

The Transition to Electric Vehicles

Article 3, second edition

EV Charging, Power Delivery Systems and Smart Grid Infrastructure

This second edition revises CSL's April 2025 paper on EV charging, power delivery and smart grid infrastructure, with evidence brought up to 11 October 2026. It sets out how a site schedules power within its grid connection, using data from communications links. It then shows what an outage of those links puts at risk at destination, rapid, ultra-rapid and depot sites. When a mobile operator's core fails, a charger with paths through two independent cores can still start sessions that need remote authorisation or payment. Even with a working path, a charging function works only when every layer, from connector to back office, is compatible. The paper therefore looks at what protocol editions and testing show about each function, and closes with a checklist covering power, communications and testing.

Version

2.99

Date

October 2026

Executive summary

When charge point operators and fleets buy chargers, they specify each one by its power rating, its connector and the communication protocols listed on its label. Once rapid public chargers are in service, the Public Charge Point Regulations 2023 measure each one's reliability from the status it reports. Neither the specification nor the reported status shows how much energy a site can deliver, or whether a driver's session will start when a mobile network fails. Nor does either show whether a function that the vehicle, the charger and the management platform each claim to support will work between them.

Power and the grid connection

Electric vehicles (EVs) used about 250 TWh of electricity worldwide in 2025, roughly 1 per cent of final electricity demand¹. That share is small, but each site draws its part through its own grid connection. At depots and en-route hubs, that connection, rather than the chargers' rating, sets how much energy the site can deliver. Six 350 kW chargers running together at full output, for example, deliver 2.1 MW to vehicles and draw more than that from the grid. Smart charging, then, schedules the capacity the connection allows, and still has to deliver each vehicle's energy before it leaves. The schedule in turn depends on data that arrives over communications links from the vehicle, the site and the energy supplier.

Connectivity and reliability

A charger's communications link also carries the status it reports, and UK regulation measures reliability from that status. Across the network of each charge point operator that is not a micro business, public chargers of 50 kW or above must average 99 per cent reliability over a calendar year^{2,3}. A network failure outside the charge point operator's control can be excluded from that measurement, and evidence of the failure can explain a status report that arrived late. Drivers still lose the sessions the failure stops: where authorisation or payment depends on the management platform, losing the communications path can stop new sessions from starting. For example, in one US charging network's monitoring data for 2023, reported by the National Renewable Energy Laboratory (NREL), station connectivity accounted for 55 per cent of charging failures⁴.

How many chargers such a failure stops depends on where its fault lies. A faulty modem stops only the charger it is in, whereas a failure in a part that many chargers share can stop all of them at once. A mobile operator's core network is such a part, because every charger whose connection runs through that operator depends on it. A charger with a multi-network SIM and one operator's profile is no exception: the SIM can reach several radio networks, but its traffic is still routed through that operator's core⁵.

A service that has to keep working through a core outage therefore needs a second path through an independent core, with the switching decision taken inside the equipment. The decision has to be local, because an instruction from the platform would have to cross the failed network. The second path carries the same payment, authorisation and control data as the first, so a specification should also require private encrypted routing on both paths. CSL DualCore® architecture meets those three conditions. CSL provides both paths, through rSIM® technology in the charger or a CSL DualSIM® Router configured for core independence. The payment provider or the management platform can itself fail, and each charger's offline policy then sets what drivers can do until that service recovers. A specification should state that policy alongside each service's resilience tier.

Standards and interoperability

Five of the six communication standards in Table 7 have had a new edition or amendment since April 2025. A label such as 'OCPP compatible' or 'ISO 15118 ready' therefore no longer says which edition or which features a charger supports. Nor does a connector show which functions will work, since two vehicles can share one and support different Plug & Charge, smart-charging or bidirectional functions. Only testing shows whether a function works between a given vehicle and charger. At an interoperability event run by the Charging Interface Initiative (CharIN) in November 2024, 10 vehicles and 13 chargers made 344 attempts at test sequences from ChargeX, a consortium led by US national laboratories. Sixty-nine of those attempts met none of the pass criteria, though the event's report treats all the equipment as pre-production⁶. For bidirectional charging, the standards now define the messages it needs^{7,8}, but a site can rely on it only after testing, and only while vehicles are connected and owners allow export. A specification should name each protocol by version, part, edition and amendment, and ask each supplier for test evidence on the functions it supplies.

This paper takes those three questions in turn, and the checklist on page 29 brings the answers together. It covers, for example, departure times, the resilience tier for each service and the protocol editions in use.



Charging now combines power, data and energy management

A charging session now depends on a chain that runs from the grid connection to the vehicle, the management platform and the wider energy system. This paper traces that chain and what each part of it depends on. It updates Article 3 of CSL's 2025 series, *The Transition to Electric Vehicles*.

The first edition called for resilient connectivity

The first edition, published in April 2025, found distribution capacity and slow grid connections among the main constraints on meeting a growing need for chargers⁹. Its answer, alongside grid and storage upgrades, was smart charging, with control over when, where and how fast each vehicle charges.

That answer depended on connectivity. Smart charging, like payment, pricing, load management and fault detection, needed a charger that could reach its platform. On that basis, the first edition concluded that smart charging requires connectivity that is constantly available, secure and resilient⁹.

This edition follows the chain from power to data

The paper covers public and private charging, from homes and workplaces to high-power hubs and depots for cars and heavy-duty vehicles. In each setting, the grid connection limits the charging schedule, the schedule needs data from the vehicle and the site, and the data needs a communications path.

The paper follows that chain from scheduling power to keeping the communications path working. A working path, however, does not show that a function such as smart charging or Plug & Charge authorisation will work. The paper therefore turns next to testing each function before a site relies on it. It also covers vehicle-to-grid (V2G) operation, wireless power transfer and battery swapping. The first edition had found the last two still in development, and conductive charging, through a cable and connector, the most mature technology it assessed. For V2G, wireless power transfer and battery swapping alike, this edition treats a standard or a demonstration as progress rather than as proof of deployment at scale.

The evidence runs to 11 October 2026

Market figures, standards and regulations are cited as they stood on 11 October 2026. Later releases, such as the next quarterly count from the Department for Transport (DfT), may change the UK figures.

Six changes since April 2025 bear on this paper

- The DfT counted 121,171 public EV chargers in the UK on 1 July 2026, on a new basis that counts each charger rather than each charging device, and one device can hold more than one charger¹⁰; UK figures in this paper use that basis
- The European Alternative Fuels Observatory (EAFO) recorded 1,159,838 public recharging points in the EU27 in its preliminary data for August 2026, 13.6 per cent more than a year earlier¹¹; EU figures in this paper use that release
- The Open Charge Alliance released edition 2 of OCPP 2.1, the protocol between a charger and its management platform, in December 2025; it adds certification profiles and test cases¹², against which a charger's OCPP support can now be tested
- The International Electrotechnical Commission (IEC) published the second edition of IEC 63584-210, its standard based on OCPP 2.1, on 22 September 2026, replacing the 2025 edition¹³; a specification that cites IEC 63584-210 should name the edition
- Amendment 1 to ISO 15118-20, the standard for communication between vehicle and charger, added a distributed energy resource (DER) service for alternating-current (AC) charging and a megawatt charging system (MCS) service in July 2026¹⁴; a charger's support for either should name the amendment
- The Department for Energy Security and Net Zero (DESNZ) committed in July 2026 to a formal consultation on charge point communication standards by the end of 2026¹⁵; those standards are still being set



About CSL Group



CSL Group supplies managed connectivity for critical IoT in transport, utilities, healthcare, the public sector, buildings, security and alarm systems, and has more than 3.5 million active direct connections. Equipment, connectivity, provisioning, private routing, monitoring and support are delivered as one contracted service. In EV charging, CSL delivers CSL DualCore architecture in two ways: through rSIM technology in compatible chargers, and through CSL DualSIM Routers configured for core independence, fitted within individual chargers or serving multi-charger sites. At large hubs and depots, CSL also supplies CSL Outpost. It combines up to four active mobile connections into one managed link, with satellite and fixed line incorporated where needed. Because the connections carry traffic at the same time, the loss of one reduces bandwidth without necessarily interrupting the link. Across a whole charging estate, CSL IoT Platform manages the SIM subscriptions and eSIM profiles. In all, the platform orchestrates more than 30 million SIMs from multiple mobile operators.



