element energy

Energy+Environmental Economics

Implementing Open Smart Charging

Final Report

for

International ZEV Alliance

2nd October 2019

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Glossary

CO_2	Carbon Dioxide
DNO	Distribution Network Operator
DSO	Distribution System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FRR	Frequency Restoration Reserve
FFR	Firm Frequency Response
HEMS	Home Energy Management System
ICT	Information Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor Owned Utility
ISO	International Standards Organisation
MPAN	Meter Point Access Numbers
OCPI	Open Charge Point Interface
OCPP	Open Charge Point Protocol
OEM	Operational Equipment Manufacturer
OpenADR	Open Automated Demand Response
OSCP	Open Smart Charging Protocol
PV	Photovoltaic
SO	System Operator
TOU	Time of Use
V2G	Vehicle to Grid
VAT	Value Added Tax
VGI	Vehicle Grid Integration
VRE	Variable Renewable Energy

Summary and recommendations for policymakers

1. *Smart charging will be effective in offsetting (potentially completely) the significant power system costs of passive charging of EVs.*

The rapid uptake of Electric Vehicles (EVs) combined with passive charging will add significant costs to the electricity system, requiring increased peak generating capacity, network capacity expansion, and use of inefficient peaking plants that drive up CO_2 and energy costs to customers. For example, UK electricity whole system costs could increase by almost €1 billion/year due to passive charging of EVs by 2040, of which distribution network upgrades alone could account for €400 million/year. In California, distribution network upgrade costs are projected to increase by $140 million/year through 2030 with passive charging. Even at high levels of EV deployment, smart charging can substantially avoid these challenges, reducing energy costs for consumers and the grid's carbon intensity.

Policymakers must start planning for the impacts of EV roll-out on the power system, quantifying the expected EV uptake and whole system implications of passive versus smart charging. The public sector needs to work with stakeholders, e.g. System Operators (SOs) and Distribution Utilities, to develop an agreed vision for EV deployment that meets carbon ambitions and use this to assess the power system impact in the near and long term.

2. *Smart charging can generate several **diverse benefits** for a decarbonised power system.*

The inherent flexibility of EV charging means there is a significant upside to smart charging, particularly in a decarbonising power system. Smart charging can reduce curtailment of renewable energy, reduce network constraints, and provide valuable ancillary services to the System Operator. In addition, Vehicle to Grid capabilities could replace peaking generation plant.

These benefits *may* be aligned across the system, but different implementations of smart charging can concentrate benefits in one part of the system. For example, a simple static time of use tariff can shift EV charging away from peak demand, to limit network congestion and avoid or delay network reinforcement. An alternative tariff might encourage charging load to absorb otherwise-curtailed solar photovoltaic (PV) electricity, yet this may require increased network capacity. Coordination will be required to ensure smart charging achieves the greatest system benefit.

Policymakers should determine which problem is most acute in their region and ensure that smart charging solutions have appropriate capabilities, supportive regulation and commercial models that can monetise value from appropriate parts of the power system.

3. *Smart charging is a **system solution** that requires diverse actors to work together with **unprecedented coordination**.*

Effective smart charging requires unprecedented coordination of multiple stakeholders across the power system and automotive sectors. While some benefits can be generated with very limited sharing of data, further system benefits can be realised the more data is shared (such as location data for distribution networks, temporal data for renewables-responsive operation, and EV and trip data to account for consumer needs). However, as this data has value, there is a risk of data silos where stakeholders do not share the data they have generated unless they can realise adequate commercial benefit. Concerns surrounding security of sensitive customer data will increase with greater levels of data sharing.

In deregulated markets, the distinct roles of each stakeholder may impede the highly coordinated actions required to deliver optimal system value. In more vertically integrated power markets, stakeholder coordination *may* be more straightforward; but success will still require coordination with charge point providers or EV owners.

It is not yet clear which value chains will deliver best value for the system and energy customer, how to coordinate benefits across the system, and what the regulatory impact will be. In this nascent sector, it will be necessary to encourage continued innovation through trials and financial support. These should encourage multiple stakeholders to work together to deliver system benefits; to identify the data that must be generated and shared to achieve this, and how these benefits can be realised for the minimum cost. An example is the Green Deal funding for infrastructure in the Netherlands, which required data sharing collaboration amongst partners; now the Dutch have the most developed public charging infrastructure in Europe[1].

Policy makers should also review existing regulation and standards to ensure that the necessary data can be generated and shared in an open and secure manner. Where the market fails to deliver the necessary coordination at reasonable cost, policymakers could consider mandating certain stakeholders make data available (as with some smart meter programmes); especially when private companies receive public funding for infrastructure provision. However policy makers must take into account that this will reduce commercial value of data, and risk disincentivising engagement.

4. *Smart charging can be accelerated through an appropriate combination of market incentives and regulation*

Market mechanisms can be simple to implement, but may only recognise operational benefits of smart charging. For example, tariffs have long been used by the power sector to shape electricity use. They are relatively easy to implement and for customers to understand, and can reward smart charging customers for some of the system value they generate, such as operational efficiencies, but if prices and tariffs become more cost reflective, location specific and dynamic, tariff complexity will increase. There is a risk of lower consumer engagement, as well as exposing vulnerable consumers to the downside of higher prices if their charging behaviour is not sufficiently agile. The level of customer response is also not guaranteed - it is not (yet) considered reliable by network planners, so may not offset network and other capacity investments which represent a large proportion of smart benefits. Network utilities are exploring innovative commercial models to reward explicit (contracted) flexibility, such as time of use, or location and congestion reflective pricing. All stakeholders need to build confidence in the expected response to price signals if market mechanisms are to be effective in offsetting infrastructure and capacity investments.

Regulation in this sector has delivered significant benefits for customers, for example, the use of diversity factors in estimating shared network costs significantly reduces connection cost for customers while still providing high capacity access per customer. Regulation may need to be updated to reflect the benefits of smart charging and its value to each part of the energy system, particularly with regards to avoiding capacity investments.

Trials are required to increase confidence in the level of smart charging response to incentives. In the short term the public sector could trial and implement market mechanisms, including time-of-use tariffs e.g. Toronto's Charge TO or New York's SmartCharge; or reward systems, e.g. California's ChargeForward or Netherland's Jedlix, to spur innovation, to quantify level of response and measure system impact. Trials could ensure consumers who continue to charge passively do not see an increase in electricity prices, e.g. through New York Utilities' one-year price guarantees, or rebate only systems, e.g. Arizona Public Service Company (APS) programme. They could also review how existing regulation and legislation (VAT, tariffs, grid costs) are aligned to the market mechanisms and policy aims, e.g. UK & Netherland's review of double-taxing electricity storage. In the longer term, it may be beneficial to regulate a minimum level of smart charging to ensure the growing costs of passive charging are not paid by all. This minimum level will be specific to the problems identified in that region.

5. *Strategic infrastructure investments and learning by doing can spur innovation and expand methods of smart charging.*

Smart charging needs to be deployed rapidly, but there will be continued innovation in how smart charging is provided. For example, a lot of policy support is focussed on the deployment of smart charge points (EVSEs). This is pragmatic: the technology is available now and innovative charge point operators are eager partners in expanding the sector. But alternative configurations are being explored; for example smart charging controlled by the EV or a combination of the EV-EVSE unit. These have the potential to improve the effectiveness of smart charging, but only if automotive manufacturers (OEMs) recognise the value of smart and add functionality to their vehicles in a cost-efficient way. Innovation will not be limited to smart charging hardware, but will extend to incentive schemes, commercial models, and regulation.

Public sector support of trials should allow exploration of different technologies, business models, and data sharing arrangements. Information on costs and system value should be more widely shared. Regulatory impacts should be explored as these can unlock key elements of system value. Policymakers should also consider how to ensure interoperability of hardware to provide industry certainty of their investments, access to data and ease for consumers, while still allowing room for innovation. This could be achieved through regulating smart charging capability (e.g. through standards) rather than specific charging technology and ensuring that regulation allows EVs to participate in the energy markets, including Distribution System Operator (DSO) flexibility and ancillary services.

1 Introduction

The uptake of electric cars has seen rapid growth in recent years, with 2 million electric cars added to the global fleet in 2018 alone[2]. This growth will accelerate over the coming decades as vehicle costs decrease and policy support is extended to drive deeper carbon reductions and air quality improvements in the transport sector. However, this growing electric vehicle (EV) fleet will add a significant component to overall electricity demand. If left unmanaged it could add considerable costs to the power system, which would be passed to consumers and ultimately slow the adoption of EVs.

This paper outlines the potential benefits of smart charging, whereby the EV charging cycle is managed in response to the needs of the energy system and vehicle users[3], and provides recommendations for how policymakers can ensure that smart charging technologies are adopted, and these benefits are realised.

The report is structured as follows:

- Section 1 briefly introduces the benefits of smart charging, how it can be implemented, and a selection of recent smart charging trials.
- Section 2 discusses the technical barriers to implementing smart charging, including data availability, smart charging standards and implementation costs.
- Section 3 presents the consumer and institutional barriers, and discusses the potential business models to encourage adoption.
- Section 4 explores the value of smart charging to the energy system in more detail through a series of case studies for California, New York, Great Britain and Spain.
- Section 5 provides a set of conclusions, and summarises recommendations for policymakers.

1.1 Why is smart charging important?

1.1.1 The downside of passive charging

Passive (or unmanaged) charging describes an EV which charges at the maximum power available as soon as it's plugged in. If this additional electricity demand correlates with high levels of existing demand (as many studies indicate), widespread passive charging will add significant costs to the power system. These include capital investment in additional power production and network capacity to deal with higher peak demand. As peaking power plants tend to be less efficient than baseload, passive charging could offset the operational CO_2 savings from EV use. It would also increase electricity prices at peak times, reducing a key economic incentive for EV adoption.

For example, it has been estimated that at least 30% of the distribution networks in Great Britain will require upgrade investment by 2050 due to widespread adoption of electrified transport with passive charging[4]. In the UK electricity system, passive charging of EVs is predicted to increase costs by nearly £1 billion/year by 2040[5], whilst in California this could be $140 million/year through 2030[6].

Passive charging also represents an inflexible load on the power system, and rapid changes in demand, such as plugging in during the early evening when drivers return home from work, will increase ramp-rates from electricity generators – a challenge already seen by the introduction of solar PV in California.

Instead, smart charging can be employed to shift charging load in response to the needs of the power system. This could delay or avoid network and generation investments and reduce costs by increasing efficient fossil plant utilisation or utilising otherwise-curtailed renewable generation. By improving utilisation of existing assets, smart charging could reduce rates for all consumers[7].

1.1.2 The upside potential of smart charging

Power systems around the world are undergoing a period of rapid transition. Decarbonisation objectives as well as falling costs have led to increased penetration rates of variable renewable electricity sources (VRES), such as wind and solar; resulting in a decline in generating capacity from traditional baseload generators such as coal, gas and nuclear. It is estimated that in 2050, VRES will account for 62% of global electricity generation[8].

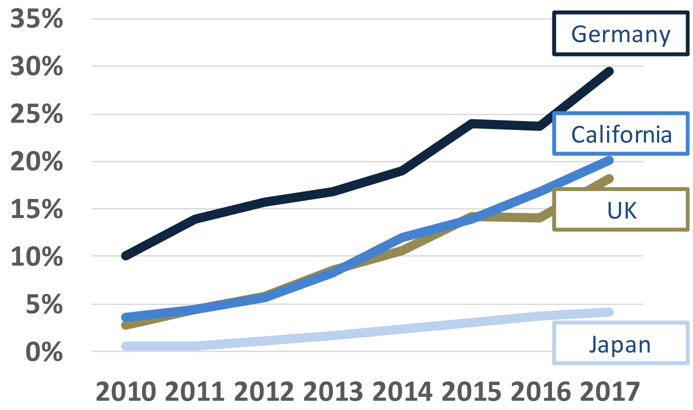

Figure 1: Wind and solar as a proportion of total electricity generation[9].

Increasing penetration of VRES leads to several system impacts:

- During periods of electricity over-supply, electricity prices are depressed and some regions have experienced negative wholesale prices, such as Germany which have high solar output coupled with relatively inflexible baseload coal generators[10] (see Figure 2), and in California and the Pacific Northwest with excess solar and wind generation curtailed to allow an increase in base-load hydro power[11]. Smart charging can move EV demand out of peak times, into these periods of low prices, providing low cost electricity to EV drivers.

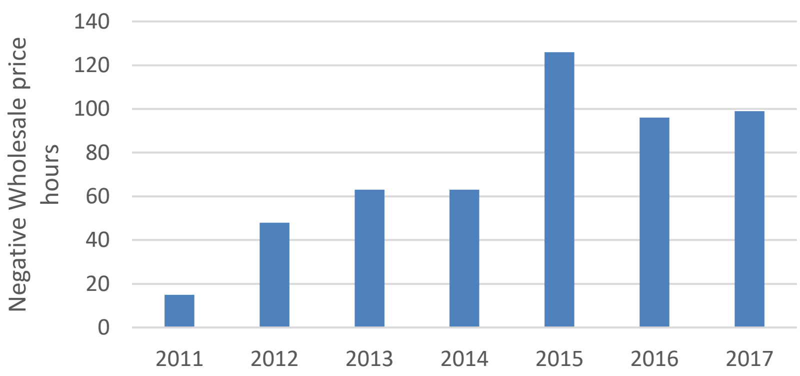

Figure 2: Number of negative hourly wholesale electricity prices on EEX-DE energy trading exchange (Germany)[10].

- At times of high renewable supply, VRES operators may be paid to decrease output (curtailment) which results in wasted renewable electricity supply and thus increased CO_2

emissions[5]. Smart charging can increase demand at these times to reduce curtailment and increase penetration of VRES, supporting grid decarbonisation efforts.
- The difficulty in predicting VRES output will lead to frequent mismatches in electricity supply and demand which will drive more volatility in wholesale electricity prices[12] and higher generator ramp-rate requirements. Also, as large thermal generators exit the power system, reduced system inertia will lead to greater variation in grid frequency[13]. Recent trials (see Table 4 in the Appendix) have shown that smart charging can respond very rapidly to deliver regulation and response services to stabilise the grid.

Additional benefits of bi-directional charging

Much of the benefit from controlled EV charging can be realised by adjusting the rate and time of EV charging demand. Beyond this, enabling electricity to flow out of an EV battery back into the grid, so called Vehicle-to-Grid (V2G), can enhance these benefits. For example, by:

- acting as a "daily" energy store by absorbing renewable energy during times of oversupply, such as when solar generation peaks, and later injecting this back into the grid when demand outstrips renewable supply.
- providing a highly responsive dispatchable peak power source equivalent to a peaking plant.
- augmenting the availability of flexibility services, such as frequency response, by acting as both a source of positive and negative response whenever an EV is plugged in.

