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V2X ROADMAP



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Shaping Energy for a Sustainable Future

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Task 28 “Home Grids and V2X Technologies”

Operating Agent:

Task Participants:

Key Findings

Vehicle-to-everything (V2X) technology has been shown through multiple research and demonstration project to provide benefits to end-users, grids or buildings. V2X also has potential to reduce the total cost of ownership of electric mobility and thus accelerate the uptake of low carbon transport. However, the business case is still unclear and the technology has yet to gain widespread public awareness or enter into mass markets. To reach this point stakeholders from across the transport and energy sectors, as well as government, must coordinate activity to maximize the potential benefits of V2X and overcome barriers that currently slow development.

Eight key goals have been identified to move the technology towards commercial readiness:

1. **Standardization and harmonization**
   Develop global standard for V2X technology and harmonize these with existing power, transport and communication systems. Application of global standards is a route to reduce costs, mitigate negative impacts and encourage participation.
2. **Consensus on battery degradation**
   Cross sectors consensus on impact of V2X on battery degradation and development of set of standards or best practices. This should enable electric vehicle manufacturers to include V2X capability without compromising existing and future battery warranties.
3. **Include V2X in grid codes**
   Reform grid codes to enable V2X to easily connect to the distribution network and inject power into the grid. This will require certification of equipment for different V2X applications, including vehicle-to-building (V2B) back-up power for buildings.
4. **Develop new tariffs and contracts for flexibility**
   Redesign energy tariffs to better reflect the real-time value of energy and capacity in the power system. This will enable buildings with smart flexible resources, such as V2X, to optimize charging and discharging.
5. **Redesign Transport System Operator (TSO) services markets**
   Remove regulatory barriers which prohibit V2X from participating fully in Transport System services, including barriers which prevent resource aggregation and the entry of new player in the market.
6. **Develop Distribution System Operator (DSO) system services market**
   Develop new Distribution System services, such as congestion management or voltage regulation, in order to monetize the externalities of flexibility at the distribution network level.
7. **Improve public awareness of V2X technology**
   Develop higher level of public and political awareness and understanding of V2X technology and its applications.
8. **Develop customer centered business models**
   Improve understanding of V2X value proposition to consumers and develop customer focused business models which distribute benefits and risk.

By following the actions outlined in the roadmap to achieve these goals, V2X technology may be capable of entering commercial markets within 5 years. This will likely take the form of successful use cases of V2X, focused at specific user groups, vehicle types and providing specific sets of services. However, outside factors, such as electric vehicles and renewable energy penetration, along with the competitiveness of alternative flexible technologies, will also influence the size and shape of the future V2X market.

Acronyms

BEMS	**B**uilding **E**nergy **M**anagement **S**ystem
BRP	**B**alancing **R**esponsible **P**arty
DER	**D**istributed **E**nergy **R**esource
DOD	**D**epth **Of** **D**ischarge
DSO	**D**istribution **S**ystem **O**perator
EMS	**E**nergy **M**anagement **S**ystem
EV	**E**lectric **V**ehicle (**P**lug-in **E**lectric **V**ehicle and **P**lug-in **H**ybrid **E**lectric **V**ehicle)
EVSE	**E**lectric **V**ehicle **S**upply **E**quipment
LOM	**L**oss **Of** **M**ains
LoLP	**L**oss **of** **L**oad **P**robability
MaaS	**M**obility **as a** **S**ervice
OCPP	**O**pen **C**harge **P**oint **P**rotocol
OEM	**O**riginal **E**quipment **M**anufacturer
PEV	**P**lug-in **E**lectric **V**ehicle
PHEV	**P**lug-in **H**ybrid **E**lectric **V**ehicle
SOC	**S**tate **of** **C**harge
TCO	**T**otal **C**ost of **O**wnership
TLS	**T**ransport **L**ayer **S**ecurity
TSO	**T**ransmission **S**ystem **O**perator
V2G	**V**ehicle to **G**rid
V2H	**V**ehicle to **H**ome
V2B	**V**ehicle to **B**uilding
V2L	**V**ehicle to **L**oad
V2V	**V**ehicle to **V**ehicle
V2X	**V**ehicle to **E**verything
VoLL	**V**alue of **L**ost **L**oad

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Introduction

Why V2X

Driven by concern over global warming, energy security and health implication of air pollution, governments, organizations and citizens around the world are choosing plug-in electric (PEV) and plug-in hybrid electric vehicles (PHEV) over petrol and diesel models. Global sales of electric vehicles (EV)[1] grew 66% percent between the first half of 2017 and 2018 (EV Volumes, 2018; Figure 1), and forecasts predict that the number of electric light-duty vehicles on the road will reach 125 million by 2030. Growth is centered on Europe, China and the United States, with Norway leading 2017 car sales in terms of percentage (39%) and Chine in terms of volumes (580,000) (International Energy Agency, 2018).

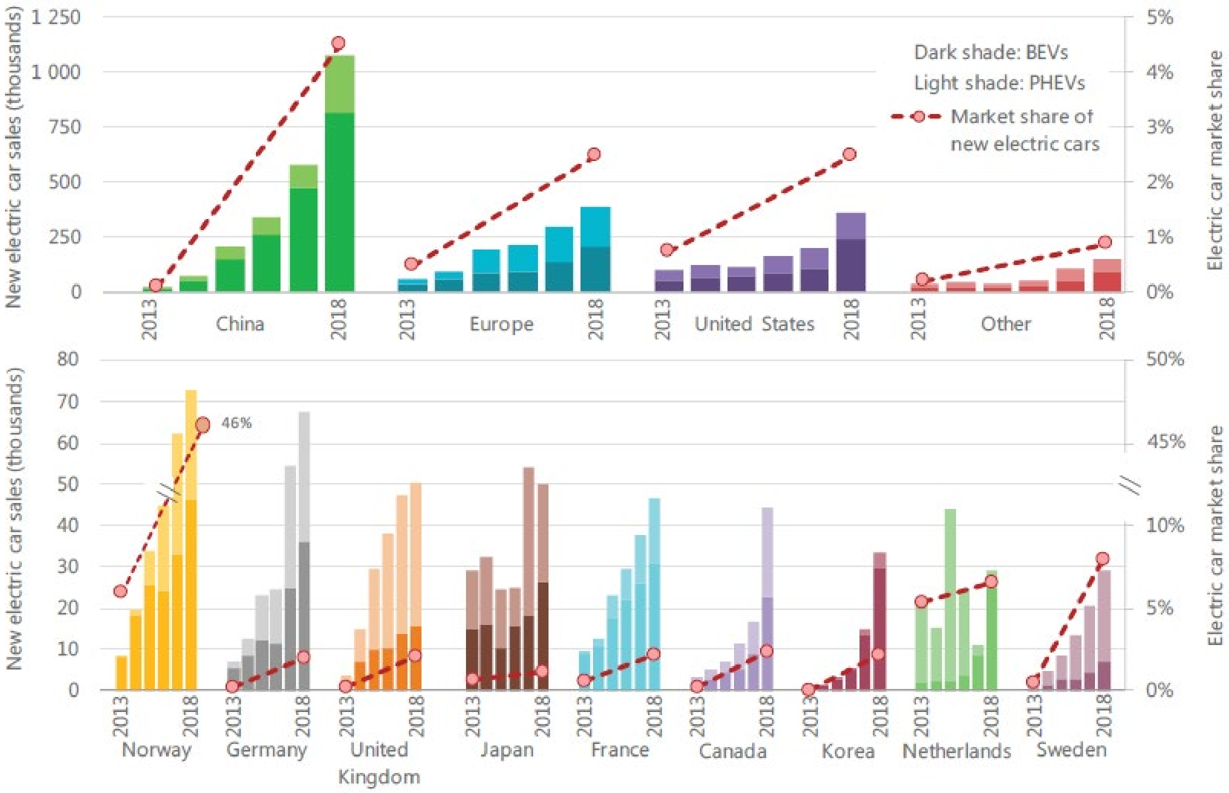

Figure 1 - Global electric car sales and market share (International Energy Agency, 2019)

This change in the transport system brings with it both challenges and opportunities for the power system. A primary concern is that vehicle charging could significantly increase peak electric load and large investments will be required in new generation and grid capacity to meet demand. However, by shifting vehicle charging to off-peak periods through "smart charging" technologies (Figure 2), it is expected that such adverse consequences can be mitigated. In the UK, National Grid predicts that by 2040 smart charging could limit the increase in peak demand caused by EVs to 8GW, equivalent to a 10% contribution towards total capacity growth (National Grid, 2018).

[1] Electric Vehicle (EV) refers to both PEVs and PHEVs

In addition to mitigating negative effects, EVs may also bring benefits to the power system. By dynamically controlling vehicle charging and enabling EV batteries to feed electricity back into the grid - a technology known as vehicle-to-grid (V2G) – EVs could one day provide flexibility and capacity at the system, distribution and building level. It is anticipated that the need for such flexibility in the power system will rise in the future, as penetration levels of variable renewable energy sources such as wind and solar increase. EVs could therefore help shape the future load curve to match renewable energy supply and provide frequency regulation services to improve grid security and stability.

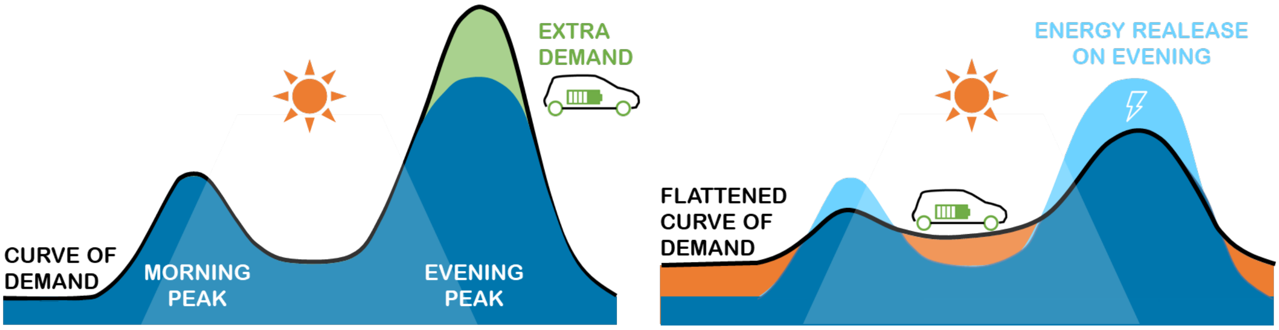

Figure 2 - Load curve without (left) and with V2G (right).

As well as supporting the electricity networks, the power stored in EV batteries may be used to fulfill a range of other applications, such as supplying power to buildings, standalone loads and other EVs. The emergence of these various applications has led to usage of an umbrella term vehicle-to-everything (V2X), which encompasses V2G and several other application (see Section 0).

Interest in the V2X concept has been growing in recent years, with over 1000 academic publications on the topic since 2010 and more than 50 demonstration projects globally (Lauinger et al., 2017; Everoze and EVConsult, 2018). A great deal of progress has been made to improve the understanding of how V2G technology can in implemented, how value may be generated and how negative impacts can be mitigated. However, V2X remains an emerging technology and the business case has yet to be proven at commercial scale.

About the Roadmap

Purpose

The aim of this roadmap is to describe the goals and actions that need to be taken to support and accelerate the development of V2X technologies. The roadmap can be used by policy-makers and industrial partners in the promotion of V2X technology as well as by different players on the EV market within their market research and business modeling.

Scope

The roadmap aims to cover a broad range of issues, which have been categorized into three “Tracks”: Technology developments, Markets and regulation, and Social acceptance. This covers the most pressing technical and policy-related activities necessary to move V2G technology towards commercial usage. The recommendations are near-term, which means they are achievable within the next 5 years.

