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Interoperability of distributed energy resources: Benefits, challenges, and solutions

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The Carbon Trust's mission is to
accelerate the move to a decarbonised future.

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Notable abbreviations

AC	Alternating Current
API	Application Programming Interface
BS	British Standard
BSI	British Standards Institute
CHAdeMO	CHArge de MOve
COP	Code of Practice
CCS	Combined Charging System
CSIP	Common Smart Inverter Profile
DCC	Data Communications Company
DSM	Demand-side Management
DSR	Demand-side Response
DC	Direct Current
DER	Distributed Energy Resource
DSO	Distribution Systems Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
CEN-CENELEC	European Committee for Standardisation; European Committee for Electrotechnical Standardisation
ESA	Energy Smart Appliance
EN	European Standard
ETSI	European Telecommunications Standards Institute
EU	European Union
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IoT	Internet of Things
IOU	Investor-Owned Utilities
MHHS	Market-Wide Half-Hourly Settlements
OGS	Off-Grid Solar
PV	Photovoltaic
PAS	Publicly Available Specification
SAREF	Smart Appliances Reference ontology
SDO	Standards Developing Organisations
TSO	Transmission System Operators
V1G/V2X/G/H/L	Unidirectional Charging / Vehicle-to-Everything / Grid / Home / Load
VPP	Virtual Power Plant

Executive summary

This report considers the benefits of interoperable distributed energy resources (DERs) for residential and commercial consumers (not including industrial- or utility-scale users) and the interoperability challenges that consumers face integrating devices with the grid or for specific use-cases (grid-trade, back-up power, ancillary services). Noting the prevalence of such interoperability challenges, and the issues of reduced functionality that can arise from limited interoperability, the report offers advice and practical solutions to consumers and policymakers.

DERs are integral to the energy transition and play an increasingly vital role in the modern power grid. With DERs installed, consumers can experience a range of benefits such as lower energy bills, cheaper EV refuelling, and access to backup power in a blackout. DERs can also provide a range of grid-side benefits, from balancing variable supply and demand, to providing black start capability. However, to maximise the benefits available to the consumer and the grid, DERs must also be to some extent 'interoperable' – capable of communicating and coordinating with other pieces of hardware, software, and various energy market actors.

Interoperability is widely considered a pre-requisite for a reliable, resilient, and sustainable energy system. However, consumers, product developers, and energy market actors currently face a range of interoperability challenges, often due to DERs that are not designed 'from the ground up' to be interoperable. Manufacturers are often hesitant to develop interoperable solutions because of cybersecurity concerns, existing market advantages, and added development costs. However, policymakers have also played a considerable part in determining the level of guaranteed or certified interoperability, with varying levels of success globally.

The interoperability challenges that consumers currently face range from the inconvenient, such as a lack of an all-in-one application or the use of unreliable APIs, to consumer 'lock-in' when purchasing certain battery and inverter combinations; and, at the other end of the scale, more significant challenges which prevent the realisation of specific DER functions, such as V2G in electric vehicles in the UK and European markets. Additionally, features such as 'back-up power' are yet to be standardised. Consumers must therefore make informed choices that consider existing interoperability issues and emerging solutions when purchasing DERs.

This report concludes that interoperability challenges facing residential and commercial-scale DERs must be addressed to maximise the potential benefits to the consumer and grid. This report is intended to provide a high-level, globally relevant overview of existing interoperability challenges and potential solutions for consumers and policymakers. The report is broken down into consumer-facing (2, 3) and policymaker-facing sections (4) to account for the varying levels of expertise and prior-knowledge. It offers a more thorough analysis of standards, regulations, and solutions in 'mature' markets due to a combination of linguistic factors, availability of information, and 'urgency' of the associated challenges. Future work may provide a more detailed analysis of regional-specific challenges and the policy approaches required.

Some key stakeholder voices have been featured within the report

Summary insights

Residential and commercial-scale distributed energy resources (DERs) are often built on different underlying hardware, software, and communications protocols. Consumers wishing to combine different devices must make informed choices depending on the level of combined functionality required. Otherwise, consumers face issues ranging from minor inconveniences to brand lock-in and potential hardware / software failure.

Consumers must make informed choices depending on the complexity of their system and the level of functionality and 'futureproofing' they desire.

DERs can provide a range of functionality for consumers, from back-up power in the event of a blackout to an additional revenue stream via grid trade and ancillary services provision. However, consumers must purchase hardware that is interoperable with a range of hardware and software solutions, as well as emerging energy market actors.

Interoperability of DER on-site and on-road becomes a greater issue for consumers when there is a need for grid integration.

Interoperability can pose a challenge for consumers before grid integration is considered. However, these issues are multiplied as consumers increasingly look to integrate and provide flexibility to the grid with DERs that do not effectively 'speak' to each other. For example, Electric Vehicle Supply Equipment (EVSE) and EV communication depends upon unreliable Application Programming Interfaces (APIs), which are not fit for purpose in an era of Market-Wide Half-Hourly Settlement and Time-of-Use tariffs.

Where you live can have a significant difference on the level of consumer choice, system value, and interoperability that is available. This is true even within countries like the United States.

The State of California can be viewed as a global leader in policy and standards that provide consumers greater certainty around the interoperability of DERs. This is not the same for every state in the US. The UK, EU, and Australia follow closely behind on interoperability between DERs, though each has regional-specific issues to contend with. In many countries across Africa, smart metering – an enabler of grid flexibility – is yet to be standardised.

Over-the-air software updates are sold as a key feature of EVSE, inverters, and batteries which could increase interoperability as new standards are released. It is not always clear to consumers where products will be updated or if hardware restrictions preclude this.

Consumers need greater clarity around DER software update commitments. Already, EVSE are shipping with out-of-date standards (e.g., Open Charge Point Protocol 1.6) and there is little clarity around what features can be added later, or whether hardware restrictions preclude this. Manufacturers could learn from the transparency of smartphone developers.

Interoperability challenges vary considerably between devices and use-cases. Interoperability is less of an issue for solar-inverter or generation-only set-ups, but there are more challenges when incorporating EVSE and batteries for storage or back-up power.

With a standard solar PV installation, the installer will ensure that a grid-compliant and interoperable solar PV and inverter are fitted. Interoperability becomes a bigger concern with the addition of a battery, though workarounds exist to ensure that any inverter can be installed alongside a battery. Consumers face the greatest challenges when looking to benefit from more complex installations and use cases such as back-up power from an EV or direct solar integration with an EVSE due to variety of options on the market, and the nascency of certain standards.

1. What is interoperability and why is it important?

As the world transitions to net zero, energy systems will become increasingly complex. A greater reliance on intermittent power sources such as solar and wind requires a system capable of utilising, storing, or selling excess power when production is high or demand is low, and drawing upon reserves when the opposite is true. The ability of the energy system to respond to such changes in demand and supply is referred to as 'flexibility', a growing system service to enable more efficient utilisation of network assets.

The twin challenges of climate change and rising energy bills are driving commercial and residential consumers to purchase and install an increasing number of behind-the-meter, DERs such as solar PV, electric vehicles, and supply equipment (EVs / EVSE), and battery energy storage systems to cut costs and reduce their carbon footprint. This rise in DERs presents challenges to grid operators, as grids designed around highly centralised energy production attempt to accommodate increasingly distributed generation.

Critical to this transition is the level of interoperability that exists between DER solutions in the market (non-interoperable, 'technical', 'syntactic', or 'semantic' interoperability) and, in-turn, with grid operators and service providers – i.e., energy retailers and aggregators / flexibility providers.[1] Interoperability is the capacity of products, devices, and applications to connect, communicate, and provide services with minimal user input. It allows consumers to easily upgrade or add new devices to their system and / or switch service providers without loss of functionality. Lack of interoperability could increase costs, prevent full consumer participation, and ultimately delay broader energy transitions, particularly at the distribution grid level (the part of a network where consumers and most energy assets lie).

The adoption of common protocols and standards can facilitate greater interoperability; however, it is often cheaper for manufacturers to adopt proprietary solutions for a quicker routes-to-market and to achieve competitive advantages. Such proprietary solutions have led to an increasingly fragmented market, where consumers are 'locked-in' to certain products and brands. This issue is exacerbated by the fact that up to 30% of (US-surveyed) consumers do not know which protocols and standards their 'smart' devices support and by extension, which brands and products are interoperable.[2]

If greater levels of DER uptake are to be achieved, it is necessary to understand the key presiding barriers facing interoperability to better inform consumer decision making and identify focal points for further policy development. To this end, this report:

- examines the range of protocols and standards relevant to interoperability of residential and commercial DER equipment,
- maps and assesses the severity of existing interoperability challenges for integrating DER technologies and the levels of interoperability between select leading product brands, and,
- provides recommendations for industry and policymakers to address interoperability issues.

[1] *Brendan Reidenbach and others, Towards Net-Zero: Interoperability of Technologies to Transform the Energy System, Going Digital Toolkit Notes, 2022*

[2] Z-Wave, *State of the Ecosystem 2022*, 2022

2. Where and how can interoperability between DER benefit the consumer?

With an ever-increasing array of DERs interfacing with the grid and a variety of new actors in the market, the ability for effective cross-communication has never been more important. These interactions, the standards and protocols that underpin them, challenges faced, how these may change, and what this means for consumer choice, should be understood by consumers when making purchasing decisions for DER equipment.

This Chapter examines five key equipment 'interfaces' or nodes that influence interoperability in a DER system and around which standards, protocols, and regulations for interoperability coalesce.