Widespread deployment of V2G could have a transformative, positive impact on the grid. However, trials have shown the value of V2G to the EV driver is highly variable; and work continues to support V2G cost reductions and understand impacts such as driver acceptance and battery degradation[14].

1.2 Implementing smart charging

Smart charging can deliver benefits to different parts of the energy system depending on how charging is controlled. How this is achieved, where the benefits arise and how these are monetised depends on partnerships between diverse stakeholders, regulatory constraints, and commercial models (see Figure 3 for an example system). The actors involved are as follows:

- *EV*: electric vehicle
- **EV driver**: the user of the EV, who is responsible for plugging the vehicle into charge.
- **Automotive OEM**: the manufacturer of the vehicles.
- *Private EVSE*: Charge point which is not available to the general public, for example in a home or workplace. Electricity usage for billing is usually metered via the property's *smart meter*.
- *Public EVSE*: Charge point available to the general public, for example, installed on-street or at a dedicated charging hub. Several business models exist but generally energy usage is metered at the charge point and users are billed accordingly.
- **Charge Point Operator (CPO)**: Manages the operation of public EVSEs, including monitoring, maintenance and billing. Private EVSEs can also be monitored by CPOs, but they do not process billing for electricity usage.
- **Distribution System Operator (DSO)**: Manages the low voltage distribution network, and actively manages their network loads.

- **System Operator (SO)**: Manages the security of the power system in real time and co-ordinates the supply of and demand for electricity, avoiding fluctuations in frequency or interruptions of supply.
- **Generator**: Manages assets which generate electricity, such as nuclear and thermal power plants or wind and solar farms.
- **Electricity Supplier**: Resposbile for purchasing electricity on wholesale markets and selling to end users (i.e. EV drivers).
- **Aggregator**: Entity which pools control of the charging of multiple EVs to optimise charging of the aggregate portfolio based on price signals.

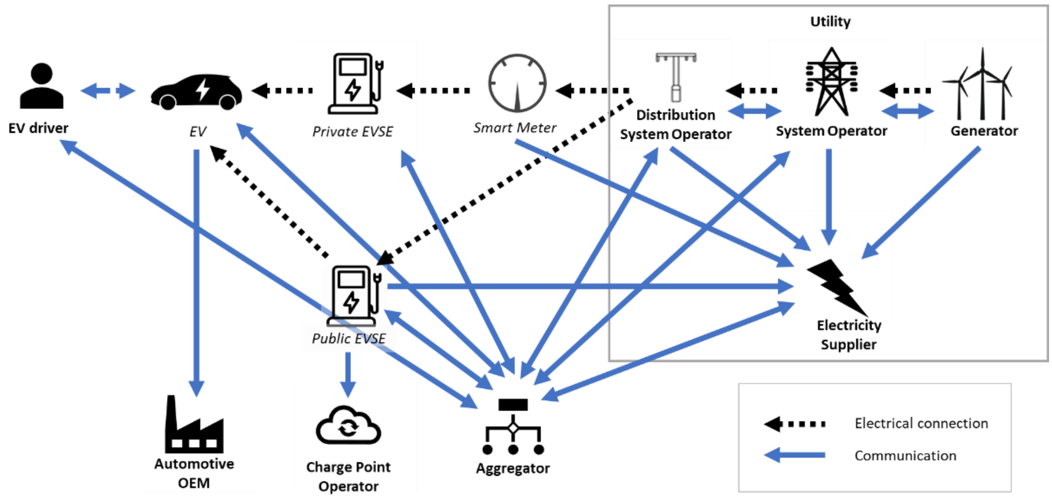

Figure 3: Smart charging involves multiple actors from across the energy, charging and automotive sectors. An aggregator can facilitate the necessary data flows between the relevant actors.

Methods of controlling charging load can be placed into two broad categories:

Smart pricing: Pricing electricity under a time-of-use (TOU) tariff, where electricity is priced at different rates throughout the day, is a simple but effective method of shifting electricity demand, and has been shown to work well in incentivising EV charging behaviour[15,16,17]. Prices can be set to reflect both energy and network requirements, but effectiveness depends on the level of sophistication of the tariff structure and user engagement (see Section 3).

Smart control: In order to guarantee a response, EVs can be externally controlled, for example, by the Distribution System Operator (DSO), System Operator (SO) or electricity supplier, or an aggregator acting on their behalf which may be connected to the automotive or chargepoint industry as well as the energy industry. This can provide higher value services and therefore realise greater benefit to the energy system. For example, DSOs could deploy systems for congestion management to reduce peak load[18,19,20], SOs to procure balancing services[21], and electricity suppliers to match demand to when electricity prices are cheapest[22]. These systems can ensure that EV charging is optimised for the energy network, but require EV drivers to cede control to an external actor.

1.3 Recent smart charging studies and trials

We reviewed over 40 of the most relevant smart charging project studies. Earlier projects often focussed on demonstrating time-shifting of charging out of peak demand times, using simpler interventions like time-of-use (TOU) tariffs. With more recent projects, energy and load related services continue to be central, especially in cases of high DSO involvement. There is an increasing level of technical sophistication with the objective of providing grid regulation services and demonstrating V2G technology. Table 1 highlights some successful smart charging studies which highlight the key benefits and difficulties that are being seen across trials in different regions trying to solve different energy system objectives. A complete list of trials reviewed is shown in the Appendix.

Table 1: Major smart charging trials

Energy system objective	Project	Key learning outcomes
Network constraint management/ peak load avoidance	**ChargeTO (Canada 2017)** My Electric Avenue (2017) Electric Nation (2019) Charge the North (2019)	• 50% reduction in peak load achieved • Must include consumer needs for charging time windows and minimum state-of-charge • Financial incentives required to "opt-in" may initially be high • Need EV only TOU rates to avoid creating secondary peaks or rewards programme.
Provide flexible demand resource capacity to System Operator in response to real time energy prices	**ChargeForward (Ca, 2018)** Power Your Drive (Ca, 2017): Jedlix (NL, 2017)	• Benefit from residential vehicles limited to evening/overnight period • Workplace charging needed to address daytime challenges (e.g. doubling of generator ramp rates due to PV) • Challenges approving technology vendors
Provision of system-critical regulation services to power system operator	**Parker project (DK, 2019)**	• V2G can provide the most technically challenging grid services • Impact of regulation/standards • Value proposition highly sensitive to many factors e.g plug in rates; prices of services, energy and technology, battery degradation

Key findings from trials:

- Trials have proved the significant technical potential to move EV charging demands in response to power system requirements; but the scale of the benefit depends on the charging location (home / workplace) and the power system challenge.
- High levels of acceptance of smart charging is reported, provided that driver needs are taken into account, i.e. minimum battery state of charge, and daily charging windows.
- Many trials provided an economic incentive to participants to move to smart charging. In some cases, the cost of paying the consumer an incentive to 'opt-in' was greater than the value of power system savings they created. Consumer inertia and decisions around opt-in and opt-out tariff designs are important in determining affordability.
- The costs of smart charging programmes are not widely reported, which inhibits a systematic evaluation of trial based cost-benefit.

- Technically advanced services such as provision of regulation could deliver value to customers, but value is uncertain and dependent on a number of factors including the market structure and prices, and technology costs.
- A common feature across trials was the large extent of innovative cross-sectoral collaboration needed to address challenges with data, regulation and commercial models.

2 Technical barriers to implementing smart charging

2.1 Data availability

Static measures, such as time-of-use tariffs, can encourage some smart charging behaviour and solve some system problems, while minimising the need for data sharing. But as EV numbers grow and grid challenges increase, delivering the greatest system value with smart charging will require the collection and sharing of high-resolution data from multiple actors in the EV charging chain. For example, location data is vital for dynamically avoiding congestion in local distribution networks, whereas balancing supply and demand at the energy system level requires temporal data on electricity supply and EV charging demand. Additional data from the EV or EV driver, such as battery state of charge and time of next trip, can also be used to better predict charging demand and improve the quality of service for the consumer[23].

Currently, a diverse number of smart systems are under development which follow different implementation strategies to provide a range of benefits. The VGI Working Group in California has carried out a comprehensive review identifying 47 different smart charging use cases and mapped the data requirements[24]. It is not yet clear what the ideal system(s) will look like but implementing smart charging to deliver optimum benefit to the complete system will require unprecedented levels of coordination between the various energy and charging system actors. Figure 4 shows the data that each energy and EV charging system actor can generate, as well as possible information and control signal flows that could be implemented to facilitate smart charging.

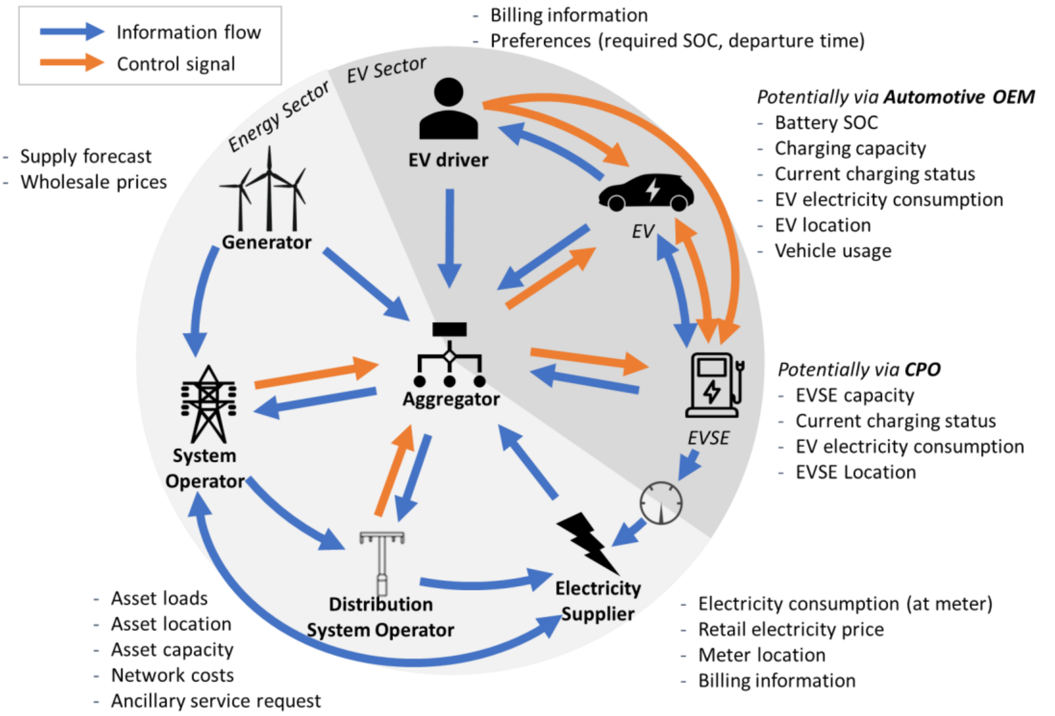

Figure 4: Unprecedented data sharing may be required to deliver system value from smart charging

In Figure 4 most data communication is shown to occur via an aggregator, although direct data exchange between energy and EV charging actors could also be put in place. The advantage of an aggregator is that it can receive information from all actors. If the benefits to the energy system and consumer are priced appropriately, they can then choose a response which fairly trades off the needs of both the energy system and charging EVs, maximising the benefit for the whole system. Conversely, direct control by a single energy system actor would prioritise the needs of that actor which could inadvertently disadvantage others. For example, electricity suppliers are incentivised to schedule charging for when wholesale electricity prices are cheapest, which may coincide with peak demand on the distribution network which DSOs will want to avoid. Maximising the benefit for the whole system is therefore a complex problem, and the potential role that each actor could play in smart charging are discussed further in Section 3.3.

Examples of commercial systems that coordinate data sharing amongst multiple actors are already appearing. The Jedlix[25] smart charging platform in the Netherlands and France and Olivine's platform used in Pacific Gas & Electric (PG&E) and BMW's Total Charge Management pilot[26] in California coordinate data exchange between EV drivers, EVs, EVSEs and utility actors:

Jedlix has developed a smart charging platform, available in the Netherlands and France, which implements an optimal charging profile based on the time when the EV is needed next, available capacity on the grid, availability of renewable energy, and energy prices. The platform collects driver inputs through a smartphone app, and communicates with compatible EVs (Tesla, Renault and BMW), public charge points and partnered electricity suppliers. Savings made by the electricity suppliers are passed onto customers as a reward payment.

The **Total Charge Management** (phase 2 of ChargeForward) pilots smart charging of BMW cars with PG&E customers in California using Olivine's smart charging platform. Olivine collects PG&E's day-ahead forecast of excess renewable supply, vehicle location and charge state from the BMW cars, and target departure time via a smartphone app to optimize charging profile based on renewable supply and the locational marginal price. The system also accounts for any customer's existing TOU tariff to avoid increasing their charging cost. Users are rewarded for their participation.

However, there is a risk that immature commercial value chains and regulatory constraints could give rise to data silos, where data is generated and stored by one entity and is not shared with other entities to benefit the system. For automotive OEMs, for example, EVs currently make up only a very small part of their sales volume and so developing smart charging may not be a focus in the short term. Data collection and communication is also not typically a core part of their business model[27], and those who have implemented data collection via telematics have tended to rely on their own proprietary systems[24]. There is therefore a risk that some automotive OEMs will either not collect data useful for smart charging, or will limit its availability to maximise their share of the value smart charging can generate. EV drivers are also a potential data silo risk, due to their reluctance to share information, such as location, trip patterns, time of next trip, over concerns surrounding data security and an unwillingness to input the requisite data[28].

Initially, innovative and bespoke communication systems may be a necessary feature of this nascent sector as technologies, commercial value chains, and regulations are tested and updated. During pre-commercial stages, policymakers should support trials that encourage appropriate data sharing amongst the various actors, to identify barriers to efficient and safe data sharing, and to determine what is required to deliver the greatest power system benefits.

The risk, however, with this approach is that diverse and non-interoperable systems continue to be deployed and the industry does not quickly coalesce around standardised solutions that allow the industry to drive down costs and scale up deployment. If this begins to act as a hindrance to smart charging adoption, as is beginning to be seen in some regions, policymakers should consider intervening to mandate the requirement for data exchange. This could be through the development and adoption of open communication standards (see section 2.2). This has the additional benefit of ensuring data security, which is of particular importance for personal data collected from the EV driver.