Contents

Executive summary	2
Charging now combines power, data and energy management	3
About CSL Group	4
Figures and tables	6
Glossary	7
 Power has to be scheduled as well as supplied	
EV charging is a small global load, drawn site by site	9
A charger count shows where chargers are, not the energy a site can deliver	10
Dwell time and site capacity set the useful charging rate	11
High-power charging moves the limit from the charger to the site	12
Smart charging sets when energy flows, and how fast	13
 Services that cannot wait need a path through an independent core	
UK regulation measures reliability from the status a charger reports	14
An excluded outage still stops sessions	15
Charging services depend on the communications path	16
Chargers that share an operator core share its failures	17
A shared dependency multiplies the cost of an outage	18
The payments at risk in an hour rise with charger power	19
Sites with more at risk need more resilient connectivity	20
A second path needs an independent core, local switching and private routing	21
The communications path carries the data other layers rely on	22
Specify what each charger does offline	23
Local switching and an offline policy carry a charger through a core outage	24
 Functions have to be tested, not assumed	
A shared connector does not guarantee shared functions	25
The protocol edition defines what a charger can support	26
V2G capacity depends on how the vehicle is used	27
Wireless charging and battery swapping bring constraints of their own	28
 Specify the charging service, not only the hardware	 29
References	31



Figures and tables

Table 1: UK public EV chargers by power band and location on 1 July 2026	10
Table 2: Charging contexts and the control priority in each	11
Figure 1: The control loop at a managed site	13
Figure 2: The interfaces a public charging session crosses, with the communications path expanded	16
Table 3: CSL's three tiers of connectivity resilience and what each leaves exposed	17
Figure 3: Causes of charging failures in one US charging network's monitoring data for 2023	18
Table 4: Energy and driver payments at risk in one hour of downtime, by power band	19
Table 5: What an outage costs in each setting, and CSL's illustrative starting point for connectivity	20
Table 6: The layer that resolves each failure, and what the connectivity design contributes	22
Figure 4: A charger with a second path, from an outage at its first operator's core to reconnection	24
Table 7: The protocol and standards stack, with the editions current on 11 October 2026	26



Glossary

Terms that CSL defines rather than inherits are marked CSL, and standards and regulations keep their own formal definitions.

AC and DC	Alternating current, as supplied by the grid, and direct current, as stored in a battery.
Access diversity CSL	More than one access path, such as several radio networks or a fixed line with cellular failover. On its own, it does not establish core independence.
Access network	The radio network or fixed line that connects a charger or a site to an operator's network.
AFIR	The EU Alternative Fuels Infrastructure Regulation, which sets coverage, power, payment and connector requirements for public recharging.
Back office	The systems a charger connects to beyond the site: its management platform and, through it, payment, roaming and energy services.
Bonded broadband	Several broadband connections combined so that they carry a site's traffic as one link.
Charge point operator	The organisation that runs public charge points and answers for their availability, pricing and data under the Public Charge Point Regulations 2023.
Combo 2	The European Combined Charging System coupler, which adds two DC contacts to the Type 2 AC connector, as specified in IEC 62196-3.
Core independence CSL	Two connectivity paths through separate operator core networks, so that a failure of one core leaves the other path working.
Correlated outage CSL	An outage that can affect many chargers at once because they share a dependency, such as an operator core or a management platform.
CSL DualCore CSL	CSL DualCore architecture is CSL's approach to resilience: two paths through independent operator cores, a switch between them decided inside the equipment, and private encrypted routing on both.
CSL DualSIM Router CSL	CSL's dual-SIM router, within a single charger or on a site network, which takes the switching decision in its own firmware. Its configuration sets its resilience tier (Table 3): with two SIMs on independent operator cores and private encrypted routing on both paths, it reaches Tier 3.
CSL IoT Platform CSL	CSL's platform for managing SIM subscriptions and eSIM profiles across mobile operators, with eSIM management aligned with SGP.32.
CSL Outpost CSL	CSL's managed service that combines up to four active mobile connections into one managed link, with satellite and fixed line incorporated where needed.
DER	Distributed energy resource: generation, storage or controllable load on the distribution network, including an EV able to export energy.
Driver payments at risk CSL	In CSL's model, what drivers would have paid, including VAT, for the energy an outage stops: a charger's power multiplied by its utilisation, the tariff per kilowatt-hour and the hours of downtime.
Duty cycle	The pattern of trips, stops and charging that a vehicle follows in service.
Dwell time	How long a vehicle stays parked at a charger, a period that limits the energy it can take.
e-mobility service provider	The company whose app, card or contract a driver uses to find, start and pay for charging.
eSIM	A SIM whose operator profiles can be downloaded and changed remotely, rather than by replacing the card.
EVSE	Electric vehicle supply equipment: the equipment that supplies energy to one vehicle at a time, and the level at which the DfT counts chargers.
Flexibility signal	A request from an aggregator or an electricity network operator to change a site's demand at a given time.



Glossary

Independent outage CSL	An outage that affects a single charger, such as a failed modem, a damaged antenna or a local configuration fault.
Local fallback scheduler	A scheduler at the site that keeps vehicles charging to a plan held locally while the management platform cannot be reached.
Management platform	The system through which a charge point operator manages its chargers, usually over OCPP, which calls it the charging station management system (CSMS).
MCS	Megawatt Charging System: the coupler, supply equipment and communication system for heavy-duty vehicles.
OCPI	Open Charge Point Interface: the protocol through which charge point operators share locations, status, tariffs and sessions with service providers.
OCPP	Open Charge Point Protocol: the protocol between a charger and its management platform, adopted by the IEC as the IEC 63584 series.
Offline policy	What a charger lets drivers do while it cannot reach its management platform or payment provider, such as local authorisation, free charging or a fallback payment method.
Operator core network	The part of a mobile network that authenticates each SIM and routes its data. A multi-network SIM with one operator's profile can use several radio networks, but its traffic depends on that operator's core.
Plug & Charge	Authorisation by a certificate in the vehicle under ISO 15118, without a card or app.
Private encrypted routing	A route from the charger to its platform over private infrastructure, such as a private access point name (APN) on a mobile network, with the data encrypted and the charger not reachable from the public internet.
Recharging pool	AFIR's term for one or more recharging stations at one location.
Resilience tier CSL	One of the three levels of connectivity resilience in Table 3: single path, multi-network, and CSL DualCore architecture.
Roaming	For a driver, paying for charging through another provider's app, card or contract, which OCPI supports. For a SIM, using radio networks other than those of the operator that issued its profile.
rSIM CSL	rSIM technology is CSL's resilient SIM: two independent multi-network roaming profiles on one SIM, reaching the platform through separate operator cores, with switching logic on the SIM.
SGP.32	The GSMA's specification for provisioning and managing eSIM profiles in IoT devices remotely. The GSMA is the mobile industry's global association.
SIM profile	The subscription and credentials a SIM uses to connect through one mobile operator. An eSIM can hold more than one profile.
Site controller	The system that shares a site's grid connection among its chargers and other loads.
State of charge	The energy held in a battery as a percentage of its usable capacity.
TEN-T	The EU's Trans-European Transport Network, whose core and comprehensive road networks set where AFIR's distance-based charging requirements apply.
Utilisation CSL	In CSL's model of driver payments at risk, the share of a charger's rated capacity that it would otherwise have delivered during an outage.
V1G	One-way managed charging: the timing or rate changes, and the vehicle exports no energy.
V2G and V2X	Vehicle-to-grid and vehicle-to-everything: charging in which a connected vehicle can also export energy to the grid, a building or a load.
Virtual power plant	Many distributed energy resources, such as parked EVs, dispatched together as one resource.
Wireless power transfer	Charging by magnetic coupling between a ground or road coil and a coil on the vehicle.



EV charging is a small global load, drawn site by site

The global EV stock used around 250 TWh of electricity in 2025, about 1 per cent of final electricity demand worldwide¹. The load, however, arrives at homes, depots, workplaces, destinations and high-power sites, each with its own dwell times and grid connection.

Planning therefore starts at each site, with three questions: how many vehicles need energy, by when, and through which connection. How much of that load a site can schedule depends on a fourth: which part can be moved or limited without leaving a vehicle short of energy.

The electricity mix sets the emissions saving

The emissions saving from the EV load depends on the electricity behind it, and so partly on when that electricity is drawn. A battery electric vehicle has no tailpipe emissions, but generating its electricity can still emit greenhouse gases. The International Energy Agency (IEA) measures the saving from well to wheel, a basis that counts the emissions from generating the electricity. On that basis, the global EV stock avoided net emissions of 190 Mt CO₂-equivalent in 2025, similar to the energy-related emissions of Spain¹.

A coal-heavy grid reduces the saving without removing it, and lower-carbon generation enlarges it. China, for example, provided more than half of the 2025 saving, even though unabated coal generates the majority of its electricity¹.

The generation mix is one lever on that saving. Smart charging adds a second, by moving the part of the load that can wait into periods when low-carbon generation and spare grid capacity are available.

China added more than three quarters of new public points

Part of the EV load is drawn through public charging points. The IEA estimates that nearly 1.8 million were added worldwide in 2025, taking the total to more than 7 million¹⁶. China accounted for more than three quarters of the points added, and its public points passed 4.7 million. Of China's public points, the IEA estimates that fast and ultra-fast points grew by 40 per cent, to 2.2 million.

The average power of public charging points rose in 2025, because fast and ultra-fast points grew faster than slow ones¹⁶. In China, the estimated average passed 55 kW, against a global average of nearly 50 kW.

For the EU27, a later count runs to August 2026: EAFO's preliminary data recorded 1,159,838 public recharging points, 13.6 per cent more than in August 2025¹¹. None of these totals, though, shows the capacity of any one site, so a specification starts from the site's own connection and demand.