The recommendations made in the roadmap are relevant to most countries and the EV industry in general. However, this global perspective also means that certain national and regional level issues may not be covered.

The roadmap also focuses on V2X technology involving the bidirectional power flows to and from light-duty PEV and PHEV passenger vehicles that typically use lithium-ion batteries.

Objectives

Objectives for the roadmap comprise:

- Update stakeholders on the current state of V2X technology.
- Identify barriers which are slowing or preventing development and propose realistic and achievable near-term solutions.
- Facilitate investment decisions by bring clarity and reducing risk.
- Identify the most profitable markets and business models for V2X.
- Suggest ways to achieve greater levels of public understanding and engagement.
- Help those involved in research to identify knowledge gaps and prioritize funding support.
- Promote knowledge sharing and dissemination between different stakeholder groups.

International Energy Agency

The IEA acts as energy policy advisor for the governments of its 29 member countries and beyond, to promote reliable, affordable, and clean energy for the world's consumers. The core agency objectives include improving energy efficiency, protecting the climate, enabling collaboration on energy technologies, and sharing its accumulated energy policy experience with the rest of the world. The IEA's Technology Collaboration Programme for co-operation on Hybrid and Electric Vehicle Technologies (HEV TCP) was created in 1993 to collaborate on research, development and deployment of EV technologies. Work is carried out through a variety of different "Tasks" that are focused on specific topics. Please refer to http://www.ieahev.org/ for a complete list of these tasks. This V2X roadmap is an output from the HEV TCP Task 28: "Home Grids and V2X Technologies".

Task 28: "Home Grids and V2X Technologies"

Task 28 explored the technologies and accompanying issues associated with the use of electric storage from EVs for uses other than powering the vehicles. It aimed to address the technical and economic knowledge gaps including regulatory issues preventing V2X technology to fully deploy.

The Task comprises twelve member countries (Belgium, Canada, Denmark, France, Germany, Ireland, Netherlands, South Korea, Spain, Switzerland, United Kingdom and United States) and three private companies (Endesa/Enel, Nissan and Vedecom). Work has been carried out by means of bi-annual international expert Workshops that provide the opportunity to bring together the key actors in the EV industry, including research, industry players and energy policymakers in order to discuss the requirements for the development and the use of V2X technology.

Overview of V2X technologies

Vehicle-to-everything (V2X) is defined in this roadmap as the bidirectional electricity transfer between the onboard battery of an EV and the system it is connected to. By enabling vehicles to control their charging behavior and supply power, V2X technology aims to offer services to homes, buildings, electricity grids and other electrical system, whilst simultaneously minimizing battery degradation and inconvenience to EV users. In this section of the roadmap, an overview of V2X technology, its potential applications and routes to generate value is provided.

Smart charging

An early distinction to be made is that between V2X and "smart charging", also known as "controlled charging" and sometimes going by the acronym V1G. Whilst both smart charging and V2X are able to remotely and intelligently control the rate at which an EV battery is charged, only V2X technology enables an onboard EV battery to discharge energy back to the system. In other words, whilst a V2X system can behave as both flexible generator and flexible load, smart charging can only can behave as a flexible load.

Smart charging can be seen as a first approach to market integration by allowing the EV to respond to variable energy prices and other control signals. Indeed, smart charging is becoming widely available in many commercial markets. The V2X equipment on the other hand, which unlike smart charging is still at a research and development phase, can be seen as the second step where the EV increases its potential as a resource to the grid. The focus of the roadmap is on V2X.

V2X technology

V2X requires additional electrical equipment compared with standard or smart charging, such as an bidirectional inverter to convert the DC power output from the on-board battery to AC for both charging and discharging the EV battery. This conversion equipment is normally integrated into EVSE[2] (Electric Vehicle Supply Equipment), as seen in Figure 3, although some manufactures are considering integrating the bidirectional equipment within the vehicle (Astorg, 2019). Control units are also required for efficient, reliable and safe battery charging and discharging, along with upstream communication protocols to manage these interactions with the electrical systems where the vehicle is connected.

If a V2X system is connected to the main distribution grid a number of additional technical requirements must be met. For example, the EVSE must also have appropriate Loss of Mains (LOM) protection equipment to ensure the vehicle does not feed power into the grid during a fault or when maintenance work may be underway. Also, two-way metering capability is also necessary to measure electricity exchanges with the grid for settlement (Rautiainen et al., 2011). All such requirements must comply with grid codes stipulated by local or national network operators.

[2] EVSE is synonymous with the term "charging point"

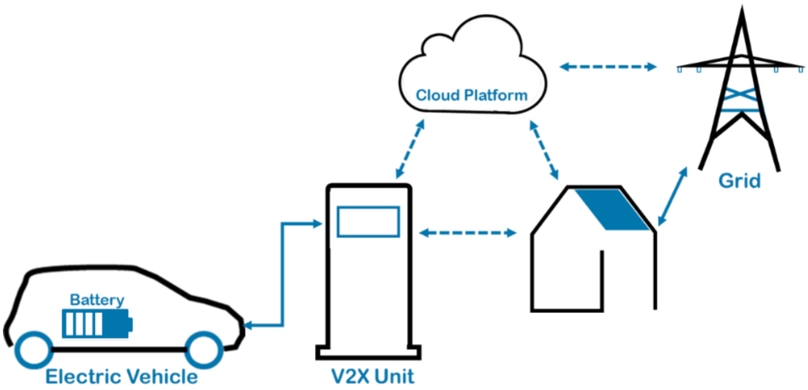

Figure 3 - V2G diagram.

V2X applications

V2X technology can be used for a number of different applications (Figure 4). Probably the most important is **vehicle-to-grid (V2G[3])**, where the EV is connected the distribution network and provides services to different actors in the power system. V2G services include congestion management services to the Distribution System Operator (DSO), balancing services to the Transmission System Operator (TSO) and energy trading with Balancing Responsible Parties (BRPs). In order to deliver a sufficiently large and reliable response to the grid, V2G services require the aggregation of multiple EVSE, leading to the new "aggregator" role to emerge in the power system.

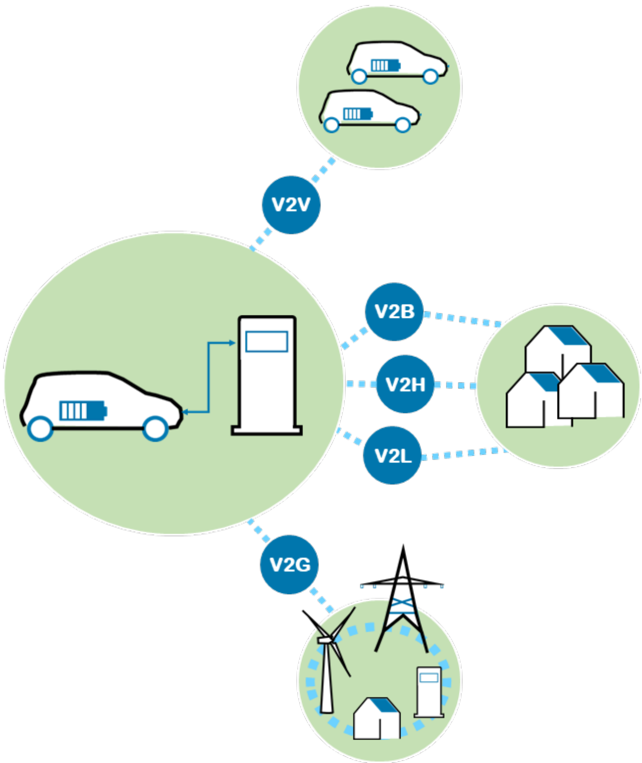

Figure 4 – V2X applications.

[3] V2G is synonymous with Vehicle-Grid Integration (VGI), often used in the U.S.A.

The other major application is **vehicle-to-home (V2H)** or **vehicle-to-building (V2B)**. These applications are similar to V2G in terms of electrical connection, but instead of offering services to grid operators or participating directly in energy markets via an aggregator, services are instead provided to the home or building user where the vehicle is connected. V2H/V2B can generate value through behind-the-meter optimization to reduce energy costs to building users and maximize self-supply from on-site generation[4]. Additionally, V2B/V2H may provide a back-up power supply in post contingency conditions, enabling a building or home to be powered from the vehicle's battery when grid electricity is temporarily unavailable.

The final applications are **vehicle-to-load (V2L)** and **vehicle-to-vehicle (V2V)**, characterized by power flows to islanded system that are not normally connected to the distribution network. These loads may include campsite and construction site in the case of V2L and other EVs which do not have access to a charging point in the case of V2V.

V2X value proposition

In this section, the key routes for V2X applications to generate value and challenges in quantifying and releasing some of this value are summarized.

System Services to the TSO (V2G)

To date, probably the most widespread and commercially proven service is the use of V2G aggregation to provide system services to the TSO. These services - which include frequency regulation, reserve and capacity markets - are designed to improve power quality, provide greater system stability and meet minimum capacity margin requirements (Figure 5). Different system services have diverse characteristics in terms of response time, ramp rate, direction, utilization and duration. The system services best suited to V2G are those characterized by fast response times, symmetrical response patterns, minimal energy through-put, short durations and few activations (Cenex, 2018). Also, since the TSO sets a minimum power and reliability threshold for system service contracts, an aggregator is required to coordinate the response of multiple EVs (and potentially other distributed resources) in order to meet these requirements.

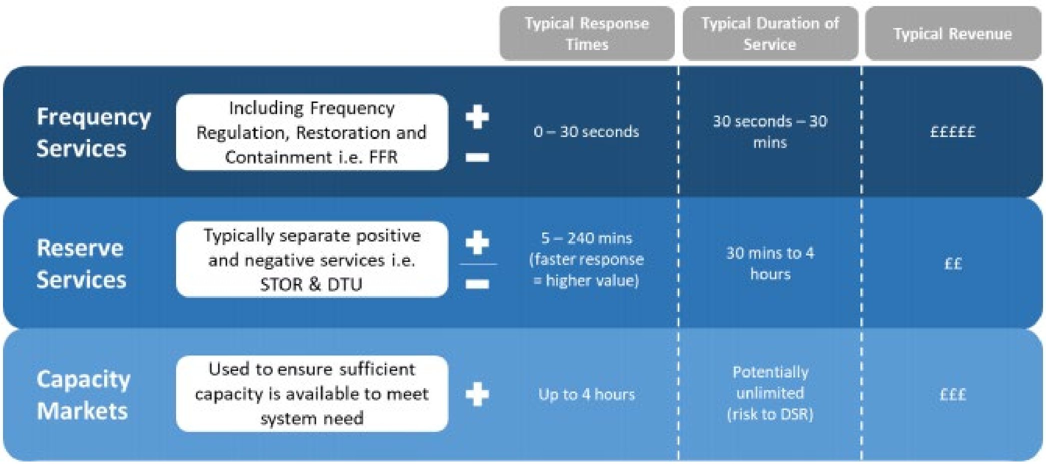

Figure 5 - Summary of TSO system service markets in Great Britain (Cenex, 2018)

[4] Note that this kind of optimization is sometimes categorized as V2G in other literature

Additional value may also be realized by enabling V2G to participate in multiple markets through the day, as shown in Figure 6.