Further streamlining could be achieved through the creation of centralised repositories whereby data from multiple actors is collected together into a single format and made accessible to the necessary market actors. In Norway, the central database NOBIL provides open access to information on charging infrastructure that was captured from public funding. This led to increased information for early EV adopters and supported the early and rapid uptake of EVs in Norway along with provision of national funding[29]. A similar approach has been implemented in the UK with the creation of the Data Communication Company[30] to manage the communication of smart meter data with the business systems of energy suppliers, network operators and other authorised users. However, mandating data collection and exchange can undermine the commercial value of the data and thus disincentivise actors to engage. For example, commercialising the value of their data may be key to getting automotive OEMs to engage, particularly as this additional revenue stream may become increasingly appealing as EV deployment seems likely to erode their revenue streams in vehicle maintenance[31]. Policymakers must therefore ensure that the introduction of any data sharing requirements does not discourage participation and commercialisation.

2.2 Need for open interoperable standards

Adopting standards and protocols can ensure all the hardware and software developed and purchased in a region can provide the data and services necessary for smart charging in a safe and secure manner. A range of standards to facilitate communication between various system actors are currently in development in this space (see Figure 5).

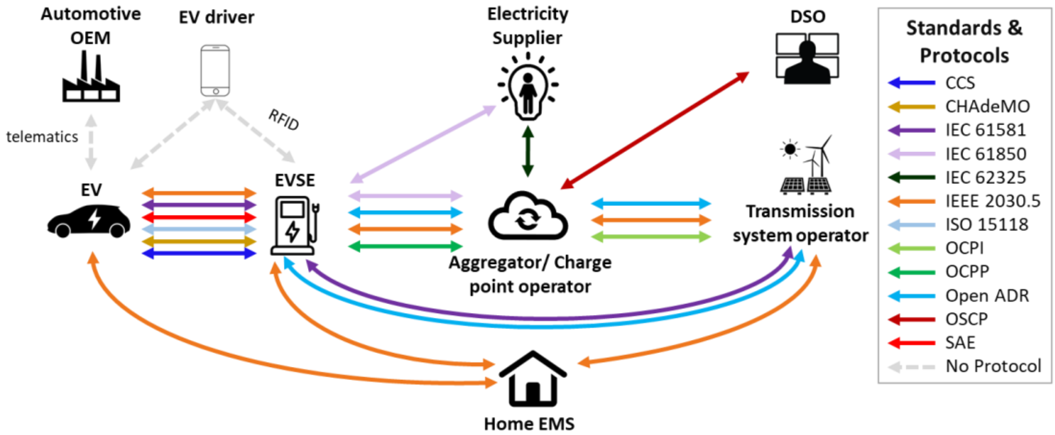

Figure 5: Combinations of standards and protocols relating to EV smart charging

Table 2 shows the range of functionality that several of these standards offer:

Table 2: Smart charging functions enabled by different standards and protocols

Function	ISO 15118	IEC 61850	OCPP (v1.6)	OSCP (v1.0)	OCPI	IEEE 2030.5	Open ADR
Location	EV-EVSE	EVSE-CPO	EVSE-CPO	CPO-DSO	CPO-SO	Various	Various
Start/ stop charging	✓	✓	✓		✓	✓	✓

Verify response	✓	✓	✓		✓	✓	✓
Modulate charge flow/ direction	✓		(v2.0)				✓
Manage battery	✓						
Monitor grid						✓	✓
Monitor distribution network				✓			
Developer	ISO & IEC - *cooperating international standards organisations*		Open Charge Alliance -*Public-private collaborative organisation*		eViolin & Elaad- *NL led*	IEEE - *USDE & NREL led*	Open ADR Alliance - *CA Utility led*
Users	Trials and initial adoption by OEMs[32]	Global adoption	Global use	NL market parties	NL market parties	CA, US & Korea research	Global use, adoption in North America & Asia

Smart charging functionality can be achieved through a number of different combinations of these standards. The minimum functionality that is required is the ability to start and stop vehicle charging in response to an external signal, such as a price signal or direct command. Verification that appropriate action was taken is also required to be rewarded for the action. OCPP is currently the widespread industry standard for EVSEs to respond to control signals from an outside system and integrates with most other standards. It should be considered by policymakers when implementing standards for privately funded EVSEs. IEC 61580 only communicates instantaneous data, and thus may be used where direct control from network operators is preferred.

OCPP 1.6 and IEC 61580 are only capable of controlling the on-off functionality of a charge point. Additional benefits from smart charging can be realised through dynamically modulating the charging power and direction, and as discussed in Section 2.1, accounting for battery state of charge and EV driver preferences. This requires this information to be shared with external actors, from either the EV, EVSE or a combination of the two. At present, communication between EV and EVSE is generally governed by IEC 61580. This passes information to verify the EV and EVSE are connected and to start and stop power flow. Additional data flows are therefore necessary to realise the full benefits of smart charging. For this purpose ISO 15118 has been developed. This allows information, such as battery state of charge and charging schedules, to be passed from the EV to EVSE, and the amount of power the EV can draw can be received from the EVSE. ISO 15118 therefore provides a communication pathway between the EV and the grid via the EVSE. To facilitate this communication pathway OCPP 2.0 was released in 2018 with ongoing trials to support ISO 15118 capabilities.

Further features of ISO 15118 include so called 'plug and charge', which provides secure authentication between the EV and EVSE. This allows charging sessions to begin as soon as EVs are plugged in and the EV is automatically billed for the session. ISO 15118 also supports wireless charging and bi-directional charging, although these have additional hardware requirements. The CHAdeMO connector standard is currently the only one that facilitates bi-directional DC charging. Bi-directional DC CCS charging is set to be released by 2025 and AC V2G components are beginning to be trialled in the Netherlands with no standards developed yet. Initial smart charging and V2G trials have shown consumers are more likely to participate if their vehicle state of charge is considered[23]. ISO 15118 provides this vehicle information along with end-to-end security[33].

Adoption of ISO 15118 is not yet widespread but is expected in the near term and it has received strong support from automotive and EVSE OEMs. The CharIN e.V. Assocatiation, which develops the CCS DC charging standard, and includes a large number of major automotive OEMs as members, such as Audi, BMW, Daimler, Ford, FCA, GM, Honda, Hyundai, PSA, Tesla, VW and Volvo, has publicly backed ISO 15118 as the preferred standard for communication between the EV and EVSE[34]. To ensure future interoperability, introducing ISO 15118 as a minimum requirement in EVs and EVSEs should therefore be considered by policy makers.

Data and control signals can be shared between the EV, EVSE or home energy management system (HEMS) and the SO, DSO, aggregator, electricity supplier or charge point operator using a range of different combinations of standards (see Figure 5). For example, the SO can communicate to an aggregator using OpenADR, and an aggregator can use OCPP to communicate to the EVSE to pause the charging. Or the SO can communicate to the EV via the home energy management system using IEE 2030.5. Dynamically reducing curtailment of renewables requires information to be communicated from the grid on energy generation and wholesale prices. Protocols that enable communication of energy generation include OpenADR, IEEE 2030.5, and OCPI. OpenADR is the most mature and widely used protocol of the three, but it is broad in nature and may require additional specifications for regional needs. IEEE 2030.5 allows communication with a broader set of actors (e.g. home energy management system and the EV), but it is not widely adopted. OCPI is still being drafted but includes information on location and desired EV use schedule.

Reducing network congestion may require additional information on the capacity of the network cables to be communicated by the DSO. OSCP was specifically developed to budget network capacity. However, the standard is not widely used and still requires development of certification and testing[35]. OpenADR and IEEE 2030.5 could also be used to send price and load signals.

Interoperability and access to standards is critical to their adoption. Open protocols, such as OCPP, are widespread in Europe and gaining traction in USA for this reason. Software platforms are an alternative method to enable interoperability. For example, the Hubject platform seeks to provide connectivity to charge points from many different charge point operators. There is no open standard or platform yet to control charging via the EV (using telematics) or obtain information from the automotive OEMs who each use their own proprietary telematics systems. There is also no widely used standard for controlling charging via the home energy management system (HEMS), although the UK is trialling different methods to control charging via the next generation smart meters (SMETS2)[36]. IEEE 2030.5 may be able to support these functionalities however there is little industry development. Alternatively, OCPP could be adopted to include ISO 15118 capabilities, but further support is necessary to ensure this.

There is no ‘one size fits all’ standard that should be adopted in every region, but rather there may be multiple standards that will need to work together to ensure smart charging functionalities are achieved without overburdening the consumer. However, there is a risk that public funding will not be optimally spent if standards are not considered. For example, Norway provided early funding of public infrastructure for Schuko outlets (type 1 chargers) which will need to be replaced for long term EV charging. For this reason, many regions are beginning to require hardware purchased with public funding is compliant with industry standards e.g. in Germany, the Netherlands and Norway. Mapping data flows could support a system cost-benefit analysis that ensures the combination of standards support the minimum data and verification necessary for country specific solutions. To enable widespread access and innovation, policy makers should consider:

- Involvement in collaborative standard developments e.g. Elaad's support of the Open Charge Alliance.
- Collaboration between standards development for EVs and wider DSR e.g. the British Standards Institute (BSI) collaborating with the Office for Low Emission Vehicles (OLEV) and Department for Business, Energy and Industrial Strategy (BEIS) to develop a framework for DSR[37].
- Where possible, development of standards without being prescriptive, e.g. adopting open protocols rather than a specific piece of hardware.

Trials and financial support of protocol development can provide additional use cases to increase adoption, but policy makers should also consider adoption of open standards once the commercial arrangements have been proven.

2.3 Costs of smart charging

The costs of smart charging are somewhat uncertain since the systems being implemented are diverse and still under development, and attempt to solve a variety of grid issues with varying degree of capability. Simple time-of-use tariffs, for example, can be implemented through just a smart meter, whereas systems that employ dynamic control require communication and control components, and involvement of other energy system actors, which adds cost. In addition, the published cost data on the required components for these systems reflects current costs and are not necessarily representative of the cost of smart charging deployed at scale. In order to understand the range of costs of deploying smart charging, the cost components can be separated into four distinct areas:

1. **Smart components to communicate with external actors and control charging:** these can be located either in the EV or EVSE or both[38].The cost of adding simple remote control and monitoring functionality to a home EVSE is around $100[39], with no ongoing cost because the unit can utilise a building's existing internet connection via WiFi or ethernet. Paid public EVSEs already have control and communication functionality, as this is required for billing customers for usage, and so smart charging capability should not add significant further cost. For example, the widely used OCPP standard, which enables communication between EVSE and charge point operator, has supported smart charging commands since Version 1.6[40].

With growth in the level of connectedness in cars, similar communication and control functions are also provided directly by some EVs, although these do not have the same authentication and billing functionalities of the current smart EVSEs. They tend to be paid for via monthly service fees rather than an upfront cost. These fees will vary between region and automotive OEM but are in the range of free to $5/month:

- Tesla Standard Plan and NissanConnect are free and include remote charging control.
- BMW Digital Charging Service costs $4.90/month[41].
- Renault My ZE Interactive costs $5.40/month[42].

However, these prices are for a standalone remote charging function. Some automotive OEMs instead bundle remote charging within a suite of connectivity services, e.g. music streaming, Wi-Fi hotspot, vehicle health monitoring, vehicle locator. Car owners are charged a monthly fee, although a free subscription is usually provided for the first few months or years of ownership, allowing the hardware to be installed as standard. For example:

- Hyundai Blue Link packages cost from $10 to $30/month (free for 3 years) and are available on nearly all new models. Features include remote charging control, remote diagnostics, remote start, remote climate control, geofencing and car finder[43].
- Chevrolet Connected Services plans cost from free to $60/month, with some premium features available for free for a limited time after purchase. Features include remote charging control, emergency assistance, remote diagnostics, car finder, and unlimited data streaming[44].

The marginal cost of adding remote charging control to an already connected car is likely to be low. Thus, potential cost savings for deploying smart charging can be made if bundled with other connectivity services.

2. **Smart metering:** An energy meter is required to accurately measure the volume and time of electricity consumption, and communicate this with external actors, such as the electricity supplier for billing purposes or an aggregator to validate the requisite response to a control signal. For charging at a private EVSE, the simplest approach is to use a smart meter installed in the household or building from which the EV draws its electricity supply, although this requires the rest of the household load to be billed under the smart charging tariff. Based on the UK's Cost-Benefit Analysis of its smart meter programme, the cost of a smart meter is estimated to be $260 per building, although the meter and communication equipment cost makes up only $95 of this[45]. The remainder includes cost of installation, maintenance and setting up the communications network. However, many countries are already deploying smart meter programmes as part of their general upgrade to smart grids. The EU's Third Energy Package, for example, requires Member States to implement smart metering, and aims to replace at least 80% of electricity meters with smart meters by 2020[46]. In this case smart charging can take advantage of this existing metering capability.

   In future, a meter component could also be installed in the EV or EVSE, providing submetering of the EV charging load. Submetering allows the EV charging to be billed separately from the rest of the household load, which has benefits for consumer acceptance of smart charging (see Section 3.1), without the need for a new dedicated circuit and utility grade meter to be installed, which costs in the range of $2,000-$3,000[47]. Connected EVs and EVSEs can already provide some level of metering, however regulatory requirements mean that the measuring devices used may not be certified for the purpose of billing electricity usage. For example, in the EU, new electricity meters must comply with the Measuring Instruments Directive[48]. This will increase the cost of providing this metering function from the EV or EVSE. The cost of a standalone submeter, such as the WattBox from eMotorWerks, is $250 plus installation[49], but costs could be lower if integrated at scale into an EV or EVSE.

   The true cost of adding connectivity and a certified meter is therefore somewhat uncertain. A possible cost saving measure could be to deploy billing approaches that can tolerate lower accuracy, for example, through rewarding users with fixed payments for participating in smart charging. This approach is used in the BMW ChargeForward pilot, where participants can earn up to $900 depending on how often they opt-in to smart charging[50]. This is cheaper to implement from a hardware perspective but provides less control over incentivising consumer behaviour, and so may not unlock the full benefits of smart charging.

   Provision of ancillary services may require additional metering capabilities to prequalify assets or verify the response from the EV. However, the testing and metering requirements set for MW scale assets may be cost prohibitive to deploy at scale for large portfolios of EVs.

For example, prequalification for frequency response services in the UK requires live frequency injections and the industry standard is to use synectic meters[51] for this test, which cost $300-$450. In Finland, one-minute measurements are required for frequency containment reserve markets at increased costs. Regulators could work with aggregators to determine acceptable levels of accuracy, latency and time scales for power, energy and frequency. Trials could determine how to lower metering costs by using cheaper meters, e.g with integrated circuit (IC) chips which use electronic measurements for reduced cost[52], or requiring fewer meters, e.g. by metering the response of multiple assets in an area with one meter[53].

