium	High
South Korea	High	N/A	Medium
Spain	Low	Medium	High
UK	High	N/A	N/A
USA	Medium	High	High

Key
High
Medium
Low
N/A

Table 4: Lead market identification for UK V2G technologies

Countries are also scored based on the export opportunity for V2G technologies, considering the likely barriers to entry and the likely competition from domestic suppliers of hardware and energy services. The result is a combination of the market scores, summarised as via a traffic light analysis, as shown in Table 4, where green is positive for V2G export potential, whereas amber demonstrates potential and red indicates an unattractive early market opportunity due to the limited presence of market drivers and/or the presence of barriers to market entry.

Export potential is measured separately from the criteria for lead and secondary markets and is an indication of a number of factors, including the maturity of current technologies and industries relating to V2G and EV within the country, and historic willingness to adopt European or western products, services or business models. This is combined with the market potential to give an indication of the opportunity for export. Therefore, some countries which score low or medium as lead markets may have better export potential than some of the core lead markets. An example, Japan is a leading EV and V2G hardware manufacturer. Therefore, despite being a lead market, the potential to export products and services to Japan may be limited compared to other markets.

4.4.3 Results

Across all countries, there is a clear trend showing the European market to currently be most receptive to V2G technologies. This is supported by the number of innovation projects that are currently being undertaken across Europe utilising Research and Development funding. France and the UK are lead markets in terms of project activities. In both countries, energy markets are open to demand side response systems which would allow V2G services to be used at scale to create income and allow for a more compelling business cases to be developed to incentivise the use of V2G. Scandinavia and Benelux have been early adopters of EV and have seen rapidly growing markets. However, the smaller new car market, combined with barriers to participation of DSR in energy markets, make these less attractive initial markets for V2G. With that in mind, they present a good mid-term opportunity (secondary markets) for V2G and especially for export of V2G from the UK. Germany, as the home of many key automotive companies, also presents an important secondary market, with battery use supporting solar PV having been incentivised. However, barriers to DSR and the lack of German EV manufacturer support for V2G, prevent this from being a leading market.

The lead market in the Americas is Canada. While Canada only accounts for 2% of the worldwide automotive market, it has seen strong and consistent growth in EV sales over recent years, as well as being open and active in supporting participation of DSR in its energy markets. The USA ought also to be a strong market for V2G, due to its size at 30% of the world's automotive transport. However, the US market is made up of different regional markets for both EVs and for energy. Federal policy exists to support EVs but policy at a state level is very positive for EVs in some states, but much less so in others. This is also true of DSR participation in energy markets. At present the lead markets within the USA would be viewed as California, the West Coast States and some North East States. These states currently have the largest uptake of EVs and EVSE and local energy markets where DSR is enabled. California is the largest car market. It also has high solar PV uptake and policy that favours new solar PV over fossil power generation, so the opportunity to optimise the combination of solar PV and EVs using V2G.

For the rest of the world, the key opportunities are clustered around Japan, China and South Korea. Japan is home to many of the leading EV manufacturers as well as 12% of the world's automotive transport vehicles. However, EVs are struggling to take a major foothold and there are still barriers to DSR participation in the energy markets. Despite these challenges, Japan remains a latent market for V2G, be it with limited opportunity for export of V2G from the UK due to the high number of technology manufacturers in the region. The evidence to-date points to UK companies developing first mover V2G business models using imported Japanese V2G hardware rather than designing and manufacturing hardware that could then be exported to Japan. However, it is also worth noting that Japan is looking to reform its energy market (by 2020/21), and while it may be difficult to export hardware solutions to Japan, there is an increasing trend to look towards western countries for innovative business models and customer-focused propositions to link into existing technologies.

China accounts for the second largest automotive market in the world. However, despite relatively strong adoption of EVs the energy markets still remain relatively closed to DSR, making it a secondary opportunity for V2G only. The prospects would be worse were it not for the current concentration of EV roll out in a limited number of cities, which, if this trend continues, will lead to issues for local distribution and a need to embrace V1G and potentially also V2G. The Chinese EV market has been strongly shaped by Government policy (as for example with battery swapping) and this policy could switch to support V2G.

South Korea, by contrast to Japan and China, presents an interesting opportunity for V2G, due in part to the active nature of the DSR market and openness of the energy market to DSR participation. At present the EV uptake is still low but transport is expected to become increasingly electrified and an increasing number of South Korean EV manufacturers and the availability of government incentives for EVs are expected to drive rapid growth in the EV market and the V2G market along with it.

4.4.4 Key Market V2G Uptake

Forecasting V2G uptake is challenging due to the many uncertainties, including:

- The cost-down potential of V2G hardware,
- How revenue value will be shared between actors,
- Business cases are seen as customer, location and market specific rather than there being common comparators,
- DSR markets are seen as uncertain with the potential for value to erode or markets to saturate

Without clarity in these areas, it is difficult to present a realistic value for V2G services, which is achievable at scale.

Furthermore, little work has been done (or published) to identify the key value opportunities and target customers for V2G. It is therefore challenging to predict the future uptake of V2G or break this down into specific customer segments. However, V2G is unlikely to be commercially viable at scale in a domestic setting before the mid-2020s and will likely only account for a small proportion of the market due to the higher costs of V2G relative to V1G. In addition, the economically viable use cases for V2G outside of domestic settings may be limited to scenarios with high and predictable dwell times. In order to demonstrate the potential scale of the market the following assumptions have been applied:

- V2G units account for no more than 10% of the total EVSE respectively by 2030,
- While uptake of EVs has always been higher than the installation of public EVSE, it is assumed that, as the EV market matures and more models become available, uptake of EVs will increase at a greater rate than public EVSE installs. As a result, it is assumed that the ratio of EVs to public EVSE will increase to 20:1 by 2030, compared to the current ratio of 6:1[12],
- Initially, 100% of domestic EV owners have home chargers. However, by 2030 the percentage of EV owners who have a home charger will be 62.5% as EV ownership extends to more users without private driveways,
- Smart charging (V1G) units will be mandatory by 2020, with the phase out of non-smart charging units and replacement with V1G units.

Taking these assumptions, it is possible to model the uptake of V2G in each of the key markets. This is shown in Figure 15.