Figure 1 provides a visual indication of the current level of interoperability at each interface. Major standards and protocols listed in this Chapter are described in Chapter 4 and Annexes A to C accompanying this report.

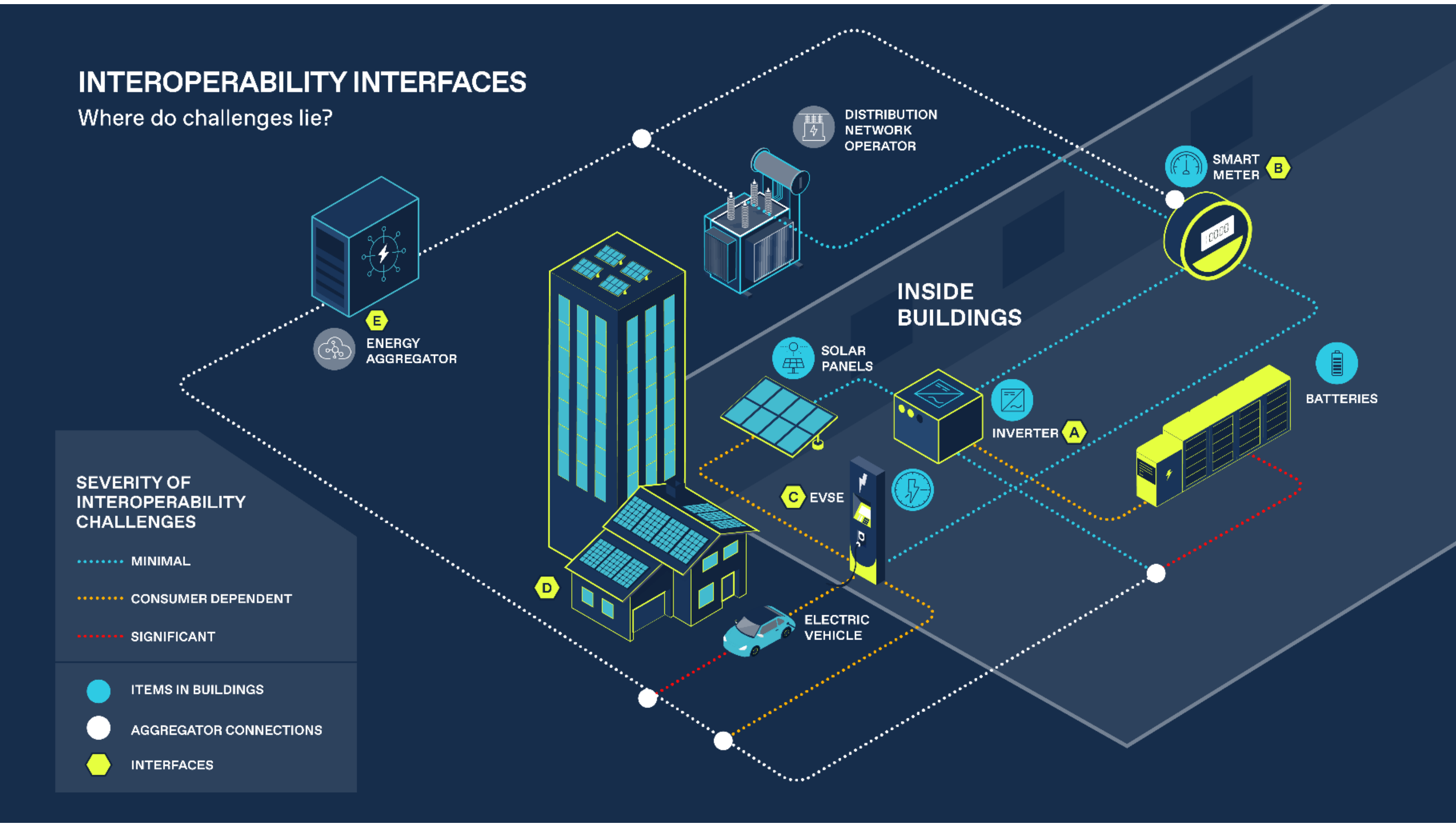

Figure 1: Global Interoperability Between DER – A High-Level Overview of Key Challenges

Interface A: Inverters

An inverter enables consumers to convert electricity from direct current (DC) to alternating current (AC) for consumption onsite or export to the grid. This is a critical piece of equipment in any residential or commercial DER set-up, as the electricity produced by a solar PV installation or discharged directly from a battery is always DC.

The ease of interoperability between an inverter and other DER equipment largely depends on the complexity of the system and its use case (grid-trade, back-up power, ancillary services). Challenges across interfaces are rated green (minimal), amber (dependent on consumer choice), and red (significant), and include:

	Inverter-battery interoperability is often restricted under warranty, meaning consumers must choose wisely or risk losing their protection.
	Battery-specific functionality, such as back-up power, has not yet been standardised.
	Not all inverters sold are connected to the internet or capable of communicating effectively in the emerging aggregator market. This varies by region.

Inverter-Solar-Battery Interoperability

Consumers have two main options to choose from when purchasing an inverter for their solar installation: a unidirectional solar inverter, which converts DC electricity from solar panels to AC for use in homes or buildings, or for exporting electricity back to the grid; or a bi-directional 'hybrid' inverter for those with a battery system for those who also wish to store electricity. These solutions are referred to as 'AC-coupled' and 'DC-coupled' respectively.

I already have rooftop solar PV installed and want to add a battery. What type of inverter do I need?

If you already have solar PV installed, you can keep your grid-tied solar inverter and add an AC-Coupled battery. If you plan to install both solar PV and a battery, a DC-Coupled solution with a hybrid inverter may be the best choice as it offers greater efficiency, meaning you can store more of the energy you produce. While interoperability between an existing solar inverter and an AC-Coupled battery generally faces few challenges, equipment brands will often test and recommend compatible DC-coupled products (detailed below) and failure to purchase these could void your warranty.

Consumers may also choose between an AC-Coupled or a DC-Coupled battery. With an AC-coupled battery, two inverters exist in the system, one for the conversion of DC power from the solar panels to AC, and a separate on-board inverter in the battery unit for the conversion of AC back to DC to charge the battery. This configuration allows the battery to be easily retrofitted, as no changes to the existing solar installation is required. A DC-Coupled battery, however, 'shares' a single hybrid inverter with the solar panels, allowing charging of the battery with DC power directly from the solar panels, removing the need for AC-DC conversion. This increases the roundtrip efficiency of the system by up to 5%. Additionally, because all solar inverters are 'oversized' to ensure that generated output power will not exceed the maximum AC power rating, energy output may be 'clipped', or reduced, in an AC-coupled system. This is avoided in DC-Coupled systems, where the excess energy can be diverted to the battery. However, retrofitting of DC-Coupled systems into existing solar systems is more complicated and costly, as changes are required to the existing solar installation, and the hybrid inverter must be able to communicate directly with the battery's on-board Battery Management System (BMS) to control the rate of charge and prevent thermal runaways. The difference between an AC-coupled and DC-coupled solution is illustrated in Figure 2.

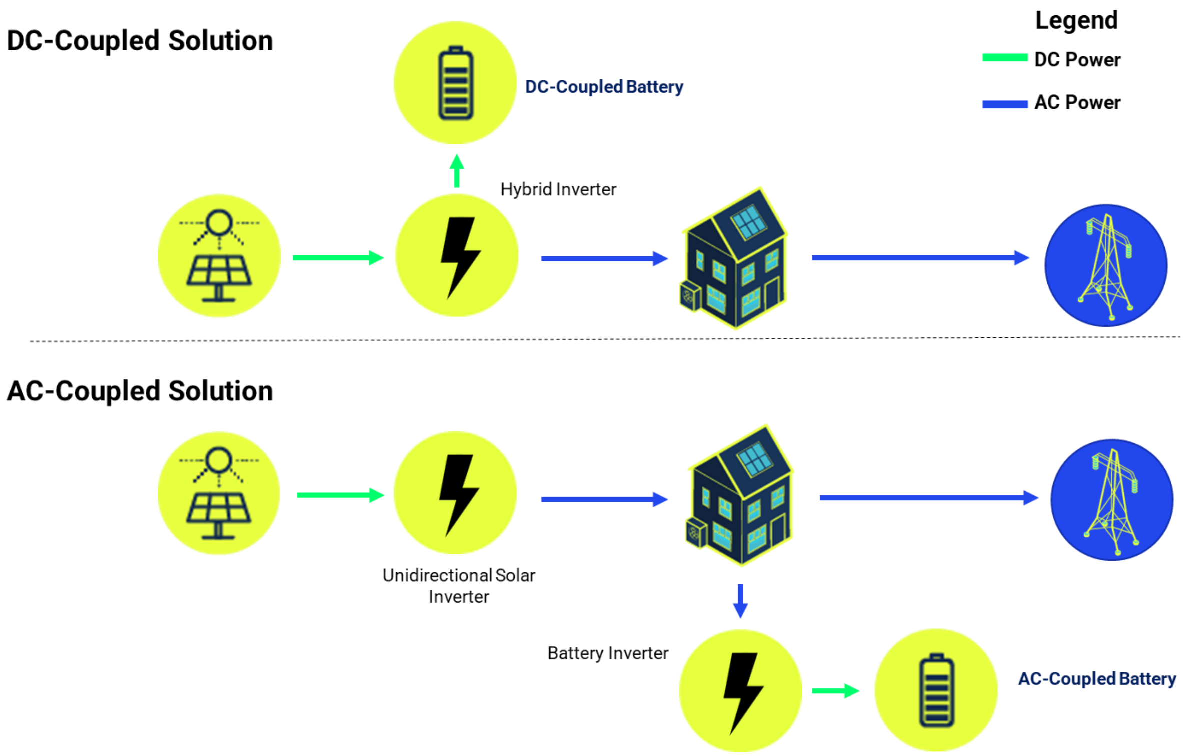

Figure 2: Comparison between DC-Coupled (Top) and AC-Coupled (Bottom) Solutions

While challenges related to interoperability between inverter, solar, and battery equipment in DER systems are few, suppliers often provide a list of compatible inverters or batteries that have been tested and approved for use with their equipment. In many cases for DC-coupled solutions, if a consumer were to attempt to pair their existing equipment with another piece outside of the supplier's list of compatible inverters or batteries, the warranty is immediately voided. Consumers must therefore consider their options carefully if they wish to prevent lock-in to a particular product ecosystem. An indicative list of compatible brands is provided in Chapter 3.