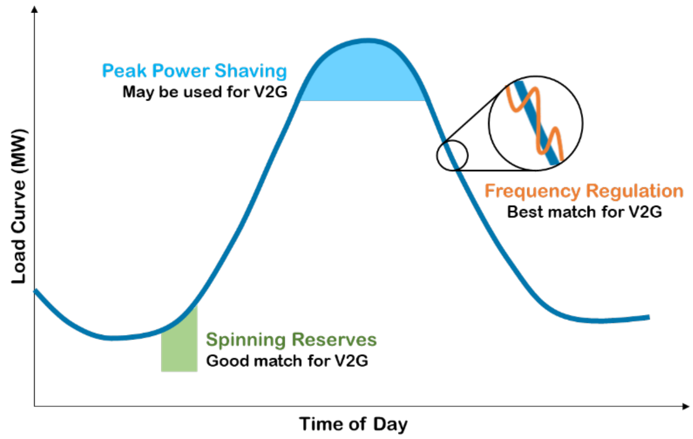

Figure 6 - Participation of V2G in different TSO services.

System Services to the DSO (V2G)

V2G could in the future provide a range of pre and post contingency services to DSOs, including congestion management and voltage regulation. Like TSO system services, an aggregator is required to coordinate the behavior of multiple V2G units in order to produce sufficiently large and reliable response. The value of providing these services is likely to be highly dependent on location and such markets for distribution system services are still in their infancy. It is therefore challenging to quantify and generalize the value that a V2G unit can expect to generate through provision of such services.

Wholesale Market Arbitrage (V2G)

Flexibility from V2G could also be aggregated and traded in energy wholesale markets or through bilateral contracts with BRPs. Currently, there is limited interest in this area for V2G since the value of these markets is not very high compared with system services and imbalances are difficult to account for.

Behind-the-Meter Optimization (V2B[5])

If a home or building is subject to certain price signals for electricity imports and exports, value can be gained by optimally scheduling EV charging and discharging. Three types of charging regime can facilitate this kind behavior:

1. Time of Use (ToU) tariffs
   A consumer is subject to electricity prices, measured in $/kWh, that vary as a function of time and may comprise both electricity import and export prices. Possible ToU tariffs include peak and off-peak tariffs, dynamic pricing, real-time pricing and critical peak pricing. Value may be generated by scheduling V2X charging when electricity prices are low and discarding when prices are high. ToU price signals could reflect fluctuations in electricity wholesale market prices, distribution and transmission use of system charges or incentivize load reduction during periods of high system stress.

[5] Behind-the-meter optimization also applies to V2H

2. Capacity Charges
   A customer is subject to fixed daily charge for network access based on their maximum permitted import or export capacity, measured in terms of $/kW/day. V2X may be used for "peak shaving" in order to reduce capacity requirements of the building and therefore generate value through diminished daily capacity charges.
3. Self-consumption
   If a building has integrated on-site generation and is subject to asymmetric import and export prices, then value may be generated by maximizing self-consumption and thus reducing electricity imports and exports. Typically, V2X would generate value by optimally scheduling charging during periods when there is on-site generation and discharging when demand is high.

Unlike DSO and TSO system services provision, based on centralized control by an aggregator, control of behind-the-meter V2B is more likely to be fully distributed, with each V2B unit optimizing its charging behavior independently based on national or regional price signals and the needs of the EV user (Bach Andersen et al., 2012).

Currently many domestic properties are not exposed to time varying electricity prices and therefore have limited opportunity to generate value through behind-the-meter V2B. However, the global role out of smart metering is likely to enable such tariffs in the near future. Commercial buildings are more likely to buy electricity through a ToU tariff, although these tariffs are generally yet to fully reflect the value of flexibility and capacity.

Back-up Power Supply (V2H[6])

The value of a back-up power supply will vary significantly between different building types and user requirements. It will also depend on how prone a region is to power system outages. One way to estimate the value of a back-up power supply is to use metrics developed by regulators to quantify the cost of power loss to consumers. In the UK, a Value of Lost Load (VoLL) metric is used and can vary between £6,957/MWh and £44,149/MWh depending on time of day, season and user type (London Economics, 2013). Figures such as these, combined with Loss of Load Probability (LoLP) data, could be used to approximate the value of back-up power supply to customers. However, since EVs are obviously not connected at the building at all times, their value as a back-up power source must be discounted and would not be appropriate in certain situations when an Uninterruptible Power Supply is required.

V2L and V2V

The value proposition of V2L and V2V applications will depend on the utility these technologies provide to users. Since there are many possible manifestations of V2L and mass markets do not yet exist, it is not easy to quantify the value. V2V may be used to provide emergency road recovery services if a battery becomes exhausted mid-journey. In this example, the value of that service is likely to be similar to that of existing road recovery services, but the size of this market is not likely to be large.

[6] Back-up power supply may also be used for commercial buildings (V2B)

Current status of V2X

Nowadays scientific research and studies such as multiple international pilot projects have proven the economic and environmental advantages that V2X technology can provide to, not only end-users, but to a wide community within the electric power system, EV car industry and infrastructure stakeholders. Nevertheless, V2X applications are still in a research and development stage with some obstacles preventing the roll-out of this technology and the business case is yet to be proven in a purely commercial context. In these sections, a review of the current business case of V2X is presented, identifying barriers to development and looking at some case studies of pilot projects.

Business case

So far, there is not a real mass market for bidirectional chargers. The cost of EVSE with V2X capability is still high, around €10-6000 per unit, and only a few models of EV are available which support V2X (Cenex, 2018). OEMs (Original Equipment Manufacturer) are still reluctance to implement V2X capability into EVs since they believe there is not sufficient demand for V2X functionality from end users to justify additional manufacturing costs. This lack of demand for V2X capability by end users results from the lack of opportunities for them to benefit from V2X services. The challenge is that this V2X service market, which could potentially release value to EV owners, cannot develop until there is a sufficient penetration of V2X capable hardware in the market. This situation leads to a chicken and egg problem for V2X (Figure 7).

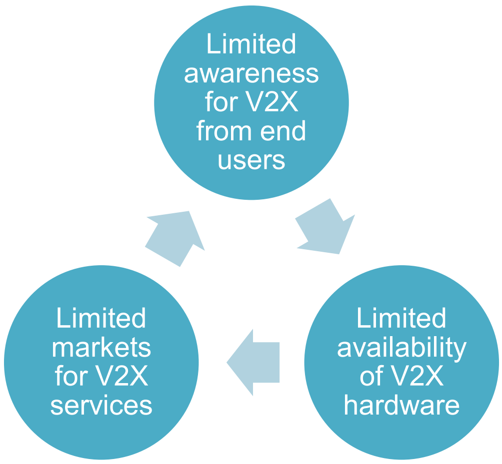

Figure 7 - Vicious cycle for V2X development

Subsidies could help break this cycle, encourage the uptake of this technology and bring down cost, but proper cost-benefit analyses including externalities would be required in advance.

There are some positive signs on the horizon. Demonstration projects in Denmark and the U.S. have generated significant incomes from aggregation of EV fleets to participate in TSO frequency response and behind-the-meter services (Søren, Lindegaard, 2015). In the U.S. case, annual income per EV has been estimated at $1,800 for grid services and $600 for peak shifting, enabling EVs to compete with equivalent Internal Combustion Engine (ICE) vehicles in terms of Total Cost of Ownership (TCO).

However, risk of saturation for TSO frequency response markets is a prevalent concern. In *Cenex, 2018*, the authors note that the entire Great Britain TSO system service market represents less that 2GW of flexibility, which could be provided by just 200,000 EVs. A significant oversupply of flexible resources to the market would likely reduce the value of these services and may jeopardize the business case. The cost of other flexible technologies that compete in flexibility and capacity markets should also be monitored carefully, such as centralized battery storage and demand side response.

There are many opportunities for cost reduction too. Through economies of scale, standardization and commoditization, V2X manufacturing cost should drop significantly (Tugrul, 2016). Additionally, the cost of grid connection and tax for bidirectional charging points should also reduce once storage at the distribution level becomes established and regulations aligned. Currently distributed storage units often suffer from a double charging problem – levies as both a generator and a consumer (Everoze and EVConsult, 2018).

Further, studies have shown that the payback periods for V2G can be significantly reduced when incorporated with on-site renewable generation, such as solar PV. Encouraging synergies such as this, among V2X bidirectional chargers, EV fast chargers, local DERs and local energy storage systems can improve the business models and therefore empower the market uptake for V2X.

Ultimately, it is likely that a handful of business models for V2X will emerge, based on particular commercial arrangements between actors, EV user types and services. Currently the first approach likely to reach commercial readiness is aggregation of commercial EV fleets in order to provide TSO frequency response services and behind-the-meter optimization.

Barriers

Seven barriers have been identified that currently slow the development of V2X technology:

1. Lack of hardware capable of V2X
   Currently there is a limited number of EVs in the market capable of providing of bidirectional power flow between vehicle and charging point. There is also limited availability of V2X ready EVSE. This is likely due to concerns by OEMs over the impacts of V2X on battery aging, along with a lack of demand from vehicle users for V2X capability.
2. Lack of aggregation capability
   The communication and control infrastructure required for V2X aggregation is still at an early stage of development and there are few commercial aggregators in the market.
3. Grid code lacks provision for V2X
   Grid codes in many countries do not recognize EVs or EVSE as a distributed energy storage resources capable of injecting power into the network. The grid interconnection and certification process is therefore slow, expensive or often prohibited.
4. Building not exposed to price signal
   Many buildings, especially domestic properties, are not exposed to ToU tariffs or capacity charges which enable them to optimally schedule V2X charging and discharging.
5. TSO market unsuitable for V2X
   Access to TSO system service markets is either prohibited or market design prevents full participation by V2X.

6. DSO market not developed
   DSO system services are in their infancy and currently there are few ways of realizing the value of flexibility and capacity at the distribution network level.
7. Low levels of customer awareness
   Currently there is low levels of customer awareness of V2X technology and the value proposition to end users is poorly understood.

Many of these barriers are addressed either directly or indirectly in Section 0 of the roadmap on goals and actions.

It is also important to note that different barriers affect different V2X applications and value propositions. To understand this relationship, eight “use cases” and their associated barriers are shown in Figure 8. Three of these use cases are for uni-directional smart charging, whilst the remaining five are for different V2X solutions, based on the value propositions introduced in Section 0. It can be seen that some barriers affect all use cases, others are specific to V2X technology, whilst others are specific to the service being provided. This means that certain use cases may be achieved more easily by having to overcome fewer barriers. However, it is also widely recognized that V2X will likely need to provide multiple services in order to generate sufficient value for stakeholders. It is therefore likely that most, if not all, of the barriers identified will need to be overcome in order for V2X technology to succeed in a commercial setting.