A charger count shows where chargers are, not the energy a site can deliver

The same number of chargers can represent very different combinations of power, utilisation and dwell time.

In the UK, for example, the DfT recorded 121,171 public EV chargers on 1 July 2026¹⁰. Nearly half were rated at 3 kW to under 8 kW, while 28,887, or 24 per cent, were rated at 50 kW or above. Chargers at destination sites made up just over half, and on-street chargers a third (Table 1).

One charging device can now count as more than one charger

The 121,171 figure rests on a new counting basis. From its 1 January 2026 statistics, the DfT counts public EV chargers at the level of electric vehicle supply equipment (EVSE) rather than as charging devices¹⁰. A charging device can hold more than one charger. The January 2026 release counted 116,052 EV chargers and 87,796 charging devices, an average of 1.32 chargers for every device. The DfT reported that the two measures had grown at comparable rates¹⁷.

The two series differ in level, however, so a trend that crosses the change should be read from one series at a time. The device series is still published, in table EVC19001¹⁷. Following the DfT, the paper uses 'charger' to mean one EVSE, the equipment that supplies one vehicle at a time. It keeps 'EVSE' where a regulation or protocol uses that term.

A national ratio averages very different uses

Set against the number of vehicles, a charger count gives a national ratio. On 1 April 2026, there was one public EV charger for every 17 battery electric vehicles in the UK¹⁰. The ratio combines on-street, destination, en-route and semi-public chargers across every power band, so it does not describe any single location.

Regional figures hide the same mix, because a high count per head of population can come mostly from slower chargers. London, for example, has many more public chargers per head than the rest of the UK, but it has the second-lowest provision of rapid-or-above chargers per head¹⁰. The DfT attributes the difference to the standard on-street chargers that make up much of London's network. More generally, variation across regions is lower for rapid-or-above chargers than for all chargers.

Planning needs local demand and site power

Neither a national nor a regional count can show a location's demand, its site power or the behaviour of the vehicles that use it. This paper therefore makes no estimate of how many chargers a town, region or country needs.

Power band	Share
Standard, 3 kW to under 8 kW	49%
Standard plus, 8 kW to under 50 kW	27%
Rapid, 50 kW to under 150 kW	12%
Ultra-rapid, 150 kW and above	12%

Location	Share
Destination	52%
On-street	33%
En-route	11%
Other, semi-public	4%

Table 1: UK public EV chargers by power band and location on 1 July 2026. Source: DfT¹⁰.



Dwell time and site capacity set the useful charging rate

A higher charger rating can be the wrong choice for the dwell time and grid connection a site has.

Context	Dwell time	Power	Control priority
Domestic	Overnight	Mainly AC	Off-peak scheduling within the overnight window
On-street	Overnight or several hours	AC	Lower power for long stays and price-sensitive charging
Workplace	Several hours	AC	Sharing one grid connection across many bays
Destination	Length of visit	AC or DC	Matching power to typical stay and bay turnover
En-route	Short	DC, high power	Availability, queueing and the site's energy capacity
Depot	Scheduled	AC or DC	Each vehicle's energy delivered by its departure time

Table 2: Charging contexts and the control priority in each.

A vehicle takes the power its battery accepts

Charging time depends on the vehicle's acceptance rate, the battery's state of charge and temperature, and the charger's available power. A high nameplate rating does not therefore mean that a vehicle draws that power for the whole session.

A multi-bay site adds a second limit: the site controller shares one power budget among the chargers running together. The budget and the way it is shared, then, are often a better basis for a specification than a charger's nameplate rating, because they limit the power each vehicle can receive.

Five sets of variables shape a site

Each context in Table 2 gives different values to the same five sets of variables:

- **Energy demand:** vehicles, arrival profile, dwell time, required energy and seasonal variation
- **Electrical capacity:** import limit, reinforcement, load diversity, storage and on-site generation
- **Operational use:** bay turnover, queueing, accessibility, maintenance access and fault response
- **Commercial use:** expected utilisation, tariff design and the cost of unused capacity
- **Digital use:** mobile coverage, the site's communications link, remote management, payment and data-service dependencies



High-power charging moves the limit from the charger to the site

At en-route hubs and heavy-duty depots, simultaneous charging creates demand measured in megawatts.

Six chargers rated at 350 kW, for example, deliver a combined 2.1 MW to vehicles when all run at full output. Conversion losses and auxiliary loads, such as cooling, raise the demand on the grid above that figure. The practical limits then include the grid connection, upstream reinforcement, switchgear, thermal management and transformer capacity.

Given those limits, many vehicles charging ultra-fast at once might cause peak-load problems, as a 2026 review of charging research by Mohan et al. finds. The review calls for demand response, storage and smart grid technologies¹⁸.

Within the site, dynamic load management, a smart-charging function, shares the grid connection among the chargers running at any moment. More connectors can then share one connection, because it need not be sized for every vehicle drawing its maximum at once.

Storage, which the review names, can also relieve the grid-connection constraint by reducing the power drawn from the grid at any moment and shifting energy between periods. It does not remove the energy requirement, and its economics depend on utilisation, tariffs, losses, battery cycling and the limits of the connection.

AFIR sets power for the whole pool as well as for each point

EU regulation also sets power for the site as a whole. The Alternative Fuels Infrastructure Regulation (AFIR) requires member states to ensure that publicly accessible light-duty recharging pools are deployed along the core road network of the Trans-European Transport Network (TEN-T)¹⁹. A recharging pool is one or more recharging stations at one location.

On that network, pools must be no more than 60 km apart in each direction, with derogations for low-traffic roads¹⁹. Since 31 December 2025, each pool has had to offer at least 400 kW, including at least one point of 150 kW or more. From 31 December 2027, each pool must offer at least 600 kW and two such points.

Those minimums fix the power a pool must offer. At a public hub, though, the aim is to deliver the most energy through peak periods without exceeding the grid connection or slowing sessions beyond service targets. Installing the highest rating in every bay does not achieve that by itself, because the bays share one grid connection and each vehicle draws only the power its battery accepts. Within that connection, load management and storage decide how much energy reaches vehicles at peak.

Depot charging plans around a fixed departure time

At depots, fleet operators often know departure times and the energy each route requires, which gives the site controller more planning data than an unplanned public session provides. The departure time is also a hard limit, because a vehicle that misses its readiness target can delay its next scheduled trip.

For heavy-duty vehicles, Amendment 1 to ISO 15118-20 now defines a service for communication between vehicle and charger in the megawatt charging system (MCS)¹⁴. The new service changes how vehicle and charger communicate, not the power the site's grid connection can supply.

Even with MCS, a depot specification starts from each vehicle's departure time and energy need rather than from a charger rating.

Design for the duty cycle

Departure times belong to a vehicle's duty cycle, the pattern of trips, stops and charging it follows in service. The duty cycle determines when chargers run together. A 1 MW charger used for short, sequential sessions, for example, draws its power for one vehicle at a time. A group of chargers operating at high output together, by contrast, places all of their demand on the grid at once. Fleet departure waves make that simultaneous demand predictable, so load management and storage have a defined job.

The ratio of charger capacity to grid connection depends on duty cycles, simultaneous demand, connection capacity and operating policy, so this paper sets no universal value for it.



Smart charging sets when energy flows, and how fast

A schedule that lowers a site's peak demand but leaves a fleet vehicle short of its departure energy has failed the operation it serves. At a public site, a schedule fails the same way when it keeps within the grid limit by slowing sessions beyond service targets.

A useful schedule is therefore built from each vehicle's arrival time, departure time, state of charge and required energy, together with the charger's power, the site's capacity and any tariff. It also responds to any flexibility signal, which is a request from an aggregator or an electricity network operator to change demand at a given time.

How far a schedule can respond depends on the direction of flow. Managed charging in one direction, known as V1G, changes only the timing and the rate. Vehicle-to-everything (V2X) charging, by contrast, adds the option of exporting energy where the vehicle, charger, connection and commercial arrangement allow it.

Home and workplace charge points sold in Great Britain since June 2022 must be smart

The Electric Vehicles (Smart Charge Points) Regulations 2021 cover charge points sold for domestic and workplace use in Great Britain since 30 June 2022^{20,21}. Public and rapid charge points are excluded.

Each relevant charge point must be able to send and receive information over a communications network, and to respond to signals by changing the rate or timing of charging²⁰. If it loses its connection to that network, it must still be able to charge.

The standards for that communication are still being set. DESNZ's July 2026 update to its Clean Flexibility Roadmap records informal consultation on the communication standards that smart charging and V2X charging require, with a formal consultation to follow by the end of 2026¹⁵. Until those standards are set, a specification should name the protocol and edition that each smart-charging function uses.

A local energy system shares one finite grid connection

At sites larger than a home, the charger is one controllable load among generation, storage and other building or process loads, which a site controller fits within one grid connection. The controller schedules the chargers in a loop (Figure 1), and a change in the power available to the site starts a new pass.