3. **Aggregator platform costs:** Aggregators who provide a platform to externally control EV charging based on an optimisation of the needs of the EV driver and energy system actors add an additional cost component to smart charging. The exact fee they command will be dependent on the level of service they provide and the demand for this service. Current evidence suggests a cost of approximately $30/EV/year when the aggregator has scaled this service to thousands of EVs.[54]

4. Additional Utility, DSO or SO costs: in order to take advantage of smart charging EVs, DSOs and SOs will need to be capable of forecasting and monitoring demand and supply, and send control signals to be actioned by EVs, potentially via aggregators.

For SOs, procurement of balancing services is part of their business as usual operation however procurement services are based on larger scale assets. Some existing systems have utilised software platforms to send signals based on the grid generation to EVs e.g. eMotorworks Juicenet platform in Minnesota[55] and Jedlix platform in the Netherlands. EVs participating in existing ancillary service mechanisms are already observed today (see section 3.2.3), e.g. in Delaware, an EV project supplied services using the existing REG-D (Dynamic Regulation) signal for flywheels and stationary batteries with an aggregator acting as the intermediary[56]. However, the systems require aggregators to pool EV charging loads and the effective markets for aggregators to participate in.

For DSOs, transitioning from traditional Distribution Network Operators (DNO) is likely to incur significant investment to improve network monitoring, establish marketplaces for flexibility, and create a level playing field for actors. For example, in New York the regulatory 'Reforming Energy Vision' enabled the utilities to file an innovative three step plan to upgrade the distribution grid with data collection hardware, create a marketplace for utilities and distributed resources, and then open it to third party providers[57]. In the UK, new price controls are spurring the transition from DNOs to DSOs; Northern Powergrid plans to invest £83m to install monitoring and control equipment in more than 8,000 substations[58] and Western Power Distribution values their transition at £125m[59]. Adapting market design, regulation, and consumer incentives to deliver DSO load services (see section 3.2.3) may also require additional costs. But these costs are part of the transition to a smart grid and so should not be wholly attributed to implementing smart EV charging.

Outlook

Whilst the system design that provides the best trade-off between system benefit and cost is yet to be determined, it is recommended that policymakers continue to support trials which allow the market to test novel smart charging approaches which have the potential to deliver cost savings. In initial smart charging trials, additional incentive payments may be required to encourage some consumers to participate e.g. Con Edison Smart Charge New York provides $150 for signing up and the possibility of up to $500 in rewards[60] and ChargeTO study found one-off payments up to $40 were able to persuade participants to reduce the minimum battery state of charge at which they chose to opt-out of smart charging[61]. In the short term, public funding may therefore be needed to offset this additional costs. These incentives may not be necessary for some consumers and may also be phased out as the market develops to allow consumers to capture the energy system benefits of smart charging.

Regulation should also be reviewed to ensure it is not imposing unnecessary costs on smart charging components, for example, public utility codes that specify requirements for revenue grade meters to participate in energy market. These could be amended to provide pathways for automotive OEMs and EVSE providers to meet utility requirements, with the necessary measurement and verification protocols, without levying high certification costs.

2.4 Where should the 'smartness' lie?

As discussed in Section 2.3, smart charging requires a number of functions to be effective. A meter is required to measure the provision of the service, and this will need to meet the standard required by the service. A communication route will be required for metering data to be sent out; and to receive control signals or to respond to dynamic tariffs. Finally, to provide services to the Distribution Network operator, the EV-EVSE "unit" will need location data so that it can be registered as providing services to a particular section of congested network. This could be a metering point, for example, each of the Meter Point Access Numbers (MPANs) used in the UK have a specific location associated.

To date, regulation that encourages smart charging has tended to favour the EVSE as the point of this 'smartness'. For example, the UK's Automated and Electric Vehicles Act 2018 gives the government the power to mandate all EVSEs to have remote monitoring and control capability[62], and as of July 2019 this is a condition to receiving a government grant for home EVSEs. The European Commission has also proposed to update the Building Energy Efficiency Directive to require charge points in new and renovated homes with ICT capabilities to enable smart charging[63]. This approach is reasonable since government intervention is effective in the nascent EVSE market which is more dependent on public funding, the charge point providers are willing to add capabilities and standards have been developed incorporating the necessary functionality. But policymakers should also be aware that integrating smart components into EVs could provide additional solutions in the future.

The location of "smartness" will have implications on smart charging costs and capabilities:

Cost: Smart charging can leverage the 'connected car' service, which is being deployed by automotive OEMs to offer services to drivers including safety, maintenance, mapping and media purposes (see Section 2.3). This would allow the costs of charging, monitoring and control to be shared across these other services. Embedded connectivity is expected to become increasingly common, estimated to be installed in 55% of new cars in 2020 and 64% in 2025, with the remainder offering connectivity via a smartphone[64]. However, connectivity is already widespread in EVs. A review of EV models sold in the US in 2018 found that 97% have embedded connectivity, including remote charging control via a smartphone app[65]. However the additional cost of metering and authentication would need to be borne by the EV (or the charging cable, as mentioned below).

Capabilities: The capabilities of a smart charging system, and thus the benefits it can realise, improve the greater the volume and quality of data that is available. Smart EVSEs are already highly capable and can safely provide locational charging data, so they are able to start providing load management services immediately. But the key benefit of adding charging 'smartness' in the EV would be that it grants access to vehicle data, such as trip patterns, battery state of charge and battery temperature, which are important for designing systems that meet the needs of the consumer. However, this relies on accessing data from vehicle telematics, which are currently all supplied through the automotive OEMs' own proprietary systems. In addition, telematics generally do not yet have the authentication and billing capabilities that EVSEs have which would be needed for load management and payments. Alternatively, EVSEs could provide these capabilities and also access the vehicle data if the EVSE can communicate with the EV (e.g. via ISO 15118). However, EVSEs are not necessarily involved in all EV charging events, since EVs can be charged from a traditional domestic outlet with a Mode 2 charging cable. Therefore a roll-out of smart EVSEs does not guarantee all EVs are charged in a smart manner. Installing all the necessary smart components in an EV, on the other hand, could ensure a consistent level of capability regardless of where/how the EV is charging, although does not guarantee the same level of load management capabilities now.

Metering: If submetering is required, installing the metering components in the EV poses challenges over an EVSE. EVSEs are static and so can easily be associated with a primary meter for submetering purposes. EVs on the other hand can charge at any number of locations, not just at home, and a form of mobile metering with locational data would be required. However, mobile metering is an area under active development:

- The FleetCarma C2 device offers mobile submeters that can be plugged into an EV without any installation cost and use telematics to transmit data usage to the utility or third party. They have been used in trials in New York, Toronto, And Arizona[66].
- Ubitricity is trialling EV charging with "Mobile MPANs" in London. This uses meters approved for 15 minute electricity consumption installed in a 'smart' charging cable[67]. Simple charging points, which do not have internet connection, are installed in lamp posts and Ubitiricity holds a register of where these are located on the distribution network. The cable identifies the charge point and communicates the required information over the mobile data network for billing purposes. If a data connection is not available, the cable is also able to store charging information until it regains a signal. The method for accounting for the mobile meter has been formally approved by ELEXON (the regulator responsible for unmetered arrangements). While this system is not providing a full range of system services, this "EV-centric" approach to smart charging has the potential to do so. Ubitricity has also revealed ambitions to integrate its mobile metering technology directly into vehicles[68].

On-board metering could offer a lower cost alternative to static meters but utilities and energy system providers may require substantial testing of mobile metering solutions, updating regulation, and aligning specifications across jurisdictions, before adoption.

In designing smart charging policy, policymakers should consider solutions that will ensure all new charging infrastructure will be capable of smart charging in some manner, but care must be taken to ensure the market has an opportunity to explore all options. If intervention is deemed necessary to ensure smart charging is adopted, it may be prudent to mandate minimum smart charging capabilities which are EV and EVSE agnostic, rather than specific hardware, and allow the market to develop the most cost-effective solution to deliver this. Policy makers should also consider supporting communication capabilities between EVs and EVSEs to support both solutions in the future.

3 Consumer and institutional barriers to implementing smart charging

3.1 Consumer barriers

Successful deployment of smart charging is highly dependent on widespread acceptance by consumers. Trial data on nascent technologies always requires careful extrapolation to mass market, but trials do indicate broad acceptance of externally managed charging[4,17]. The ETI Consumers, Vehicles and Energy Integration (CVEI) trial, the first to explore the attitudes of mainstream consumers rather than early adopters, found that nearly 90% of participants would prefer to smart charge over passive charging, with responses marginally in favour of charging with time-of-use tariffs rather than allowing external control.

However, although attitudes are generally positive, in practice consumer inertia means that widespread adoption of smart charging is not guaranteed. Consumer unwillingness to engage in energy markets is widely observed[69], for example, in liberalised electricity supply markets many consumers rarely switch energy supplier despite a cheaper offer with identical levels of service being available[70]. An analysis of consumers taking part in The Big Switch, a collective energy switching exercise in the UK, found that although consumers were more likely to switch to a cheaper energy supplier the greater the savings, less than 45% chose to switch even with a potential saving of more than £300 per year [71]. Similarly, consumers may be slow to adopt smart charging even if it saves them money and has no negative impacts on their driving requirements. System value of smart charging may well be lower than the cost of overcoming inertia and shifting from passive to smart. Therefore, understanding the barriers that consumers face is critical to developing a viable and fair smart charging market. These barriers, and their potential mitigation, include:

Loss of control: Giving up control of charging to an external actor is a concern for some consumers[28,72], as this reduces certainty regarding vehicle state of charge. Delayed charging increases the risk that the state of charge, and thus driving range, may not be sufficient if the EV is needed earlier than expected. This may be exacerbated if the load management optimisation does not factor in driver preferences. Smart charging systems must account for the needs of the consumer to ensure that they do not result in lost consumer confidence in the technology. If some level of smart charging is to be mandated in future, policymakers must first support and allow the market to develop smart charging mechanisms that meet the needs of consumers. They should also consider how to ensure that smart charging systems automatically optimise for both consumer driving needs as well as energy system needs. It has also been shown that installation of a dense public charging network makes consumers more comfortable with smart charging, particularly with external control, since this is perceived to act as a back-up in case the smart charging system fails[17].

Inconvenience: Requiring drivers to change their charging behaviour (e.g. to start charging during off-peak times) or input information adds inconvenience[73]. During the Electric Nation trial, 57% of participants had no interest in using the provided apps to input charging or journey information, and a further 8% used them only once[4]. Policy makers should consider how to capture consumer driving needs in a convenient manner. Where possible, systems should be automated to reduce the burden on the consumer of having to input information and being responsible for balancing the needs of the energy system with their own. E.g. the Mobility House trial used EVSEs that scheduled charging based on changing price signals.

Data security: Privacy and data security are key concerns involved with the collection and aggregation of vehicle driving and charging data[73]. It is therefore critical that sensitive personal data is communicated in a secure fashion. The development of clear regulation and standardisation surrounding ownership and use of data for smart charging is recommended e.g. the General Data Protection Regulation (GDPR) in the EU requires data to be anonymised, and was updated for smart meter data based on the 'Clean Energy For All Europeans' directive to ensure data protection issues were tackled[74]. This approach is similar to that used by FleetCarma, who addressed privacy concerns by anonymising user data sent to Utilities[66].

Cost uncertainty: There is concern amongst some consumers that smart charging will actually increase their electricity bills, for example, if they frequently have to charge during peak times, or because they must switch their entire household electricity supply to a smart tariff[75]. Submetering or separate metering on a dedicated charging circuit, which allow an EV's charging load to be billed separately from the rest of the house, are potential tools to alleviate consumer concerns around inadvertent increases in household electricity bills. In a survey carried out for California Public Utility Commission's (CPUC) submetering pilot, 41% of respondents wanted to utilise submetering, provided they could save money on electricity and/or charging equipment[76]. Therefore, regulation may need to be reviewed to ensure it allows EV drivers to receive some form of financial benefit for smart charging measured through a potentially lower grade submeter installed in either the EV or EVSE.

In the short term, policymakers can continue to support the market in developing innovative smart charging solutions and allow consumers to participate in the ones that work best for them. This will provide valuable real-world insight into attitudes towards smart charging and how effective various solutions are. Allowing this flexibility will also ensure that the transition to EVs isn't inadvertently curtailed by overly restrictive charging regulation. However, longer term intervention to limit passive charging may become necessary if the socialised costs of passive charging become a burden on all electricity consumers. Total adoption of smart charging could be guaranteed by mandating its usage and banning passive charging, but this could have serious negative consequences for consumers who are unable to charge outside of peak times.

Instead, policymakers could take advantage of consumer inertia by making some form of smart charging the default option and require consumers to actively opt-out if they need to passive charge or want to smart charge using a different system. This strategy has been employed by the CPUC which has mandated California's three investor owned utilities to transition all customers onto TOU tariffs by default by 2019. Customers who do not want to be charged on a TOU basis must then choose to opt-out, although evidence suggests that few actually do. PG&E transitioned 115,000 customers to a TOU tariff in a pilot and found over 90% remained on the plan[77]. A strategy similar has been deployed in Spain where a dynamic TOU tariff, the *Voluntary Price for Small Consumers*, is the default tariff and consumers can opt-out to subscribe to another supplier or contract structure[78]. This has resulted in 40% of consumers using this tariff, however this is down from 60% in 2016 as consumers have demanded price certainty.

3.2 Smart charging business models

Public sector programmes have been vital for supporting EV charge point deployment. Examples include Germany funding €300 million for public charging infrastructure through to 2020, and the CPUC granting an additional $750 million for the state's large utilities to expand EV infrastructure and rebate programmes. Infrastructure upgrade costs (i.e. on the utility side of the meter) can be a significant fraction of the overall cost of charge point deployment[3]. While it is expected that there will be a transition in the medium term to viable public charge point commercial models,[79] charge points are capital intensive assets where revenues are uncertain. There remains a question of the role of the public sector and utilities versus a market driven approach in addressing infrastructure costs, in particular monetising smart charging savings to improve the commercial case.

3.2.1 Monetising smart savings

In evaluating the commercial case for smart charge point deployment, the ability of the investor to monetise (smart) savings is central. It is important to differentiate between operational savings (such as consuming energy at the lowest daily prices) and capacity savings (where smart charging can defer or avoid investment). Smart charging can generate value throughout the energy system, but it may be challenging to monetise all these savings. For example, the New York State Public Service Commission (PSC) showed utility and social value of investing in charging infrastructure were greater than cost of the charge point deployment programmes[80], however each utility did not have access to all these revenues.

A utility may have the scope to value these system savings; in this way, a regulated utility is able to defend investment in charge point deployment because it delivers overall value to the customer e.g. US utilities are rapidly deploying charging stations, with SCE adding 48,000 over 4 years and New York installing 1,000 EV chargers[81]. However, they may be better suited to deliver cost effective infrastructure e.g. SDG&E's Power Your Drive program cost nearly 50% more per unit for deployment than those of the non-vertically integrated California utilities.