Inverter-to-Grid Interoperability - Standards for DER Functionality

Grid interconnection standards are a major determinant of inverter-based functionality and interoperability. They determine whether a DER system is allowed to be connected to the grid and under what circumstances the consumer can benefit from the trade of electricity and / or grid services. The launch of new standards, such as Rule 21 and the 'Common Smart Inverter Profile' (CSIP) in California reflects the new reality of the growing adoption of DERs by providing reassurance to consumers that their devices are 'future-proofed' and ready to participate in evolving energy market. Many key DER functions such as black start capability and providing back-up power in the event of a blackout are either not yet available or not specified by legislation, though this will not affect the ability of consumers to provide flexibility and other services to the grid. Consumers looking for back-up power should consider which batteries offer this functionality before purchasing.

If back-up capabilities are not standardised or mandated, can I still use my battery in a blackout?

Grid codes, which detail the technical requirements for connecting to and using the electricity grid, contain provisions for 'anti-islanding' protection, which means that DERs should automatically turn off to prevent maintenance teams from being electrocuted in the event of a blackout. A mechanism for DERs to provide back-up functionality to individual households has not yet been standardised or mandated, though many supplier brands provide the functionality. The Tesla Gateway 2 will allow buildings to disconnect from the grid so that the Tesla Powerwall 2 can continue to provide power to the building and reconnect when power to the grid is restored.

Interoperability Challenges and Considerations

Although interoperability challenges do exist at this interface, consumers can make informed choices about the types of DERs and brands they purchase to avoid them. Consumers looking to retrofit existing solar installations with a battery can purchase an AC-coupled battery. Those wishing to purchase a battery and inverter at the same time can purchase compatible products, with brands highlighting which other brands they test and support (Table 1). Additionally, although back-up capabilities are not yet standardised, consumers can find proprietary solutions; with some able to power small appliances, while others, such as the Tesla Powerwall 2, can provide more robust back-up power with the assistance of the Tesla Gateway device. In California and Australia, CSIP-compatible inverters ensure that consumers can provide a range of grid services as the aggregator market emerges, providing an additional potential revenue stream to them.

Interface B: Smart Meters

Smart meters are a cornerstone of intelligent energy management. These meters provide consumers with accurate data on their energy usage, eliminate the need for estimation, and give energy providers data and insight into consumer energy use patterns. Additionally, smart meters provide opportunities for consumers to benefit from innovative pricing tariffs and encourage positive behavioural change.[3] For example, under the UK's Market-Wide Half-Hourly Settlement (MHHS), a system of half-hourly meter readings and variable energy prices, consumers would be encouraged to better manage their energy use and be rewarded for consuming and exporting electricity at times which are beneficial for the system.[4]

[3] Benjamin K. Sovacool and others, 'Global Sustainability, Innovation and Governance Dynamics of National Smart Electricity Meter Transitions', *Global Environmental Change*, 68 (2021

[4] Ofgem, *Potential Consumer Impacts Following the Implementation of Market-Wide Half-Hourly Settlement*, 2020

An interoperable smart meter and DER set-up can assist a consumer in benefitting from such schemes, through automated shifting of their energy demand. For example, a smart meter combined with a smart Electric Vehicle Supply Equipment (EVSE,) could automatically charge an EV when the cost of electricity falls below a user-defined threshold (and vice versa where charging is limited).

Below are the main interoperability challenges facing smart meters:

	First-generation smart meters often turned 'dumb' when switching energy providers.
	Issues with accurately reporting electricity generated from solar PV with first-generation smart meters.
	In the UK, first-generation smart meters did not have a Han-Auxiliary Load Control Switch, which offers a potential means of coordinating DERs with Time-of-Use tariffs.

First and Second-Generation Smart Meters

The global smart meter rollout has been underway for well over a decade. In all regions, interoperability challenges with 'first-generation' meters have come to light, which have been addressed with the rollout of 'second-generation' smart meters. In the UK, first- and second-generation meters are classified as SMETS-1 and SMETS-2 respectively.

For early adopters of the SMETS-1 specification meters, switching energy providers risked the loss of 'smart' functionality, including the provision of automatic meter readings. They also presented additional challenges for those with solar PV installations. A report from Which? suggests as many as 5% of solar PV owners were refused a SMETS-1 smart meter due to existing "industry-wide technical problems", while 53% reported issues with measuring generated and exported electricity since installation.[5] SMETS-2 meters have addressed many of these issues and provide additional DER-related functionality of interest to the consumer, such as a HAN-Connected Auxiliary Load Control Switch (HCALCS), which enables the scheduling of large loads such as EV charging over the Home Area Network allowing the customer to benefit from Time-of-Use tariffs and provide demand response services to the grid.[6]

Interoperability Challenges and Considerations

Although there were some issues with first-generation smart meters turning 'dumb' when switching energy providers or failing to accurately report energy produced when integrating with solar PV arrays, these appear to have been resolved through first-generation smart meter updates to the DCC in the UK (which are still ongoing), and with the rollout of second-generation smart meters. Second-generation smart meters also introduced new functionality, such as the HCALCS, which could be used to turn DER equipment (such as EVSE) on and off, though other methods of control appear to be favoured currently. Consumers may not be able to get a replacement second generation smart meter, as the rollout is

[5] Sarah Ingrams, 'Smart Meters and Solar Panels: What's the Sticking Point?', *Which?*, 2017

[6] Citizens Advice, *Citizens Advice Response to BEIS' Consultation on the Final SMETS1 and Advanced Meter Exception End Date*, 2018

focusing on new installations currently. However, over-the-air updates to first-generation smart meters mean this is unlikely to have a major impact on consumers.

Do I need a second-generation smart meter to be paid for exporting energy to the grid?

In the case of the UK, the 'feed-in tariff' (FiT) reimbursed customers for energy exported to the grid using manual meter readings. The Smart Export Guarantee has since replaced the FiT and requires a smart meter. Both SMETS-1 and SMETS-2 meters record consumption and 'active energy exported' or produced by your solar PV installations, though it must be capable of providing half-hourly meter readings to the Data Communications Company (DCC). Most first-generation meters have already been updated to communicate via the DCC and UK consumers can check what type of smart meter they have on the Smart DCC website

Interface C: Electric Vehicle Supply Equipment

EVs, when properly integrated into the grid via EVSE, can help to reduce consumer charging costs, increase the utilisation of locally-generated energy, and deliver grid flexibility services. This is made possible by a range of common standards and protocols that prospective EV owners should be familiar with. These can be separated into front-end, such as plug-types, electrical and safety requirements, and the front-end communication interface; and back-end, defining the link between charge point and a third-party operator.

As electric vehicles have only recently entered the mainstream, there is considerable fragmentation in terms of standards and protocols adopted, which leads to varying levels of functionality. This is reflected in the main interoperability challenges below:

	Limited vehicle-to-grid (V2G) and bi-directional charging capabilities, particularly in the EU and US, which have legislated in favour of less-developed standard plug types such as the Combined Charging System (CCS).
	Although EVSE can receive over-the-air updates, many ship with out-of-date software (e.g., OCPP 1.6) and there is little indication as to which EVSE will be updated in the future.
	V2G-enabled Type 1, Type 2, and CCS chargers have not yet launched. Although V2G-enabled CHAdeMO chargers are available, their availability is limited.
	Difficulty integrating EVSE into aggregator solutions as OCPP compliant charge points still require integration.
	Communication between EV and EVSE is currently heavily reliant upon EV manufacturer's APIs, which can be prone to failure.

Front-End Protocols

Charging Modes and Data Exchange

The IEC 61851-1 standard defines the four modes of EV charging, safety, and levels of communication applicable to both residential and commercial use cases (Annex D).[7] The standard is easily tested and certified and has been universally adopted in EVs across Europe.[8] However, it does not guarantee the level of data exchange required for advanced charging strategies, such as charging based on tariff information and meter readings, limiting consumer flexibility value and options.

In the UK, the ability for an EVSE to respond to signals to provide these services is now mandated under the 'Electric Vehicles (Smart Charge Points) Regulation'. Although UK 'smart chargers' offer improved interoperability over regular EVSE, upcoming standards and protocols may provide more sophisticated integration between EV, EVSE, and service operators in the future, as highlighted in subsequent sections.

Plug Types and Charging Protocols

There are range of EV plug types (charging protocols) available around the world. Many countries have legislated in favour of a particular combination of AC and DC charging protocols, though some EVs and EVSE with alternative protocols are still available (e.g., Nissan in the EU). Each charging protocol is at a different stage of development, so a consumer's choice of EV may have significant implications on the DER services and benefits offered to them.