[12] "Global EV Outlook", IEA, 2017

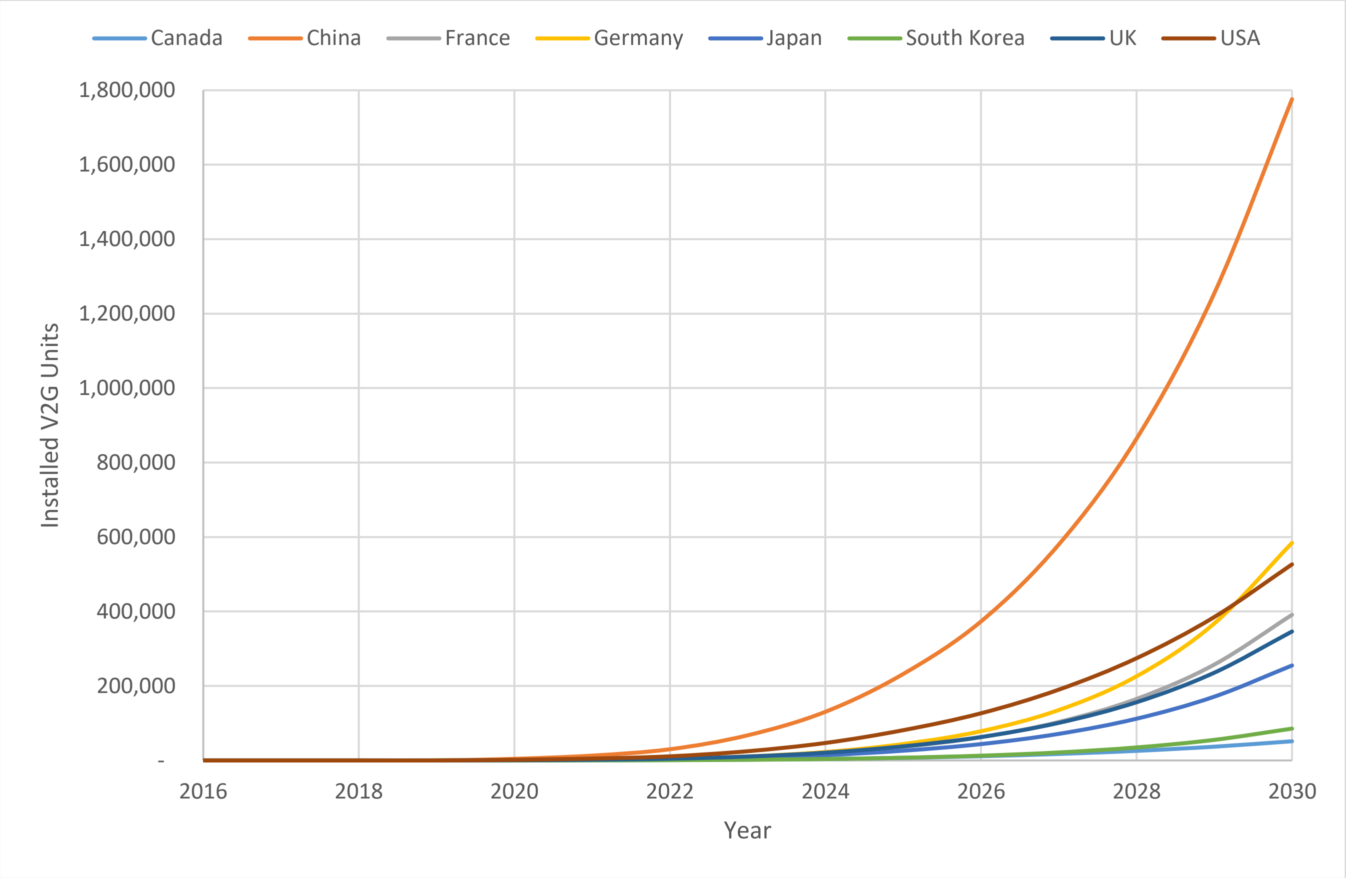

Figure 15: Forecast of the number of V2G units installed in each of the lead markets

From this it can be seen that the V2G market is expected to remain extremely small until the mid-2020s. After this point the volume and rate of uptake increase significantly. This is particularly evident in China and Germany, with Germany overtaking USA for the total number of V2G units installed by 2030. This also demonstrates that the core long term markets for V2G are expected to be China, Western and Central Europe (in particular Germany, France and the United Kingdom). For further detail, see Figure 16.

Market	Canada	China	France	Germany	Japan	S. Korea	UK	USA
V2G Units by 2020	141	4,365	531	539	410	101	624	1,714
V2G Units by 2025	0.01m	0.23m	0.04m	0.04m	0.03m	0.01m	0.04m	0.08m
V2G Units by 2030	0.05m	1.78m	0.39m	0.58m	0.26m	0.09m	0.35m	0.53m

Figure 16: Installed V2G forecast for lead markets

4.4.5 Key Sensitivities in Forward Forecasting V2G Uptake

Through the analysis within this report key sensitivities were identified that could influence the forecast, as follows:

- ***The rate of uptake of EVs*** – A rate of uptake of EVs has a direct influence on EVSE deployment. A greater number of EVs means more scenarios where V2G will be attractive.
- ***The rate of introduction of EVs that are warrantied for V2G*** – the market for V2G is currently limited to Nissan and Mitsubishi EVs (brand differentiator). The expectation is that other EV brands will follow Nissan in introducing warrantied V2G compatible EVs but the pace of V2G compatible EV roll-out will influence the market for V2G.
- ***The relative sales of EVs by type*** – BEVs, having larger battery packs than REEVs and PHEVs, offer more kWh of storage to be utilized for V2G.
- ***The maturity and development of V2G technology*** – the V2G hardware available currently is prototype or first generation commercial product. A pace of technology development, including a broadening of the availability and types of V2G hardware, as well as “cost-down” through mass production, will all strongly influence the overall size of the emerging market for V2G.
- ***The available capacity on the low voltage network*** – the value of V1G and V2G (to the DNOs) lies in enabling managed charging to keep charging demand balanced against available supply. V1G and V2G chargers will be introduced more quickly where political pressure is driving EV uptake and the political process favours smart charging as a means of managing grid constraints as an alternative to network upgrade.
- ***The pace of deregulation of electricity markets*** - the faster the deregulation the greater the potential for new country markets to open up for Demand Side Response and thereby for V2G.
- ***The rate of uptake of solar PV on buildings*** - as V1G and V2G provide a means of optimising income from the combined presence of PV and EV.
- ***Competition between V1G and V2G*** – V1G delivers managed charging benefits but no export revenues. Hardware will be cheaper than V2G so V2G will only compete effectively with V1G in markets where the value from exporting electricity is worthwhile.
- ***Competition between V2G and stationary battery energy storage*** – stationary battery energy storage systems are emerging for use in grid scale energy storage, as well as for homes and buildings. Stationary battery storage is considered more attractive at grid scale because of the guaranteed availability and less complicated business model (fewer actors). At a building or domestic scale stationary battery storage may be installed as either an alternative or a complement to V2G.

Key Points:

Section 4. Market Size and Opportunity

- Business cases and realistic customer returns are currently unclear and require further work to develop a clear view of the actual V2G market potential.
- There are a number of risks and barriers which may limit the potential market for V2G or hinder the uptake of V2G entirely.
- In the short term, the market for V2G is very limited and sizeable growth is not expected until the mid-2020's.
- Based on total vehicle sales, current EV uptake, existing EV infrastructure and availability of DSR ready energy markets, the main long-term markets for V2G are seen to be (in no particular order) Canada, China, France, Germany, Japan, South Korea, the United Kingdom and the United States of America.
- Taking into account predicted EV uptake up to 2030, the largest markets for V2G are seen to be China and Western & Central Europe (Particularly the UK, France & Germany).

5 Conclusions

As a concept, vehicle-to-grid is often perceived as the 'holy grail' for combining EVs and energy systems. V2G offers an opportunity for large-scale electrification of transport whilst helping manage EV impact on the energy networks and earning the end customer money from curtailing charging or exporting electricity in response to system and market needs. V2G is also used to present both environmental and economic value to the customer. Based on the current maturity of the technology, it is unlikely that all these claims can be realised equally. Which of the benefits end up being realisable will ultimately be defined by specific customer propositions and local energy system constraints and market factors.

While the environmental claims pertaining to V2G are generally accurate, the economic claims vary significantly, often reporting income generation opportunities without the associated costs of realising the income or the payback on investment. Based on the current cost of hardware and installation, the economic claims are therefore often misleading. This can be damaging to a technology this early on in its development as unrealistic claims can set expectations, resulting in the product being perceived as having 'failed' if it does not achieve them. Inaccurate quantification of income streams can also result in the technology being developed to meet the requirements of the wrong services. It is therefore essential that both costs and value streams are well understood, allowing realistic business cases to be developed. It is typical of all new and novel technology that costs are initially high and later fall with mass production and it is reasonable to take this into account in business models. However, in the early phases of market introduction there will be uncertainties that need time to be tackled, with resolution required to aid the standardisation of V2G products or services and therefore to support quantification and reduction of production, service and maintenance costs.

The current limited range of V2G products and notable gaps (e.g. CCS V2G) combine with concerns around the impact of V2G operation on battery degradation, to act as inhibitors for early market growth. Finally, when it comes to V2G income generation, the high economic returns projected for the provision of frequency services for TSOs are expected to be transient and these markets could saturate very quickly. The potential V2G capacity by 2030 is in the multiple GW of flexibility, which far exceeds the capacity requirements of the existing TSO services. Where other services, such as the Short Term Operating Reserve (STOR), have seen significant increases in providers and overall supply capacity, historically this has resulted in the market value of the service falling markedly.