With (vertically) unbundled utilities, each actor has a narrower remit and may only be able to monetise a narrow part of the system value stack. In some cases, taking actions that benefit the complete system may contravene regulation[82]. As a result, it is far harder for a charge point investment to deliver a commercial return, unless more of the whole system value stack can be monetised. For example, an energy supplier can provide a wholesale price reflective tariff (e.g. Octopus Energy's Agile tariff[83]) to an EV customer; but valuing capacity savings (such as avoided distribution capacity investments) is significantly harder (e.g. UK DNOs using software platform Piclo Flex to create a flexibility market to avoid investment in network constrained areas)[84]. Increasingly, innovative aggregator companies have entered the space, with the objective of reconstituting more of the revenue stack, and passing savings on to customers.

3.2.2 EVs and connection costs/network tariffs

The potential network distribution upgrade costs of passive charging could be significant. For example, the 2018 load research report by California's investor-owned utilities reported that the (limited) amount of reinforcement required amounted to $1000-4000/EV where this was outside of typical residential allowances[85]. These are edge cases; EV numbers are still very low and the average rate of reinforcement per vehicle is small; but existing headroom is being used up and the rate of reinforcement will increase with deployment.

Costs for upgrades to the utility distribution system, including secondary lines and transformers, are often treated as common facility costs / socialised costs, e.g. upgrades required for adding residential chargers are currently absorbed by ratepayers in California and the UK. This is for very sound economic and engineering reasons; grouping customers allows network capacity to be shared while significantly improving utilisation rates at the lowest levels of the distribution system.

While studies show that EV charging can increase utilisation rates to lower costs for all rate payers[86] this is provided no additional capacity is required. Widespread deployment of EVs will require smart charging to limit network capacity investments. To ensure utilities plan efficient investments, they will need to have high confidence in the capability of smart charging to avoid increases in peak demand and in the metering accuracy.

3.2.3 Ways of monetising smart savings

Retail Tariffs

Electricity tariffs can be provided to EV drivers to encourage smart charging behaviour. Relative to the appropriate baseline or counterfactual, tariffs should be:

- Effective: rewards actions that benefits the power system e.g. shifting charging to avoid network congestion or capture renewable generation
- Efficient: the benefits of the tariff are greater than the costs to administer it
- Clear: transparent and simple to understand to achieve high engagement e.g. minimal rate changes and maximum visibility of price increases
- Safeguarded: consumers are protected from price increases e.g. a customer transferring to a smart tariff without changing behaviour could lose money[87]

Static TOU: These offer an agreed, set price which changes throughout the day, often in blocks of time. They are relatively straightforward to implement, requiring only a meter which can record usage within each time block. When demand, supply and electricity price patterns are predicable, the tariff can reflect these quite well and encourage appropriate behaviour. Thus, they are efficient and clear, however, they cannot respond to more rapid grid dynamics and thus may be less effective in certain regions aiming to capture variable renewable generation. This tariff is commonly used in the UK & Italy and by several retailers in the United States for home EV tariffs.

Dynamic TOU: These change the tariff price over time based on changing market conditions, usually the wholesale price. EV drivers are notified of tariff changes in advance and can either schedule charging themselves or employ a smart system to actively monitor the upcoming prices and optimise charging to minimize cost whilst meeting the driver's required state of charge and driving needs. Hourly prices can be effective at motivating consumers to shift[88], but relative complexity of the tariff risks some consumers paying higher prices if their EV charging behaviour continues to be "passive". Thus while they can be extremely effective, they may be less efficient, clear and fair. Examples of this tariff are used in Spain, at San Diego Gas and Electric's Power Your Drive charging stations, and by ComEd in Illinois on an opt-out basis. Automation of smart charging technology may increase the effectiveness and fairness of these tariffs.

Peak Pricing Tariffs: Peak pricing, which can be static or variable, is used to disincentivise electricity use at peak electricity times, either a few days a year (critical Peak) or varies dynamically (variable peak). Critical peak pricing is used in France and variable peak tariffs are used in Norway and Denmark. This pricing is able to capture seasonal variation and reduce peak demand, but risks some consumers paying higher prices if the load is not shiftable. Peak time rebates are the opposite of critical peak schemes, where rebates are provided for consuming energy at a certain period. E.g. Arizona Public Service Company (APS), a utility in the United States, proposed a programme to reduce curtailment of solar energy during periods of negative pricing in the summer by paying consumers to use the energy during those times, i.e. EVs can charge for free.

As mentioned in Section 3.1, several regions have begun to use a 'default' TOU rate where consumers must opt-out of the pricing scheme. An EU directive will likely make offering TOU tariffs mandatory in Europe by 2020. Regulated utilities, e.g. in the United States, faced significant obstacles in introducing TOU tariffs due to the risk to passive consumers and negative perception by consumers. This perception is rapidly changing, e.g. Arizona's voluntary TOU peak rebate enrols the majority of consumers, and now the majority of US utilities are studying the impacts or offering trials with TOU tariffs[89].

A key risk when using TOU tariffs for smart charging is that consumers may be unable or unwilling to shift demand for their whole house. A Deloitte study of US utilities found that half offered TOU tariffs, of which the majority provide discounts for off-peak charging and only 19% of which offered a separate meter and pricing for EVs[89]. EV only rates may need to consider if they intend to incentivise EVs or minimise cross-subsidies. However, there are a few regulatory barriers to providing separate rates for EVs. One issue associated is the additional costs of metering and billing (see Section 2.3). In the UK, a supplier was granted an electricity supply licence with reduced regulatory obligations if they contracted with a fully licenced supplier to provide only EV tariffs[90].

Network charges

Network utilities must ensure there is sufficient system capacity to meet peak demands, and studies agree that significant investment would be required under widespread passive charging. Innovative distribution utilities e.g. UKPN in the UK are trialling explicit flexibility options such as timed connection capacity agreements, and constraint management markets, which contractually bind customers to limit capacity at critical times. In Germany, DSOs can classify EVs as a controllable end use allowing them to manage the EVs' charging during network congestion events in exchange for lower network rates[91]. Such explicit flexibility (equivalent to smart control) may be more acceptable to commercial customers with better visibility of demand patterns. Implicit flexibility (where customers respond to price signals) can be more appropriate at residential level, but this has the drawback that the response to the signal is not guaranteed. Trials which clarify smart charging response rates will be important to allow utilities to incorporate implicit smart charging into their investment projections. For example, Wellington Electric, a DNO in New Zealand, trialled the response of EV owners to their EV night tariff to determine the diversity effect and future capacity needs before updating their network charges[92].

Ancillary services

The Electricity System Operator (SO) procures a portfolio of energy services across a range of timescales, to ensure the electricity grid remains in balance and stable despite contingencies. The specification and names of these services vary significantly between jurisdictions; but in a very simplified representation can be thought of as being one of these types:

1. **Fast Frequency Response:** some markets have investigated or implemented fast or enhanced frequency response (FFR and EFR) that can respond near instantaneously to support voltage and frequency on the grid.
2. **Frequency Regulation services**: these keep the frequency of the grid in prescribed limits, during normal operation and when there is a significant perturbation (such as when a large generator goes offline). Although regulation markets are small (compared to wholesale markets), assets must react very quickly (4 – 10 seconds in the US) to grid conditions and so typically these services have attracted a high specific value.
3. **Reserve services:** these are services which operate between regulation and wholesale markets, typically from 1 minute to sub 1 hour in duration. They tend to attract a lower specific value than regulation services, but the market is larger. Reserves are paid to be available, but are called upon infrequently during contingency events to support the grid.

4. **Real-time & Imbalance energy markets**: these are operated continuously in real-time at 5-, 15- and 30-minute intervals in different markets around the world to balance loads and resources and manage forecast error. Prices are more volatile than day- and hour-ahead energy markets with price spikes that are unpredictable, but provide high revenues when they occur.
5. **New services:** markets are investigating new ancillary services to support higher penetrations of renewables. Ramping or load following is the ability to rapidly increase or decrease output to manage uncertainty and forecast error for generation and load both over short (5-15 minute) and long (multiple hour) time frames. For example, in California, PV introduction has doubled net demand ramp rates (change in GW/hour) in 5 years, however the current overall value of specific services for flexible ramping is low – increasing ramping requirements are met via the real-time energy market[93].

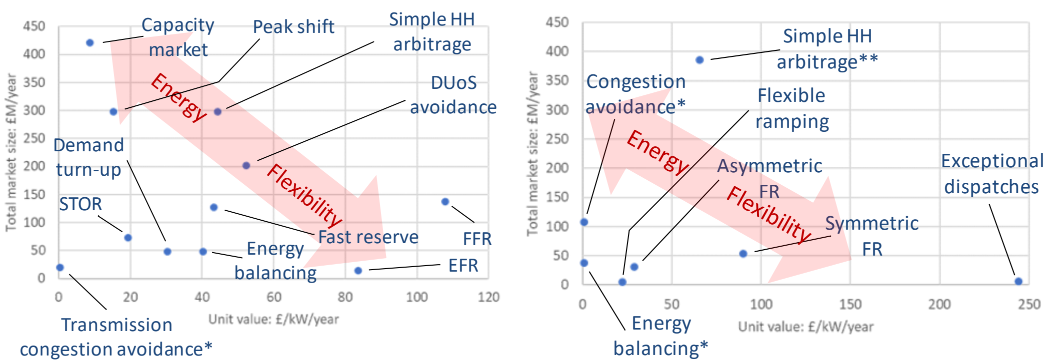

Figure 6: Indicative Specific value and Market size for a range of services: left: GB, Right, California

Due to their high specific value, and the rewarding based on capacity as well as utilisation, some EV smart charging demonstration projects have focused on providing FFR and regulation services[94]. Trials have shown the technical potential e.g. the Danish Parker project provides frequency and voltage control via V2G, and Virtual Power Plant operator Next Kraftwerke and aggregator Jedlix launched a pilot to provide FRR in the Netherlands[21]. In the right circumstances, they could provide valuable revenue streams to support the introduction of new technologies.

However, these markets are small and when deregulated, are subject to competition from new technologies. For example, the FFR market in the UK has seen a 30%-60% year on year reduction in value recently. Reserve markets are larger and so are less susceptible to dilution of value. In addition, the costs of accessing these markets (often the practice of testing and metering) may be prohibitively high.

Conclusions

In the short term, trials may be required to understand the impacts of different market incentive tariff structures including: institutional barriers, optimal pricing structures, the impacts to consumers and impact to the network and energy system. In the longer term, policy makers may need to make changes to legislation and regulation to ensure financial incentives are aligned for certain tariff components.[95]

3.3 Who should own the smart charging value chain?

Several industry players are expanding their core business model to lead in offering new smart charging services and increase their revenues or customer base. While they all have incentives to offer smart charging, they all require either an expansion in their core business model or partnerships and thus no player is yet dominating the market (see Table 3). No dominant business model for smart charging services has yet emerged.

Table 3: Comparison of potential providers of smart charging services

Leader	Strengths	Weakness	Examples
Utility/ Electricity Supplier	• Large customer base • Expertise in energy services • Experience with some tariffs to access some system benefits	• Risk of monopolies • Consumer trust may be low • Must benefit all ratepayers (if Utility)	• SGD&E Power Your Drive • WPD Electric Nation
Charge Point Operator	• Motivated to be innovative and create market • Smooth experience for consumers with public charging • Incentive to access charging data	• Risk of technology lock-in • No control of tariff or household loads • High costs at low volume production	• Virta (Luxembourg, Finland Trials) • Nuvve - Grid Motion, France
Automotive OEM	• Access to vehicle & battery data • Large customer base, driver focus reduces risk • Motivated to replace maintenance revenue streams lost through EV introduction • Smartness aligned with connected car • Potential for lowest costs at scale	• No control of energy supply or tariffs • Risk of not optimising for energy system • Risk of data silos	• BMW ChargeForward • Nissan V2G Trials
Aggregator	• Compatible with existing and future business models and technologies • Technology neutral	• Small customer base • Not driver focussed • Dilutes consumer revenues/savings	• Jedlix trials in Netherlands

Near term, trials have revealed that partnerships along the value chain are required to realise full smart charging services. Aggregators often appear to facilitate data exchange and expand the benefits of smart charging, leveraging the consumer base of suppliers. In the Netherlands, automotive OEMs Tesla, Renault-Nissan and BMW, have paired with aggregator, Jedlix, to provide energy services on a reward basis.

The optimal business model will provide smooth consumer experience and maximum additional value for both consumers and the energy system. Policymakers want to balance ensuring optimal outcomes are achieved with letting market competition reveal the winners. In many regions, there may need to be a combination of market and regulatory approaches. Trials may support innovation and competition to ensure the best solutions are offered for consumers and the energy sector and the government may need to step in when existing business model revenues do not stack up to offer the necessary infrastructure. In the longer term, as the performance of smart charging incentives becomes clearer, regulators may want to update standards around the residential electricity sector to ensure value is passed to consumers efficiently and their data is protected.

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4 The potential for smart charging

4.1 Future EV and electricity demand

Decarbonisation of the power sector will require high penetration into electricity grids of variable renewable electricity sources (VRES) such as wind and solar PV. These variable resources present a fundamental challenge to the operation of power systems, which to date have relied on flexible thermal plants to be dispatched to balance electricity demand. Instead, balancing supply and demand will increasingly pivot around balancing the net demand (the demand after netting off renewable supply). This will involve periods of backup generation or renewable curtailment, but both measures are costly. Peaking generation plants are usually of low efficiency, leading to high electricity prices. Also, in the future the expected low run hours of peaking plants make it challenging to justify the investment case for these system critical facilities.

A separate challenge with VRES integration is the provision of ancillary services that stabilise the grid over short timescales. Large thermal generators traditionally provide such services, but as their market share erodes in favour of renewables, alternative sources for these stabilising services are required.

Widespread deployment of EVs means that new charging loads will become a significant fraction of energy demands. Smart charging will need to provide a range of services; including avoiding peaks in network loads, reducing use of peaking plant, and providing ancillary services.

The potential costs and benefits smart charging can provide the energy system and consumers will vary across regions. To show this, four case studies have been selected modelling the energy system and EV charging profiles. The aim of this high-level analysis is to highlight the additional value of smart charging over passive charging in each region, and to show how determining where the biggest system benefits and costs lie can shape how to design smart charging strategies. The case studies were chosen based on their diversity of geography, regulatory frameworks, electricity market structures, generation mix, expected EV uptake, and flexibility requirements. They demonstrate the potential for smart EV charging to provide benefits to the grid while also illustrating a distinct issue emerging from the conditions in each jurisdiction. The assumptions behind each case study are outlined in Table 5 in the Appendix.