CHAdeMO and GB/T dominate in Japan and China respectively. Outside Asia, the Combined Charging System (CCS) has become the dominant DC charging port, as it combines AC charging capabilities through a Type 1 / Type 2 port and DC charging capabilities into a single port. While the EU has legislated in favour of Type 2 and CCS, it did not mandate the replacement of all CHAdeMO charging infrastructure. There are still some vehicles for sale in the region that utilise CHAdeMO, and as a result, bi-directional charging (detailed below) is possible on a limited number of vehicles. For instance, existing V2G capabilities in the CHAdeMO standard enabled Octopus Energy to undertake its 'Powerloop' trial of V2G in the UK.[9]

Despite CHAdeMO's more developed V2G capabilities, CharIn, the global EV charging Standard Developing Organisation (SDO), recommends all countries which have not yet adopted a protocol to choose Type 2 / CCS-2. In addition to being the most popular global standard, Type 2 offers the ability to use faster three-phase charging, provided the EV, EVSE, and premises allow it. This is of more relevance within commercial premises.

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[7] IEC, *IEC 61851-1:2017, Electric Vehicle Conductive Charging System - Part 1: General Requirements*, 2017

[8] Myriam Neaimeh and Peter Bach Andersen, 'Mind the Gap- Open Communication Protocols for Vehicle Grid Integration', *Energy Informatics*, 3.1 (2020), 1

[9] Energy Saving Trust, *Powerloop Vehicle-to-Grid Trial: Customer Insights and Best Practice Guide*, 2022

Does my EV / EVSE plug type matter? Can't I just buy an adapter?

It is possible to use an adapter (e.g., Type 2 to CHAdeMO) to charge your EV using different EVSE. However, as an EV with Type 2 and an EVSE with CHAdeMO use different communications protocols, you should not expect to see the same functionality (e.g., Vehicle-to-Grid (V2G) charging capabilities).

Back-End Protocols

Grid Integration Levels

The utility of EVs as a form of DER becomes increasingly apparent as they are integrated with the grid. This integration enables them to provide a range of balancing services, such as demand-side response (DSR) or frequency regulation, and pass the financial value onto the consumer, all without compromising the driving experience or capabilities of the vehicle. In a recent CCS functionality roadmap, CharIn outlined five 'Grid Integration Levels' with increasing levels of functionality:[10]

- Grid-Compliant Charging
- Level 1 – Grid Unidirectional (V1G) or Controlled Charging
- Level 2 – Grid / Home / Site Unidirectional (V1G/H) or Cooperative Charging
- Level 3 – Vehicle-to-Home (V2H), Vehicle-to-Load (V2L) or Bi-directional charging
- Level 4 – Vehicle-to-Grid (V2G) or Aggregated Bi-directional charging

Grid-Compliant Charging

Grid-compliant charging is established when an EV and EVSE are compliant with local regulations, including grid-codes and IEC-61851-1. No communication between EV, EVSE, Distribution System Operators (DSO), or aggregators is assumed at this level.

Levels 1 and 2 - Smart Charging (V1G)

V1G or Controlled Charging refers to unidirectional charging (from EVSE / Grid-to-EV) in which communication between EV, EVSE, and a smart meter may occur. A simple V1G implementation can occur when a charging point is instructed to start or stop charging according to the time of day. This is beneficial for those with a Time-of-Use tariff, which may provide cheaper 'off-peak' rates overnight.

V1G/H or Cooperative Charging allows more sophisticated communication between the EV and EVSE without the need to rely on an API from the EV manufacturer. The EV's state of charge, time required to

"We've worked with a whole host of different EVSE that all claim they are OCPP 1.6 or 2.0, and they all behave in slightly different ways".

- ***Energy systems and V2G expert, Global Flexibility Service Provider***

[10] CharIn, *Grid Integration Levels V5.2*, 2020

fully charge the EV battery, current utilisation of the electricity grid, and current and forecasted availability of renewable energy sources, are all considered to optimise charging. For EVs with CCS, this is enabled by ISO 15118-2 (2014). EVSE with Open Charge Point Protocol (OCPP) version 2.0.1. and above provide native support for ISO 15118-2. Without this standard in place, reliance on an API for vehicle and battery data can result in challenges if the API goes down or Wi-Fi / 4G connection is lost. For example, EVSE may assume the car is 'empty' and initiate a full charge, eliminating cost-saving benefits to consumers. Despite these standards being around for several years, many EVSE providers still rely on OCPP 1.6 and an API connection with the EV, which increases the risk of failure for consumers and may mean that consumers face costly hardware upgrades to obtain the more advanced charging capabilities.

Additionally, while OCPP is the *de facto* 'standard' for communications between an EVSE and a Charging Network Operator (CNO), it does not guarantee 'plug and play' interoperability, and aggregators or energy management apps looking to control the device will often need specific integrations to enable this. Third party integrations can save development time but may not always be tested to the same high standards.

Can I expect an over-the-air (OTA) update when new EVSE standards are released, or when certain functionality is mandated?

According to industry stakeholders, it is common for the manufacturer to push OTA updates to EVSE, often to ensure that the EVSE meets new policy requirements, such as the UK's 'Smart Charge Points' regulations. However, due to the range of additional features and increased memory requirements in OCPP 2.0.1 compared to 1.6, a software update may not always be possible. Consumers should also expect to purchase a new V2G-compatible EVSE for Type 1 / Type 2 vehicles when they become available due to additional hardware requirements.

Levels 3 and 4 - Vehicle-to-X

Vehicle-to-X or Vehicle-to-Everything (V2X) is a catch-all term that encompasses any form of Bi-directional Power Transfer between a vehicle and another asset. V2X consists of three main capabilities, each at different stages of implementation: Vehicle-to-Load (V2L), Vehicle-to-Home (V2H), and Vehicle-to-Grid (V2G). V2L is the simplest implementation and allows the vehicle to charge or power small appliances (e.g., via a UK 3-pin socket). V2H enables energy transfer between the EV battery and the home or commercial premises, with a focus on behind-the-meter use-cases. V2G is the most sophisticated implementation. Unlike V2H, V2G assumes a level of integration beyond the consumer's own energy system; this includes front-of-the-meter uses-cases, in which Bi-directional Power Transfer may be initiated by an aggregator to provide services to the grid.

Although CHAdeMO has been capable of vehicle-to-grid integration since 2014, Type 2 / CCS-2 have, up to this point in time, lacked V2X capabilities. However, the recent launch of the ISO 15118-20 (2022) and SAE J3072 standards, once adopted by EV and EVSE manufacturers, could soon remove this limitation. Both standards enable V2G integration through Type 1 / 2 and CCS, albeit with slightly different implementations from a hardware perspective.[11] However, CharIn, the SDO responsible for maintaining CCS, considers ISO 15118-20 (2022) to be the key enabler of V2G integration globally if Type 2 / CCS-2 continues to dominate.[12]

I've got a solar installation. Can I drive my car on 100% solar?

If you already have solar panels installed, charging your EV on your own solar power is possible with the right equipment. The myenergi Zappi, Wallbox Pulsar Plus, and Indra Smart Pro are just some examples of EVSE that offer dedicated charging modes for consumers with microgeneration already in place, allowing you to divert excess solar straight to your car and alter the charging rate depending on the amount of solar energy being generated. Some EVSE providers, such as dcbel, offer more advanced DC solar chargers which can charge at a faster rate than a standard AC EVSE, provided there is enough solar power being generated.

Interoperability Challenges and Considerations

EVs and EVSE represent one of the most promising avenues for consumer energy saving and flexibility trading. However, EVs and EVSE are still relatively new DER equipment, and consumers must make informed decisions to ensure that they can benefit from i) smart charging, ii) V2G capabilities, and iii) solar charging.

In the UK, a minimum level of smart charging capability has been introduced through legislation, so consumers with a smart meter will be able to benefit from time-of-use tariffs with any new government recommended EVSE. V2G, while possible, is only currently available on CHAdeMO EVs with specific V2G capable EVSE. While V2G capable Type 1 / 2 charge points are about to reach the market, there are currently no compatible EVs on the market.

While EU customers may be tempted to purchase a CHAdeMO-equipped Nissan to benefit from V2G, they must first find and purchase a compatible EVSE. These are currently difficult to obtain and can cost thousands of pounds. Given that Nissan is the only major EV brand to support CHAdeMO in Europe, consumers may also need a new EVSE when they upgrade to a non-Nissan car, or if Nissan ever stops using CHAdeMO in Europe. Additionally, European consumers may face difficulties on the resale market and may need to spend more on adaptors to charge on the road.

Consumers can purchase EVSE with solar charging capabilities (outlined in Chapter 4). Consumers who are willing to wait and have a bigger budget will soon be able to purchase a smart, V2G-enabled solar charger, such as the dcbel r16.

[11] California Energy Storage Alliance, *Final Report of the Vehicle to Grid Alternating Current Interconnection Subgroup*,

[12] Charin, 2020

Interface D: Smart Building Applications

Smart Energy Management Systems (EMS) can provide consumers with valuable insights into their energy usage, allow manually and autonomous control of assets or appliances when needed to reduce or increase energy consumption (e.g., if an EV was required to break from its charging schedule), and enable the automation of grid services like DSR. For an EMS to function effectively, all the equipment and devices within a building's DER system must be able to communicate using common communications protocols and semantics. This is also key to enabling consumer switching and the ability to add or upgrade equipment. The key challenges at this interface include:

	A variety of wireless and wired connectivity protocols in use across devices within the building.
	Emerging standards, such as Matter, could enable greater interoperability, but there is little clarity around which devices will be updated to support this.
	A lack of clarity around which devices can integrate into an EMS and can send, receive, and intelligently interpret data from one another.