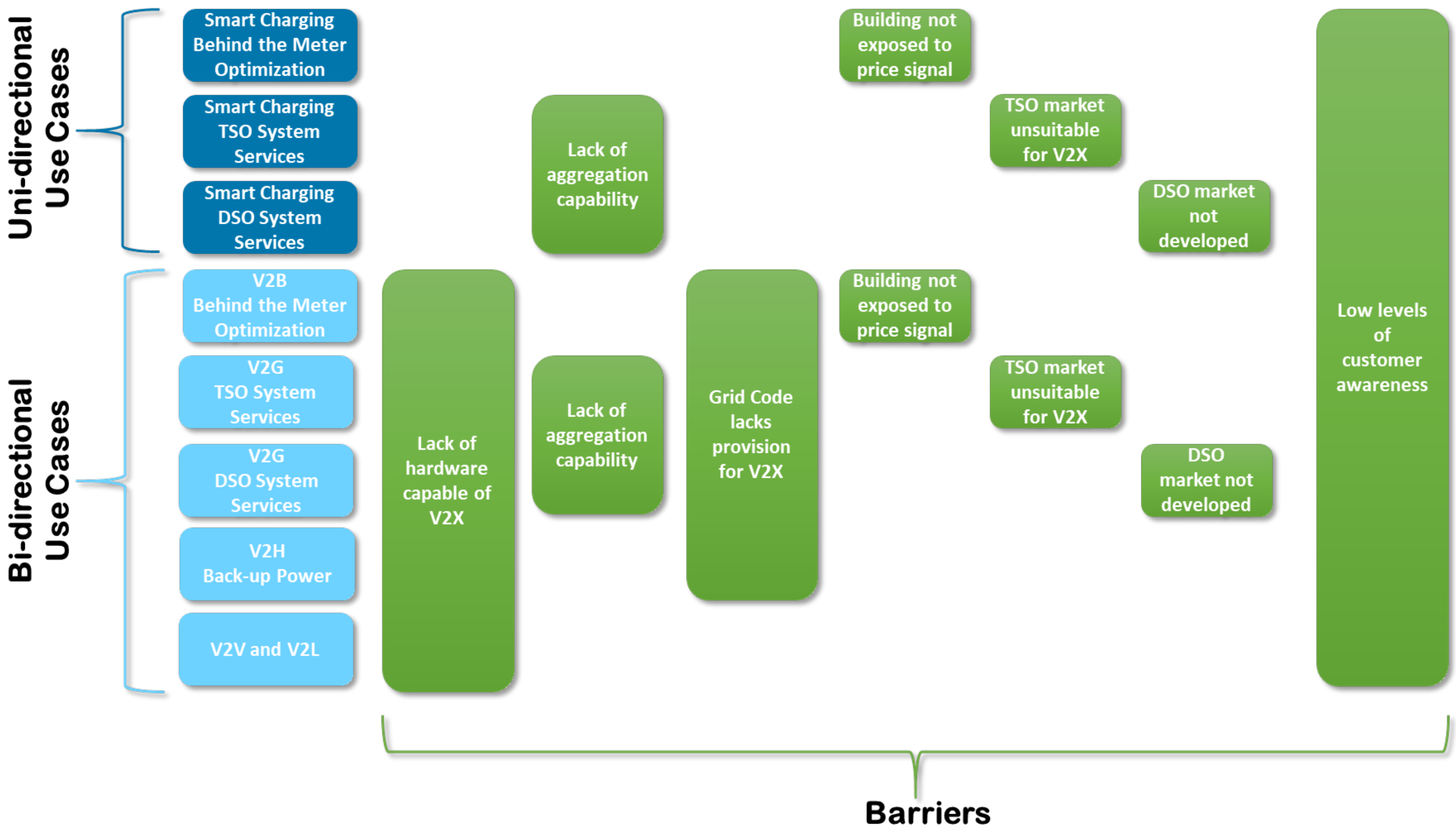

Figure 8 - Use Cases and Barriers

Case studies

There are over 70 complete and ongoing V2X pilot projects worldwide, with the EU, the USA and Japan accounting for over 90% of projects. An analysis of global projects was commissioned by Innovate UK and UK Power Networks in 2018, documenting most of these examples and key trends (Everoze and EVConsult, 2018). Most projects have been focused on technology development, typically involving less than 10 V2X charging units. However, in the last few years a handful of larger scale pilot projects have be carried out, comprising up to a 100 EV and providing real services to actors in the power system. The latest generation of pilot projects are much more focused on testing scalable business cases for V2X in preparation for entry into commercial markets.

To illustrate the size and geographic spread of V2X projects, Figure 9 below shows the 36 largest V2X pilot projects (measured in terms of number of bidirectional charge points) carried out over the last five years from 2012-2017. They range in scale from 100 to 2 charging points, with a median of 6. This excludes a Japanese V2H programme, which has over 4000 bidirectional charging systems in operations and is covered as a case study later in this section. For a full list of global pilot projects, please see the Appendix.

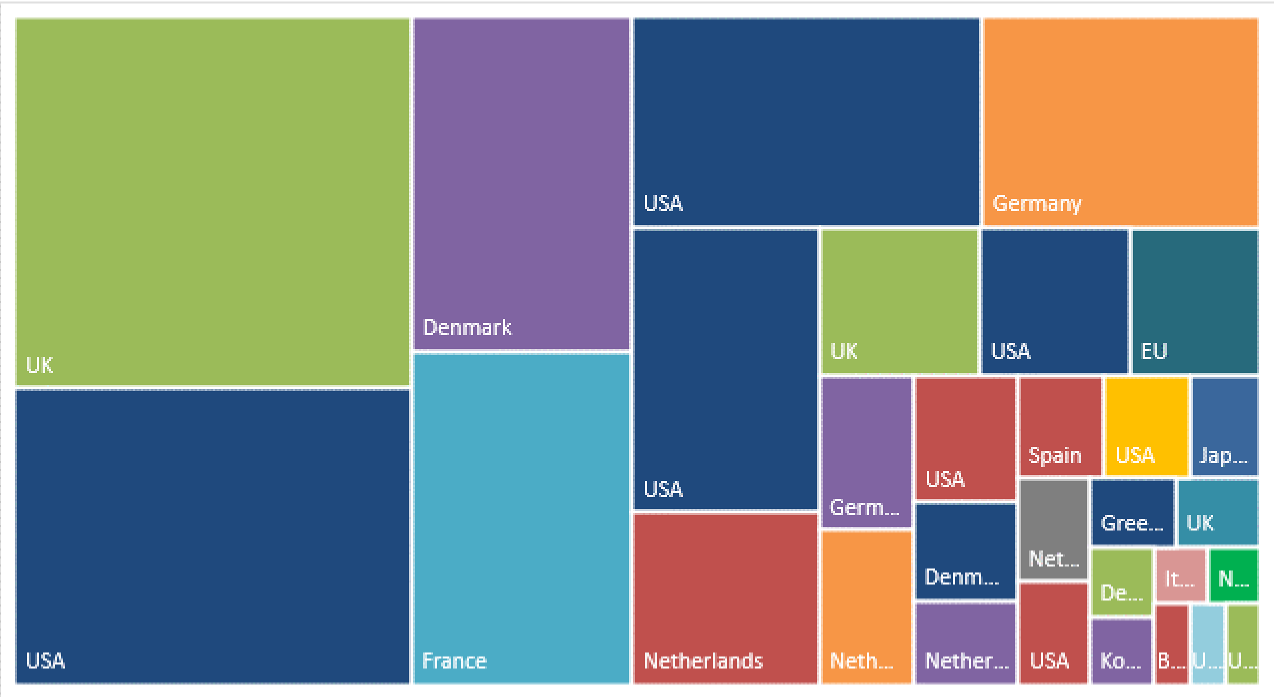

Figure 9 - Size and geographic spread of V2X projects

Below five demonstration projects are described, coving a range of scales, application and countries. Each case will be briefly described in terms of the technical setup and business potential, a reflection on whether the case seems replicable to other regions or users followed by an evaluation regarding the scalability of the case. Finally, a conclusion sums up each case.

V2G frequency response in commercial fleet, Denmark

The Danish TSO is tasked with ensuring a sufficient supply of frequency containment reserves as part of system operation. While some of the traditional providers of such services, in terms of thermal plans, are being replaced by renewables, it becomes prudent to support new providers of such services. One possibility is to have aggregators become part of the market using aggregated fleets of V2G-enabled EVs.

This is currently being done at the company “Frederiksberg Forsyning” in part of greater Copenhagen, where a fleet of vehicles, used for service and maintenance assignments, provide frequency regulation on market terms. This work has been developed through the PARKER Project and its predecessor Nikola.

At Frederiksberg, the company NUVVE is aggregating the vehicles, the utility SEAS is acting as balance service provider to the market, the vehicles used are Nissan eNV200 electric vans and Enel have developed the DC charging infrastructure used by the project. CHAdeMO allows for the use of series-produced, un-modified, vehicles supporting V2G.

By controlling the vehicles bidirectional active power set-point, according to the system frequency, NUVVE and SEAS acts in the market as to receive a capacity payment.

Figure 10 - Nissan eNV200 vans parked at Frederiksberg Forsyning, Source: Nissan

Replicability/scalability

The solution can be replicated to other regions where there is a similar need, and economic compensation, for frequency containment reserves. An example can be UK where a high penetration of wind power can drive the need for balancing services. For Denmark, the scalability is limited by the size of the markets for ancillary services. When a breakthrough of EVs in Denmark becomes reality, the market could quickly become saturated.

Conclusions

The Frederiksberg case represents a good case for the use of V2G as part of frequency containment reserves with a viable business case.

The ability to replicate this case to other regions depend on the local demand for frequency regulation and the regulatory support for aggregators in the ancillary service market.

V2L emergency power supply, Japan

For vehicles using the CHAdeMO connector it is possible to access the vehicles battery as a power source when and where access to the power grid is not possible. This has been the case in connection with the 2011 Tsunami disaster in Japan where large parts of the grid went offline. V2L can provide valuable electric power services, not otherwise available. These include access to information and instruction broadcasting in connection with an emergency, electric heating and preparation of food needed by the local population and floodlights and signs used for evacuations.

The business case for this application is to provide V2X technology as an emergency power supply as a kind of insurance which allows people to proactively prepare for future emergencies.

Replicability/scalability

The business case can be applicable in other areas of the world which are challenged by recurring power failures where access to electric power services becomes vital. The possibility of using the EVs as emergency backup may appeal both to private owners as well as companies and government institutions.

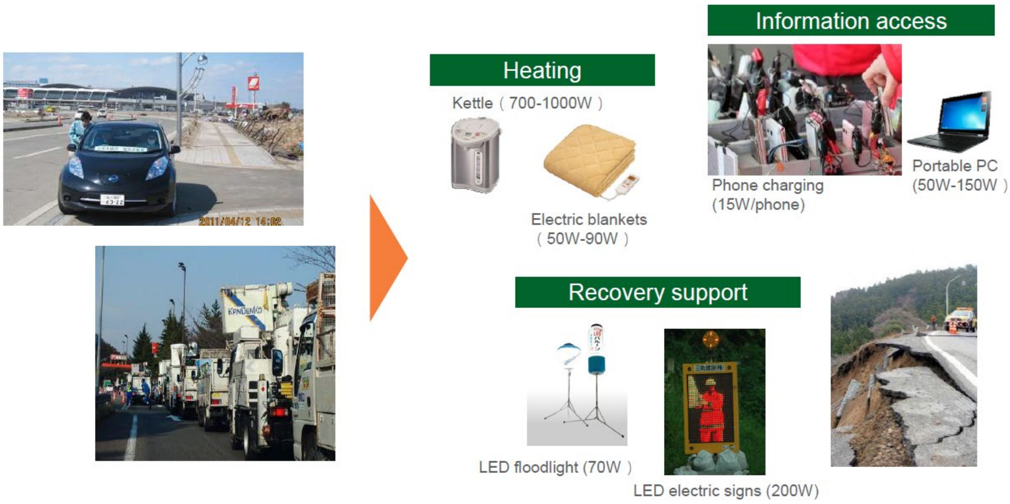

Figure 11 - Vehicle as an emergency power source. Source: CHAdeMO

The business can be scaled up to address any individual or organization which may be adversely influenced by the occurrences of natural disasters and power cuts.

Conclusions

A case building on the tragic circumstances around the 2011 Tsunami of Japan and which shows the big potential of the distributed and portable batteries used in V2X-enabled EVs in emergency situations.

This case is very specific to regions where certain condition prevents access to important electric power services. While the reasons for such a challenge may vary (old/weak grid, natural disasters) this service may be applicable to other parts of the world.

V2G frequency response and behind-the-meter optimization, U.S. Department of Defense

One of the world's first large V2G pilot projects is found at the U.S. Air Force base in Los Angeles in 2012. It comprises a 1M square foot office complex with 4MW peak electric load, along with a fleet of 36 EVs and bidirectional charging units controlled by an aggregator. V2G provides frequency response services to the TSO/ISO whilst simultaneously minimizing energy purchase costs for the complex.