4.1.1 Impact of network constraints in New York

E3 performed a benefit-cost assessment of EV adoption and evaluated the value of smart charging in New York during 2017-2039[96]. For the purposes of this study, New York was divided into three regions: New York Metropolitan Area (New York City and Westchester County), Long Island, and Upstate New York.

The study was conducted using E3's EV Grid Impacts Model (EVGrid). The model first develops charging load shapes by simulating charging behaviour in a base case. The model then uses linear optimization to produce hourly load profiles that would result from EV owners scheduling their charging to minimize out-of-pocket costs, while maintaining enough charge to be able to complete unanticipated trips. Benefits from smart charging were calculated as the difference in costs between the base case and the optimized smart charging (behaviour modification) case.

For New York Metro, the smart charging case looked at the cost savings from full deployment of Con Edison's SmartCharge NY program, which provides EV drivers with TOU periods and offers rewards for off-peak charging. This program was used in the model since it shows the actual price signals that current customers can receive by participating in the program. Because Long Island and Upstate New York did not have similar smart charging programs available at the time of the study, the analysis in these regions measured the technical potential of smart charging by exposing EV drivers to real-time rates reflecting the hourly marginal cost of service throughout the year. Therefore, the Long Island and Upstate values can be more directly compared to each other since these reflect the same methodology using system avoided costs, whereas the New York Metro values represent a separate TOU program available for customers that does not necessarily reflect avoided costs.

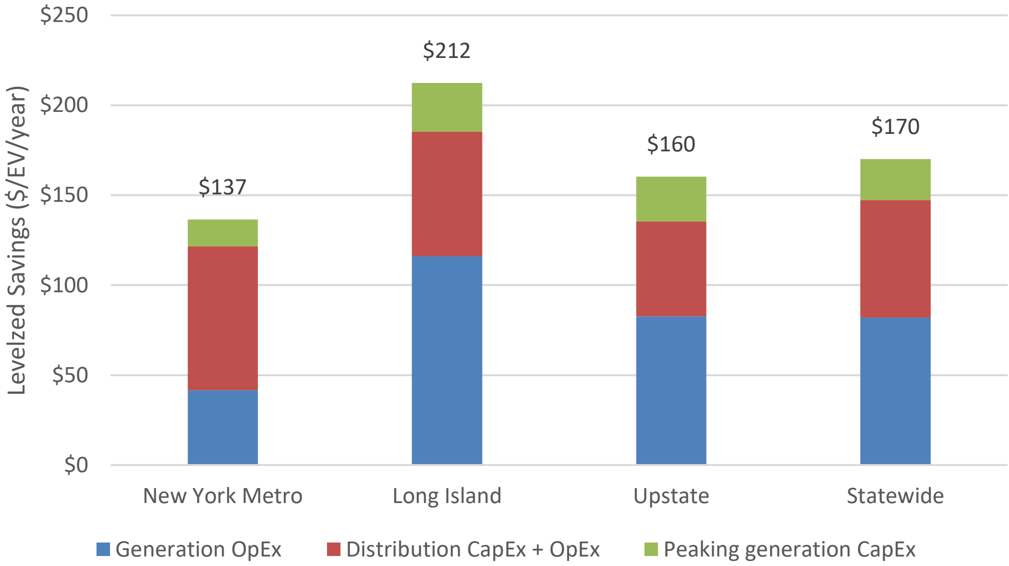

Figure 7 System savings per EV per year for smart charging vs. unmanaged

The study showed that smart charging can significantly reduce electricity supply costs, such as from delayed distribution upgrades and the shift to charging when energy is less costly. However, these benefits can vary regionally. The dense, urban grid in New York Metro area had much larger distribution benefits than Upstate New York, which is mostly suburban and rural. The distribution value will also depend on how coincident unmanaged charging is with the local distribution system peak. The more directly comparable cases of Long Island and Upstate New York show the higher generation value in Long Island, which is the more capacity constrained region with higher on to off-peak wholesale price differentials. The Long Island and Upstate cases represent an upper bound on potential smart charging benefits, since they look at the technical potential from using real-time rates, whereas the New York Metro case likely underestimates the benefits of smart charging since it models a TOU incentive program that would likely be reduced if implemented at scale.

Smart charging has the potential to increase the benefits of EVs, but regional variation in electricity costs and distribution networks can play an important role in the actual benefits realized. Regional conditions, e.g. grid mix and network congestion, should be considered when designing smart charging programs to ensure benefits are maximized.

4.1.2 Diurnal value in California

E3 performed a revenue and grid benefit analysis[97,98] on the optimized charging and discharging of EVs at home and at work in California through 2030. This study compared the benefits relative to unmanaged charging of both V1G (smart charging) and V2G.

The study used trip data from the National Household Travel Survey (NHTS) to create randomized driving patterns on a sub-hourly and annual basis for a fleet of five EVs (Chevy Bolts). E3 used this travel data to generate daily EV charging profiles for each year based on the energy discharged from the battery during driving and assuming charging availability at home and work. These unmanaged EV charging profiles were then optimized in the Solar + Storage tool for each day in V1G and V2G dispatch cases.

The study found that smart charging (V1G) produced significant energy cost savings, but only modest distribution and generation capacity cost savings. Vehicle-to-grid provided significant additional value for energy and distribution.

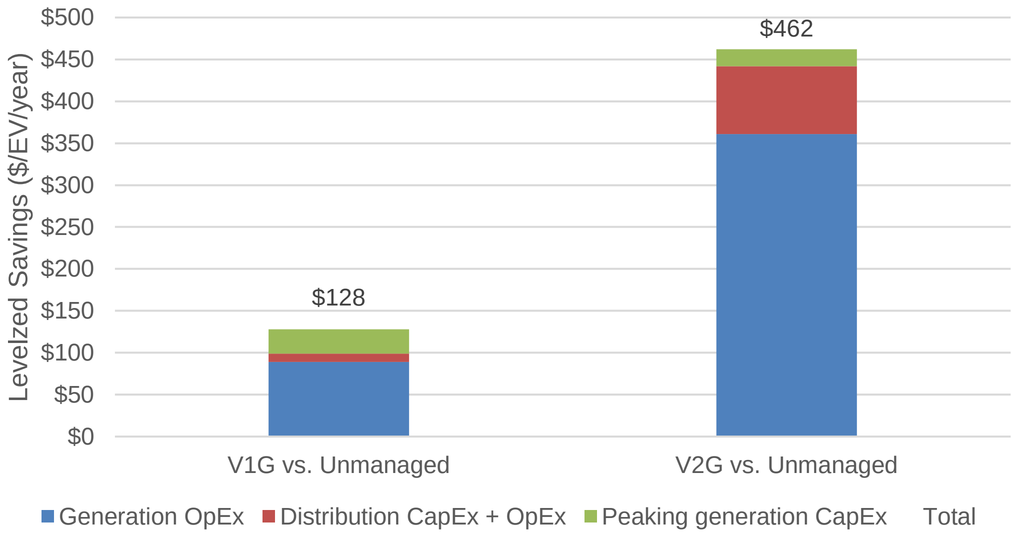

Figure 8 Savings per EV per year from V1G and V2G compared to unmanaged charging

The largest benefit in both the V1G and V2G cases comes from the generation cost savings. In the V1G case, the EV takes advantage of negative prices during solar over-generation in the middle of the day. In the V2G case, EVs can discharge before the over-generation hours, giving them more battery space to charge during solar production and obtain lower, or even negative, prices. These benefits create much greater value in the middle of the day in the springtime in California, when solar over-generation typically occurs.

For distribution and capacity avoided costs, the benefit V1G can provide is more heavily dependent on unmanaged charging behaviour than V2G. In the unmanaged charging case, drivers with shorter commutes arrived with a relatively full state of charge. Unlike with V2G, this limited the amount of charging that could be managed through V1G so the vehicle had often already reached a full charge at work before the distribution or system peak occurred.

The California study showed the effect of high solar penetration on the value of smart charging. By 2030 there are frequent zero and negative wholesale electricity prices due to excess solar generation. With managed charging, EVs are paid to soak up renewable electricity during the middle of the day. There is excess generation capacity in California due to policy driven renewable procurement, limiting generation capacity value. Increasing distributed solar generation also shifts distribution peaks to later in the day. Smart charging programs should consider the resource mix and desired value of smart charging (e.g. to obtain generation benefits or distribution benefits) when determining how and when to incentivize driver behaviour.

4.1.3 Role of workplace and rapid charging in Spain

The potential network impact of EVs and their potential for providing grid balancing support in Spain has been explored by Element Energy[5]. The ENTSO-E Global Climate Action decarbonisation scenario for 2040 was used to determine power generation capacities and baseline electricity demands. A total of 7.2m electric vehicles were deployed, representing 31% of the passenger car fleet. Given the limited availability of off-street / at home parking, an important sensitivity was to increase the percentage of charging events at the workplace or at public rapid charging sites.

A whole system electricity dispatch model was used to balance supply and demand for each hour of the year. The model determines infrastructure capacity requirements, including VRE curtailment, peaking generation and network capacity, as well as hourly energy prices. High solar PV output often leads to excess energy generation, resulting in low energy prices and renewable curtailment at these times.

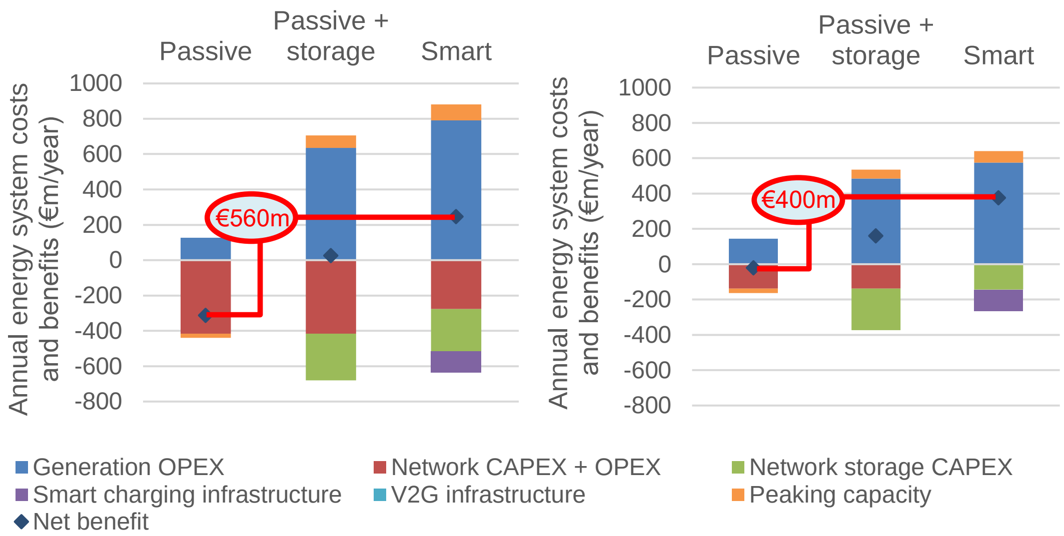

Figure 9: Whole system cost and benefits 2040 in Spain: with original EV charging pattern (left) and with higher daytime charging ratio (right)

Three scenarios are evaluated, passive EV charging, a second scenario where EV loads are still passive but with significant utility-scale battery storage deployed up to economic levels, and finally smart charging and battery storage deployed to an economic level. The figure above presents annualised costs and benefits for these scenarios, with costs incurred for distribution network upgrades, storage and smart charging infrastructure. Benefits are savings in peaking plant capacity, electricity generation, as well as the costs that are avoided from the business-as-usual passive scenario.

The model predicts a severe downside related to passive charging, centred mainly on distribution network upgrades due to predominant home charging at peak times. Smart charging works to displace some charging to the daytime period, reducing PV oversupply with savings at generation level. Despite the significant net benefit of smart charging, distribution investments are still high, and are only significantly reduced with higher daytime charging (right graph). The annual net benefits per EV of using smart charging (€115/EV/y for energy, €24/EV/y for distribution, and €20/EV/y for avoided peaker plant) are broadly in line with results from California, which may be expected given the importance of solar energy in both cases.

As with the California case study, this study demonstrates the importance of aligning future EV charging demand with future PV energy supply. In Spain, high levels of daytime charging may arise out of necessity (given limited residential parking) but this has significant advantages at generation level, in supporting high levels of PV penetration on the grid. In any national plans supporting EV infrastructure deployment, it will be important to include whole system impacts and benefits to ensure that infrastructure investments are optimised for both the demand and supply side.

4.1.4 Alignment of system benefits in Great Britain

The California and particularly the Spanish cases showed that smart EV charging could generate significant benefits at the energy level (i.e. generation) but still require investments at distribution level. This Great Britain (GB) case study is used to demonstrate under what conditions benefits of smart charging can align across the power system[5].

A 2030 whole system model of GB was also developed, similar to that for Spain, which dynamically dispatches flexible demands (such as EV charging) to minimise system costs. By 2030, GB was modelled to have ~4m electric vehicles. An ENTSO-E scenario was used to provide generation capacities as input to the model. Decarbonisation is achieved primarily via wind given this is predicted to be the cheapest low carbon resource for GB. The model also allows competition between technologies, for example between smart EV charging and grid batteries providing grid flexibility.

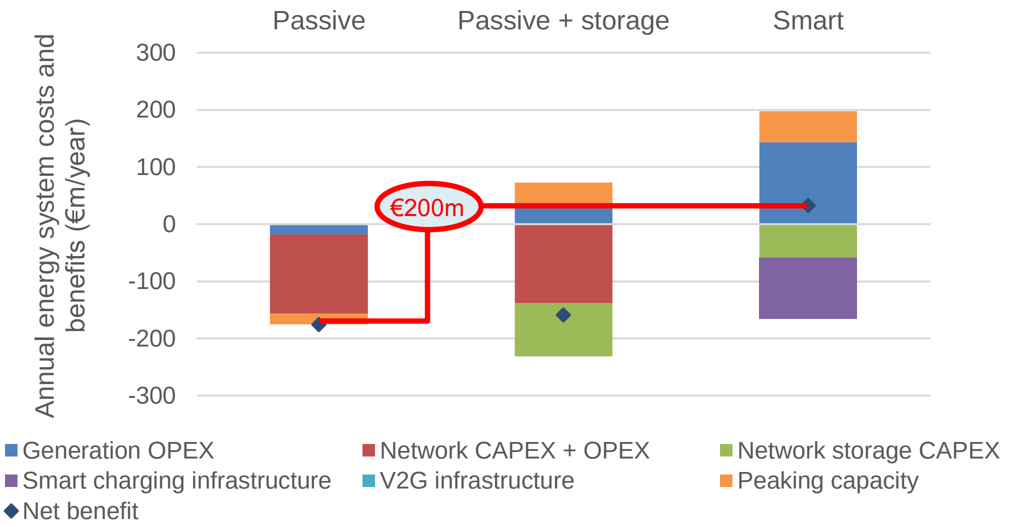

Figure 10: Whole system cost and benefits 2030 in GB

As for Spain, three scenarios are evaluated: passive EV charging, a second scenario where loads are still passive but with significant battery storage included, and finally smart charging. The passive scenario identified a significant additional investment required in distribution networks. This is because the diurnal pattern of passive EV charging demand adds to the underlying peak demand. Including grid batteries offsets some system costs; mainly avoids peaking plant requirements, but distribution reinforcement remains high. Smart charging moves charging loads to the overnight period, where underlying demand is low, and when wind energy output is high and so the net demand is low. This means that smart charging results in significant distribution network savings, as well as energy (generation) savings, due to the dominance of wind in energy supply. When compared to Spain and California, the annual net benefits in going to smart are lower for generation/energy at €41/EV/y but this is because the GB grid has not significantly decarbonised and renewable curtailment is not significant. However, the savings are balanced across the rest of the system (€35/EV/y for distribution, and €19/EV/y for avoided peaker plants) demonstrating the synergistic benefits of EV charging.