However, as energy prices continue to rise and renewable generation sources (and particularly solar PV) lose subsidies, the economic case for V2G can improve significantly. If V2G EVSE unit 'cost down' can be achieved along with falling prices for V1G (smart charging), then the business case for V2G is likely to become much stronger. The presence of large numbers of EVs whose batteries can be harnessed for V2G means that V2G will never go away as a market opportunity.

This report has demonstrated that there is significant opportunity for exporting V2G products and services, especially to Europe, China and North America. Therefore, if UK businesses are going to harness this opportunity then they must be able to overcome more than just economic challenges and they must also look for find solutions for the following barriers:

- Limited availability of compliant V2G EVs and EVSE,
- OEM warranty issues surrounding V2G operation,
- Lack of customer awareness of the benefits and opportunities presented by V2G,
- Distribution Grid Code impacts including potentially high charges, complex and lengthy application processes and limits to on-site generation,
- Sufficient volumes to access high value revenue streams.

With this in mind, the barriers presented above are relatively typical for new technology applications and, while further work is essential in all of these areas, the policy and market drive in support of EVs has reached sufficient prominence in the UK that the relevant bodies required to deliver these changes are already aware of the need to do so. UK distribution network operators (DNOs) have been active partners in recent V2G projects, with the aim of understanding the impact of V2G on their networks and the suitability of their existing processes to manage the implementation of V2G. Therefore, while these barriers are significant, it is expected that the key barrier to uptake will come in the form of identifying the appropriate business cases and customer groups that will make up the future market.

Through the use of technology demonstrators, the UK has been one of the first markets to adopt V2G. This early activity offers UK companies a first-mover advantage which paves the way for UK exports. The findings of this study demonstrate that, while the market for V2G is limited in the short term, sizeable growth is expected from the mid-2020's. Using key metrics of:

- Total size of automotive market
- Current EV uptake
- Existing levels of EVSE
- DSR enabled energy markets

It is possible to hypothesise that the main long-term markets for V2G are (in no particular order) Canada, China, France, Germany, Japan, South Korea, the United Kingdom and the United States of America. Taking into account EV uptake forecasts up to 2030, the largest markets for V2G are seen to be China and Western & Central Europe (Particularly the UK, France & Germany), making up almost 80% of the total market for V2G (based on the 8 countries identified as lead markets for V2G) by 2030.

In conclusion, while there are currently barriers facing the development of the V2G market, the most critical is the need to develop a clear understanding of the economics for V2G and the various potential revenue streams to refine understanding as to the most promising early strategic niche markets for V2G based on different customer use cases. This will enable clear identification and targeting of appropriate customer groups. Doing this will enable UK organisation to develop products and services in line with the needs of the customers, therefore reducing costs and increasing the value to the customer.

5.1 Recommendations

If UK businesses are to lead in this area, they must lead the way in resolving key uncertainties. As a result, the following recommendations have been broken down into the appropriate target audiences (see Table 5).

<table>
<tr><th>Audience</th><th>Recommendations</th></tr>
<tr><td>Policy Makers, System and Network Operators</td><td>Whether via V2G or some other technology, the continuing distribution of generation and shift to ‘prosumers’ inevitably leads to the desire by consumers to manage their energy more effectively. This is even more relevant as transport becomes increasingly electrified. As a result:
Processes, policies and standards should be reviewed for their suitability for supporting this transition.
Costs relating to these processes, in particular distribution network connection, are often prohibiting the uptake of new technologies. Better management and potential subsidisation of these costs should be considered.
Bi-directional technologies such as batteries and V2G are currently categorised as generation. However, they can be used in a number of modes, including as export limiting systems. Therefore, it is not suitable to continue to categorise these as generation and a new category is required to effectively manage the integration of these technologies into the energy system.
The cost of V2G is one of the core barriers, particularly at a domestic level. AC V2G would enable this to be more easily overcome, providing a better customer proposition (for infrastructure) compared to DC V2G. However current distribution connection requirements would make AC V2G difficult to implement. Therefore, it should be considered whether changes are required to existing policies and processes, including the distribution code and associated connection agreements, in order to support the implementation of AC V2G – particularly at a domestic level.
The process for installing V2G is currently unclear. In the past, guidance notes and codes of practice have provided clear sources of guidance for EVSE installations. The same is required for V2G to support the growth of the sector in the UK.</td></tr>
<tr><td>EVSE Manufacturers and Installers</td><td>Currently the hardware and installation processes for V2G are immature. As a result:
Development of new hardware and installation processes should incorporate the relevant distribution grid code application process requirements (particularly G98 & G99 for the UK market).
V2G in its most basic form only requires bi-directional flow of energy. However, access to different revenue streams will include additional hardware and testing requirements. These may also impact the installation requirements. It is therefore important that the business case for V2G is fully understood and that the correct hardware, testing and certification is incorporated so as to allow access to the key value streams.
ISO 15118 and OCPP 2.0 are the key technical standards for V2G hardware, although a number of additional standards and protocols are gaining prominence including OCPI. As the market moves from demonstrators towards commercial roll out, V2G hardware will need to comply with these standards and consistency or interoperability between competing standards will be essential to support longevity of the V2G market.
V2G hardware needs to be compatible with CCS (the European standard for DC EVSE) as well as CHAdeMO connectors. This is particularly important as three of the eight leading markets are European, as well as a high proportion of secondary markets.</td></tr>
</table>

Audience	Recommendations
EV Manufacturers	Without V2G compatible EVs, V2G will never be able to succeed. Therefore, EV manufactures should: • Develop a clear understanding early on of the impact of V2G operation on battery degradation and share this with industry so as to either facilitate or close the V2G market. • Create clear and, if possible, consistent warranty positions in relation to V2G operation. • Further investigate the technical costs and challenges around AC V2G and work with distribution network operators to facilitate development of grid codes to support AC V2G. • As with EVSE, ISO 15118 and OCPP 2.0 are the key technical standards for V2G hardware. V2G compatible EVs will need to comply with these standards, and consistency or interoperability between competing standards will be essential to support longevity of the V2G market.
Operators, Energy Suppliers and Aggregators	It is likely that operators will act as the face of V2G to the customer, whether this is a fleet manager or domestic customer. Therefore, Operators, Energy Supplier and Aggregators should: • Develop targeted and robust business models for V2G which allow customers to adapt operation to meet their own personal values and requirements. • Raise awareness of the value of V2G to the energy system and the customer and provide opportunities for potential customers to witness and experience V2G in operation so as to support them in overcoming any initial concerns and misconceptions relating to V2G. • The key standard relating to V2G for aggregators is likely to be OCPP2.0. Aggregators should implement this protocol into existing control systems and/or investigate methods for connecting and communicating with charge point operator systems to allow pre-aggregation. • A key element for the successful uptake of V2G is the customer interface. Customers have a range of drivers, of which economics is only one. In addition, when it comes to minimum charge levels for vehicles and usage patterns, customers will have different levels of risk which they perceive as acceptable. Therefore, it is essential that customers have the ability to enter and control the operational logic and limits. As the face of V2G to the customer, operators should ensure that the user interface meets the full needs of the customers.
Fleet operators & interested customers	As the customer, it is critical that you fully understand the opportunity V2G could present for you. As a result, customers should: • Utilise existing free tools such as eva^e lite to understand the potential value of V2G for your business (https://evae.cenex.co.uk/) • Work with knowledgeable organisation to develop a clear and independent view of the business case for V2G for a specific application, business or site. • Get involved in trials and demonstrators to build in-house understanding of the impact of V2G.