The overall aim of the project is to determine the extent to which the EV fleet cost gap can be narrowed. Whilst the business case for this pilot is still unclear, sample data coming from the project has indicated that frequency regulation services could generate a daily income of $6.28 per EV, which far exceeded the $1.08 daily energy cost associated with running an EV (Workshop VI). Overall U.S. Department of Defense V2G trials from across the U.S. concluded that the lease price of EVs could be reduced by 72%, making the operating of an EV less costly than ICE alternatives (Workshop IV).

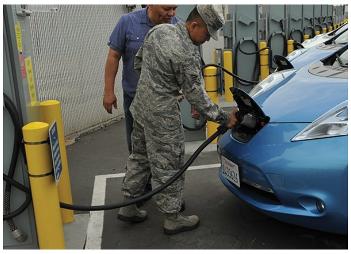

Figure 12 - Photo from Los Angeles Air Force Base V2G project. Source: Honda

Replicability/scalability

The aggregation of V2G units for fleets is probably the most active area of development for V2X technology. This model seem to be scalable and replicable for different types of fleet and in different country without significant regulatory change required. The costs of this model are likely to reduce significantly with scale too, since ICT systems required for aggregation represent a fixed cost, more or less independent from the number of EVs aggregated.

The main prerequisite for this model is that frequency response markets permit participation of distributed resources such as V2X. The design of energy tariffs for large commercial users will also play a role, along with the incentives available to reduce peak demand. In terms of project coordination and cost, aggregation of large EV fleets seem to be more attractive than individual EVs plugged in at home, therefore most commercial activity will initially be concentrated on fleets.

Conclusion

This is an interesting example of a large public institution promoting the development of V2G technology. Institutions such as the military, where innovation and technology play a central role in their core operation, are likely to be more capable of delivering this type of project. They also have the capacity to share knowledge effectively across the institution and replicate success elsewhere, for example the DoD has carried out similar projects at another 5 sites across the U.S., totaling over 100 EVs with V2G capability (Department of Defense, U.S., 2013).

V2H back-up power, Japan

Regarding V2H, Japan has become the first real market for V2H technologies as a backup emergency power in 2015. A number of prefectures incentivize its usage in order to reduce peak power demand and increase power supply reliability after the shutdown of a number of nuclear power plants in 2011. As of 2017 more than 4000 Nissan “LEAF to Home” units were sold in Japan. The technical design comprises a power control system connected to the household´s distribution board, with switching capability that enables the home to receive power from the EV in islanded mode in post contingency conditions.

Customs were also motivated to purchase these units because they offered faster charging (6kW compared with 3kW) and the capacity to schedule charging to take advantage of cheaper nighttime electricity rates and match solar generation. Studies have shown that by optimizing charging and discharging based on the differential between night and day electricity tariff rates, users can achieve annual benefits of 30,000JPY (approx. $267), although battery degradation impacts are not considered in this calculation (Nakada et al., 2015).

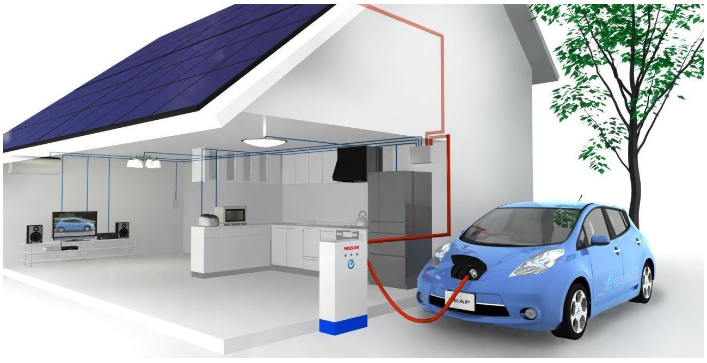

Figure 13 - Nassan vehicle-to-home system. Source: Nissan

Replicability/scalability

This model for V2H seems to be scalable and replicable on the technical level. However, the value of this scheme is highly reliant on the existence of ToU tariffs or self-generation for domestic users, as well as back-up power supply requirements. Battery warranties for this scheme have also only been permitted in Japan and only for Nissan vehicles.

Conclusion

Overall this case study provides a valuable example of how V2H may service a mass domestic market. So far this has only happened in scale in Japan, where government subsidies have significantly reduced to cost to consumers and battery warranty rules have been relaxed. V2H must be carefully compared against smart charging in these cases, since the latter may prove a better trade-off in terms of hardware costs and battery degradation.

V2X Roadmap

A framework has been developed to identify key goals and actions needed to advance V2X technology and improve the business case. Figure 14 below illustrates how these concepts relate to one another.

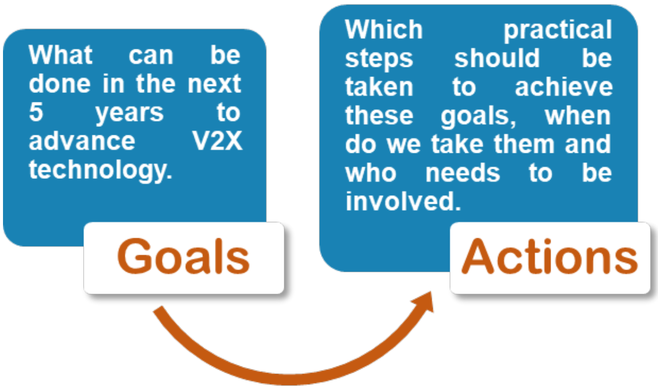

Figure 14 - Goals and actions

Goals and actions are categorized according to three tracks in the roadmap, cover the technical, regulatory and social aspects:

Track 1: Technology Development

This track comprises technical issues relating to the development of V2X hardware, software and communications systems. The two goals associated with this track are:

T1.1 Standardization and harmonization
T1.2 Consensus on battery degradation

Track 2: Markets and Regulations

This track deals with regulatory issues relating to grid interconnection and energy markets that prohibit V2X from providing services. Four goals have been identified for this track:

T2.1 Include V2X in grid codes
T2.2 Develop new tariffs and contacts for flexibility
T2.3 Redesign TSO system services markets
T2.4 Develop DSO system services market

Track 3: User Engagement

This track looks at the social issues such as public awareness and the value proposition of V2X for end users. Two goals have been identified with this track:

T3.1 Develop customer centered business models
T3.2 Improve public awareness of V2X technology

In the following sections, a background discussion is had on each goal and a number of actions are identified and prioritized from high (3) to low (1).

Track 1: Technology development

T1.1 Standardization and harmonization

Background discussion

One of the main barriers that V2X faces is related to equipment standardization and communication protocols. Consistent requirements for EVSE should be established. EVs are not always connected to the grid, and not always to the same connection point. This creates the need for standardized plugs, standardized infrastructure and a standardized communication platform. The IEC 61851 series and the IEC/ISO 15118 series are recommended and expected to be the main series of standards related to EVs. New grid codes together with common standards will enable the use of the full potential of EVs delivering ancillary services to the overall power system, the local grid, businesses and buildings.

No consistency among standards on the total V2X value chain can lead to limited access for V2G services. The same issue has been covered during the last years, with the introduction of the EVs, regarding the standards and harmonization needed both in the EV and EVSE side to allow interoperability among all actors. This is essential to get the most of the EV value chain in order to maximize its social and economic benefits.

Automakers and infrastructure operators must deploy equipment conforming to a harmonized set of standards. The lack of standards between the EVSE and the upstream electric infrastructure is a significant drawback for V2X technology deployment, although Open Charge Point Protocol (OCPP) 2.0 now includes support for smart charging and V2G. Standards are needed to harvest V2X properties such as the fast response time, high power load, possibility of V2X support and high degree of flexibility. Therefore, early development of standards can be considered a key factor to V2X deployment.

Connectivity and communication for EVs and the grid were developed independently, EV-grid interfaces must be harmonized and interoperability must be verified. Not only is harmonization key but also the enabling technologies. There is a need to harmonize standards or develop technologies to adapt interfaces and support advanced features.

Part of the challenge with V2X is that industries that developed independently for several years are now being ask to make their products compatible. EVs may allow for cross-industry interactions if standards for the different components are developed collaboratively. Traditionally (in the U.S.) the automotive industry has followed the Society of Automotive Engineers (SAE) recommended practices and standards. EVSEs are new products that need to adhere to SAE standards where it delivers power and depending on where they are installed may need to adhere to IEEE or NEC standards at the power intake side of the product. If this is tied directly into the grid Underwriter Labs (UL) standards may also apply.

With V2X we have the addition of reverse power flow which means that grid standards associated with communication as well as power will need to be addressed. With these multiple interface points it is clear to see that harmonization is necessary for vehicles to be able to connect at any charging location. In the case of the interface points there are multiple standards that are applicable depending on the location or application.

Goal and Actions

Goal T1.1: Standardization and Harmonization			
Develop global standard for V2X technology and harmonize these with existing power, transport and communication systems. Agreement and application of global standards is a route to reduce costs, mitigate negative impacts and encourage participation by manufactures and service providers.			
Actions			**Priority (1=low 3=high)**
T1.1.1	**Projects to test new and proposed standards**	This should include lab and field test of standards between EVSE and EV, as well as between EVSE and upstream actors such as end-users, Energy Management Systems and aggregators. Interpretability with existing systems should be a key aspect of these test.	3
T1.1.2	**Develop open aggregation platforms**	Development of open aggregation platforms that can be accessed by different actors that want to access flexibility or capacity provided by V2X.	1
T1.1.3	**V2X interoperability with smart home equipment**	Work with standards organizations to ensure that V2X technology is compatible with other smart and flexible home energy systems to enable whole building optimization.	3
T1.1.4	**Feed gained insights from demonstration projects into existing standards**	This could be achieved through conferences, and international meetings or contribution to standard committees involving a wide range of stakeholder groups	2
T1.1.5	**Refine V2X applications and use cases**	This will support the process of equipment certification and classification while better defining involved stakeholders and involved standards.	1

Table 1 – Goal T1.1 and actions

T1.2 Consensus on battery degradation

Background discussion

The onboard battery is an important contribution towards the total cost of an EV and therefore degradation effects due to the provision of V2X are of great interest. Currently few EV manufactures permit V2X under normal vehicle warrants due mainly to such concerns, although there are some exceptions: in Japan Nissan has permits up to 6kWh of discharge per day through a V2H scheme (Cenex, 2018).

An important question is to what extent additional use of the vehicle battery will affect the capacity over the lifetime of the battery. There have been several studies conducted towards this end, many of which claim these additional effect to be minimal or even negligible (Shinzaki et al., 2015) while others claim it to be a barrier to V2X (Bishop et al., 2013). Still others claim the additional battery degradation cost will be outweighed by the V2X income which would be generated (Han et al., 2012). Note that in (Bishop et al., 2013), only bulk power transfer was evaluated, sometimes referred to as energy arbitrage, which is an important point as there are several other V2X services such as frequency regulation which would be better suited to EVs. While there is disagreement of the viability of V2X as a whole, there is a consensus that services which require a large energy throughput would be cost prohibitive as this would cause the greatest capacity degradation.

Battery Degradation Mechanisms:

- There are four primary components of a Lithium-Ion battery cell: an anode, a cathode, a separator, and an electrolyte. Degradation will occur at each element differently through various aging mechanisms to contribute to overall life fade.
- All aging mechanisms will contribute to either an increase in internal impedance or a decrease in total battery capacity (Ignatev, 2016; Schlasza et al., 2014; Vetter et al., 2005).
- Internal impedance rise results in a reduction in the power that the battery can deliver, which is why it is sometimes referred to as Power Fade
- Capacity Fade relates to loss of battery capacity when fully charged and implies a reduced mobility range.

End of Life:

- The End of Life (EoL) is another important concept, defined as the threshold when battery aging impacts are such that the battery is no longer able to fulfil its original application.
- In the case of EVs, EoL is typically defined as when the battery loses 20% of its initial capacity, although optimally defining this threshold is an ongoing area of research.