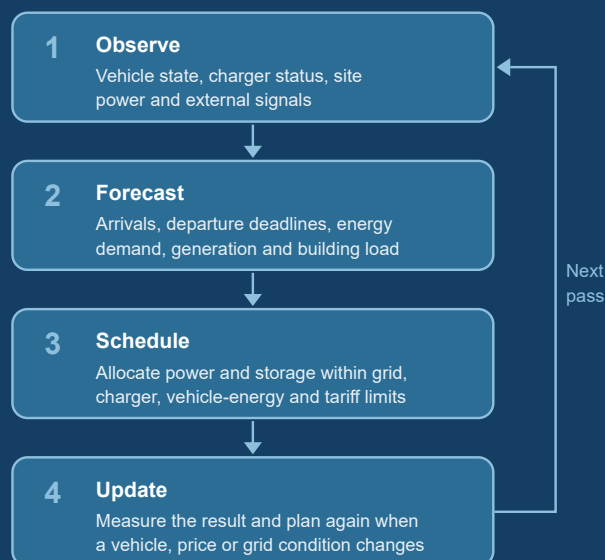


Figure 1: The control loop at a managed site.

Telematics improves the loop's forecasts

Where the charger reports what is connected, telematics can add what the vehicle is likely to need next. For fleets, telematics data on route, duty cycle, location and state of charge improves the forecast of depot demand and shows which vehicles can wait without affecting service.

For public charging, by contrast, aggregated demand and historical utilisation support capacity planning and maintenance. In both settings, forecasts have to allow for uncertainty, because arrival times, routes and drivers' choices of charging location all change.

Forecasts are one of the loop's four sources of data:

- arrival forecasts from telematics or bookings
- limits from the site meter and the chargers
- prices from the energy supplier
- flexibility signals, where the site provides flexibility services

Each of the four reaches the loop over a communications link. If the loop runs on the management platform rather than on a site controller, each charger's own link carries the schedule as well.



UK regulation measures reliability from the status a charger reports

Where the management platform sets the schedule, a site's control loop is only as current as each charger's link to that platform. The Public Charge Point Regulations 2023 depend on that link as well, because they measure each rapid charger's reliability from the status the charger reports.

Rapid charge points must average 99 per cent reliability

The reliability duty has applied since 24 November 2024 to rapid charge points, those rated at 50 kW or above^{2,3}. Charge point operators that are micro businesses are exempt from it². The duty's 99 per cent figure is averaged across all of a charge point operator's rapid charge points over each calendar year, rather than applied to each charge point.

Each charger's status takes the values defined in the Open Charge Point Interface (OCPI) 2.2.1, the data standard the Regulations mandate^{2,3}. A status of 'available', 'charging' or 'reserved' shows the charger working and counts as reliable, while 'inoperative' or 'out of order' shows it not working and counts as downtime. The Regulations class 'unknown' and 'blocked' as ineligible for measurement rather than as downtime². The government's guidance removes both from the calculation and requires the annual reliability report to evidence the time spent in either status³.

Faults in a charger's own communications equipment are not excluded: they count as downtime. So does a fault that stops contactless payment, unless the charger then defaults to free charging³. How much of a fault counts against a charger's reliability figure therefore depends on its offline behaviour. The Regulations also set these duties^{2,3}:

- contactless payment, required since 24 November 2024, at public charge points of 50 kW and above, and at those of 8 kW and above installed since 24 November 2023², unless free to use³
- payment roaming through at least one third-party provider
- a free, staffed helpline available 24 hours a day, every day
- data on each public charge point held to OCPI 2.2.1, with each change of status reflected within 30 seconds, and reference and availability data made public free of charge in a machine-readable format
- an annual reliability report to the Secretary of State, the first covering 2025
- the maximum price per kilowatt-hour shown before each session, the only duty that applies to micro businesses³

Connectivity is needed to meet the reliability, payment, roaming and open-data duties, but the Regulations set outcomes and data duties rather than a communications architecture. The design of that connectivity, including its behaviour when a network fails, is left to those who make, sell and run charge points.



An excluded outage still stops sessions

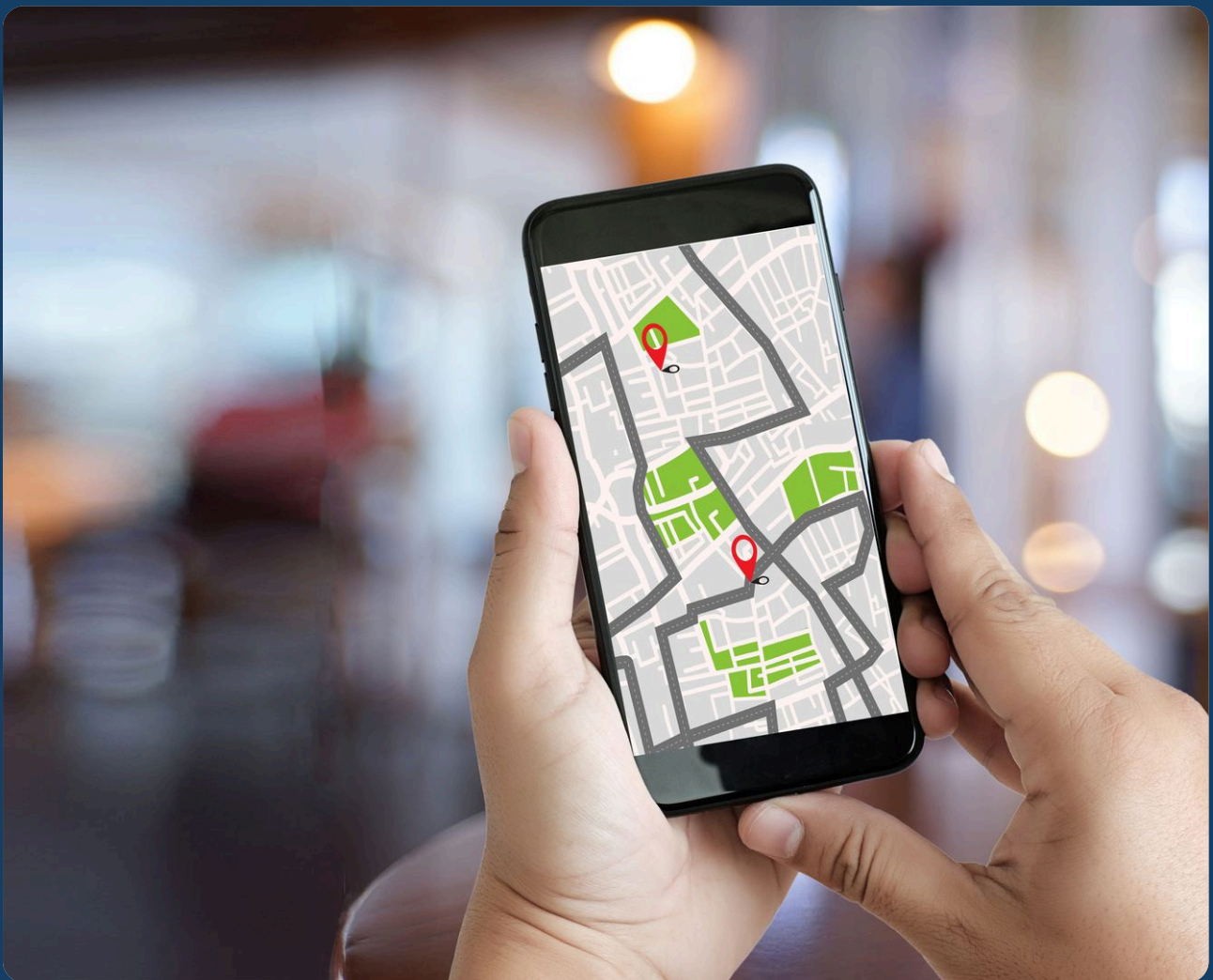
The guidance reserves 'unknown' for an exceptional circumstance outside the charge point operator's control, such as a grid or communication network failure³.

That status covers a failure of the network, not of the charger's own communications equipment. If the Office for Product Safety and Standards accepts the evidence of the failure as demonstrating a 'reasonable excuse', it cannot impose a civil penalty for any resulting non-compliance^{2,3}.

Avoiding a penalty does not recover the sessions lost while the network was down. Without a second path, sessions that need remote authorisation or payment wait for the network to return, unless the offline policy (page 23) admits them. A charger with a second path through an independent core can still start them when the first network fails, and keeps reporting its status.

The sessions lost in an outage do not appear in the reliability figure, which is built from reported status. Even without an outage, status cannot show whether a driver was able to start and complete a session. Session success shows that outcome, because it records whether a driver can authenticate, start charging, pay where required and receive energy. [CSL's EV charging FAQ](#) recommends session success over device uptime alone⁵, and the ChargeX Consortium, led by three US national laboratories, defines a comparable measure²².

Drivers' own reports measure the same outcome from their side, as in J.D. Power's 2026 survey of 6,594 US owners of battery electric and plug-in hybrid vehicles. In its latest quarter, 12 per cent of owners' reported visits to a public charger ended without charging, against 14 per cent a year earlier²³. The figures describe US owners' visits rather than a UK rate.