Table 5: Table of recommendations

5.1.1 Further Recommendations

It is also recommended that further work should be carried out in the following areas:

- **V2G Business Case:** The most critical barrier facing V2G is the lack of clarity, understanding and quantification around the potential value streams and how these stack together. However, these are also dependent on the specific customer use cases. Therefore, it is proposed that these should be further investigated, providing public, clear guidance on the value of V2G for different customer archetypes. In particular, the split of opportunity between domestic and commercial applications should be investigated.
- **Public Knowledge Sharing:** Many of the current V2G projects from the recent Innovate UK competition are investigating methods for tackling the barriers facing V2G. However, historically the sharing of this knowledge has been challenging. It is proposed that more effective methods of communicating and sharing these findings publicly should be explored, including training and web-based tools.
- **Smart Charging (V1G):** While this report focuses on V2G, it is believed that many of the benefits of V2G can, in part at least, be achieved through the application of smart charging. V1G also presents a potentially lower cost alternative to V2G with reduced risk associated with battery degradation. It is therefore likely that both V1G and V2G will continue to play important roles in the EVSE market, each appealing to different customer groups and business models. However, the comparative value of V2G compared to V1G is yet to be quantified. Further analysis and modelling of this value could support product and service developers in identifying the most appropriate customer groups for their products, while also supporting customers in selecting the solution which best meets their needs.

Appendices

Appendix A: EV Charging

EV charging methods can be broken down into two main connector types; AC connectors and DC connectors. The main difference between two connector types is the way in which charge is delivered to the batteries on board the vehicle. Battery storage requires the charge delivered to be DC, which in the case of AC chargers means that an AC-DC converter is required onboard the vehicle to feed the correct current type to the vehicles batteries. Alternatively, DC connectors typically have the conversion taking place in the charging unit itself as the electricity received from the grid is always in AC form. Figure A1:[13] shows the most common connection types for both AC and DC chargers.

Figure A1: Types of Slow, Fast and Rapid Connectors (Zap-Map, 2017)

Table A1 shows the charging speeds of the different AC and DC chargers types. Charging times quoted in the table are based on a 24kWh traction battery being charged from a very low state of charge. Table A1 (overleaf) also provides examples of the types of location where the different charger types are being deployed. Not included in either figure however, are first generation ultra-charger products which are capable of delivering up to 350 kW of DC power. These products use the CCS connector and are being deployed at motorway service areas.

[13] "Charging Speeds and Connectors", Zap Map, 2018

Table A1: EV connection types, charging speeds and suggested site suitability

Charger Type	Charging Time [0-100%]	Charging Mode	Charge Point Connector Type	Vehicle Connector Type	Suitable Locations
Slow or Standard; 2.4kW or 3kW	8-12 hours	2	Standard Three Pin Socket	Five Pin "Yazaki"	Domestic; Workplace (Emergency)
			Standard Three Pin Socket	Seven Pin "Type 2"	Domestic; Workplace (Emergency)
Fast; 3.7kW or 7kW	4-6 hours	3	Seven Pin "Type 2" Socket	Five Pin "Type 1"	Domestic; Workplace; On-street; Public car park
			Tethered Lead	Five Pin "Type 1"	Domestic; Workplace
Fast; 11kW or 22kW	1-2 hours		Seven Pin "Type 2" Socket	Seven Pin "Type 2"	Workplace; On-street; Public Car Park
AC Quick; 43kW	30 minutes [0-80%]	3	Tethered Lead	Seven Pin "Type 2"	Workplace; On-street; Public Car Park
DC Quick; 50kW	20-30 minutes [0-80%]	4	Tethered Lead	Heavy Duty "JEVS G105"	
DC Quick; 50kW	20-30 minutes [0-80%]	ISO 15118	Tethered Lead	Heavy Duty "CCS"	
DC Super Charger; 130kW	30 minutes [0-70%]	Tesla Proprietary	Tethered Lead	Tesla Adapted "Type 2"	Workplace; On-street; Public Car Park

Source: General Procurement Guidance for Electric Vehicle Charge Points, UK Electric Vehicle Supply Equipment Association (UKEVSE, 2015)

Appendix B: AC & DC V2G Systems

V2G can be achieved by the vehicle in one of two configurations. The first being on board, where the EV includes an onboard AC-DC converter and a DC/AC inverter with combined converter-inverter units, referred to as a bi-directional converter, being used (Figure B1). The main disadvantages of this approach are two-fold. Firstly, it increases the capital cost for the EV and secondly, the approach whereby the car controls the export of power isn't compatible with the regulations that apply to electrical supply equipment in key target countries for V2G adoption.

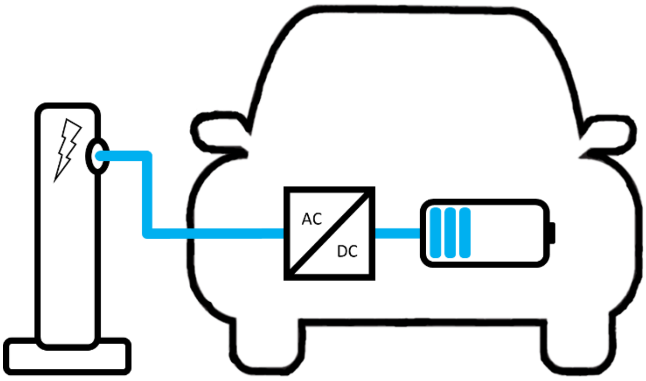

Figure B1 On-board bidirectional charging

The alternative method of utilising bidirectional charging is to place the conversion equipment in the charging unit, as shown in Figure B2. This means that the charger would have to be connected directly up to the vehicle's DC battery connections. This is the configuration that has been adopted by the first movers who have used the Japanese CHAdeMO connector. The CHAdeMO connector is used by Nissan EVs and the Mitsubishi Outlander PHEV, which are two of the best-selling EVs in Europe over the last 5 years.

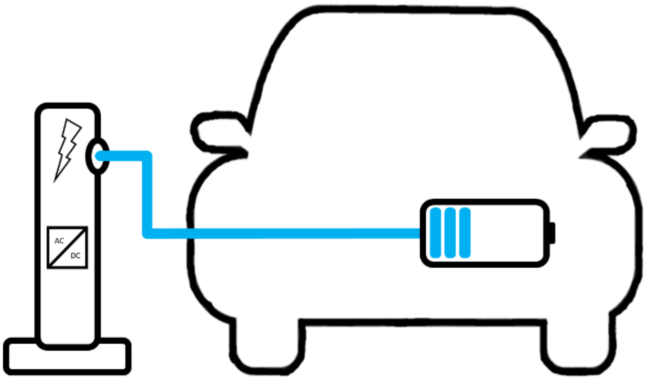

Figure B2: Charger based converter/inverter

By locating the secondary inverter in the charge point rather than in the EV prevents any weight increases and associated efficiency losses for the EV user during vehicle use. However, this does mean that the cost of the bi-directional inverter is transferred to the charging unit, resulting in the V2G unit being intrinsically more expensive than a standard charge point.