In summary, battery degradation is a complex science and further research is required to better understand the impacts of V2X on battery performance and life span. Specifically, more sophisticated battery aging models are required, along with data from demonstration projects to validate and improve current models. Uncertainty regarding battery degradation impacts is a major barrier to V2G development, discouraging manufactures from equipping EV with V2X capability and including provision from V2X within battery warranties. However, current research gives a strong indications that battery degradation from V2X is comparable to, or less than, that caused by charging and driving behaviors, as well as fast charge usage (Ribberink et al., 2015) (Petit et al., 2016). In addition, a recent study has suggested that as the new generation of EVs evolves with increased battery capacity, aging impact of V2X may become almost negligible (Workshop XI). It is thus highly likely that benefits of V2X will outweigh battery degradation impacts providing V2X be used appropriately. Therefore, EV manufactures should be encouraged to build V2X capability into their vehicles, with simple safeguarding measures in place to mitigate the worst effects of V2X on battery aging. Later, compensation mechanisms for battery degradation effects may emerge, enabling more economically optimal solutions. But for the time being, whilst V2X becomes established, the first step is simply to make vehicles V2X capable.

Goal and Actions

Goal T1.2: Consensus on battery degradation			
Cross OEM consensus on impact of V2X on battery degradation and development of set of standards or best practices. This should enable OEMs to include V2X capability without compromising existing and future battery warranties.			
Actions			**Priority (1=low 3=high)**
T1.2.1	**Dissemination of scientific literature on battery aging and impacts of V2X**	This can be achieved through conferences and meetings between researches and EV manufacturers.	3
T1.2.2	**Develop standards to limit battery degradation impacts from V2X**	Ensure that V2X standards include constraints to minimize battery aging effects and that these standards are adopted by EV OEMs. Develop harmonized V2X battery testing protocol.	3
T1.2.3	**Validation of battery aging models**	Data sets from EVs currently on the road or performing in V2X project should be analyzed to validate and improve existing battery aging models, with attention payed to driving and charging behaviors, as well as environmental conditions like ambient outside temperature.	2

Table 2 – Goal T1.2 and actions

Track 2: Market and regulation

T2.1 Include V2X in grid codes

Background discussion

Grid codes should be designed to accommodate for flexible loads, generation and storage resources connected at the distribution and building level. One of the main regulatory challenges that V2X faces is the barrier to inject power into distribution networks and grid connected buildings. In order to connect to the distribution network, V2X equipment must meet a range of technical requirements stipulated by the DSO to mitigate risk of negative impacts on the local network. These requirements include LOM protection, synchronization and power quality. Currently bidirectional EVSE is not widely recognized by DSOs as potential generators and demonstration projects have repeatedly come up against challenges of slow, costly and in some countries prohibited grid connection procedures.

Certification of V2X equipment by DSOs is a critical first step to streamline connection procedures. This should be based on a standardized grid interface, a clear framework and consistency between DSOs. Once V2X equipment can be shown to reliably meet DSO requirements, it will likely qualify under existing connection procedures for other distributed generation and storage equipment, such as rooftop solar PV.

DSO grid codes should also make provision for V2B as a back-up power supply. This application of V2B requires that the building (or micro-grid) where the vehicle is connected can be isolated from the public distribution network during a LOM event. Currently many countries, such as Denmark, do not have provision for this at the domestic scale (Workshop III).

In the case of EVs that have in-built V2X capability (an on-board DC/AC bidirectional converter), grid connection is particularly challenging since the vehicle are capable of injecting power at different points in the network. In this situation, it is probable that the EVSE will continue to service as the gateway to grid connection, ensuring that DSO requirements are met and local grid impacts are managed.

Costly metering equipment and stringent metering procedures have also been identified as a further barrier to V2X associated with grid connection. Additionally, in many countries electricity storage units suffer from a double-charging problem – levies as an electricity producer and consumer (Everoza & EVConsult, 2018). Stakeholders have noted that such costs may be reduced by share the cost of connection, metering and power conversion equipment with other micro-generation systems, such as solar PV (Workshop XI). Further, many believe that demonstration projects should be exempted of certain technical regulations to encourage trial and error.

Goal and Actions

Goal T2.1: Include V2X in grid codes			
Reform grid codes to enable V2X to easily connect to the distribution network and inject power into the grid. This will require certification of equipment for different V2X applications, including V2B back-up power for buildings in post contingency conditions.			
Actions			**Priority (1=low 3=high)**
T2.1.1	**Dissemination of scientific literature on grid impacts of EV and value of V2X**	This should include results from demonstration projects and other research being shared with network operators and regulators.	2
T2.1.2	**Development of tools to assist DSO**	Develop tools to help DSOs predict the future impacts of EVs and V2X on their networks.	2
T2.1.3	**Dissemination of best practice between countries**	Share knowledge of DSO innovations from across the world, particularly on innovative connection arrangements and distributed storage.	2
T2.1.4	**Lobby for recognition of V2X in grid codes**	Lobby DSOs and regulators to include provision for V2X in grid codes and resolution of double charging problem. Certification should include provision for V2X as back-up power supply.	3

Table 3 – Goal T2.1 and actions

T2.2 Develop new tariffs and contacts for flexibility

Background discussion

As highlighted in Section 0, value may be generated through behind-the-meter optimization if a building is exposed the certain price signals for energy import and exports, as well as changes for capacity. Such benefits can be enhanced in the presence of on-site generation, since the EV battery may be used a local storage to maximize self-supply and minimize reliance on the grid.

However, currently most energy tariffs and capacity charges do not properly reflect the real-time value of flexibility and capacity to end users or generators. This prohibits V2X optimization based on national or regional price signals, which could generate value for end users and benefits for the power system overall. A key enabling technology for this kind of tariff is precise metering technology required for settlement, such as smart meters, and energy managements systems (EMS) that enable optimization with minimal input from the home or building user.

One barrier for this kind of V2X is complexity and risk to customer. As the complexity of energy tariffs and connection agreements increases there is risk of the energy market becoming opaque to end-users, in other words it will become increasing challenging for consumers to compare tariffs in the market and make an informed choice. In the UK for example, stringent regulations are in place to simplify energy tariffs for domestic users, which currently prohibit suppliers from offering sophisticated ToU tariffs or critical peak pricing schemes. One solution to such challenges could be an aggregator or retailor offering fixed tariffs combined with agreements to control flexible loads within a pre-defined threshold. The development of new commercial arrangements such as these should be a focus for development.

Goal and Actions

Goal 2.2: Develop new tariffs and contacts for flexibility			
Redesign energy tariffs to better reflect the real-time value of energy and capacity in the power system. This will enable buildings with smart flexible resources, such as V2X, to optimize charging and discharging.			
Actions			**Priority (1=low 3=high)**
T2.2.1	**Implement enabling technology**	Promote the implementation of enabling technologies for behind-the-meter optimization, such as smart metering and energy management systems.	1
T2.2.2	**Lobby to remove barrier that prevent ToU tariffs implementation**	Work with policy makers and regulators to remove barriers that restrict tariffs from reflect the real-time value of flexibility and capacity to users.	2
T2.2.3	**Educate building users and energy service operators**	Ensure that building users and operators are aware of how V2X operation can be optimized based on tariff conditions and on-site generation.	2
T2.2.4	**Develop innovative commercial arrangements**	Collaboration between research, industry and rule makers to develop new types of energy contracts, including energy service contracting and flexibility contracts.	3

Table 4 – Goal T2.2 and actions

T2.3 Redesign TSO system services markets

Background discussion

One of the main opportunities for V2G to generate revenue is through the provision of frequency regulation and reserve services to the TSO. However, historically these services have been provided exclusively by centralized thermal power plants and consequently rules and regulations are often ill-suited to new decentralized sources of flexibility, such as aggregated V2G. In (Borne et al., 2018), the barriers preventing aggregator participation are divided into three categories: (1) those which prevent aggregators from entering into the market, (2) those that prevent aggregators from delivering their full flexibility, and (3) those that prevent aggregators from being fully remunerated for the service. These barriers have been adapted and built on in the context of V2X below.

Barriers which prevent V2G from entering into the market:

- Rules prevent participation of aggregation at the distribution level all together.
- Rules prevent aggregation across more than one DSO network.
- Rules prohibit loads or storage from providing system services (i.e. only allow generators).
- Minimum capacity thresholds makes it harder for new players/projects to enter the market.
- Reliability requirements and penalties for under-delivery are too severe for V2G.
- Lack of mechanism for aggregators to compensate energy retailors for imbalance resulting from system service delivery action (Cenex, 2018).

Barriers that prevent V2G from delivering their full flexibility:

- Service delivery periods are too long to account for the hourly fluctuations associated with V2G.
- Service procurement is carried out several months or years before delivery and this makes resource forecasting for new projects challenging, which results in participants to place conservative bids.

- Symmetrical products (those that require equal capacities of up and down reserve) are not well suited to V2G.

Barriers that prevent V2G from being full remunerated for the service:

- The value of very fast response is not fully accounted for in system service markets, often markets permit up to 150s response time but V2G could response within 5s (Workshop IV).
- Some TSOs, such as in the UK, require that thermal generators provide mandatory frequency response services. This reduces the size and value of the system service market.
- Bidding strategies used in pay-as-bid and pay-as-clear markets are difficult for new entrants to perform well in.

When considering whether to open up system service market to aggregators, (Borne et al., 2018) also stresses the importance of recognizing that this may cause additional costs to the TSO. For example, by reducing the minimum capacity and duration of bids, the TSO will increase contract number and associated transactional cost would increase. In order to procure system services which maximize welfare, these additional costs should also been taken into account.

Goal and Actions

Goal T2.3: Redesign TSO system services markets			
Remove regulatory barriers which prohibit V2X from participating fully in TSO system service markets, including barriers which prevent resource aggregation and the entry of new player in the market.			
Actions			Priority (1=low 3=high)
T2.3.1	**Lobby governments and regulators to reform TSO system service markets**	Demonstrate to policy marker the benefit of reformed TSO system service markets which enable full participation of V2X and other emerging flexible technologies.	3
T2.3.2	**Develop methodology for TSOs to account for additional cost of aggregation**	Research to enable TSOs to monetize externalities of market reform, such as increased transaction costs, in order to maximize whole system utility.	1
T2.3.3	**Develop tools to support TSO - aggregator interaction**	Engagement with TSOs to help them work with aggregators to deliver system services	2

Table 5 – Goal T2.3 and actions

T2.4 Develop DSO system service market

Background discussion

Traditionally DSOs have played a passive role in the operation of the power system. The second-by second system balance and powerflow monitoring was the domain of the TSO, whereas distribution networks simply drew power from the transmission network, stepped the voltage down and supplied this to residential and commercial consumers. The principle day-to-day operation of the DSO comprised of two activities. Firstly, to detect when faults occur in the distribution network and coordinate repairs, the objective being to maintain a high level of security of supply to customers. Secondly, to manage the connection of new loads and generators to the network and, when necessary, expanding networks capacity to meet these new requirements. Since DSOs traditionally have not had the ability to control the production and consumption of these loads and generators, additional network capacity requirements were always calculated based on worst-case scenario assumptions. Whilst this approach was the only way to safely manage these new connections, it was not very cost efficient, since it led to high levels of redundancy in the network during normal operations.

Over the past twenty years, ever since the advent of the internet and advanced ICT, there has been increasing interest in the concept of smart grids. This concept proposes that sophisticated communication and control technologies are used to control power flow at the distribution level. This approach would lead to the DSO taking on a much more active role the operation of their network. For example, rather than investing in additional network capacity to meet growing demand (as they had done previously), DSO could instead remotely curtail certain loads during peak hours. By avoiding or delaying the need for network reinforcement in this way, many stakeholders believe DSOs can reduce the over network cost to users. With the growth of distributed renewable energy generation and the electrification of heating and transport sectors across the world, the potential for smart grid applications to reduce network investment has become a salient issue.