Charging services depend on the communications path

When a charger's communications fail, remote authorisation, payment and the other functions that need data from elsewhere are interrupted.

Public charging needs data for status publication, driver authentication, payment, roaming, remote diagnostics and firmware management. Smart charging adds tariff, site-energy and grid signals. Each function tolerates delay or loss differently. A short outage delays a status report rather than losing it, and the operator can evidence the outage afterwards in its annual reliability report. A session that cannot start, by contrast, is lost.

The data crosses three interfaces, each with its own protocol (Figure 2):

- ISO 15118, between the vehicle and the charger⁸
- OCPP, between the charger and its management platform¹³, over a path that can include a site network, an access network and, on a cellular path, a mobile operator's core network
- OCPI, from the charge point operator's platform to e-mobility service providers, directly or through roaming hubs²⁴

A failed session needs evidence from charger, path and platform

Communications are one of several causes that can stop a session from completing, alongside power electronics, the vehicle, the connector, software, payment and identity. The cause of a failed session can therefore be traced only with evidence from three sources: the charger, the communications path and the platform.

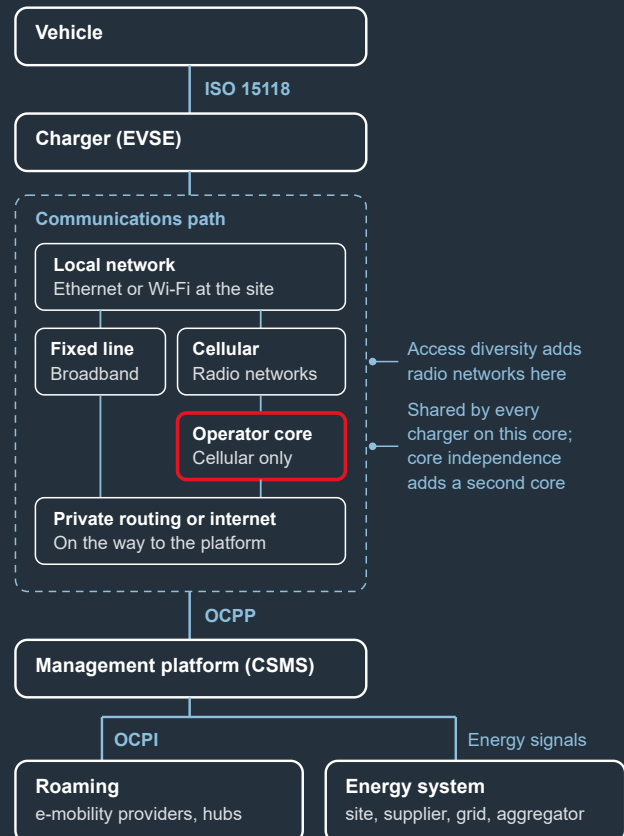


Figure 2: The interfaces a public charging session crosses, with the communications path expanded, and the energy system that smart charging adds. Card payment, which reaches its own provider, is not shown.



Chargers that share an operator core share its failures

In Figure 2, an operator's core network is shared by every charger whose SIM profile belongs to that operator, at every site and over every radio network. A failure there is a correlated outage, which can stop them all at once. Resilience design should therefore start by naming the services that must remain available, such as authorisation and payment at a public charger, and the dependencies they use.

A multi-network SIM with one operator's profile can use several radio networks but one core

A multi-network SIM protects a charger against the loss of one radio network, because it can reach another. But its profile is a subscription with one mobile operator. Whichever radio network the SIM uses, its traffic is routed through that operator's core network, which authenticates the SIM and forwards its data⁵. If that core fails, reaching another radio network does not restore service. Nor can signal strength show a core failure, so a charger that selects networks by signal stays on a strong network that cannot pass its data.

Two UK-wide disruptions to call services in 2025, including calls to the emergency services, were not reported as a loss of radio coverage. They occurred at different UK mobile operators, one in June and one in July, and Ofcom opened investigations into both in December 2025²⁵. In Australia, the cause of an operator's outage on 8 July 2026 lay in its mobile core. A findings report by Technology Audit Partners traced it to the core's timing architecture: a GPS card had reset during a change and began sending a date from 2006 into the network. The report records that some users could not access mobile data services, and that the outage affected all forms of devices, including IoT devices²⁶.

A shared site link can stop every bay at once

A correlated outage can also begin at the site. Where a hub's chargers reach their platform through one communications link, the data that every bay uses for authorisation, payment and status passes through it. A failure of that link then stops every session that needs data, even while each charger and its power supply are working. The link's design therefore sets the exposure of the whole hub.

That design can add access diversity, which in CSL's terms means more than one access path, such as several radio networks or a fixed line with cellular failover. Access diversity does not by itself establish core independence, so the cellular paths may still share one operator core. Access diversity may therefore suffice for status reports, which a core outage delays rather than loses. Where authorisation and payment must work through such an outage, however, they need core independence, a second cellular path through a separate operator core (Table 3).

Tier	What it is	What remains exposed
1. Single path	Fixed broadband only, or a single-network cellular service	Everything on the path: when it fails, the charger stops reporting and no alternative path exists
2. Multi-network	Access diversity with a single cellular core: several radio access networks through one SIM, or broadband with failover to one cellular network	On a multi-network SIM, the operator core its radio networks share, and network selection by signal strength, which cannot see a core failure. With broadband failover to one cellular network, every service depends on one operator core while the line is down
3. CSL DualCore architecture	Multi-network access with independent cores, switching inside the equipment and private encrypted routing on both paths	A failure common to both paths, such as a fault in equipment they share, and the delay before a switch, which the configured failure policy sets

Table 3: CSL's three tiers of connectivity resilience and what each leaves exposed.



A shared dependency multiplies the cost of an outage

Station connectivity accounts for 55 per cent of charging failures in one US network's 2023 monitoring data, reported by the National Renewable Energy Laboratory (NREL)⁴ (Figure 3). The data do not say whether a connectivity failure began in an operator's core, which many chargers share, or at the site. The cost of each failure grows with the power of the chargers it affects, how heavily they are used and how many share the part that failed.

Four values set the driver payments at risk

CSL's [EV charging FAQ](#), published in July 2026, estimates that cost at one charger from four values: a charger's power in kilowatts, its utilisation, the tariff per kilowatt-hour and the hours of downtime⁵. Power, utilisation and hours together give the energy the charger would have delivered during the outage, and the tariff turns that energy into what drivers would have paid. Utilisation here is energy-based: the share of the charger's rated capacity that it would otherwise have delivered, rather than the share of time a vehicle occupies it. The two differ because each vehicle draws only the power its battery accepts, so a charger can be occupied for an hour and deliver less than its rating. The tariff is the price a driver pays and includes VAT, since HM Revenue and Customs treats public charging as standard-rated²⁷. The payments at risk therefore include VAT. The figure is gross, with no costs deducted.

Those four values give the payments at risk at one charger, and the number of chargers an outage reaches then sets the total. An independent outage, such as a failed modem or a damaged antenna, affects only that charger. A correlated outage can affect every charger that shares the failed part, so the loss scales with the number of chargers involved⁵.

A shared failure can outweigh many local faults

The hub scenario in CSL's illustrative model puts figures on that difference. In it, one mobile operator's core serves 50 ultra-rapid sites with six 150 kW chargers each, at 3.4 per cent average utilisation and a pay-as-you-go tariff of £0.78 per kWh⁵. A fault at one of those chargers puts about £4 in driver payments at risk for each hour. A one-hour failure of the core reaches all 300 chargers at once and puts about £1,200 at risk, as much as 300 local faults together.

That £1,200 comes from one shared core. A second path through an independent core removes that dependence: when one core fails, the chargers can still reach their platform through the other. It does not prevent internal station faults, 38 per cent of failures in the NREL data⁴, but each stays at one charger, and diagnostics over a working path can direct its repair.

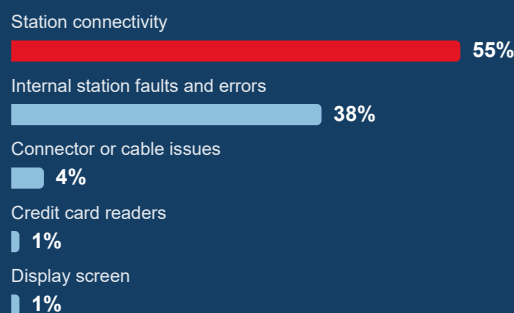


Figure 3: Causes of charging failures in one US charging network's monitoring data for 2023, as shares of all failures. The five causes shown account for 99 per cent of failures, and the source does not report how many failures the data cover. Source: NREL⁴.