The GB study shows that smart charging can benefit all levels of the power system, but this is dependent on underlying demand and energy supply patterns. Smart charging incentives should be designed to reflect and encourage grid synergies to achieve greatest overall system benefit.

4.2 Competition with alternative technologies

The above case studies show how smart charging can avoid unnecessary investments in the electricity grid, and can provide valuable grid services. As the grid decarbonises, opportunities for providing grid services will grow, but that will also encourage alternative technologies to compete to serve these markets.

A recent example is in Great Britain where batteries have led to a factor of three reduction in the value of FFR (frequency response) services in recent years. The FFR market is small and prices are very sensitive to competition, but the impact of competition between technologies will be more widespread. Using Element's whole system electricity dispatch model (see previous sections 4.1.3 and 4.1.4), two scenarios are compared for four European countries: passive charging with deployment of storage up to an economic threshold vs. smart charging. The graph below shows the expected interaction between smart charging and grid batteries, in decarbonised scenarios in 2040. In the UK and France (FR), smart charging is effective in bringing demand closer to supply patterns and so grid battery deployment is depressed. In Spain (ES) and Italy (IT), issues with solar overgeneration are so acute that even with smart charging, very high levels of economic battery deployment still occur.

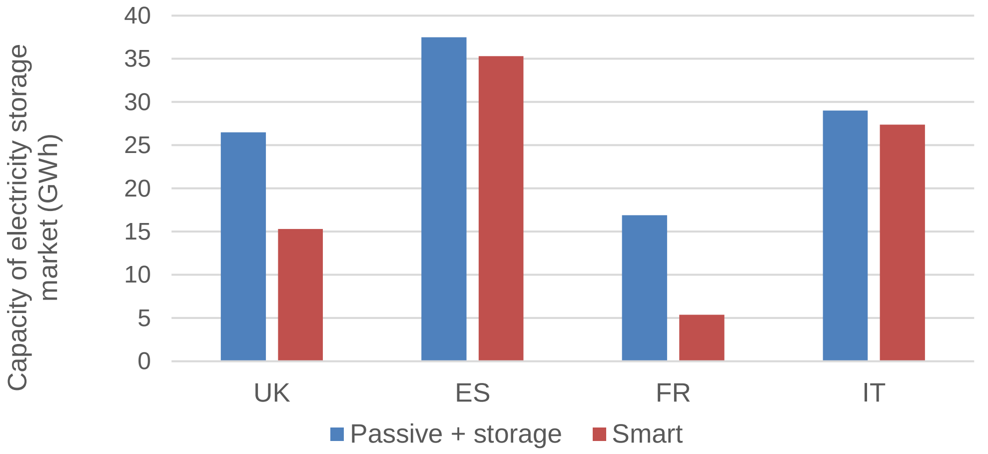

Figure 11: Comparison of the size of the electricity storage market across four countries when there is passive or smart charging.

5 Conclusions

5.1 Current State of Smart Charging & Future Opportunities

Smart charging will be effective in offsetting (potentially completely) the significant power system costs of passive charging of EVs.

The rapid uptake of Electric Vehicles (EVs) combined with passive charging will add significant costs to the electricity system, requiring increased peak generating capacity, network capacity expansion, and use of inefficient peaking plants that drive up CO_2 and energy costs to customers. But, even at high levels of EV deployment, smart charging can substantially avoid these challenges, reducing energy costs for consumers and grid carbon intensity. The inherent flexibility of EV charging means there is a significant upside to smart charging, particularly in a decarbonising power system. Smart charging can reduce curtailment of renewable energy, reduce network constraints, and provide valuable ancillary services to the System Operator. In addition, Vehicle to Grid capabilities could replace the need for peaking generation plants.

Utilities, TSOs and DNOs are beginning to develop commercial mechanisms to reward smart charging behaviour. The Minnesota utility Xcel Energy is using smart charging to provide grid balancing services, using residential chargers which they own and operate, offering consumers a reduced EV-only rate for charging. In Europe, smart charging trials are underway to determine how to provide ancillary services to the System Operator, with Kraftwerke and Jedlix trialling offering secondary control reserve (aFRR) in the Netherlands and the Suvilahti pilot providing Frequency Regulation in Finland. In the UK, the DNO UKPN has launched a smart charging marketplace trial called Shift to determine how DNOs can develop market mechanisms for congestion avoidance.

Trials have tended to focus on proving the provision of one (or a limited set) of services to a specific stakeholder. Coordination will be required to ensure smart charging achieves the greatest overall system benefit. The Grid Motion project in France will look at how energy services can be stacked and the INVADE project is developing platforms for integrated control with storage and decentralised energy. Trials developing the provision of services to TSOs and DSOs may increase as companies aim to develop revenue stacks to support innovative business models.

Smart charging is a system solution that requires diverse actors to work together with unprecedented coordination.

Effective smart charging that benefits the power system will require unprecedented coordination of multiple stakeholders across the power and automotive sectors. It is not yet clear which value chains will deliver best value for the system and energy customer, how to coordinate benefits across the system, and what the regulatory impact will be.

While some benefits can be generated with very limited sharing of data, further system benefits can be realised the more data is shared (such as location data for distribution networks, temporal data for renewables-responsive operation, and EV and trip data to account for consumer needs). However, as this data has value, there is a risk of data silos where stakeholders do not share the data they have generated unless they can realise adequate commercial benefit. Concerns surrounding security of sensitive customer data will increase with greater levels of data sharing.

Adoption of standards and data protection measures may enable increased adoption of smart charging technology and services. The Netherlands and California have lead in the development of standards e.g. Elaad supporting the Flexpower Amsterdam pilot to use OCPP for the first time in public networks and the California Energy Commission grant for the Centre for Sustainable Energy to develop the first standards based smart charging platform using ISO 15118[99]. In Europe, additional protecting consumer data may become an increasing focus, for example, data protection and cyber security principles are informing the design of the European INVADE pilot.

Smart charging can be accelerated through an appropriate combination of market incentives and regulation.

Market mechanisms that encourage smart charging can be simple to implement, but their effectiveness may be limited to rewarding only the operational benefits of smart charging. For example many trials have used static time of use (TOU) tariffs to shift charging demand. They are relatively easy to implement and for customers to understand. Examples of static TOU tariffs include Charge TO in Toronto, Electric Nation in the UK, and We* in Wellington, which used a simple day night tariff to delay charging to the night. These have been found to be simple and effective, however, there is a risk of imposing higher costs on customers who continue to charge passively. The Charge the North trial in Canada also found a risk of smart charging coinciding with peak demand if TOU tariffs are not EV specific. To avoid such impacts, some regions have used off-peak incentive schemes e.g. ConEdison NY or rewarding participants for third parties shifting charging e.g. Jedlix in the Netherlands.

Some regions have trialled Dynamic TOU tariffs that improve use of variable renewable energy e.g. SDG&E’s Power Your Drive in California; ComEd Illinois; Mobility House in Germany. However, if prices and tariffs become more cost reflective, location specific and dynamic, tariff complexity will increase. The level of customer response is also not guaranteed - it is not (yet) considered reliable by network planners, so may not offset network expansion and other capacity investments which represent a significant proportion of smart benefits. Pilot studies typically aim to establish consumer charging behaviour and the effectiveness of incentives encouraging smart charging. All stakeholders need to build confidence in the expected response to price signals if market mechanisms are to be effective in offsetting infrastructure and capacity investments. Then, improving affordability and passing value onto consumers is an essential consideration of future trials.

Regulation in this sector has also delivered significant benefits for customers, for example, the use of diversity factors in estimating shared network costs significantly reduces connection cost for customers while still providing high capacity access per customer. Regulation may need to be updated to reflect the benefits of smart charging and its value to each part of the energy system, particularly with regard to avoiding capacity investments.

Strategic infrastructure investments and learning by doing can spur innovation and expand methods of smart charging.

Smart charging needs to be deployed rapidly, however there is a diverse range of hardware currently providing smart charging, and there will be continued innovation in how smart charging is provided. For example, a lot of policy support is focussed on the deployment of smart charge points (EVSEs). In the UK, the majority of trials have included smart charge points e.g. Electric Nation and CVEI. This is pragmatic: the technology is available now and innovative charge point operators are eager partners in expanding the sector. Other regions may also want to consider encouraging investments in smart EVSEs, but alternative configurations are being explored. For example, smart charging controlled by the EV, as in the case of the second phase of the BMW ChargeForward pilot project. Leveraging vehicle telematics has the potential to improve the effectiveness of smart charging (including battery state of charge and health data), but only if automotive manufacturers (OEMs) recognise the value of smart and add functionality to their vehicles in a cost-efficient way.

Metering hardware is also critical to consider as it may also provide a cost and regulatory barrier to smart charging provision. In the Electric Nation trial in the UK, metering was via a residential smart meter or Economy 7 meter, however this required participants to put their EV and household consumption on the same tariff. Since many consumers prefer to have an EV only tariff to avoid risk of not-shifting household load, separate meters or submeters may be required. Industry and the energy system operators are exploring how to reduce costs of submetering but have still found the costs to remain prohibitively high. To avoid consumers paying prohibitively high submetering costs, either utilities may pay for the standalone submeter, consider different metering methods, such as using a utility-approved EVSE with embedded load monitoring as in Minnesota's Xcel energy trial[100], or avoid metering requirements through offering rewards e.g. in Jedlix offerings in the Netherlands and France.

Bi-directional smart charging has the potential to offer increased benefits to the energy system, but business models and technology are still in the early stages of development. Different applications becoming a focus across smart charging trials, including bi-directional applications of EV to home, building and grid (V2H, V2B, V2G). For example, the Parker project by Nuuve in Denmark tested V2G with fleet vehicles to provide frequency response; Jump SmartMAUI looking at V2H for load and frequency management, and METI Japan focused on V2B. Innovate UK awarded £30 million in 2018 to 21 V2G projects to explore the technology and commercial opportunities considering stacking and optimising revenues, looking at propositions for consumers, fleets and buses[101].

5.2 Policy Recommendations

Initial smart charging trials have revealed the significant benefits that can be realised through smart charging, either from reductions in costs of energy generation, avoided peaking plant investment, or avoided distribution network upgrades. There are many approaches to smart charging and trials to date have tended to focus on providing services to one part of the energy system, rather than optimising whole system value (see section 1.2).

1. Policymakers must start planning for the impacts of EV roll-out on the power system, quantifying the expected EV uptake and whole system implications of passive versus smart charging. The public sector needs to work with stakeholders, e.g. System Operators (SOs) and Distribution Utilities, to develop an agreed vision for EV deployment that meets carbon ambitions and use this to assess power system impact in the near and long term.

2. Policymakers should determine which problem is most acute in their region and ensure that smart charging solutions have appropriate capabilities, supportive regulation and commercial models that can monetise value from appropriate parts of the power system. Considering the power mix will be a critical factor. In solar dominated systems, workplace and commercial charging should be investigated. For example, in solar dominated California, the SCE trial looked into workplace charging to test the application of open standards for managing loads. Maximising synergies between energy and network needs should also be considered. E.g. FlexPower Amsterdam is the first trial to utilise the public network using an open standard application to lower charging speed during peak demand and increase charging speeds during high solar production. Later, monetary and non-monetary incentives can be used to support these applications e.g. through free charging or pre-cabling.

Coordination between actors and sharing of data will be required for smart charging to produce system benefits (see sections 2.1 and 2.2). No one-size-fits-all solution has been identified, however emerging best practice trials have explored a variety of partnership models and adopted various standards, which increase innovation and interoperability while maintaining competition.

3. Policy makers should consider how to enable stakeholders to access and share data to deliver system benefits. Initial trials can require access to data to identify and map the data that must be generated and shared to achieve system benefits, and how these can be realised for efficient cost and data sharing. Policy makers should review existing regulation and standards to determine where open standards will need to be adopted in the near term to ensure the necessary data can be shared in an open, interoperable, secure and cost-effective manner. Support can be provided for the development of open protocols through collaborations such as the Open Charge Alliance or ISO as has been done by Elaad and California governments. To support industry adoption in the near term, public funding for infrastructure can require the technology to use open standards as has occurred in Germany and the Netherlands or that the data be collected in an open central database as in Norway.

4. Reflecting the diversity of solutions to smart charging, trials should encourage diverse strategic partnerships between energy system and electric vehicle actors including aggregators, automotive OEMs, utilities, electricity suppliers, DNOs and SOs. Policy makers may have a continued role to play in facilitating mobility providers and energy system to work together, as demonstrated through the Netherlands Knowledge Platform for Charging Infrastructure (NKL). Where the market fails to deliver the necessary coordination at reasonable cost, policy makers could consider mandating certain stakeholders make data available (as with some smart meter programmes); especially when private companies receive public funding. An example is the Green Deal funding for infrastructure in the Netherlands, which required data sharing collaboration amongst partners; now the Dutch have the most developed public charging infrastructure in Europe[1] or the NOBIL central database on charging infrastructure in Norway, now the country with the highest adoption of EVs[29]. However, policy makers must take into account that this will reduce commercial value of data, and risk disincentivising engagement.

In this nascent sector, the costs of implementing smart charging are not certain, nor the and the most cost-effective solutions to tackle the different problems (see section 2.3). Policymakers must provide direction on the desired role of government, utilities and the private sector in leading the development of EV infrastructure and monetising smart charging benefits (see section 3.2) and identify and support the most cost effective solutions.