These new flexible services to DSOs could be provided by any controllable loads (or generators) connected at the distribution level, including V2G charging units. As mentioned previously, the markets for such services are still in the infancy and their potential value is likely to be location specific. However, one day distribution system services could very well improve the business case.

One of the key requirements for this kind of local grid balancing is improved interaction between TSO and DSO. This is because the control of flexible resources at the distribution level by one party may have negative consequences on the other party. For example, a TSO may increase demand of several V2G units in order to absorb excess renewable generation elsewhere in the system, yet this action could potentially cause unacceptable overloading or voltage drop in the distribution network. Coordination is therefore required between DSO and TSO to optimise the utilisation of flexible resources and mitigate network damage. Presently there is a very limited framework in place to facilitate such interactions and grid codes are no appropriate for dealing with V2G and other distributed energy resources.

In summary, combinations of TSO/DSO V2X market applications should therefore be considered to maximize the value of V2X. To do this, coordination between DSO and TSO is fundamental to ensure the creation of a common marketplace and regulatory framework that enables a transparent, secure and cost-effective flexibility service provision. This must fundamentally be based on the monetization of flexibility at the distribution level through the emergence of DSO system service markets.

Goal and Actions

Goal T2.4: Develop DSO system service market			
Develop new DSO system services markets, such as congestion management or voltage regulation, in order to monetize the externalities of flexibility at the distribution network level.			
Actions			**Priority (1=low 3=high)**
T2.4.1	**Demonstration projects to test V2X provision of DSO system services**	These will be based on DSO monetizing benefits of delayed network reinforcement and making this value available through markets and value sharing arrangements.	3
T2.4.2	**Dissemination of best practices for DSO services**	Share knowledge of existing DSO service markets from around the world through workshops and conferences.	2
T2.4.3	**Lobby to change regulation to encourage innovation by DSOs**	Reform grid codes to encourage new DSO system service markets and innovative connection agreements. These should internalize value of distributed flexibility and include provision for different V2X applications, including building islanding.	3

Table 6 – Goal T2.4 and actions

Track 3: Social acceptance

T3.1 Develop customer centered business models

Background discussion

Adoption of V2X technology will be driven mostly by the TCO of a transport mode and the ease of use of the technology for end-user (Workshop V). Research shows that the likelihood of people to plug-in their vehicles is directly related to the benefit they can obtain, that end users prioritize upfront discounts or pay-as-you-go contract rather than obligations, and that reliability and flexibility are highly valued by EV users.

To achieve ease of use, much of the complexity involved in V2X technology will need to be hidden behind a much simpler offering to customers. For example, when a customer connects to a bidirectional charger they could be offered a delayed charge option, where they select what SOC they need and by what time. In return for providing this kind of flexibility, they would receiver cheaper electricity or a rebate payment, which could be clearly communicated to them via a text message or mobile app (Workshop XI). Other types of incentive may also be variable, such as gamification, air miles, free power and credits. Bundled services, such as lease agreements for vehicle and V2X charge point together may also be offered by new players in the market.

As well as promoting the economic benefits of V2X, it will also be important to stress other benefits too, such as environmental benefits, energy security and energy autonomy. Limited work has been done to understand how these aspects influence the value proposition of V2X to end-users and most demonstration project to date have not explored these factors (Everoze and EVConsult, 2018).

Different types of customer will require different engagement strategies and offerings. There are five principle EV user types which V2X could target:

- Private motorists which typically charge their cars at home, work or using public charging networks.
- Fleet operators which would typically charge their vehicle fleet overnight at a single location
- Mobility as a Service (MaaS) providers such as E-car sharing schemes which may not have a fixed charging location or driving routine, and may rely largely on public charging networks
- Public charging infrastructure providers that would offer flexible charging options to EV users in return for benefits such as discounted charging costs.
- Public transport providers such as electric bus and taxi services, which operate in a similar way to commercial fleets.

These different customer groups have varying characteristics in terms of EV driving and charging pattern, financial motivations and willingness to adopt new technologies and behavior patterns. Generally, large fleets operators, such as public transport providers, public sector organizations and private companies, have proved to be the most promising customer group for early adoption of V2X technology. This is reflected in the large share of pilot projects forced on fleets. Large fleets provide technical benefits in terms of charging point operation and maintenance, aggregation system design, predictability of charging patters and contractual simplicity. This user group also seems more commercially motivated compared with private motorists, which value ease of use more.

Goal and Actions

Goal 3.1: Develop customer centered business models			
Improve understanding of V2X value proposition to consumers and develop customer focused business models which distribute benefits and risk			
Actions			**Priority (1=low to 3=high)**
3.1.1.	**Demonstration project to understand value proposition to end users**	These should focus on the development of scalable business model which explore the value proposition of V2X to different types of user.	3
3.1.2	**Development of new business models and incentive/risk sharing arrangements**	Research into new business models which could provide an attractive offer to end-users whilst sharing benefits with other actors necessary to motivate investment.	3
3.1.3	**Cross sector collaborations to offer bundles services**	Linking up actors from a range of utilities, including energy, transport, communication, to assess potential for bundled services.	1

Table 7 – Goal T3.1 and actions

T3.2 Improve public awareness of V2X technology

Background discussion

Dissemination and knowledge exchange between stakeholders will be central to the success of V2X technology, but currently there is limited coordination between manufacturers, grid operators and policy makers (CAISO, 2014). Lessons from research and pilot projects must be shared and made widely available so that stakeholders are well informed and come to consensus on the best way forward. This should result in outputs such as global and regional standards and protocols for technologies, incorporation of V2X within regulation and markets, and agreement on battery degradation effects and warranty implications.

Large-scale demonstration projects are also highly needed to bring attention to V2X technology, build capacity and gain knowledge. These projects should pay special attention to replicability and scalability as to facilitate entry into commercial markets. They should also be used as a platform to engage with a wider audience about the technology so that the V2X concept enters the social and political debate.

Marketing strategies should be focused on regions with greatest potential for V2X uptake, i.e. those with high penetrations of EVs, variable renewable energy resources and favorable regulation and markets. They should also be focused on specific user groups, such as fleet owners and users with on-site renewable generation.

National level plans for developing infrastructure to reduce emissions and improve energy security are now commonplace in most developed countries and many include provision for smart charging and V2X. Ensuring that these plans fully recognize the potential of V2X technology is important.

Engagement with EV users is critical too. V2X technology is often seen as being too complex for the general public's interest and current awareness among the general public remains scares. Most V2X pilot projects to date have been technology focused, with less emphasis placed on user experience and perception (Everoze and EVConsult, 2018). However, since EV owners are ultimately the customers for V2X, understanding the value proposition for users will be critical to the success of the technology.

As has been seen in the EV sector, it is easy to generate public concerns and misunderstandings with the introduction of a new technology. Survey results taken in 2017 at the European Battery Hybrid and Fuel Cell Electrical Vehicle Congress in Geneva showed that 60% of respondents chose battery derogation as their main concern for V2X technology, followed by range anxiety (27%) and revenue (13%). Whilst this survey reflects only the views of those working in the EV sector, it is prudent to assume that similar concerns will apply to the general public. Another issue that is likely to be important to the public, not reported in the survey, is that of cyber security and data privacy.

Goal and Actions

Goal 3.2: Improve public awareness of V2X technology			
Develop higher level of public and political awareness of V2X technology and its applications.			
Actions			**Priority (1=low to 3=high)**
3.2.1	**Large scale demonstration projects**	These will be necessary for grabbing public and political attention so that the V2X concepts enter in key conversations and decisions.	3
3.2.2.	**Lobbying to include V2X and smart charging in nation plans**	Work with policy makers to make sure that V2X us fairly represented alongside other emerging energy technology and accounted for in long-term planning.	1

Table 8 – Goal T3.2 and actions

Conclusions

Whilst V2X is still at a research and development phase, we are nearing the point when this technology could begin to enter in commercial mass markets. However, this transition is unlikely to happen until a number of issues have been resolved which currently hinder the developing of V2X technology and its capacity to provide value to end-users and other actors. This roadmap has set out plan for how these issues may be overcome, based on eight key goals that the automotive industry, network operators and policy makers should aim to achieve. Suggestions for near-term activities that may be carried out towards meeting these goals have also been identified.

A fundamental prerequisite for the success of V2X is the support of automakers and power system operators. So far, there has been no strong commitment from these actors to enable V2X in vehicles and integrate bidirectional chargers into the power system and energy markets. By facilitating cooperation between the mobility and energy sectors, along with supporting rule-makers to realign regulation towards decarburization, these critical actors will be motivated to lead change towards V2X.

Ultimately, the mass uptake of V2X will be determined by the value proposition and ease of adoption to end-users and other actors. It is likely that a number of winning use cases will begin to emerge, based on a simple offering to different EV user groups and sets of standard commercial arrangements between new and existing actors in the power and mobility systems. Already some typologies are crystalizing from pilot projects, such as the aggregation of commercial fleets to provide frequency response and behind-the meter optimization.

Next steps

The next stage is for the players in the energy and transport sectors to carry out the actions identified in the roadmap. This requires working out when actions should be carried out and who needs to be involved. To assist with this process, Figure 15 and Figure 16 on the following pages set out estimated timescales for each action over the next five years, along with identification of which actors need to be involved in each step.

We recommend that efforts to encourage international collaboration and knowledge exchange on V2X are maintained. A large amount of knowledge is being cultivated from research and demonstration projects around the world and it is vital that this is consolidated to move forward. Cooperation and agreement between actors on the best way forward will be vital for V2X to become truly scalable and replicable between counties.

Figure 15 - Action Gantt chart

Track	Goal	Actions	Priority (1=low to 3=high)	Electric Vehicle OEM	EVSE OEM	TSO	DSO	Aggregators	Energy Retailors	End users	Charger Operators	Regulators	Policy Makers	Standards Insitutions	Researcher Institutions
Track 1: Technology Development	Standardization and harmonization	Projects to test new and proposed standards	3	X	X									X	X
		Develop open aggregation platforms	1			X	X	X			X			X	X
		V2X interoperability with smart home equipment	3	X	X									X	
		Feed gained insights from demonstration projects into existing standards	2											X	X
		Refine V2X applications and use cases	1									X			X
	Consensus on battery degradation	Dissemination of scientific literature on battery aging and impacts of V2X	3	X											X
		Develop standards to limit battery degradation impacts from V2X	3	X										X	X
		Validation of battery aging models	2	X											X
Track 2: Markets and Regulation	Include V2X in grid codes	Dissemination of scientific literature on grid impacts of EV and V2X	2			X	X					X			X
		Development of tools to assist DSO	2				X					X			X
		Dissemination of best practice between countries	2			X	X					X	X		X
		Lobby for recognition of V2X in grid codes	3		X		X					X	X		
	Develop new tariffs and contacts for flexibility	Implement enabling technology	1						X	X		X	X	X	
		Lobby to remove barrier that prevent ToU tariffs implementation	2						X	X		X	X		
		Educate building users and energy service operators	2							X			X		
		Develop innovative commercial arrangements	3		X									X	X
	Redesign TSO system services markets	Lobby governments and regulators to reform TSO system service markets	3			X		X				X	X		
		Develop methodology for TSOs to account for additional cost of aggregation	1			X						X	X		X
		Develop tools to support TSO - aggregator interaction	2			X		X				X		X	X
	Develop DSO system services market	Demonstration projects to test V2X provision of DSO system services	3	X	X		X	X	X	X		X			X
		Dissemination of best practices for DSO services	2				X						X		X
		Lobby to change regulation to encourage innovation by DSOs	3									X	X		
Track 3: Social Acceptance	Develop customer centered	Demonstration project to understand value proposition to end users	3	X	X	X	X	X	X	X	X				
		Development of new business models and sharing arrangements	3							X			X		X
		Cross sector collaborations to offer bundles services	1	X	X			X	X	X					
	Improve public awareness of	Large scale demonstration projects	3	X	X			X		X	X	X		X	X
		Lobbying to include V2X and smart charging in nation plans	1									X	X		X