Excluded hours still put payments at risk

The fourth value, the hours of downtime, can be set against the reliability duty. For a rapid charger accessible around the clock, with no excluded time, 99 per cent reliability corresponds to 87.6 hours not working^{2,3}, 1 per cent of the 8,760 hours in a non-leap year. The requirement, though, is an annual average across the charge point operator's rapid network, so an individual charger may be down for more or fewer hours. A network that meets the duty can therefore still average about 87.6 hours a year out of service per rapid charger. Time recorded as 'unknown' for a qualifying communication network failure comes on top of those hours, because it is removed from the reliability calculation. Drivers' payments are still at risk in that time, so the model counts it as downtime.

Lost driver payments are only part of the cost

The FAQ lists the secondary costs of an outage: penalties under service level agreements, driver compensation, regulatory reporting or compliance exposure, contract and landlord risk, and damage to reputation that pushes drivers to competing sites⁵. Connectivity faults also cause avoidable engineer visits, including the 'no fault found' call-out, where the problem lies in the communications path rather than the charger. The FAQ adds that, in some incidents, these costs may exceed the payments lost.



The payments at risk in an hour rise with charger power

The model on page 18 can be applied to each power band of the UK public network. An hour of downtime then puts about £0.22 at risk at a 7 kW charger and about £4 at a 150 kW charger (Table 4).

Power band	Example rating	Energy-based utilisation, Q4 2025 ²⁸	Energy at risk per hour	Tariff per kWh	Driver payments at risk per hour
Standard, 3 kW to under 8 kW	7 kW	5.7%	0.40 kWh	£0.54 ²⁹	£0.22
Standard plus AC, 8 kW to under 50 kW	22 kW	2.5%	0.55 kWh	£0.54 ²⁹	£0.30
Rapid, 50 kW to under 150 kW	50 kW	4.0%	2.0 kWh	£0.78 ⁵	£1.56
Ultra-rapid, 150 kW and above	150 kW	3.4%	5.1 kWh	£0.78 ⁵	£3.98

Table 4: Energy and driver payments at risk in one hour of downtime, by power band. Each row is an example charger; the figures are illustrative model outputs, not observed losses, and the payments include VAT. Utilisation: Green Finance Institute and Zapmap²⁸. Tariffs: Zapmap's September 2026 average below 50 kW²⁹, and the model's tariff from 50 kW⁵.

Each power band has its own utilisation and tariff

Table 4 runs the model's calculation for an example charger in each UK power band, so the bands can be compared hour for hour. Each band's utilisation comes from outside the model, and so does the tariff below 50 kW.

Utilisation comes from the Green Finance Institute and Zapmap, who report the average for each band in the last quarter of 2025²⁸. They measure it as energy delivered against rated capacity, as the model does²⁸. Their figure for chargers of 150 kW and above, 3.4 per cent, is the one the hub scenario on page 18 uses. Their figure for Standard plus DC chargers is left out of Table 4, because they attribute that quarter's rise in it mainly to a new operator joining their dataset rather than to higher demand²⁸. Because every figure is a quarterly average, an outage at a busier time puts more at risk than Table 4 shows.

The tariff below 50 kW is Zapmap's average pay-as-you-go price for September 2026, £0.54 per kWh, weighted by energy²⁹. From 50 kW, the table keeps the model's £0.78, against Zapmap's £0.79 for the same month²⁹.

Charger power outweighs utilisation

Average utilisation ranges from 2.5 to 5.7 per cent across the bands in Table 4, while rated power ranges from 7 to 150 kW. An hour of downtime at a 150 kW charger therefore puts about 13 times as much energy at risk as an hour at a 7 kW charger.

That comparison understates the exposure at slower chargers, though, where faults go unnoticed. CSL's FAQ notes that faults across long-dwell estates can persist undetected, so losses build over weeks⁵. At about £0.22 an hour, each week that a 7 kW charger stays offline puts more than £36 at risk.



Sites with more at risk need more resilient connectivity

What an outage puts at risk also differs by setting. CSL's illustrative starting point for connectivity therefore becomes more resilient where more is at risk (Table 5)⁵.

Setting	What an outage costs	CSL's illustrative starting point
Destination and residential AC	Lower driver payments at risk per hour, but faults across long-dwell estates can persist undetected, so losses, support calls and driver frustration build over weeks rather than minutes	A <u>managed SIM</u> with monitoring, or <u>rSIM technology</u> where uptime matters, with site Ethernet or Wi-Fi as an additional path where available
Public rapid, 50 kW to under 150 kW	Immediate driver impact, lost sessions and exposure under service level agreements, with potential relevance to the reliability, payment and reporting duties of the Regulations	Wired backhaul, with cellular backup through <u>rSIM technology</u> or a <u>CSL DualSIM Router</u> configured for core independence, and monitoring of payment and OCPP connectivity
Ultra-rapid hub, 150 kW and above	Potentially high driver payments per hour, and a correlated failure can affect every bay that depends on the failed service. In one scenario of <u>CSL's illustrative model</u> (page 18), a core failure at one mobile operator puts an average of about £1,200 an hour in driver payments at risk across 50 sites	Layered paths configured to the site design: fixed or bonded broadband, separate cellular paths (through independent cores, as page 21 specifies) and an optional satellite emergency path, which <u>CSL Outpost</u> can combine
Fleet depot	Lost vehicle availability rather than lost driver payments. Each outage's cost scales with fleet size and the cost of a vehicle's lost availability; the annual cost also scales with outage frequency	A wired primary connection, with cellular backup through <u>rSIM technology</u> or a <u>CSL DualSIM Router</u> configured for core independence, optional satellite contingency and a local fallback scheduler

Table 5: What an outage costs in each setting, and CSL's illustrative starting point for connectivity. Source: CSL's EV charging FAQ⁵. The hub figure is an illustrative model output, from the scenario on page 18, not an observed loss. It counts only what drivers would have paid for the energy, and leaves out the secondary costs listed on that page, such as service level penalties, driver compensation and engineer visits.

Slower chargers need fault detection, and rapid sites need a second path

For chargers from 3 kW to under 8 kW, the typical connectivity priority is fault detection and remote management across long-dwell estates⁵. From 8 kW to under 50 kW, it is coverage in marginal locations, plus remote reset⁵. At rapid sites, by contrast, the emphasis moves to avoiding correlated outages across a shared site link and meeting service levels⁵.

An ultra-rapid hub is the highest-powered of the rapid sites. The reliability duty applies to it unless its operator is a micro business, because the duty covers public chargers of 50 kW or above^{2,3}. It also carries potentially high driver payments per hour, and a correlated risk across several bays⁵. CSL's starting point for it therefore includes separate cellular paths and an optional satellite path⁵. CSL Outpost can combine those paths into one managed link, so losing one connection reduces bandwidth without necessarily interrupting the link. Page 21 describes CSL Outpost, and sets out why the cellular paths need independent cores.

At a depot, a correlated outage that interrupts overnight charging can leave vehicles without enough energy for their departure windows⁵. A local fallback scheduler, however, keeps vehicles charging to the last plan held at the site while the management platform cannot be reached. That plan stays current only while the depot's wired and cellular paths carry its updates.

A specification should start from the estate's own figures

CSL's starting points in Table 5 are illustrative, because the final architecture depends on the site survey, the connections available, device configuration and the consequences of failure at that site⁵. To weigh those consequences, an estate's own figures should replace the model's values for charger power, utilisation, tariffs and the cost of lost vehicle availability. Its incident records should give the frequency and duration of outages. The checklist on page 29 asks for each of these figures, so the design can rest on the estate's own records rather than the model's averages.



A second path needs an independent core, local switching and private routing

CSL DualCore architecture provides both paths through independent operator cores, with the switch between them decided inside the equipment and private encrypted routing on each. Whichever product carries it, its three conditions give authorisation, payment and control data a private encrypted route through a second operator core when the first fails.

A specification should set three conditions for the second path:

- Operator cores that are independent of each other, rather than several radio networks sharing one core
- Switching that does not wait for a platform reachable only through the failed network
- Private encrypted routing on the second path as well as the first

The second condition applies because an instruction from the platform would have to cross the failed network. The third applies because the second path carries the same payment, authorisation and control data as the first.

CSL provides both paths, in the charger and at the site

rSIM technology meets all three conditions in the charger. It places the switching logic on the charger's SIM, which holds two independent multi-network roaming profiles³⁰. The two reach the charger's management platform through separate operator cores⁵, and both use private encrypted routing. The logic monitors connectivity⁵, rather than relying only on signal strength, which cannot show a core failure. A configured failure policy separates a sustained loss of service from a transient one, and so sets how long a switch takes. After a sustained loss, the SIM selects the other profile and the modem re-registers, with no instruction needed through the failed network.

Because the switching decision is taken on the SIM, the charger's firmware does not need to contain the failover logic. Deployment, though, still requires validation of the SIM form factor, the modem's behaviour, the routing configuration and the charger's compatibility before rollout. A fault in the modem or antenna, which both profiles share, stops both; like any independent outage, it affects only that charger.

A charger maker can also meet the three conditions in its own design, as a dual-SIM charger. Such a design needs two SIM profiles on independent operator cores, purpose-built failover logic in the charger's firmware and private encrypted routing on both paths.