Appendix C: Regulatory Standards Applying to EV & V2G

C1: Standards Applying to the Electric Vehicle

ISO 6469-1:2009	Electrically propelled road vehicles -- Safety specifications -- Part 1: On-board rechargeable energy storage system (RESS)
ISO/NP 6469-1 [Under development]	Electrically propelled road vehicles -- Safety specifications -- Part 1: On-board rechargeable energy storage system (RESS)
ISO 6469-2:2018	Electrically propelled road vehicles -- Safety specifications -- Part 2: Vehicle operational safety
ISO 6469-3:2011	Electrically propelled road vehicles -- Safety specifications -- Part 3: Protection of persons against electric shock
ISO/DIS 6469-3 [Under development]	Electrically propelled road vehicles -- Safety specifications -- Part 3: Electrical safety
ISO 6469-4:2015	Electrically propelled road vehicles -- Safety specifications -- Part 4: Post crash electrical safety
ISO/NP TR 8713 [Under development]	Electrically propelled road vehicles -- Vocabulary
ISO/TR 8713:2012	Electrically propelled road vehicles -- Vocabulary
ISO 8714:2002	Electric road vehicles -- Reference energy consumption and range -- Test procedures for passenger cars and light commercial vehicles
ISO 8715:2001	Electric road vehicles -- Road operating characteristics
ISO/TR 11955:2008	Hybrid-electric road vehicles -- Guidelines for charge balance measurement
ISO 12405-1:2011	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 1: High-power applications
ISO 12405-2:2012	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 2: High-energy applications
ISO 12405-3:2014	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 3: Safety performance requirements
ISO/FDIS 12405-4 [Under development]	Electrically propelled road vehicles --Test specification for lithium-ion traction battery packs and systems -- Part 4: Performance testing
ISO/PAS 16898:2012	Electrically propelled road vehicles -- Dimensions and designation of secondary lithium-ion cells
ISO 18300:2016	Electrically propelled vehicles -- Test specifications for lithium-ion battery systems combined with lead acid battery or capacitor
ISO/PAS 19295:2016	Electrically propelled road vehicles -- Specification of voltage sub-classes for voltage class B
ISO/DIS 20762 [Under development]	Electrically propelled road vehicles -- Determination of power for propulsion of hybrid electric vehicle
ISO/CD 21498 [Under development]	Electrically propelled road vehicles -- Electrical tests for voltage class B components
ISO/CD 21782-1 [Under development]	Electrically propelled road vehicles -- Test specification for components for electric propulsion -- Part 1: General
ISO/CD 21782-2 [Under development]	Electrically propelled road vehicles -- Test specification for components for electric propulsion -- Part 2: Testing performance of systems
ISO/CD 21782-3 [Under development]	Electrically propelled road vehicles -- Test specification for components for electric propulsion -- Part 3: Testing performance of motor and inverter
ISO/CD 21782-6 [Under development]	Electrically propelled road vehicles -- Test specification for components for electric propulsion -- Part 6: Testing reliability of motor and inverter
ISO 23274-1:2013	Hybrid-electric road vehicles -- Exhaust emissions and fuel consumption measurements -- Part 1: Non-externally chargeable vehicles
ISO 23274-2:2012	Hybrid-electric road vehicles -- Exhaust emissions and fuel consumption measurements -- Part 2: Externally chargeable vehicles

J2907_201802	Performance Characterization of Electrified Powertrain Motor-Drive Subsystem
J551/5_201711	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, 150 kHz to 30 MHz
J2908_201709	Vehicle Power Test for Electrified Powertrains
J1634_201707	Battery Electric Vehicle Energy Consumption and Range Test Procedure
J3108_201703	xEV Labels to Assist First and Second Responders, and Others
J1797_201608	Recommended Practice for Packaging of Electric Vehicle Battery Modules
J3040_201512	Electric Vehicle (E-Vehicle) Crash Test Lab Safety Guidelines
J2990/2_201501	Hybrid and Electric Vehicle Safety Systems Information Report
J1715_201410	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
J3007_201402	Top Speed Test Procedure for Electric Motorcycles
J1167_201401	Motorcycle Stop Lamp Switch
J108_201312	Brake System Road Test Code – Motorcycles
J2982_201306	Riding Range Test Procedure for On-Highway Electric Motorcycles
J2929_201302	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells
J2990_201211	Hybrid and EV First and Second Responder Recommended Practice
J2825_201211	Measurement of Exhaust Sound Pressure Levels of Stationary On-Highway Motorcycles
J2929_201102	Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells
J1192_201011	Performance of Audible Warning Devices for Motorcycles
J2841_201009	Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data
J1711_201006	Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles
J2344_201003	Guidelines for Electric Vehicle Safety
J2841_200903	Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data
J1715_200802	Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology
J1715_200006	Electric Vehicle Terminology
J2464_199903	Electric Vehicle Battery Abuse Testing
J1711_199903	Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles
J2344_199806	Guidelines for Electric Vehicle Safety
J1766_199602	Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
J1718_199412	Measurement of Hydrogen Gas Emission from Battery-Powered Passenger Cars and Light Trucks During Battery Charging
J227_199212	Electric Vehicle Test Procedure
J1167_197712	Motorcycle Stop Lamp Switch
J47_197505	Maximum Sound Level Potential for Motorcycles
IEC 62576:2009	Electric double-layer capacitors for use in hybrid electric vehicles - Test methods for electrical characteristics
IEC 62660-1:2010	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing
IEC 62660-2:2010	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing

IEC 62660-3:2016	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 3: Safety requirements
IEC TS 62840-1:2016	Electric vehicle battery swap system - Part 1: General and guidance
IEC 62840-2:2016	Electric vehicle battery swap system - Part 2: Safety requirements
ISO/IEC PAS 16898:2012	Electrically propelled road vehicles -- Dimensions and designation of secondary lithium-ion cells
458A	Outline of Investigation for Power Converters/Inverters for Electric Land Vehicles
1973	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications
2231-1	Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General Requirements
2271	Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications
2271	Batteries for Use In Light Electric Vehicle (LEV) Applications
2580	Batteries for Use In Electric Vehicles
2580	STANDARD ON BATTERIES FOR USE IN ELECTRIC VEHICLES
60034-2-1	Standard for Rotating Electrical Machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)

C2: Standards Applying to the Charging System

ISO 17409:2015	Electrically propelled road vehicles -- Connection to an external electric power supply -- Safety requirements
ISO/AWI 17409 [Under development]	Electrically propelled road vehicles -- Conductive power transfer -- Safety requirements
ISO/CD 19363 [Under development]	Electrically propelled road vehicles -- Magnetic field wireless power transfer -- Safety and interoperability requirements
ISO/PAS 19363:2017	Electrically propelled road vehicles -- Magnetic field wireless power transfer -- Safety and interoperability requirements
IEC 62752:2016	In-Cable Control and Protection Device for mode 2 charging of electric road vehicles (IC-CPD)
J2954_201711	Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology
J1772_201710	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
J2954_201605	Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology
J1772_201602	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
J2894/2_201503	Power Quality Test Procedures for Plug-In Electric Vehicle Chargers
J1773_201406	SAE Electric Vehicle Inductively Coupled Charging
J2293/1_201402	Energy Transfer System for Electric Vehicles - Part 1: Functional Requirements and System Architectures
J2953/2_201401	Test Procedures for the Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE
J2847/1_201311	Communication for Smart Charging of Plug-in Electric Vehicles using Smart Energy Profile 2.0

J2953/1_201310	Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)
J2836/6_201305	Use Cases for Wireless Charging Communication for Plug-in Electric Vehicles
J1772_201210	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
J1772_201202	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
J1772_201001	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
J1773_200905	SAE Electric Vehicle Inductively Coupled Charging
J1718_200811	Measurement of Hydrogen Gas Emission from Battery-Powered Passenger Cars and Light Trucks During Battery Charging
J2293/1_200807	Energy Transfer System for Electric Vehicles--Part 1: Functional Requirements and System Architectures
J1772_200111	SAE Electric Vehicle Conductive Charge Coupler
J1773_199911	SAE Electric Vehicle Inductively Coupled Charging
J1772_199610	SAE Electric Vehicle Conductive Charge Coupler
IEC 60335-2-114:2018 PRV	Household and similar electrical appliances - Safety - Part 2-114: Particular requirements for self-balancing personal transport devices for use with batteries containing alkaline or other non-acid electrolytes
IEC 60364-7-722:2015	Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles
IEC 61851-1:2017	Electric vehicle conductive charging system - Part 1: General requirements
IEC 61851-21-1:2017	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply
IEC 61851-23:2014	Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station
IEC 61851-24:2014	Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging
IEC 61980-1:2015	Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements
IEC 62196-1:2014	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements
IEC 62196-2:2016	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories
IEC 62196-3:2014	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers
IEC 62827-3:2016	Wireless power transfer - Management - Part 3: Multiple source control management
IEC 62893-1:2017	Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV - Part 1: General requirements
IEC 62893-2:2017	Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV - Part 2: Test methods

IEC 62893-3:2017	Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV - Part 3: Cables for AC charging according to modes 1, 2 and 3 of IEC 61851-1 of rated voltages up to and including 450/750 V
ISO 17409:2015	Electrically propelled road vehicles -- Connection to an external electric power supply -- Safety requirements
2202	Standard for Electric Vehicle (EV) Charging System Equipment
2231-2	Standard for Safety for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems
2251	Standard for Plugs, Receptacles, and Couplers for Electric Vehicles
2594	Standard for Electric Vehicle Supply Equipment
2734	Outline for Connectors and Service Plugs for Use with On-Board Electrical Vehicle (EV) Charging Systems
2747	Outline of Investigation for Electric Vehicle Power Supplies
2871	Outline of Investigation for Electric Vehicle (EV) Service and Production Chargers