Connectivity protocols

The 'smart home / building' is set to be a key driver of interoperability. EVSE from SolarEdge and eMotorWerks gave an early indication of the potential for the smart home to drive interoperability when they were made Google Assistant compatible in 2019, and native support for Google Assistant-compatible EVSE launched the following year.[13,14] However, there are several communications protocols for manufacturers to choose from when designing 'smart' DER devices. This can create potential interoperability issues for consumers if their devices do not all share a common protocol. Compounding this challenge is that a sizeable portion of consumers do not know what technologies or standards underpin their smart devices. This was highlighted by Z-Wave's 'State of The Ecosystem 2022' report, in which 30% of 1,500 U.S. homeowners surveyed could not answer this question. The battle between wireless communication standards like Zigbee and Z-Wave will have potentially significant implications for consumers' ability to successfully integrate DERs into smart buildings.

Despite having more companies behind the standard, Z-Wave is predicted to lose out to Zigbee on the basis of 'technological superiority', the availability of 'complementary goods' within the ecosystem, and 'big fish' adopting the standard.[15] Zigbee is also the protocol used by SMETS meters in the UK, which consumers should take into account if they are considering further integration of devices with smart energy tariffs. Additionally, many devices will gain functionality from being connected to the internet, and it is crucial that consumers weigh up the pros and cons of each connection type before making a

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[13] 'Hey Google, What's New with the Assistant at CES This Year?', *Google*, 2019

[14] Rita El Khoury, '"OK Google, Charge My Car" - Assistant Adds Native Control for Chargers and Batteries', *Android Police*, 2020

[15] G. Van de Kaa, S. Stoccuto, and C. Valladolid Calderón, 'A Battle over Smart Standards: Compatibility, Governance, and Innovation in Home Energy Management Systems and Smart Meters in the Netherlands', *Energy Research & Social Science*, 82 (2021),

purchase, as dropouts or signal failure could impede the ability of the user and energy service providers to communicate with the device and provide flexibility.

Wi-Fi, 4G, Ethernet – Which connection do I choose?

Your choice of internet connection might seem insignificant, but it can have a substantial impact on the way that your devices communicate with manufacturers and cloud-based energy management solutions. Signal dropouts or changing internet providers could limit DSR capabilities of equipment or restrict OTA updates and predictive maintenance. For some manufacturers, such as Tesla, prolonged disconnection can even void your warranty.

Application Layer

Although equipment such as EVSE are already being integrated into voice assistants for features like voice-activated charging, levels of integration remain limited. The recently launched 'Matter' standard which has the support of Google, Apple, Amazon, and Samsung, amongst others, aims to provide interoperability at the application layer – the layer closest to the user which is responsible for enabling recognition and authentication of devices and determining protocol and data syntax rules. However, few DERs have been certified to this standard so far, and DERs will not be officially supported until 2024.

Interoperability Challenges and Considerations

Despite smart buildings driving interoperability, policymakers have been reluctant to standardise in favour of interoperability between devices and energy management systems (or customer energy managers), leading to a proliferation of connectivity standards and smartphone apps. One of the most promising solutions is the Matter standard. DER providers such as LG, Samsung, and Schneider Electric are already onboard. Although DERs will feature more heavily in Matter 2.0 (launched in 2024), Schneider Electric has already released a compatible EVSE.

Interface E: Aggregators

Aggregators are emerging as a key player in the energy market, enabling consumers to benefit from trading flexibility with the grid by bundling and managing the capabilities of small producers and consumers. There are several key interoperability challenges facing consumers and aggregators in this emerging market, including:

- **There are issues surrounding the access to and control of inverter-based resources due to chosen communications protocols.**
- **There has historically been no way to balance individual assets providing balancing services on complex sites.**

The ability of an aggregator to communicate and operate inverter-based resources is already being addressed through initiatives like the CSIP, outlined previously. Increasingly, manufacturers are looking beyond smart meters, or behind the 'grid edge' (the point of connection between the site and the electricity distribution network), to record the amount of electricity produced or consumed by individual assets for the purpose of settlement. While this could offer additional benefits for consumers capable of providing sophisticated balancing services, it is not without its challenges.

Under the newly launched modification to the Balancing and Settlement Code, P375, and companion COP11 in the UK, Secondary Meters, or 'asset meters' (Figure 3) will allow individual assets (e.g., an EV or battery) sitting behind-the-meter to be settled independently of one another, providing complete visibility of balancing services provided and ensuring that asset owners are properly compensated. The modification was proposed by UK DSR service provider Flexitricity and will ensure that balancing services provided by individual assets (and increasingly managed by aggregators) are recognised and rewarded.

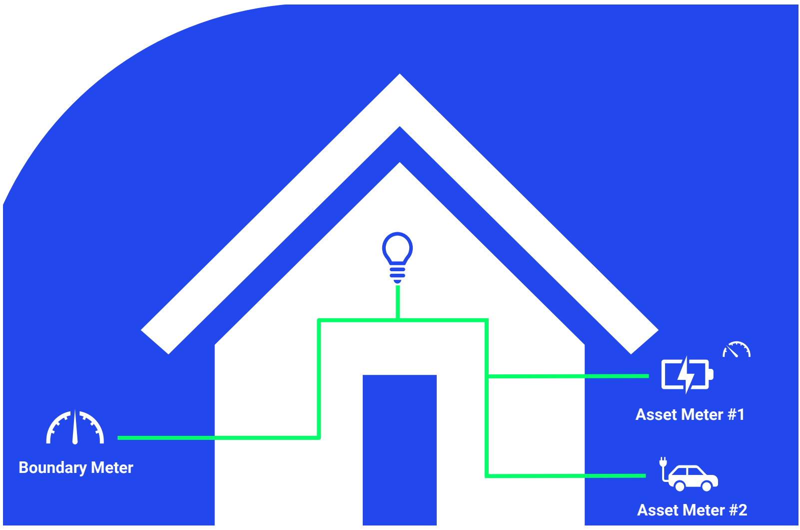


Figure 3: Asset metering for individual appliances

COP11 sets an important metering standard for asset meters, including EVSE, to measure the consumption or generation of equipment. It will be critical to ensuring such asset meters are able to take part in flexibility markets, and could have important residential and commercial implications, e.g., by enabling separate payment to be disaggregated between EVs and commercial entities within a large business park. It is therefore crucial that manufacturers implement COP11 standards as a minimum requirement, and that other countries introduce actions. However, a key challenge remains from a hardware perspective – the cost and technical feasibility of implementing standardised individual meters across a range of equipment types. Although this standard is in its early stages, commercial consumers and residential developers should seek to understand its implications when consulting on new DER installations, and whether their equipment would benefit from being certified to the appropriate metering standard.

Interoperability Challenges and Considerations

The aggregator market is still emerging in many parts of the world, so aggregator-ready products are not always clearly certified and visible to consumers. Nevertheless, CSIP-compatible inverters in parts of the US and Australia have been designed as future-proof for the aggregator market. In the UK, aggregators such as Flexitricity have recommended that all equipment suitable for the aggregator market, such as EVSE, should be designed in accordance with BSI PAS 1878 and COP11 – capable of communicating via OpenADR 2.0 and with standardised asset meters.[16] Consumers may therefore look for OpenADR compatible equipment within the UK.

[16] Flexitricity, 'Flexitricity's Response to Competition and Markets Authority's Study into Electric Vehicle Charging', 2021

3. Brand Interoperability

With so many brands out there, consumers rightfully want to know that their devices will 'play nicely' and that their home or commercial premises will be future-proofed should they ever wish to upgrade or expand their DER set-up. The following section details, at a high-level, the interoperability of various brands of DER equipment. Information has been obtained from publicly available specification sheets on manufacturers websites (EU and US markets), and specification sheets varied in the level of detail provided on compliance to standards and protocols.

3.1.1. Inverter / Battery Interoperable Models

Table 1 provides a comparison matrix of battery and inverter brands by compatibility. Exclusively AC-coupled battery units, such as Tesla's Powerwall and Powervault, are excluded from this table as they will not have to interface directly with the solar inverter and will therefore not face compatibility issues with them (as described in Chapter 2). Although consumer choice will be influenced by many factors when selecting equipment brands (cost, features, performance and reliability, cycle life, installation and servicing, safety, form factors etc.) understanding their breadth of compatibility with other branded products in the market should be a key consideration in decision making.

A greater breadth of compatibility can reduce overall costs and lead times in installation and servicing and increase consumer choice in features and functionalities to meet consumer requirements or local standards. From the brands analysed, LG, BYD, and Dyness battery solutions were most open to compatibility with other major inverter brands, while Huawei operates within a 'closed' product ecosystem. Some key consumer takeaways from this analysis are:

- Consumers can purchase AC-coupled batteries to retrofit to any existing solar installations.
- Brands vary in their degree of openness to DC-coupled products outside of their own ecosystems. Huawei has a clear preference for own-brand product pairing and failure to consider this could void the consumer's warranty. This should be a long-term consideration for consumers who wish to add equipment such as a battery down the line.