A CSL DualSIM Router configured for core independence

meets the same three conditions, whether it is fitted within a single charger or provides the shared link at a multi-charger site. Purpose-built failover logic in the router's firmware takes the switching decision, and both cellular paths use private encrypted routing. The tier the router reaches in Table 3, however, depends on its configuration, so a specification should state the required tier. A router that fails over from broadband to one cellular network is Tier 2. While the broadband line works, a core outage does not reach the site; once the line is down, every bay depends on one operator core. A router configured for core independence keeps a cellular path through either core, whether or not the line is working.

CSL Outpost, rather than switching between paths, combines up to four active mobile connections into one managed link, with satellite and fixed line incorporated where needed. Because the connections carry traffic at the same time, the loss of one reduces the bandwidth available without necessarily interrupting the managed link. Traffic is redistributed across the remaining connections, typically in under a second^{31,32}. CSL Outpost's satellite and fixed-line connections add paths that depend on no cellular network, a separate layer of diversity that can be combined with core independence. As with the router, the tier of its cellular paths depends on the operator cores its SIMs use. CSL Outpost suits large charging hubs, depots and remote sites that need more bandwidth than one mobile connection gives, or a satellite or fixed-line path.

For the estate as a whole, **CSL IoT Platform** manages SIM subscriptions and eSIM profiles, including the profiles that rSIM technology holds on each charger's SIM. It does so across devices, mobile operators, connectivity management platforms and countries throughout the lifecycle of an estate³³. A SIM profile is a subscription with one mobile operator, so when the platform changes a profile, it coordinates the change with that operator's subscription³³. Its eSIM management is aligned with SGP.32³⁴. The switch during an outage, though, does not need CSL IoT Platform to reach the charger, because the profiles and the failure policy are already on the charger's SIM³³.



The communications path carries the data other layers rely on

Faults in a network, core or link are resolved within the communications layer, by switching to another path where the design provides one (Table 6). Faults in power, charger hardware, payment services or the management platform, by contrast, are resolved in their own layers. Those layers still rely on the communications path in Figure 2 for control signals, diagnostics and transactions, so the connectivity design contributes to resolving their failures too.

Failure	Layer that resolves it	What the connectivity design contributes
Radio network unavailable in the area	Communications	Reach another radio network through a multi-network SIM, or use a satellite path where the site has one
Operator core outage	Communications	Switch to a path through an independent core, at Tier 3
Fixed broadband failure	Communications	Switch to a cellular or satellite link through a router or CSL Outpost
Platform, cloud or payment provider outage	The platform or payment provider, with the offline policy in the meantime	Keep each charger's route to the service open, so that the charger can reconnect when the service recovers
Grid connection at its limit	Power, through load management, storage or a larger connection	Carry the control signals that manage the load
Site power or charger hardware failure	The site's power supply or the charger's maintenance	Keep remote diagnostics available where the path survives, to help trace the fault to its layer

Table 6: The layer that resolves each failure, and what the connectivity design contributes.

A specification should plan for the end of 2G

The networks that carry each path change as well as fail during an estate's lifecycle: UK networks are retiring 2G. EE begins switching it off from May 2029, O2 from summer 2029 and Vodafone during 2030, and every operator has confirmed that 2G will end by 2033³⁵. A specification should therefore identify any modem that still falls back to 2G and plan its replacement.

Keep the TLS connection on both paths

Private encrypted routing protects both paths. The charger's connection to its management platform has its own protection as well, through one of OCPP's three security profiles³⁶. Of these, the Open Charge Alliance recommends a Transport Layer Security (TLS) profile in the field³⁶. OCPP's rules are written so that a charger does not fall back to a lower profile when its connection fails³⁶. A specification should therefore require the second path to carry the TLS connection to the same platform endpoint, so that the charger can reconnect at the same profile after a switch.

Evidence from each layer separates the faults

Where the charger, the router and the management platform each report telemetry, the source of a fault can be traced to the relevant layer rather than inferred solely from a failed session. Switching telemetry, where the connectivity provider's managed service exposes it, also records each change of SIM profile, so the response to a failure can be shown rather than assumed. Together, the telemetry and the switching records can help show that a period recorded as 'unknown' was a network failure, not a fault in the charger's own equipment. The government's guidance requires the charge point operator to give that evidence in its annual reliability report (page 14).



Specify what each charger does offline

Whenever a charger cannot reach its platform or payment provider, because the path or the service has failed, it relies on its offline policy (Table 6). At a public site, that policy has to fit the rules that apply there and the charge point operator's commercial model. In the UK, for example, a fault that stops contactless payment counts as downtime unless the charger then defaults to free charging (page 14).

The policy's options include local authorisation, free charging, buffered transactions and a fallback payment method. Whichever it uses, the policy should set which driver credentials are honoured offline, what payment risk the charge point operator accepts and how transactions are reconciled. A second path through an independent core shortens the communications downtime that the policy has to cover, so the path and the policy belong in one specification.

OCPP provides the tools for local authorisation

OCPP 2.1 gives a charger two optional stores of driver identifiers, the credentials a driver presents to start a session, which it can check without reaching its platform³⁷. The platform sends the Local Authorization List and keeps it up to date, while the charger's Authorization Cache keeps the status the platform last returned for each identifier presented at that charger. Configuration variables report whether the charger supports each store and whether each is in use, and whether, when offline, it accepts identifiers that are in neither store. The variables that switch these on are writable, so the platform can also turn each one on or off³⁷.

One of those configuration variables, `OfflineTxForUnknownIdEnabled`, governs identifiers that are in neither store. When it is true, the charger accepts identifiers it holds no record of, and learns whether the platform accepts each one only when the connection returns³⁷.

Whichever identifiers it accepts, the charger queues the messages that record each transaction while offline, and sends them when the connection returns. Each carries a sequence number, so the platform can check that it holds the full record before billing³⁷.

Record each service's tier and the design for each failure

A specification should record the tier chosen for each service, the operator cores its cellular paths use and the component that takes the switching decision. It should also name the design that covers each failure in Table 6, including those resolved outside communications.



Local switching and an offline policy carry a charger through a core outage

When one mobile operator's core fails, the management platform cannot reach the charger to instruct it. Switching logic in the equipment, such as on the charger's SIM or in its router, therefore decides when to change paths. The charger's offline policy covers sessions that start before it reconnects (Figure 4).

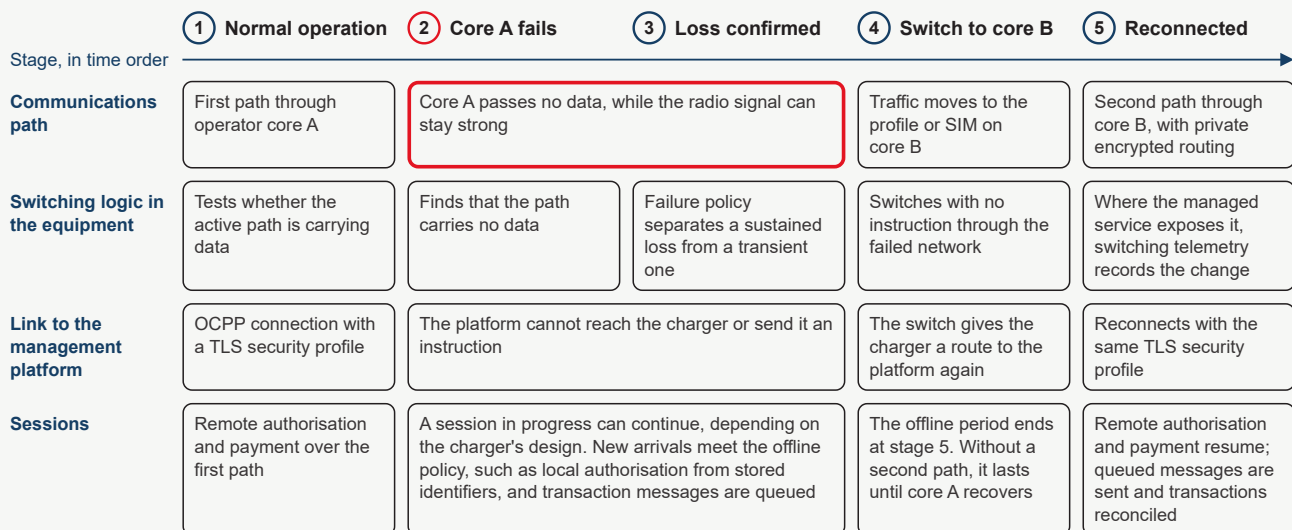


Figure 4: The sequence at a charger with a second path, specified as this paper recommends, from an outage at its first operator's core (core A) to reconnection through an independent operator core (core B). It shows the order of events, not their duration, and assumes switching logic that, like rSIM technology, monitors connectivity rather than relying on signal strength, which cannot show a core failure.

Sessions in progress and new arrivals are covered differently

Depending on its design, a charger can keep delivering energy to a session already in progress while its path is down. At a depot with a local fallback scheduler, vehicles keep charging to the last plan held at the site. A driver who arrives before the charger reconnects meets the offline policy instead, as page 23 sets it out. In Figure 4, the offline policy applies from stage 2 until the charger reconnects at stage 5. Without a second path, that period would last until core A recovered. With one, it ends once the switching logic has confirmed the loss and switched to core B, and the charger has reconnected to its platform.