C3: Standards Applying to V2G

ISO 15118-1:2013	Road vehicles -- Vehicle to grid communication interface -- Part 1: General information and use-case definition
ISO/DIS 15118-1 [Under development]	Road vehicles -- Vehicle to grid communication interface -- Part 1: General information and use-case definition
ISO 15118-2:2014	Road vehicles -- Vehicle-to-Grid Communication Interface -- Part 2: Network and application protocol requirements
ISO/CD 15118-2 [Under development]	Road vehicles -- Vehicle to grid communication interface -- Part 2: Network and application protocol requirements
ISO 15118-3:2015	Road vehicles -- Vehicle to grid communication interface -- Part 3: Physical and data link layer requirements
ISO 15118-4 [Under development]	Road vehicles -- Vehicle to grid communication interface -- Part 4: Network and application protocol conformance test
ISO 15118-5 [Under development]	Road vehicles -- Vehicle to grid communication interface -- Part 5: Physical layer and data link layer conformance test
ISO 15118-8 [Under development]	Road vehicles -- Vehicle to grid communication interface -- Part 8: Physical layer and data link layer requirements for wireless communication
J2836/3_201701	Use Cases for Plug-In Vehicle Communication as a Distributed Energy Resource
J2847/3_201312	Communication for Plug-in Vehicles as a Distributed Energy Resource
J2836/3_201301	Use Cases for Plug-in Vehicle Communication as a Distributed Energy Resource
J2847/1_201105	Communication between Plug-in Vehicles and the Utility Grid
J2847/1_201006	Communication between Plug-in Vehicles and the Utility Grid
J2836/1_201004	Use Cases for Communication Between Plug-in Vehicles and the Utility Grid
ISO 15118-1:2013	Road vehicles -- Vehicle to grid communication interface -- Part 1: General information and use-case definition
ISO 15118-2:2014	Road vehicles -- Vehicle-to-Grid Communication Interface -- Part 2: Network and application protocol requirements

ISO 15118-3:2015	Road vehicles -- Vehicle to grid communication interface -- Part 3: Physical and data link layer requirements
9741	Outline of Investigation for Bidirectional Electric Vehicle (EV) Charging System Equipment

C4: Standards Applying to EV Communications

J2931/7_201802	security for Plug-In Electric Vehicle Communications
J2931/7_201710	Security for Plug-In Electric Vehicle Communications
J2836/4_201706	Use Cases for Diagnostic Communication for Plug-in Electric Vehicles
J2931/6_201508	Signalling Communication for Wirelessly Charged Electric Vehicles
J2836/5_201505	Use Cases for Customer Communication for Plug-in Electric Vehicles
J2931/4_201410	Broadband PLC Communication for Plug-in Electric Vehicles
J2293/2_201402	Energy Transfer System for Electric Vehicles - Part 2: Communication Requirements and Network Architecture
J2293/2_200807	Energy Transfer System for Electric Vehicles - Part 2: Communication Requirements and Network Architecture
J2293/2_199706	Energy Transfer System for Electric Vehicles - Part 2: Communication Requirements and Network Architecture

Appendix D: Summary of European V2G Projects

European V2G Projects Repository					
	Projects	About the project	Location	Scale	Timescale
1	NewMotion V2G project	High-end smart technology optimizes use of renewable energy. NewMotion, one of Europe's biggest providers of smart charging solutions for electric driving - announces the implementation of a bi-directional loading pilot, also known as 'Vehicle to Grid' (V2G). With V2G-technology, peak demand on the electricity grid can be better balanced, by allowing electric vehicles to not just take power from the grid, but also return it to the network. NewMotion joins forces with Mitsubishi, and grid operator TenneT using V2G chargers from Enel and grid services and technology from Nuvve. The pilot features the popular Mitsubishi Outlander PHEV.	Amsterdam	10 EV drivers	Announced 2017 October
2	Amsterdam Vehicle2Grid	Vehicle-to-grid (V2G) technology enables electric cars to be used as (temporary) batteries, for example to power households. The supply of solar power is growing rapidly. That is a great news as our daily energy demand is increasing too. We could however benefit even more from this growing supply if we would be able to store the generated electricity in times of overproduction. Electric Vehicles offer great storage potential. Additionally, by combining multiple batteries, accumulated capacity can become large enough to effectively prevent unbalance in the electricity grid. In the demo environment in Amsterdam, several bi- directional chargers, needed to charge and discharge the batteries, will be installed to be tested by Alliander.	Lochem	2 households in Lochem, Gelderland	until end of 2017
3	SEEV4-City	The main aim of SEEV4-City is to develop the concept 'Vehicle4Energy* services' into sustainable (commercially and socially viable) business models to integrate EVs and renewable energy in a Sustainable Urban Mobility and Energy Plan (SUMEP).	Amsterdam Arena, Amsterdam city, Loughborough, Oslo, Kortrijk, Leicester	6 operational pilots, 6 countries (50+ EVs); In the Netherlands - Amsterdam (52 Charging poles, smart charging	2016-2019

European V2G Projects Repository					
	Projects	About the project	Location	Scale	Timescale
		. * - (The implementation of Smart Charging (where the timing of EV charging is controlled to benefit network operation), V2G (where EVs are used as energy stores, enabling a better balance to be achieved between energy supply and demand) and the other 'ancillary' services they can provide are collectively known as 'Vehicle4Energy Services' or V4ES).		enabled, no V2G yet); Amsterdam Arena (2 V2G units is being installed)	
4	SMART Solar Charging, Utrecht, NL	To develop a sustainable energy system: storing local solar energy in (shared) EV batteries and supplying to the grid at a later moment.	Lombok, Houten, Utrecht Science park: De Uithof, Utrecht Central Station Area and Driebergen-Zeist	V2G charging stations in 5 different regions in Utrecht and 70 additional community shared EVs	Ongoing
5	Solar-powered bidirectional EV Charging Station	A first of its kind integrated EV charger that is directly powered by PV panels has been developed. The charger enables direct DC charging of EV from PV without converting to AC. The charger is bidirectional, so energy from the EV battery can also be fed to the grid, via vehicle to grid (V2G). The charger can realize four power flows: EV -> PV, EV -> Grid, Grid -> EV, PV -> Grid. The 10kW modules are modularly built and can be paralleled for fast charging. The charger is based on silicon carbide and quasi-resonant technology which results in high efficiency and high power density. The integrated EV-PV solution has a lower component count, increased reliability, smaller size and lower cost than using separate EV charger and PV inverter. The charger is compatible with the CHAdeMO and CCS/Combo charging standard and is designed for implementing smart charging.	TU Delft, PRE	Demo with 1 V2G charging station with solar roof (parking area) and Nissan Leaf EV was done in Delft University of Technology in June 2017; 10kW solar powered bidirectional EV charger commercially available via PRE	Completed
6	Grid motion	The aim of the project is to evaluate possible savings achieved by real-	France	2-year demo pilot project	2017 -2019