Figure 16 - Stakeholder - Action analysis

Appendix – V2X Project Catalogue

Information in this table of projects has been gathered during Task 28 events and from two recent publications:

1. V2G Global Roadtrip: Around the World in 50 Projects (Everoze and EVConsult, 2018)
2. V2G Market Study (Cenex, 2018)

Project Name	Summary	Year	Country	# Charge
Elia V2G	Leading Belgium project evaluating a mix of V2G and V1G to provide FCR services to TSO Elia.	2018	Belgium	2
IREQ	Technology demonstration of back up supply and export to the grid for an assembled electric test vehicle and charging station.	2012	Canada	1
Powerstream pilot	Small scale, micro grid proof-of-concept trial incorporating V2G in phase 2	2013	Canada	
Canadian V2X project	Investigate: the impact of V2X on EV battery life, the potential to mitigate this impact using a smart supercapacitor module and the economics of V2X	2014	Canada	
EDISON	The EDISON project has utilised Danish and international competences to develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies	2011	Denmark	
Nikola Project	Nikola is a Danish research and demonstration project with a focus on the synergies between the electric vehicle (EV) and the power system.	2013	Denmark	3
Cotevos	Concepts capacities and methods for testing EV systems and their interoperability within the Smart Grid	2013	Denmark	
EnergyLab Nordhavn	The project utilizes Copenhagen's Nordhavn as a full-scale smart city energy lab and demonstrates how electricity and heating, energy-efficient buildings and electric transport can be integrated into an intelligent, flexible and optimized energy system	2015	Denmark	
ACES	The ACES project intends to holistically investigate technical and economic system benefits and impacts by large scale electric vehicles integration in Bornholm, augmented by real usage patterns, grid data and field testing for across continents replicability	2017	Denmark	50
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.	2017	Denmark	7
e-DASH	The e-DASH project aims at the harmonization of electricity demand in Smart Grids for sustainable integration of electric vehicles.	2011	EU	
PlanGridEV	Distribution grid planning and operational principles for EV mass roll-out while enabling DER integration	2013	EU	
SEEV4City	Large-scale Northern European trial delivering 5 pilots in 4 countries. Pilots include: Loughborough Living Lab - single residential household with solar also installed; Amsterdam ArenA - Up to 200 uni- and bidirectional connected EVs will be part of the smart energy system; City depot of Kortrijk - single Nissan LEAF van providing V2B with onsite solar; Leicester City	2016	EU	13

	Hall - Vehicle to business trial with four vehicles at present; Vulkan Real Estate Building Oslo - innovative EV parking garage seeking to deploy V2G in next phase			
Suvilahti pilot	The vehicle-to-grid (V2G) charging point complements an existing solar power plant and a stationary energy 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.	2017	Finland	1
Grid motion	The aim of the project is to evaluate possible savings achieved by real-life electric vehicle (EV) users through the implementation of smart charging and discharging strategies (V2G) for EVs.	2017	France	50
E-mobility Berlin pilot project	Paper P. Bach ("A comparison of electric vehicle integration projects")	2008	Germany	
INEES	German 'lighthouse' project which demonstrated the real world technical feasibility of V2G through the use of 20 SMA bidirectional inverters and modified Volkswagen UP vehicles.	2012	Germany	40
Vehicle-to-coffee	The Mobility House's office is powered in part from Nissan LEAF in practical demonstration of vehicle to office concept.	2015	Germany	1
Honda, Offenbach	Honda are testing V2B application on a building with on-site solar.	2017	Germany	1
Redispatch V2G	German trial with 10 electric vehicles, with uni- and bidirectional capability. Seeking to prove 'dispatchability' of Evs to manage network constraints, reduce curtailment and reduce upgrades.	2018	Germany	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.	2015	Greece	4
Hong Kong V2G	Small scale proof of concept trial in Hong Kong	2011	Hong Kong	1
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 energy to the network and contribute to its stability.	2016	Italy	2
M-tech Labo	Early V2B trial using 5 iMiEVs, reducing peaks by 12.7% at Mitsubishi Motors' office – together with second life battery	2010	Japan	5
Leaf to home	Commercially available vehicle-to-home product in Japan with over 4000 units sold (press release 2017).	2012	Japan	4000
Toyota Tsuho / Chubu Electric / Nuvve	Expected to be first ever V2G (as opposed to V2B) project in Japan. Government-funded trial announced in 2018	2018	Japan	-
V2G Aggregator project	Government-funded project just announced to build V2G system and test business models in Japan	2018	Japan	-
Osaka business park	Small scale trial for V2B, with little information available publicly	2016	Japan	-
Korean V2G	KEPCO project laying technical groundwork for EV roll out in Korea. In the Jeju Island pilot project (2016-2030), they are developing an AC/AC V2G charger including V2G service demonstration (2015-2017), building security infrastructure for smart grid vulnerability test and analysis (2015-2017) and developing a 6.6 kW wireless power transfer EV charger (with special focus on luxury class EVs and autonomous	2015	Korea	3

	EVs). The services planned to be introduced are demand response (peak reduction and load levelling) at distribution level. At present, V2H is limited due to regulation, but can be performed as a demand response (DR) service through a EVSE or V2G provider.			
Smart Solar Charging	Pioneering AC V2G project with 22 chargers installed as part of city-car share scheme and solar in Lombok. Now seeking to scale up to 1000 chargers across region of Utrecht.	2015	Netherlands	22
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.	2015	Netherlands	1
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 the 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.	2016	Netherlands	2
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 bidirectional 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.	2017	Netherlands	10
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.	2017	Netherlands	6
Hitachi, Mitsubishi and Engie	One V2G charger installed at Engie office in order to increase self consumption of on-site generation from solar PV. A stationary energy battery system also on site.	2018	Netherlands	1
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.	2016	Netherlands	5
Porto Santo	Project seeking to make Porto Santo a fossil-free island through the use of EVs to stabilize the grid. At present just V1G.	2018	Portugal	-

Smart V2G	Its major target is the connection of electric vehicles to the grid by enabling controlled flow of energy and power through safe, secure, energy efficient and convenient transfer of electricity and data.	2011	Spain	
Zem2All	At this time largest real world V2G trial in world, forming part of wider e-mobility trial in Malaga.	2012	Spain	6
ZEM2ALL	200 utilitarios 100% eléctricos Mitsubishi i-MiEV que se alquilarán a particulares y empresas, junto con una base de recarga, un smartphone y una unidad de comunicación a bordo (OBU), por una cuota de alquiler de 300 euros al mes, con un kilometraje anual pactado.	2012	Spain	
GrowSmarter	6 V2G chargers installed at Endesa facility and used for Time shift, Power balancing and Power quality support.	2015	Spain	6
EFES	Cenex led project developing V2G technology and software for residential and commercial applications, with installation of 3 V2G chargers at residential and commercial properties.	2013	UK	4
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.	2014	UK	
Intelligent Transport, Heating and Control Agent (ITHECA)	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.	2015	UK	1
ITHECA	Micro-grid demonstration project at Aston University which installed UK's first ever V2G charger.	2015	UK	1
Nissan Enel UK	Large-scale trial proposed in UK by Enel and Nissan seeking to connect one hundred V2G units. Current status not clear and this trial may have become one of latest Innovate UK projects.	2016	UK	100
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.	2016	UK	2
Hitachi - Isle of Scilly Smart Island	Wide-ranging smart-grid programme on island network. V2G element appears relatively small at present	2017	UK	-
The Network Impact of Grid-Integrated Vehicles	DNO-run project aiming to understand the negative and positive impacts of V2G-enabled EVs on the distribution network.	2018	UK	16
Bus2Grid	Bus: Evaluation of provision of V2G services from buses while at depot	2018	UK	
e4Future	Mixed: Validation of stacked V2G services in diverse scenarios	2018	UK	
E-FLEX - Real-world Energy Flexibility through Electric Vehicle Energy Trading	Car Club: V2G enabled fleets in urban area	2018	UK	
EV-elocity	Fleets and Airport: Validation of customer acceptance and business viability	2018	UK	
Powerloop: Domestic V2G Demonstrator Project	Domestic: Implementation of domestic V2G systems interoperable with all providers	2018	UK	
Sciurus	Domestic: Implementation of VPP and bundling of energy services with vehicle lease/price	2018	UK	
SMARTHUBS Demonstrator	Smart Hub: Integration of V2G charger, battery and PV controller into a smart hub	2018	UK	
V2GO	Fleets: fleet-based trial, including customer profiling and suitability for V2G services	2018	UK	

Jump Smart Maui	Deployed 80 V2H/B chargers which demonstrated discharge, in response to grid signals, over 6-9pm peak period thereby helping manage distribution system loads and frequency events	2012	USA	80
Los Angeles Air Force Base Vehicle to Grid Pilot Project	The project will assess both the technical challenge of V2G participation and the potential financial benefit.	2012	USA	36
Grid on wheels	First, real world field test of V2G technology with 15 vehicles providing frequency response services over two year period and range of driving patterns.	2012	USA	15
US DoD – Fort Carson	A V2G grid services demonstration was performed at Fort Carson. This was part of the three-phase SPIDERS programme that sought to demonstrate the practicality and benefits of creating secure microgrid architecture across three DoD installations.	2013	USA	5
Clinton Global Initiative School Bus Demo	Project seeking to improve economic viability of electric school buses through V2G and V2B trials in two school districts.	2014	USA	6
Torrance V2G School Bus	Department of Energy funded project which retrofitted 2 school buses.	2014	USA	2
Massachusetts Electric School Bus Pilot	Pilot project to test deployment of three electric school buses in cold weather environments in US.	2015	USA	-
NRG Evgo, UCSD	EVgo partnership with UC San Diego testing use case and interconnection standards with range of auto manufacturers on the UCSD campus (which also has solar PV and stationary storage).	2015	USA	9
Distribution System V2G for Improved Grid Stability for Reliability	EPRI project seeking to assess the value of, and barriers to, V2G at the distribution level, including whether these benefits can be monetised and quantified.	2015	USA	2
KIA Motors, Hyundai Technical Center Inc., UCI	UC Irvine partnered with KIA/Hyundai to demonstrate V2G control software, understand charging behaviour and assess impact on the grid.	2016	USA	6
NYSERDA	6 Nissan LEAF vehicles used to provide bidirectional grid services on the CUNY Queens College campus	2016	USA	5
INVENT	Nuvve seeking to deploy V2G technology on 50 UC San Diego electric vehicles, in project part funded by California Energy Commission.	2017	USA	50
BlueBird School Bus V2G	8 Bluebird electric school buses deployed at the Rialto Unified School District providing ancillary services and energy management services.	2017	USA	8
NREL Integrate / living lab	Use cases for V2G assessed for one vehicle and one school bus using grid simulator and on-site solar.	Not known	USA	3
UCLA WinSmartEV	Research project seeking to achieve maximum power flow from vehicles, while addressing response time and control, for a variety of applications including reactive power, voltage regulation and distributed storage.	Not known	USA	1
Fiat-Chrysler V2G	Large scale demonstration with 140 PHEVs, a portion of which were fitted with bidirectional charging capability, to test V2H and V2G capability.	2009	USA	-

Table 9 - V2X Pilot Projects

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