Compatible. Specified under warranty | Not listed as compatible

Table 1: Interoperability between inverters and batteries by brands

		Batteries								
		LG Energy Solution	Huawei	Victron Energy	GoodWe	BYD	SolarEdge	SMA	Dyness	Growatt
Inverters	LG Energy Solution	Compatible								
	Huawei		Compatible							
	Victron Energy			Compatible					Compatible	
	Kostal	Compatible				Compatible				
	GoodWe	Compatible			Compatible	Compatible			Compatible	
	Fronius	Compatible				Compatible				
	SolarEdge	Compatible					Compatible			
	SMA	Compatible				Compatible		Compatible	Compatible	
	Sungrow					Compatible				
	Solis	Compatible				Compatible			Compatible	
	Growatt								Compatible	Compatible

Note: This matrix contains the most popular brands. Some brands within this matrix provide a more extensive list of compatible inverters which are not listed here as they fall outside the most popular brands.

Electric Vehicles and EVSE

As the previous chapter highlights, the ability for EVs to usefully integrate with the grid for residential and commercial consumers is largely determined by the protocols and standards with which they comply. As the following matrix suggests, Nissan is currently the only manufacturer offering V2G capabilities. All

Nissan Leafs have been V2G 'ready' since 2014 as they ship with a CHAdeMO charging port. With the release of ISO 15118-20 (2022), it is expected that other manufacturers will soon follow suit. The following key (used for Table 2 and 3) demonstrates how brands have been scored:

Complies with standard	Partial implementation	Does not comply with standard	Data not available	Proprietary protocol

Table 2: Prominent standards and protocols mapped to key EV brands (see Chapter 2 for an explanation of relevant protocols)

Standards	Tesla	Volkswagen	BMW	Kia	Renault	Nissan
			Plug Type and Charging Protocols			
CHAdeMO						
Type 1 / 2 and CCS	Proprietary in U.S.					
			Grid / Site Integration Protocols			
V1G "cooperative charging"- ISO 15118-2 (2014)						
V2X - Bi-Directional Charging	V2L	V2L	V2L	V2L	V2L	V2G
V2G - CHAdeMO						
V2G - ISO 15118-20 (2022)						

It is worth noting the paucity of information on vehicle compliance with ISO 15118-2 and -20. Both protocols are relevant for the vehicle to grid communication interface, dictating V2G capabilities, Plug & Charge, and automatic vehicle identification. It is also not clear to what extent these capabilities can or will be provided later through OTA updates, both due to hardware restrictions and a lack of clarity from EVSE manufacturers. Consumers looking to purchase a V2G-ready vehicle should either choose a CHAdeMO-equipped Nissan (being mindful of the fact that CHAdeMO EVSE are much less common in the EU and US due to legislation in favour of CCS) or wait for V2G-ready CCS vehicles to launch.

If the consumer is considering switching from ICE to EV, they can still benefit from cost-saving time-of-use tariffs and 'smart charging', provided they have a smart EVSE. When purchasing an EV, consumers must also select a compatible EVSE to maximise their functionality and reduce costs (e.g., those associated with purchasing unnecessary adaptors). Consumers wishing to purchase an EVSE will need to consider several factors. Consumers with CHAdeMO-equipped EVs such as the Nissan Leaf looking to provide flexibility to the grid or back-up power to their home can purchase V2G-capable chargers such as the Wallbox Quasar and myenergi Zappi. In the EU, manufacturers like Alfen are on the cusp of releasing V2G-capable DC chargers, suitable for commercial sites, like the 'Twin', with AC V2G-capable devices to follow soon. This will still require a V2G-enabled CCS-equipped EV, which is yet to materialise, but it will ensure that charging infrastructure is futureproofed.

Table 3: Prominent standards and protocols mapped to key EVSE brands and products. Please use the same key for Table 2.

Standards	Schneider Electric EVLink Home	Schneider Electric EVLink Fast	Tesla Wall Connector	Wallbox Quasar	Wallbox Pulsar	Ohme Home Pro	Myenergi Zappi	Alfen EVE Single S	Alfen Twin	EVBox Livo	Dcbel R16	Indra Smart Pro
CHAdeMO												
Type 1 / 2 and CCS												
V1G "cooperative charging"- ISO 15118-2 (2014)**												
V2X - Bi-Directional Charging												
V2G - CHAdeMO												
V2G - ISO 15118-20 (2022)**												
Wi-Fi												
Ethernet												
3G / 4G												
OCPP	1.6	1.6		1.6	1.6	1.6		2.0.1	2.0.1	2.0.1		
OpenADR***												
Matter Certified												
Solar Integration (EEBUS)												

Note: This matrix contains a selection of the most popular brands. As of April 2023, there are 66 brands on the UK's approved residential smart charger list alone. It is therefore not intended to recommend products, but rather indicate potential options for consumers.

* Text within boxes refers to products available on the market, or in the case of OCPP, the listed software version.
** California: commitment to 'ISO 15118 Ready' (2023).
*** Based on list of OpenADR certified products.

'Smart' functionality, such as being able to control charging remotely or automate based on state of charge, will require a reliable internet connection. Wi-Fi signal may be better than 3G / 4G when installations are within garages, but functionality may be lost if Wi-Fi is unreliable or the consumer switches providers. 4G capable devices with an any-network sim can be a solution, but consumers will often need to purchase a data plan at some point after installation. Schneider Electric's EVLink Home Smart is the only Matter-certified product which will enable seamless integration with Matter building energy management apps, though more manufacturers will likely come onboard with Matter Spec 2.0 in 2024.

Solar integration can be achieved with an EEBUS compatible EVSE. This will allow those with an EV looking to charge with cheaper domestically produced solar energy to do so with solutions such as the Wallbox Pulsar Plus and myenergi Zappi charger. The dcbel r16 charger, which is a domestic DC charger, also enables faster charging rates using excess solar energy by supplying DC power directly to the vehicle, as well as V2G capabilities. This solution will provide the most options and 'futureproofing' for those with solar PV and an EV, though this brings a significant cost to the consumer.

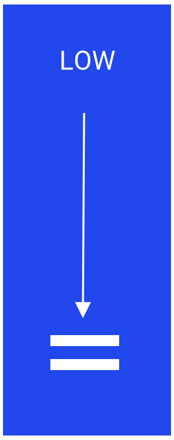
Key consumer takeaways

- V2G-capable cars with CHAdeMO plugs are already on the market, but the relevant protocols for CCS-equipped vehicles (dominant in EU and US) are yet to filter through to EVs on the market.
- Consumers can purchase CHAdeMO-equipped vehicles (e.g., Nissan) for V2G capabilities in the EU and US. However, CHAdeMO charging facilities are not mandated on highways and consumers may prefer other brands with larger batteries. Consumers should consider future resale values.
- Customers will need a new EVSE capable of V2G to benefit from their EV as a back-up storage facility or to sell energy back to the grid. Both standard and V2G capable EVSE represent a considerable investment, but consumers can 'future-proof' their set-up for a V2G-capable CCS-equipped vehicle.
- Consumers with solar PV can benefit from solar charging with an EEBUS compatible charger such as the Indra Smart Pro, or maximise their options with a V2G-capable solar charger such as the dcbel r16.
- OpenADR compliance is limited, which may pose a risk for UK consumers looking to align with the UK's new PAS 1878 specification.
- Manufacturers promise software updates with new features, but it is not clear whether these will always materialise due to hardware restrictions or product support schedules. Software updates such as OCPP 2.0.1 with ISO 15118-2 can offer more reliable smart charging support by removing the need for an API. However, consumers should not always assume a software update if functionality is not listed on the datasheet.

4. Interoperability Ratings, Solutions, and Policy

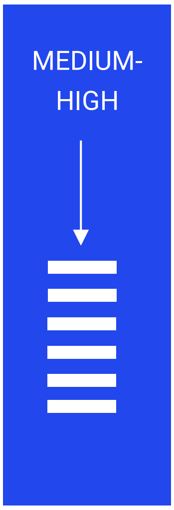
DER Interoperability Challenges

This report has highlighted a range of interoperability challenges for residential and commercial users looking to integrate DER solutions and participate in emerging flexibility markets. This section summarises these challenges across common DER configurations and for key DER interfaces. It is important to note that these summaries are not region specific, but encompass the main challenges that are likely to be faced by consumers.



Solar and Inverter

This configuration presents the least interoperability challenges for consumers. Installation of solar PV and inverters will be carried out by a qualified technician, with knowledge of compatible products. Typically, solar inverters are ‘unidirectional’, which is sufficient for a solar-only installation. However, if an AC-coupled battery is retrofitted later, it will not benefit from the same efficiencies achieved by a DC-coupled battery installed with the solar panels and using a shared hybrid inverter (discussed below). Consumers must also ensure that their inverter complies with grid-connection standards appropriate to their region, e.g., CSIP in California, G83 / G98 in UK, and the NC RFG in the EU.



Solar, Inverter, Battery

Consumers looking to benefit from solar generation and battery storage can either opt for an AC-coupled battery (easy to install with an existing solar PV installation and unidirectional inverter) or install a hybrid inverter and DC-coupled battery. The latter is ~ 5% more efficient in terms of storing energy as there is no AC-DC conversion required to charge the battery. Consumers can benefit from redirecting ‘excess’ solar power straight to the battery, without clipping. The addition of a battery however can create interoperability challenges between the battery and inverter, based on whether compatibility testing has been conducted by manufacturers and resulting impacts on warranties. Back-up power functionality has not been standardised, though solutions are on the market (e.g., Tesla Powerwall 2). Challenges may also lie with the software applications needed to interface with the battery and smart home management systems.