European V2G Projects Repository					
	Projects	About the project	Location	Scale	Timescale
		life electric vehicle (EV) users through the implementation of smart charging and discharging strategies (V2G) for EVs.		50 smart charging cars 15 (B2B) V2G enabled cars	
7	Parker	The objective of this project is to validate electric vehicles as part of an operational vehicle fleet that can support the power grid by becoming a vertically integrated resource, providing seamless support (i.e. V2G) to the power grid both locally and system-wide.	Denmark	7 V2G enabled Electric cars 6 Charging stations + data access to 20+ V2G vehicles in the field	2016-2018
8	Integrated Transport and Smart Energy Solutions (ITSES)	Projects sets out to find new technical solutions and business models for integrating Vehicle- to-Grid (V2G) with two urban systems: energy and transport.	Rail stations of Old Oak Common and Park Royal, London, United Kingdom	2 pilot sites - rail stations in London for V2G application	2015-2017 (August)
9	Intelligent Transport, Heating and Control Agent (ITHECA), UK	ITHECA aims to collaborate transport, frequency response services, energy storage and district heat solutions to establish the potential of Vehicle-to-Grid (V2G) to maximise a combined heat and power (CHP) plant.	European Bioenergy Research Institute (EBRI) at Aston University, United Kingdom	1 Pilot, 1 Nissan Leaf EV, 1 V2G unit	2015 -2017 (Currently active)
10	SHAR-Q	Storage capacity over virtual neighbourhood of energy ecosystem: The SHAR-Q project aims to establish an interoperability network that connects the capacities of the neighbourhood and wide regional RES+EES ecosystems into a collaboration framework, that mitigates the requirement on the overall EES capacities thanks to the shared capacities among the participating actors. Note: Adaptive charging of e-vehicles (EVS) and V2G services.	Greece	4 in Meltemi Greece	2016-2019
11	Denmark V2G	World's first fully commercial vehicle-to-grid hub in Denmark	Copenhagen, Denmark	10 V2G units, 10 e-NV 200s	2016-present
12	Genoa pilot	The first corporate electric car sharing pilot project with V2G (Vehicle to Grid) charging infrastructure in Italy, a system that could allow electric cars to discharge power to the network and contribute to its stability.	Italian Institute of Technology, Italy	IIT headquarters in Genoa 2 Nissan LEAF EVs; 2 V2G units	2017 (May) (still in operation)
13	Suvilahti pilot (as part of	The vehicle-to-grid (V2G) charging point complements an existing solar power plant and a stationary energy	Helsinki, Finland.	1 public charging V2G unit	2017-present

European V2G Projects Repository

	Projects	About the project	Location	Scale	Timescale
	mySMARTLife project)	storage, and enables using EVs as energy storages and to stabilize the electricity grid. A public bidirectional electric vehicle charging point is being installed in Helsinki, Finland.			
14	City-Zen Smart City	9 DC V2G chargers will be installed starting December 2017, both in the public domain and at corporate locations. The charging sessions will be operated using varied algorithms, in order to test the value of V2G for grid congestion, power quality, imbalance and energy trading and others.	Amsterdam, the Netherlands	3 corporate and 6 public charging units	2014-2019
16	Net-Form	The project seeks to assess the feasibility of turning a car park into a MW -scale battery to provide power on demand to the electricity grid. The project will develop secure, dynamic data management platform that collects, aggregates and optimises energy collected by large populations of grid-connected electric vehicle batteries at a single location.	HS2 station, Birmingham, UK	Not known	1-year project
17	UK Vehicle-2-Grid (V2G)	First ever vehicle-to-grid (V2G) trial in the UK	Multiple locations in UK (mostly in London)	100 V2G units; several Nissan LEAF and e-NV200 electric vans	2016-present
18	GrowSmarter	GrowSmarter brings together cities and industry to integrate and demonstrate '12 smart city solutions' in energy, infrastructure and transport, to provide other cities with valuable insights on how they work in practice and opportunities for replication. The idea is to create a ready market for these smart solutions to support growth and the transition to a smart, sustainable Europe.	Barcelona, Spain	6 V2G units; aggregated power of 60kW	January 2015 - 31 December 2019.
19	Hajime Project	Trialling of 50 V2G units at the Nissan HQ in France	Nissan HQ, France	50 V2G units	
20	Nissan Energy Solar	Domestic focused project aiming to create an all in one home energy solution combining solar and V2G.	UK	1,080 V2G units	2017-2021
21	Blockchain Enabled Vehicle to	Innovate UK funded feasibility study investigating the opportunity for blockchain enabled V2G with a	UK	Feasibility only	2018-2019

European V2G Projects Repository

	Projects	About the project	Location	Scale	Timescale
	Local Grid (BEV2LG)	focus on vehicle hubs such as car clubs.			
22	HAVEN - Home as a Virtual Energy Network	Innovate UK funded feasibility study. HAVEN will examine the value that V2G and V2H (vehicle-to-home) enabled EVs can provide to consumers within the context of other energy storage systems (e.g. LI-Ion batteries attached to solar PV arrays; thermal storage via hot water tanks) in the home.	UK	Feasibility only	2018-2019
23	V2GB – Vehicle to Grid Britain	Innovate UK funded feasibility study investigating the short, medium and long-term opportunities and economic value for V2G.	UK	Feasibility only	2018-2019
24	The Smart Home Enabled Domestic Charge-point Solution	Innovate UK funded feasibility study looking at the value of developing a home battery connected V2G charging point.	UK	Feasibility only	2018-2019
25	Western Isles Consolidated V2G and RE Study	Innovate UK funded feasibility study. This study will assess the potential for islands to decarbonise their power and transport markets.	UK	Feasibility only	2018-2019
26	Integrated Energy Systems for Commercial Vehicles	Innovate UK funded feasibility study focusing on the business case for V2G with HGVs, Light Vans, Buses and Coaches.	UK	Feasibility only	2018-2019
27	BADGE - Battery Degradation for Grid-connected Electric vehicles	Innovate UK funded feasibility study investigating the impact of V2G operation on battery degradation.	UK	Feasibility only	2018-2019
28	Project ENVINCE	This Innovate UK funded feasibility study seeks to determine the opportunity and impact of V2G opportunities in different usage scenarios for these new technologies and highlight the new market opportunities they can accelerate through the additional V2G funding stream.	UK	Feasibility only	2018-2019
29	Universal modular Vehicle-to-Grid bi-directional on-board charger	Innovate UK Collaborative R&D. This project aims to develop a novel, universal, modular, on board charging system implementing bi-directional charging at a reasonable cost.	UK	R&D Only	2018-2020

European V2G Projects Repository					
	Projects	About the project	Location	Scale	Timescale
	with SiC technologies				
30	Vehicle-to-Grid Intelligent control (VIGIL)	Innovate UK Collaborative R&D. This project will provide a robust communications and control platform (VIGIL: Vehicle-to-Grid Intelligent controL) that supports different V2G/V2B charge-points while ensuring distribution network voltage and/or thermal limits are not breached.	UK	R&D Only	2018-2020
31	V2Street	Innovate UK Collaborative R&D. V2Street explores routes to support the business case for public EVSE by developing a novel consumer value proposition that uses flexibility in V2G-enabled charging to provide demand side response (DSR) services to the energy system	UK	R&D Only	2018-2020
32	GenDrive: Gamification for consumer engagement in V2G services	Innovate UK Collaborative R&D. Research and development into the use of gamification (competitions, games and virtual rewards) and other methods to engage ULEV owners with V2G technology and incentivise behaviours such as the discharging/charging of their EV batteries to support the energy system.	UK	R&D Only	2018-2020
33	PowerLoop: Domestic V2G Demonstrator Project	Innovate UK Demonstrator project focused on developing a unique domestic proposition for V2G.	UK	135 V2G Units	Started 2018
34	e4Future	Innovate UK Demonstrator project. A large-scale V2G demonstrator, deployed in groups and controlled by an innovative aggregator platform stacking multiple services that supports a more efficient electricity system and decreases ownership costs to vehicle users.	UK	1000 V2G Units	Started 2018
35	SMARTHUBS Demonstrator	Innovate UK Demonstrator project. Targeting early adopters in order to practically assess realistic revenue streams and the optimum power rating and technical requirements for a V2G unit.	UK	150 V2G Units	Started 2018