5. The public sector support of trials that explore different technologies, business models, and data sharing arrangements until cost effective solutions have been identified. They should recognise that not all the trials can be expected to reach commercial maturity, however vital information on smart charging costs, incentives, and power system value can be more widely shared to improve future offerings. In the short-term public funding may be needed to offset additional initial incentives required to encourage consumers to participate in trials, e.g. New York's ConEdison smart charging trial pays $150 for enrolment. Policymakers should advocate the benefits achieved during these trials to encourage increased competition and participants. Additional monetary incentives may also be required to support infrastructure where the business case does not stack up e.g. rapid charging and multi-unit dwellings.

6. The System Operators, DSOs or utilities should be partners or lead trials so that they can establish the potential for smart charging to provide reliable flexibility. This will allow them to develop strategic plans for smart charging to reduce capital investments, for example in avoiding network expansion or peaking plant. For example, California's three investor-owned utilities each ran smart charging trials in 2016 to determine costs, benefits, and customer perception of various smart charging approaches prior to proposing new TOU tariffs and $750 million in ratepayer funded infrastructure investment programmes representing an opportunity to future proof investments. Similar programmes are being supported in New York, Minnesota, the UK, and New Zealand.

7. Regulatory impacts should be explored as this is a critical lever for policymakers to unlock and promote key elements of system value. Regulation may need to be updated to allow EVs to participate fairly in energy markets, including DSO flexibility and providing ancillary services. It may also need to be reviewed to ensure financial incentives are aligned (VAT, tariffs, grid costs) and regulation does not add unnecessary costs, e.g. metering requirements. For example, in the UK & Netherland they have reviewed the regulation on the double-taxing electricity storage to remove dis-incentives for V2G. Policymakers should also consider how to ensure smart charging capabilities are included in investments in an interoperable way that supports future innovation.

Successful deployment of smart charging is more than just infrastructure provision; it requires widespread consumer acceptance and subsequent shifting of their charging behaviour (see sections 3.1 and 3.2). This may require a mixture of market incentives and regulation.

8. Pilots are required to understand consumer preferences and increase confidence in the level of smart charging response to incentives. In the short term the public sector could trial or support commercial pilots of market mechanisms, including time-of-use tariffs e.g. Toronto's Charge TO, New York's SmartCharge, UK's Electric Nation; or reward systems, e.g. California's ChargeForward, Netherland's Jedlix, to spur innovation, to quantify level of response and measure system impact. These results can be used to inform the public of the benefits of participation to increase their acceptance as well as informing development of efficient incentive structures. Once developed at a commercial scale, policy makers should aim to support incentives that are efficient and effective at achieving the desired outcome, and simple for consumers to understand.

9. Policy makers should be careful to identify and avoid situations where consumers may be negatively affected by smart charging (such as TOU tariffs increasing bills to EV owners who continue to charge passively). Regulators may need to monitor or support pilots to ensure consumers who continue to charge passively do not see an increase in electricity prices by offering rewards e.g. through New York Utilities' one-year price guarantees, or rebate only systems, e.g. Arizona Public Service Company (APS) programme. Additionally, they can ensure consumers can opt-out of any third-party control or tariffs and they can identify where systems can be automated and support technological development of automated smart charging systems like in the Mobility House trial in Germany. Support for automation and integration of consumer driving preferences into future smart charging arrangements may also be beneficial.

10. In the longer-term regulators may consider requiring a minimum level of smart charging to be deployed. Evidence suggests that EV owners are comfortable with smart charging, but there is (potentially significant) inertia in switching from passive to smart; and the cost of incentivising this could be greater than the system value of

smart. To avoid this, policymakers should work to establish smart charging as the baseline, rather than passive charging. Policy makers should consider methods to ensure smart charging becomes the norm e.g. by regulating TOU tariffs on an opt-out basis like in Spain, California, Illinois, Ontario to take advantage of consumer inertia.

6 Appendix

Table 4: List of major smart charging studies reviewed

Project name	Location	Scale	Smart charging service	(Expected) completion	Lead partners	EVSE Location
SEC PEV Workplace Charging Pilot	USA: California	80 EV chargers	ToUT; DSR	2014	Southern California Edison (SCE); EVSE LLC; Greenlots	Commercial
Mobility House Smart Charging Process	Germany	11 EVs	Dynamic ToUT	2015	Mobility House; Renault	Residential
Low Carbon London	UK	10 EVs, 62 public EVSE	ToUT; Congestion management	2015	UKPN, CGI, EDF, Enernoc, flexitricity, Imperial College London, Institute for Sustainability, Mayor of London, National Grid, Siemens, Smart Grid Solutions, TfL	Public; residential
My Electric Avenue	UK	200 Evs	Congestion management	2015	SSEPD (distribution); EA tech; Nissan; NPg	Residential
Green eMotion	EU	Several linked projects; umbrella scheme	ToUT; energy balancing; congestion management	2015	European Commission; emi3 group; SMATRICS; BMW	Public; residential
INEES Project	Germany	20 EVs, 40 EVSEs	Energy balancing; ancillary services	2015	Lichtblick; Fraunhofer IWES; VW; SMA	Residential
PIV Charging Pilot Program	USA: Maryland	150 EVs	ToUT; submetering	2016	ITRON: ICT; PEPCO: Network & energy; ClipperCreek: Charging stations	
ChargeTO	Canada	30 residential EV owners (PHEV and BEV)	Congestion management	2017	FleetCarma, Toronto Hydro, AddÉnergie Technologies	Residential
City-Zen Smart City - Vehicle2Grid	Netherlands	9 V2G chargers	Congestion management; optimised consumption of local VRE; energy balancing	2017	Alliander, NewMotion, Enervalis, MagnumCap	Public; commercial
Jump Smart Maui	USA: Hawaii	200 Nissan Leaf owners, 44 chargers across 13 fast charge stations	Congestion management, energy balancing	2017	NEDO, Hitachi Ltd./Hitachi Advanced Clean Energy Corporation, Mizuho Corporate Bank and Cyber Defense Institute, Nissan; the State of Hawaii; the County of Maui; Maui Electric Company and Hawaiian Electric Company; Hawaii Natural Energy Institute; Maui Economic Development Board, Inc.; University of Hawaii Maui College	
Parker	Denmark	10 EVs and 10 EVSEs	Frequency response; energy balancing; congestion management; grid CO2 optimisation	2018	Nissan, NUVVE, Frederiksberg Forsyning, Mitsubishi Motors, Mitsubishi Corporation, PSA ID, ENEL, Insero and DTU Electrical Engineering (PowerLabDK).	Commercial
CPUC Submetering Trial	USA: California	449 participants	ToUT; submetering	2018	CPUC, Nexant	Residential
We* Wellington EV Charging Trial	Wellington, New Zealand	77 households	Night ToUT, Dynamic ToUT, control	2018	Wellington Electricity Lines Limited	Residential
GrowSmarter	Spain	6 V2G chargers	Energy balancing; energy arbitrage; DSR	2019	Endesa; Enel; 20+ public and academic partners	Public; residential
ETI CVEI	UK	250 EVs	ToUT; DSR	2019	ETI; TRL	Residential
Electric Nation	UK	673 EVs	Congestion management	2019	WPD; Nichicon; Hitachi; CrowdCHarge; Greenflux	Residential
Smart charging behind the meter	Netherlands		Energy balancing; Optimised consumption of local VRE	2019	Cohere, Enpuls, Enexis Netbeheer, ElaadNL and Living Lab Smart Charging	Residential
Interflex	Czech Republic, France, Germany, Netherlands, Sweden		Energy balancing; congestion management	2019	Enedis, ElaadNL	

Charge the North	Canada	1,000 EVs	ToUT	2019	FleetCarma, Toronto Hydro, AddÉnergie Technologies	Residential, public, commercial
Grid motion	France	50 smart-charging EVs; 15 V2G EVs	Energy balancing, ancillary services	2020	Groupe PSA, Direct Energie, Enel, Nuvve, Proxiserve and the Technical University of Denmark	Residential; commercial
Invade	Bulgaria, Germany, Spain, Norway, the Netherlands	Pilots in 5 countries	Energy balancing; Optimised consumption of local VRE; Local load management	2020	ElaadNL, Estabanell Energia, Lyse Elnett AS, Albena JsCo, Universitat Politècnica de Catalunya (UPC), The Norwegian University of Science and Technology (NTNU), VTT Technical Research Centre of Finland, Smart Innovation Norway, eSmart Systems, Schneider Electric Norge, GreenFlux Assets BV	Residential, commercial, public
Smart charging in practice	Netherlands	7 charge points	Optimised consumption of local VRE	2020	Stichting Limburg Elektrisch, Ecotap, Enexis, ElaadNL and SunProjects	Public
Xcel Energy Smart Charging Programme	USA: Minnesota	100 participants	TouT; energy balancing; congestion management; ancillary services	2020	Xcel Energy, eMotorWerks	Residential
Network Impact of Grid-Integrated Vehicles	UK	1,100 V2G charge points	Congestion management	2020	Northern Powergrid, NUVVE, Newcastle University	
Jedlix Frequency Response Trial	Netherlands		Frequency response	2021	Jedlix, Next Kraftwerke	Residential, public
SGD&E Power Your Drive	USA: California	2,900 charge points, aiming to install 3,500	ToUT; energy balancing	2021	San Diego Gas & Electric	Multiple occupancy residential; commercial
UC San Diego V2G Trial	USA: California	50 V2G chargers	Optimised consumption of local VRE; energy balancing; energy arbitrage	Ongoing	SDG&E; UCSD; Nuvve; Nissan, Mitsubishi; Honda	Public
SEEV4-City	Netherlands; UK; Norway; Germany; Belgium	50+ EVs; 6 EVSEs in participant cities	Local energy management (V2H, V2B)	Ongoing	13 partners from 5 cities across Europe (Amsterdam Arena, HvA, UNN, CENEX, AVERE, POLIS, Municipality of Amsterdam, Leicester, OSLO Kommune, KU LEUVEN	Public, commercial, residential
SMART Solar Charging, Utrecht, NL	Netherlands	20 charging stations, 150+ Renault Zoes	Energy balancing; optimised consumption of local VRE; congestion management	Ongoing	Renault; Utrecht Sustainability Institute, LomboXnet, Hogeschool Utrecht, Universiteit Utrecht, Last Mile Solutions, We Drive Solar, New Solar, Vidyn, Jedlix, Stedin, ElaadNL	Public
Suvilahti pilot (as part of mySMARTLife project)	Finland	1 charging station	Frequency regulation	Ongoing	Helen, Virta and Nissan	Public
V2G Aggregator Project, METI	Japan	Several demonstration sites	Energy balancing; VPP	Ongoing	TEPCO; Mitsubishi; Hitachi	
BMW ChargeForward	USA: California	279 EVs	Energy balancing	Ongoing	PG&E; BMW; Olivine; Whisker	Public
E4Future	UK	Target of 1000 V2G-capable EVSEs	Energy arbitrage; energy balancing	Ongoing	Nissan, NPg, U of Newcastle; NG; UKPN; Nuvve; ICL	Commercial
FlexPower Amsterdam	Netherlands	912 charging points	Energy balancing; congestion management	Ongoing	City of Amsterdam, Nuon/Vattenvall, Liander, ELaadNL, and Amsterdam University of Applied Sciences (HvA).	Public
ConEdsion NY EV Charging Programme	USA: New York	Offered state-wide	ToUT	Ongoing	ConEdison	Residential
Orchestrating Smart Charging in mass Deployment	Netherlands		Energy balancing; Congestion management; Ancillary services	Ongoing	Austrian Institute Of Technology; Delft University of Technology; Driivz; EBG compleo GmbH; ElaadNL	

Table 5: Case Studies modelling methodology

	New York	California	Spain	Great Britain
Goals of model	Estimate the benefits and costs of EV adoption and optimized smart charging from three different perspectives: societal perspective, participant perspective, and ratepayer perspective	Estimate the benefits and costs of V1G (smart charging) and V2G for the electric grid and California ratepayers based on randomized EV driving patterns	Estimate the electricity consumption and production at hourly level to determine the fuel and carbon costs, VRE curtailment, peaking generation and network capacity requirements.	Estimate the electricity consumption and production at hourly level to determine the fuel and carbon costs, VRE curtailment, peaking generation and network capacity requirements.
Key inputs/ variables	Time period: 2017-2039 Discount rate: 3% EV Adoption: Approximately 2 million EVs in New York State by 2030 Rates: New York Metro - ConEd rates and SmartCharge NY program; Long Island - Long Island Power Authority and PSEG Long Island rates; Upstate NY - National Grid rates	Time period: 2018-2030 EV Adoption: The model used a fleet of 5 EVs with different driving patterns, but performed some calculations on total potential assuming 3.3 million (mid case) and 5 million (high case) EVs in 2030 Rates: San Diego Gas and Electric rates Other: Randomized driving patterns based on data from The National Household Travel Survey (NHTS)	Time period: 2018-2030 ENTSO-E TYNDP 2018, Global Climate Action (GCA) 2040 scenario determines power capacity and baseline electricity. Transport demand based on stock of EVs, efficiency, daily usage, arrival and departure times. Generation determined from hourly weather data. Projections of 2040 battery storage cost and the revenues that could be generated from daily electricity arbitrage as well as network congestion relief and security of supply services.	Time period: 2018-2040 ENTSO-E TYNDP 2018, Global Climate Action (GCA) 2040 scenario determines power capacity and baseline electricity. Transport demand based on stock of EVs, efficiency, daily usage, arrival and departure times. Generation determine from hourly weather data.
Key assumptions / limitations	For the NYC Metro case, the study assumes full deployment of ConEd's SmartCharge NY incentive program to all EV drivers. It is worth noting that the incentives available in this type of customer program would likely be reduced if implemented at scale;	This was a grid benefit analysis where the only costs are the costs of delivering energy for EV charging. No costs for the EV, EVSE or V2G enabling technology are included.	ENTSO-E scenario does not assume significant levels of flexibility in the system – loads are predominantly passive. Utility batteries and smart EV charging can provide	ENTSO-E scenario does not assume significant levels of flexibility in the system – loads are predominantly passive. Utility batteries and smart EV charging can provide alternative sources of flexibility

	therefore, the benefits shown in this region likely underestimate the potential benefits. Because there was no similar program in Long Island and Upstate NY at the time of the study, the analysis measured the technical potential of smart charging by exposing EV drivers to real-time rates reflecting the hourly marginal cost of service throughout the year. Therefore, the analysis in these regions likely estimates an upper bound on the potential benefits. Because of the methodology differences, the Long Island and Upstate NY results can be compared to each other more easily.	Additionally, the impact of increased cycling on battery life (from V2G) is not considered.	alternative sources of flexibility Stationary battery storage is sized by the model based on economic viability.	Stationary battery storage is sized by the model based on economic viability.

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