HIGH

Solar, Inverter, Battery, EVSE (Grid Integration)

An EVSE provides an additional means of storing energy produced via solar while at the same time providing flexibility to the grid. This will inherently mean that complexity is increased. Solar can be redirected to the EVSE using a manufacturer-developed solution such as the AC-powered myenergi Zappi. A DC-powered charger such as the dcbel r16 may allow even faster charging speeds using 'excess' solar energy. Alternatively, users may programme their 'smart', connected EVSE to initiate charging when solar production reaches a certain output or energy prices drop below a certain threshold on a MHHS tariff. However, most EVs in the UK and United States are equipped with CCS, and the standards for V2G integration have only recently been released and have not been adopted. In most cases, EVs will not be able to supply energy back to the grid or home. Those with a CHAdeMO-equipped EV such as the Nissan Leaf may be able to source a Wallbox Quasar from recent V2G trials for instance, though they are currently unavailable to purchase.

Table 4 (following page) summarises the key interoperability challenges at each interface in a DER system, as discussed in Chapter 2. These are ranked according to their degree of severity in each region, and possible solutions are provided based on existing workarounds or current policy initiatives around the globe.

Policy Focal Points

Ongoing policy development to increase the interoperability of DER systems will be key to driving standardisation in the sector, augmenting DER value and grid participation, and unlocking new potential markets. This chapter summarises focus points for further policy development identified through the research.

Smart inverters will be key to a flexible, future-proofed grid, but they are often not mandatory, nor do existing international standards provide clear guidance on how they should work.

Despite progress on interconnection standards, internet-connected inverters that are interoperable with aggregators are often not mandated.[17] As a recent case study from FlexiblePower Alliance Network and DeltaEE (LCP Delta) highlights, of the approximately 300,000 residential PV inverters installed in the Netherlands in 2020, only between 57–75% would be suited to a flexible energy system often due to a lack of internet connection, common standards and communications protocols.[18] This is a significant issue for consumers looking to benefit from the emerging DSR and aggregator markets, as the ability for service operators to communicate with and instruct DER equipment remotely is critical, and largely absent.

[17] Shuang Xu, Yaosuo Xue, and Liuchen Chang, 'Review of Power System Support Functions for Inverter-Based Distributed Energy Resources- Standards, Control Algorithms, and Trends', *IEEE Open Journal of Power Electronics*, 2 (2021), 88–105

[18] FlexiblePower Alliance Network, *Solar Energy Needs Smart Inverters: Market Insight on Flexible Connected Residential PV Inverters*, 2021

Minimal	Dependent on consumer choice	Significant

Table 4: Summary of interoperability challenges at key interfaces across four 'representative' countries / states in Europe, North America, Asia, and Africa

Interface With Challenge			UK	CA	JA	SA	Solutions
Inverter	Battery	Compatibility, warranties.					Consumer can purchase an AC-coupled inverter and battery for retrofits or replace existing solar inverter with a hybrid inverter.
Inverter	Battery and Solar	No standardised means of enabling backup power.					Consumer can purchase proprietary solutions (e.g., Tesla Powerwall and Gateway, Victron Energy Inverter).
Inverter	Service Provider	Readiness for aggregator market.					**Policy Focus:** California's CSIP and CSIP-AUS provide a model for DER-aggregator interoperability.
Smart Meter	EVSE	Time-of-use tariff integration.					Enabled by UK Smart Charger Regulations. Clear list of compatible EVSE.
EVSE	EV	Communicating State of Charge.					Currently through an API. **Policy Focus:** Mandate ISO 15118-2, or -20.
EVSE	EV	Vehicle-to-Grid (flexibility trade, backup power).					Only possible with CHAdeMO equipped EVs, EVSE. **Policy Focus:** Accelerate testing and rollout of V2G hardware and standards.
EVSE	Solar	Charging using locally generated solar.					Not standardised. Consumer must purchase specific equipment.
EVSE	Service Provider	EVs as an aggregated flexibility provider.					Aggregators can communicate with an EVSE, but not directly with an EV. **Policy Focus**: Standards such as ISO 15118-20 and IEC 63110 pave the way for aggregating EV loads.

Note: UK: United Kingdom, CA: State of California (US), JA: Japan, SA: South Africa. These areas were chosen as models for interoperability in their respective regions (UK for Europe region, South Africa in Africa, Japan in Asia), with California representing a global best-case-scenario.

The IEEE 1547:2018 standard defines required data elements for inverter control but does not whether IEEE 2030.5, IEEE 1815, or Modbus communication protocol must be used. This results in many possible permutations that makes it difficult to test and certify an inverter under IEEE 1547 as compatible with all energy service providers and provide reassurance to consumers looking to participate in emerging flexibility markets.[19] This issue has been addressed in California and Australia with the adoption of the CSIP under California Rule 21. Though based on the IEEE 1547 standard, the CSIP specifies IEEE 2030.5 as the required communication protocol and IEC 61850 as the necessary information model, facilitating greater interoperability. Certification and testing programmes for the CSIP requirement have since been developed, and the requirement has been exported to other parts of the United States. Australia has also modelled its own CSIP-AUS on this profile. [20]

Policy Focus

Policy makers should investigate the adoption of a version of the Common Smart Inverter Profile used in California and Australia, and ensure that all devices are capable of connecting to the internet. This will ensure devices are capable of interacting with the emerging aggregator market.

Many EVSE from emerging start-ups are OCPP-compliant, but this does not guarantee interoperability with DSR service providers.

Several industry stakeholders providing DSR services highlighted the lack of guaranteed interoperability with EVSE as a significant challenge which required extra development time. OCPP compatible devices still need to be 'integrated' with the service provider before they will work. This problem is particularly acute in the UK, where there has been a rapid expansion in the number of start-ups offering OCPP compatible commercial and residential EVSE equipment.

Policy Focus

Policymakers should work to accelerate the implementation of standards such as IEC 63110 and ISO 15118 that guarantee interoperability between EVSE and DSR service providers.

The UK, Europe, and parts of the United States are falling behind on ISO 15118 adoption, which is key to 'Plug and Charge' and Vehicle-to-Grid charging with Type 2 / CCS-enabled vehicles.

Since 2014, the CHAdeMO charging standard has been technically capable of V2G charging. Europe and the United States have since moved away from the standard in favour of the Combined Charging System

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[19] Avi Gopstein and others, *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0*Gaithersburg, MD: National Institute of Standards and Technology,

[20] FTI Consulting, *DER Interoperability Assessment Framework: An Assessment Framework to Develop Interoperability Policy for Distributed Energy Resources in Australia*,

(CCS) which merges an EV's AC and DC charging ports into one. As a result, and due to lengthy standard development times, the majority of EVs and EVSE in each region use Type 1 / 2 and CCS for AC and DC charging respectively, while still conducting V2G trials using the CHAdeMO cable and V2G standard. Currently, only those who buy a Nissan vehicle can participate in trials and purchase V2G-enabled chargers.

The ISO 15118 (2014) standard enables ease of charging with its 'plug and charge' functionality by facilitating automatic vehicle identification and authorisation. This could reduce the number of apps required for roaming customers and enable straightforward communication of the State of Charge with the EVSE, thus reducing reliance on unreliable APIs. However, uptake remains low. ISO 15118 (2022) makes V2G technically possible, though policy support is needed to speed up the rollout of V2G chargers and compatible vehicles.

Policy Focus

UK and European policymakers should follow California's lead to ensure that all new EVSE are 'ISO 15118 ready'. Under this legislation, the EVSE provider may or may not provide V2G capable hardware, but the level of communication between EV and EVSE would be such that there is no longer a reliance on APIs. A 'V2G ready' standard could also be developed to increase consumer confidence in future-proofed hardware as they upgrade or purchase additional EVs with V2G capabilities. Conditions for the UK's EV Chargepoint grant could be updated to reflect the need for future-proofed 'V2G' to provide grid services

Considerable uncertainty remains around the communications protocols which should be used to ensure interoperability between DER equipment and devices on the premises, as well as with the Customer Energy Manager.

The British Standards Institute launched PAS 1878 in 2021, defining the attributes, functionalities, and performance criteria for 'Energy Smart Appliances' (ESAs). While it clarified the potential communications protocol between ESAs and service providers, it failed to define the communications protocol for 'interface B', that is, between ESA and Customer Energy Manager. This could remain a major challenge in enabling mass market control of a range of ESAs, whether that be EV chargers, heat pumps, solar inverters, or battery storage.

The recently launched 'Matter' standard, developed by the Connectivity Standards Alliance, is an attempt to remove potential barriers to interoperability resulting from the proliferation of proprietary standards by smart home service providers (e.g., Google, Amazon, Apple). The standard aims to "define the fundamental requirements to enable an interoperable application layer solution for smart home devices over the Internet Protocol". All Matter compatible devices communicate using a combination of Wi-Fi, Thread, and Bluetooth Low Energy. Home Energy Management provider Schneider Electric has already released its first Matter-certified devices, including an EV charging point.

Matter Specification 1.0, which was released in November 2022, does not feature DERs but specification updates follow a bi-annual release cadence, with 'Energy Management' to feature more prominently in Specification 2.0 which is due to be released in early 2024. If Matter is to spur further integration of DERs, it will need to work with DER providers to ensure that all voices are heard. As it stands, EV manufacturers are a notable absence from the list of Matter promoters and given that EVs will have a significant role to play in enabling flexibility services through V2G charging, this gap will need addressing.