	European V2G Projects Repository				
	Projects	**About the project**	**Location**	**Scale**	**Timescale**
36	V2GO (Vehicle-To-Grid Oxford)	This Innovate UK Demonstrator project aims to develop, trial and evaluate potential business models, on- and off-vehicle hardware and V2G products and services relating to UK fleet operators.	UK	100 V2G Units	2018-2020
37	Bus2Grid	This Innovate UK Demonstrator project is a kind large scale, multi-megawatt, demonstration of Vehicle to Grid (V2G) technology in electric bus depots in London.	UK	30 V2G Units	Started 2018
38	Sciurus	Innovate UK Demonstrator project. A domestic focused demonstration project aimed at proving the commercial business case for domestic V2G.	UK	1000 V2G Units	2018-2020
39	E-FLEX - Real-world Energy Flexibility through Electric Vehicle Energy Trading	Innovate UK Demonstrator project. E-FLEX aims to create a scale demonstration of a functioning V2G market. It will combine a number of fleets with variable duty cycles, a mixed hardware ecology, and diverse energy users (grid plus facilities) with a market design that captures as much value as possible as private benefit.	UK	200 V2G Units	2018-2021
40	EV-elocity	Innovate UK Demonstrator project. The project aims to develop and test the commercial business case for V2G in a large-scale demonstrator.	UK	100 V2G Units	2018-2021

Appendix E: EV Ownership Incentives

Country	Incentive Description
AUSTRIA	Electric vehicles are exempt from the fuel consumption tax and from the monthly vehicle tax. Since January 2016 a deduction of VAT is also applicable for zero-CO2 emission cars (eg electric and hydrogen-powered cars). The Austrian automobile club ÖAMTC publishes the incentives granted by local authorities on its website (www.oeamtc.at/elektrofahrzeuge).
BELGIUM	Electric vehicles pay the lowest rate of tax under the annual circulation tax in all three regions. In the Brussels-Capital Region, financial incentives apply to companies which purchase electric, hybrid or fuel-cell vehicles. In the Flemish Region, electric and plug-in hybrid (emitting no more than 50g CO2/km) vehicles are exempt from registration tax. Moreover, incentives for electric and hydrogen-powered cars (Zero Emission Bonus) were introduced as of January 2016. Finally, the Flemish Government grants an Ecology Premium to companies that invest in environmentally friendly and/or energy-efficient technologies (www.ecologiepremie.be). The deductibility rate from corporate income of expenses related to the use of company cars is 120% for zero-emissions vehicles and 100% for vehicles emitting between 1 and 60g CO2/km. Above 60g CO2/km, the deductibility rate decreases from 90% to 50% progressively.
BULGARIA	Electric vehicles are exempt from the annual circulation tax.
CROATIA	None
CYPRUS	Vehicles emitting less than 120g CO2/km are exempt from registration tax.
CZECH REPUBLIC	Electric, hybrid and other alternative fuel vehicles are exempt from the road tax (this tax applies to cars used for business purposes only).
DENMARK	From 2016, battery electric vehicles are included in the same tax scheme of petrol and diesel cars. The resulting increase in the registration tax will be gradually phased in, at 20% of the full tax in 2016, 40% in 2017, 65% in 2018, 90% in 2019 and 100% in 2020. Hydrogen and fuel cell-powered vehicles are exempt from registration tax until the end of 2018.
ESTONIA	None
FINLAND	Pure electric vehicles always pay the minimum rate of the CO2 based registration tax.
FRANCE	Regions have the option to provide an exemption from the registration tax (either total or 50%) for alternative fuel vehicles(ie electric, hybrids, CNG, LPG, and E85). Under a bonus-malus system, a premium is granted for the purchase of a new electric vehicle (from 1 January 2017, hybrid cars combining an electric energy storage system and an internal combustion engine are no longer eligible for the bonus): For a vehicle (car or LCV) emitting between 21 and 60g CO2/km, the bonus amounts to €1,000. For a vehicle (car or LCV) emitting 20g CO2/km or less, the bonus amounts to €6,300. An incentive scheme grants €10,000 to electric vehicle buyers when they scrap an old diesel-powered vehicle. In 2017, the scheme was extended to LCVs. Electric vehicles are exempt from the company car tax, while hybrids emitting less than 110g CO2/km are exempt during the first two years after registration.

GERMANY	Electric vehicles are exempt from the annual circulation tax for a period of ten years from the date of their first registration. From July 2016, the government granted an environmental bonus of €4,000 for pure electric and fuel-cell vehicles and €3,000 for plug-in hybrid and range-extended electric vehicles.
GREECE	Electric and hybrid vehicles are exempt from registration tax, luxury tax and luxury living tax. Electric and hybrid cars (with an engine capacity of up to 1,549cc) are also exempt from circulation tax.
HUNGARY	Electric vehicles are exempt from registration tax, annual circulation tax and company car tax.
IRELAND	Until December 2021, electric vehicles benefit from VRT (vehicle registration tax) relief up to a maximum of €5,000. For plug-in hybrids, the maximum relief is €2,500 (until December 2018). For conventional hybrids and other flexible fuel vehicles, the maximum relief is €1,500 (until December 2018). In addition, electric and plug-in hybrid vehicles receive a grant of up to €5,000 on purchase (until December 2021 for EVs and 2018 for PHEVs). Electric vehicles also pay the minimum rate of the road tax (€120).
ITALY	Electric vehicles are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of the first registration. After this five-year period, they benefit from a 75% reduction of the tax rate applied to the equivalent petrol vehicles.
LATVIA	Electric vehicles pay the lowest amount for the company car tax (€10).
LITHUANIA	None
LUXEMBOURG	Electric and fuel cell vehicles benefit from a tax allowance on the registration fees of €5,000. Electric vehicles also pay the minimum rate of the annual circulation tax.
MALTA	None
NETHERLANDS	Electric vehicles are exempt from the registration tax BPM. As of 1 January 2017, a special BPM rate is applied for all new plug-in hybrid vehicles sold. Passenger cars with zero CO2 emissions are exempt from motor vehicle tax up to 2020. A discounted income tax (4%) is levied on fuel-efficient cars (i.e. with zero CO2 emissions).
POLAND	None
PORTUGAL	Pure electric cars are exempt from the registration tax (*Imposto Sobre Veículos* or *ISV*). Plug-in hybrid cars with all-electric mode up to 25km only pay 25% of the registration tax.
ROMANIA	Electric vehicles are exempt from the annual circulation tax (ownership tax).
SLOVAKIA	Pure electric vehicles pay the lowest amount for the registration tax (€33) and are exempt from the annual circulation tax. Hybrids, vehicles powered by compressed natural gas (CNG) and vehicles used at least 60 times in the hybrid mode within the tax period benefit from a 50% reduction on the annual circulation tax.
SLOVENIA	Financial incentives, ranging from €3,000 to €7,500 depending on vehicle category, are granted for: The purchase of a new electric vehicle with zero CO2 emissions or the conversion of an internal combustion engine vehicle (ICEV) to electric propulsion; The purchase of a new plug-in hybrid vehicle with CO2 emissions lower than 50g CO2/km.

SPAIN	Main city councils (e.g. Madrid, Barcelona, Zaragoza, Valencia etc) are reducing the annual circulation tax (ownership tax) for electric and fuel-efficient vehicles by 75%. Reductions are applied on company car taxation for pure electric and plug-in hybrid vehicles (30%), and for hybrids, LPG and CNG vehicles (20%).
SWEDEN	A premium (*Supermiljöbilspremie*) is granted for the purchase of a new electric or hybrid electric vehicle: - SEK20,000 for cars with CO2 emissions between 1 and 50g/km (plug-in hybrids) - SEK40,000 for cars with zero CO2 emissions (electric cars) A five-year exemption from annual circulation tax applies for green cars (electric cars and plug-in hybrids, with electrical energy consumption per 100km which not exceed 37kWh). 40% reduction is applied on company car taxation for electric cars and plug-in hybrids.
UNITED KINGDOM	Electric vehicles (with CO2 emissions up to 100g/km) are exempt from the annual circulation tax, while other alternative fuel cars receive a £10 discount on the paid rates. Pure electric cars are exempt from the company car tax, while all cars with CO2 emissions lower than 50g/km pay 5% for the tax year 2015/2016. For more details on these changes see: www.gov.uk/government/publications/finance-bill-2017- draft-legislation-overview-documents/overview-of-legislation-in-draft

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