Home Energy Management providers such as Green Energy Options are already betting on the adoption of the Matter standard for interoperable DER. This will be tested in the Government's 'Interoperable Demand-Side Response Programme', which follows from PAS 1878. Here, Matter is the 'Interface B' protocol between two DERs, a heat pump and an EVSE, and a customer energy manager. Given that Matter aims to provide an interoperable application layer solution between major IOT and DER manufacturers, this could soon enable consumers to control all their DERs and ESAs from in one place and should be a consideration when purchasing new equipment.

Policy Focus

Policymakers and manufacturers must work together to provide greater clarity around the communications protocols required for interoperability between devices, as well as between devices and Customer Energy Managers to ensure the longevity of consumer's equipment. This could include working with industry initiatives such as the Matter standard to explore and support possible implementations.

5. Conclusion

Existing interoperability challenges between residential and commercial DERs represent a considerable obstacle to the development of a robust and integrated energy system that maximises financial and energy security benefits to the consumer. Consumers must make informed decisions when purchasing DER equipment to i) avoid brand lock-in, ii) enable the full range of functionalities (back-up, grid trade, etc.), and iii) ensure that they are future-proofed as new standards, technologies, and energy markets emerge. These issues vary in severity between different DER devices and geographies.

In some cases, interoperability is not guaranteed due to an absence of standards and testing – EVSE and EV solutions are still heavily reliant on unreliable third-party APIs, back-up capabilities in batteries are not required or standardised, and manufacturers tend to approve interoperable DC-coupled batteries and inverters under warranty to ensure performance and safety. Consumers should understand these limitations and the options available to them when considering the integration of DER systems for their desired use cases.

Issues may also stem from a lack of shared standards for communication and data exchange between different devices, platforms, and energy service providers. In many instances, market drivers for producing interoperable equipment do not exist as manufacturers stand to lose their leverage in the market, including their ability to sell on additional services. This is where policy has a key role to play. Where rooftop solar generation potential is high (California, Australia), policymakers have had a greater incentive to intervene and ensure the interoperability of inverters and inverter-based resources (solar panels and batteries) with emerging aggregator markets, which will have notable benefits to residential and commercial consumers looking to sell energy services. Policy must also accelerate the roll out of V2G ready EVs and EVSE across geographies to limit the cost to consumers for replacing equipment, draw out advanced functionality such as flexibility trading and back-up power to the home / site, and establish the infrastructure for the growth and development of new grid flexibility markets.

While the challenges are in some cases significant, the potential benefits of seamlessly integrated, DER-enhanced, renewable energy (increased grid resilience, improved energy efficiency, reduced greenhouse gas emissions, additional cost savings etc.) are too great to ignore. Policymakers and industry must work together to ensure that the full potential of DERs is realised, for the benefit of all.

Annex A

Table A1: Prominent standards / protocols relevant to PV, battery, and inverter DER technology

IEEE 1547	*First developed in 2003, this standard has played a key role in grid interaction for DERs and Inverters.*
Rule 21	*A major change to requirements for generation and storage facilities in California. The Common Smart Inverter Profile was an offshoot which has influenced other regions around the world.*
NC RfG	*The Network Code on Requirements for Generators is an EU regulation that covers network code requirements for connection of generators and establishes harmonised connection rules for power-generating modules.*
EN 50549	*An EU standard setting out requirements for generating plants to be connected in parallel with distribution networks.*
IEEE P2030.5	*A commonly used communications protocol globally.*
CSIP-AUS	*An Australian standard that is an interoperability profile that improves consumer choice and switching.*
BSI PAS	*The British Standard Institute (BSI) produces Publicly Available Specifications (PAS), of which, some play key roles in interoperability models.*

Table A2: Prominent standards / protocols relevant to EV, and charge point DER technology

IEC 61851-1	*Determines general charging requirements for EVs and outlines the four 'modes' of charging.*
Type 1 / 2	*Type 1 is the main AC charging standard in the United States. Type 2 is the main AC charging standard outside of Asia.*
CHAdeMO	*CHAdeMO is a DC charging standard. Although present outside of Japan, it is now less common. It was the first EV charging standard to implement V2X capabilities.*
CCS-1 / CCS-2	*Unlike CHAdeMO, the Combined Charging System enables AC and DC charging from the same port. Type 1 and Type 2 plugs are used for AC charging.*
ISO 15118-2	*Enables EVSE to manage charging and discharging by communicating instructions over conductive or wireless link to the EV. Also includes 'Plug & Charge' functionality.*
ISO 15118-20	*Facilitates V2G charging for Type 1 / 2 and CCS equipped cars.*
SAE J3072	*Covers communication between the EVSE and an on-board (EV) V2G inverter. Can enable an alternative V2G implementation for CCS-equipped EVs.*

Table A3: Prominent standards / protocols relevant to Smart Energy Management Systems

Zigbee	*Maintained by the Zigbee Alliance, this protocol (IEEE 802.15.4) provides energy efficient communication in smart buildings.*
Thread	*A wireless protocol built specifically for IoT devices and based on IEEE 802.15.4. It can communicate directly with other IP-based devices.*
Z-Wave	*A wireless communication protocol used primarily in smart buildings.*
PLC	*Power Line Communication is a wired communication protocol that utilises the same cable for AC power supply.*
2G / 3G / 4G	*2nd, 3rd, and 4th generation cellular networks. These are used for communications outside the home.*
Matter	*An industry alliance and protocol for IoT. In the future, this will have a greater focus on DER technologies.*

Annex B

Table B1: Prominent Standard Setting Bodies by region

<table>
<tr><th>National</th><th>Regional</th><th>International</th></tr>
<tr>
<td>United Kingdom
BSI (British Standards Institute)
United States of America
ANSI (American National Standards Institute)
South Africa
ESLC (Electricity Suppliers Liaison Committee)
China
SAC (Standardisation Administration of China)
Japan
JISC (Japanese Industrial Standards Committee)</td>
<td>Europe
ETSI
CEN-CENELEC (European Committee for Standardisation; European Committee for Electrotechnical Standardisation)
AIOTI (The Alliance for Internet of Things Innovation)
Deutsches Institut für Normung (DIN)
Africa
ANSO (African National Standards Organisation)
AFSEC (African Electrotechnical Standardization Commission)</td>
<td>General Standards
IEC (International Electrotechnical Commission)
SmartM2M
IEEE (Institute of Electrical and Electronics Engineers)
ISO (International Organisation for Standardisation)
CharIn
Communications-Specific
Zigbee Alliance (Connectivity Standards Alliance)
Z-Wave
Bluetooth
Wi-Fi</td>
</tr>
</table>

Annex C

Table C1: Mapping protocols and standards by region and technology relevance.

Standard / Protocol	Smart Meter	EV	EVSE	Batteries	Solar PV	Inverters	Region
PAS 1878	■	■	■	■	■	■	*UK*
PAS 1879	■	■	■	■	■	■	*UK*
P375 'Metering behind the boundary point'	■	■	■	■	■	■	*UK*
COP 11	■	■	■	■	■	■	*UK*
OpenADR		■	■	■	■	■	*Global*
IEC 61850	■	■	■	■	■	■	*Global*
IEC 61851 (Edition 3)		■	■				*Global*
Code of Conduct (CoC) for ESAs	■	■	■	■	■	■	*UK*
Matter (formerly Connected Home over IP)	*TBC*	*TBC*	■	*TBC*	*TBC*	*TBC*	*Global*
ISO 15118 ed.1		■	■				*Global*
Tesla Proprietary Plug and Charge		■	■				*Global*
DIN SPEC 70121		■	■				*Global*
OCPP		■	■				*Global*
Common Smart Inverter Profile						■	*California, Australia*
G83, G98			■	■	■	■	*UK*
NC RfG			■	■	■	■	*Europe*
SAREF			■	■	■	■	*Europe*
IEEE 1547						■	*Global*
EN 50549		■	■	■	■	■	*Europe*
IEEE 2030.5		■	■	■	■	■	*Global*
Modbus					■	■	*Global*
IEC 62746			■	■	■	■	*Europe*
EEBus			■	■	■	■	*Global*
SMETS-1 / SMETS-2	■						*UK*
AS70000-1	■						*Africa*
CCS-1 / -2		■	■				*Global*
Type 1 / 2 charger		■	■				*Global*
CHAdeMO		■	■				*Japan, Global*
GB/T		■	■				*China*
IEC 63110		■	■				*Global*
SAE J3072		■	■				*US*
Zigbee	■						*Global*
Wi-Fi		■	■	■	■	■	*Global*
Thread			■				*Global*
Bluetooth / BLE		■	■				*Global*

Annex D

EV CHARGING MODES

- Mode 1 consists of a direct connection from the EV to a standard (domestic) plug socket. The current is converted from AC to DC inside the vehicle. A Mode 1 cable does not include a Residual Current Device (RCD) which will switch off electricity automatically if there is a fault. For this reason, it is not considered safe.[21]

- Mode 2 also connects directly to a standard (domestic) plug socket. However, the cable has an in-built RCD for added safety. The current is converted from AC to DC inside the vehicle.

- Mode 3 utilises a dedicated EVSE or charge point. Charging speeds will vary according to the, i) availability of single- or three-phase power on the premises, ii) specifications of the EVSE, and iii) maximum AC charge rate on the EV. The current is converted from AC to DC inside the vehicle. Basic data exchange between EV and EVSE is possible.

- Mode 4 charging involves directly supplying DC power to the EV. Charging speeds will vary according to the capabilities of the EV and EVSE and the EV and EVSE are able to communicate. However, the type of data exchanged is determined by shared protocols and standards.

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