The offline policy covers two other failures

A fault in the modem, antenna or router that the two paths share stops both, as does any other common failure (Table 3). A platform or payment outage, by contrast, leaves both paths working (Table 6). In either case, switching to the other path does not reconnect the charger, so the offline policy sets what drivers can do until the failure is cleared.

A specification can record the switch, the policy and the return

For the outage in Figure 4, the checklist on page 29 asks a specification to state the failure policy that triggers a switch and the component that takes the decision. It also asks what each charger does offline, and how and when it returns to its preferred path after an outage.



A shared connector does not guarantee shared functions

A working path does not show that a function the vehicle, charger and back office claim to support will work between them. In conductive charging, which remains the mainstream way to transfer energy, each layer of a session has its own standards. A charging function works only when every layer is compatible, so it has to be tested before a site relies on it.

A session completes only when four layers are compatible

- **Physical:** coupler geometry, ratings and safety
- **Power control:** the charger's behaviour and the energy transfer
- **Vehicle communication:** identity, charging parameters and bidirectional functions
- **Back office:** the charger's connection to its management platform, with remote management, payment roaming and energy control

Two vehicles can share a connector family and still support different sets of Plug & Charge authorisation, smart-charging or bidirectional functions. A shared connector therefore establishes compatibility at the physical layer only.

Regions standardise different couplers

Even the physical layer differs by region. In the EU, AFIR requires AC normal-power points for light-duty vehicles installed or renovated from 8 January 2026 to offer at least Type 2 connectors¹⁹. DC high-power points installed or renovated from the same date must offer at least Combo 2, the European coupler of the Combined Charging System (CCS).

In North America, SAE J3400, a Recommended Practice revised in September 2024, specifies the North American Charging System coupler for DC or single-phase AC power³⁸.

In China, according to the review by Mohan et al., GB/T is the standard that governs the market, supporting up to 350 kW¹⁸. The review associates CHAdeMO with Japan and other Asian markets and describes its use as declining globally. It describes CHAdeMO's upgraded ChaoJi variant as supporting more than 400 kW but not yet widely implemented.

Across the CHAdeMO, CCS and GB/T families, the same review describes interoperability and standardisation as inconsistent. It states that this inconsistency stands in the way of bidirectional systems such as V2G working across the three families. The review also finds cybersecurity vulnerabilities persisting.

Each layer has its own standard and edition

For the coupler itself, IEC 62196-3:2026 sets dimensional compatibility requirements for DC and AC/DC pin and contact-tube vehicle couplers³⁹. The 2026 edition replaces the 2022 edition and increases the ratings for all configurations.

For power control, IEC 61851-23:2023 sets requirements for DC charging equipment of three systems: system A for CHAdeMO, system B for GB/T and system C for CCS⁴⁰. Its bidirectional requirements, however, cover only system A, for equipment rated at up to 1,000 V AC or 1,500 V DC on its supply side. The standard does not yet specify bidirectional requirements for systems B and C. For the Combo 2 equipment that AFIR requires, a specification can therefore cite IEC 61851-23 for DC charging, but not yet for bidirectional operation.

For vehicle communication, a separate layer, ISO 15118-20 specifies the application-layer communication between vehicle and charger, including the messages for bidirectional power transfer⁸.

The megawatt charging system has its own standards at these layers. IEC TS 63379:2026, a Technical Specification published in January 2026, specifies its vehicle connector, inlet and cable assembly⁴¹. IEC 61851-23-3:2026, published in August 2026, specifies the supply equipment and refers to ISO 15118-10 and ISO 15118-20 for communication between vehicle and charger⁴².



The protocol edition defines what a charger can support

Five of the six standards in Table 7 have had a new edition or amendment since April 2025. A protocol name or a label such as 'OCPP compatible' or 'ISO 15118 ready' therefore no longer shows which edition or which features a charger supports.

Interface	Standard and current edition	Scope, and what changed after April 2025
Vehicle and charger	ISO 15118-20:2022, with Amendment 1:2026 (July 2026)	Second-generation network and application layer, including the messages for bidirectional power transfer. The amendment adds AC DER and MCS services and an improved security concept ^{8,14}
Charger and platform	OCPP 2.1, edition 2 (Open Charge Alliance, December 2025)	ISO 15118-20 support with bidirectional power transfer, bidirectional charging, DER control, improved smart charging and battery swapping. Edition 2 adds certification profiles and test cases ^{7,12}
Charger and platform, IEC	IEC 63584-210:2026, second edition (22 September 2026)	The IEC standard based on OCPP 2.1. It adds certification profiles and clarifications and replaces the 2025 edition. Because OCPP 2.1 is backwards-compatible with OCPP 2.0.1, it also incorporates the errata published for OCPP 2.0.1 ^{7,13}
Charger and platform, IEC	IEC 63584-201:2026 (18 September 2026)	The IEC standard based on OCPP 2.0.1: a technical revision that clarifies requirements, use cases and test case descriptions, and replaces IEC 63584:2024 ⁴³
Operator and service provider	OCPI 2.3.0, edition 2 (18 June 2026); the UK Regulations cite OCPI 2.2.1	Locations, status, tariffs and sessions between operators, service providers and hubs. Edition 2 adds the Invoice Reconciliation module, lengthens two sets of fields and updates the documentation ^{2,44}
Infrastructure management	IEC 63110-1:2022	Definitions, use cases and architecture for managing charging and discharging infrastructure, covering energy transfer, asset management, authentication and payment, and cybersecurity ⁴⁵

Table 7: The protocol and standards stack, with the editions current on 11 October 2026.

Only testing shows interoperability

Instead of a label, support for OCPP should be stated by version and edition, and support for ISO 15118 by part, edition, amendment and feature. A site that uses OCPP to control bidirectional charging or DER, for example, needs the functions that OCPP 2.1 introduced for them, which a label reading only 'OCPP' does not show. A specification that cites the IEC versions of OCPP should name IEC 63584-210 for OCPP 2.1 or IEC 63584-201 for OCPP 2.0.1, each with its edition. OCPI also needs a stated version: in the UK, charge point operators other than micro businesses must hold data that the Regulations define by reference to OCPI 2.2.1. Stating the edition, however, does not show that a function will work.

Conformance to that edition, implementation choices, back-office support and vehicle capability still have to be tested together before a site relies on a function. Beyond the connector, the vehicle and charger must negotiate safely, the platform must support the OCPP features deployed, and the roaming or payment service must accept the session.

A CharIN interoperability test event in November 2024 shows what testing vehicles and chargers together can find. Its 10 vehicles and 13 chargers made 344 attempts at the ChargeX test sequences. Sixty-nine of those attempts met none of the pass criteria, and the sequence using ISO 15118-20 met all of them in one of its seven attempts. The event's report treats all the equipment tested as pre-production, so the results describe equipment in development rather than chargers in service⁶. For chargers in service, a specification should therefore ask each supplier for test evidence on the functions it supplies.



V2G capacity depends on how the vehicle is used

Where vehicle, charger and platform support it, bidirectional charging turns a parked EV from a controllable load into a potential distributed energy resource. Even then, it is available only while the vehicle is connected and its owner allows export. The vehicle is first a transport asset, and it may be away when an aggregator or an electricity network operator needs it. V2G capacity therefore has to be established from how vehicles are used rather than assumed.

Beyond how vehicles are used, V2G needs a chain of standards and arrangements, and the standards in Table 7 now cover more of it. Amendment 1 to ISO 15118-20, for example, added a DER service for AC charging¹⁴. Deployment, however, still needs a compatible vehicle, a bidirectional charger, a permitted grid connection, arrangements for control and settlement, and a driver or fleet willing to make the battery available.

Control depends on data passing between the charger and its management platform over OCPP, which version 2.1 extends to bidirectional charging and DER control⁷. Settlement needs the transaction records that pass the same way, together with metering and market arrangements beyond the charger.

Across the energy system, DESNZ expects smart and bidirectional charging 'to unlock significant flexibility from EVs over the coming years', in its July 2026 roadmap update¹⁵. It also plans, in 2027, to future-proof its technical specifications for energy smart appliance interoperability, so that they can be expanded to include V2X charging.

Scaling up V2G, however, remains a critical challenge, as a 2026 technical roadmap by Li et al. finds⁴⁶. The roadmap notes numerous demonstration projects that validate technical and economic feasibility. Among the obstacles to running many vehicles as one virtual power plant, though, it names two: combining dissimilar resources and predicting how drivers will use their vehicles.

V2G has to earn more than the battery wear it causes

How much wear V2G causes depends on how a battery ages. Leijon's 2025 review relates battery ageing to six conditions: temperature, state of charge, charging rate, depth of discharge, calendar time and cell chemistry⁴⁷. Leijon adds that some combinations, such as fast charging at low temperature, degrade batteries faster, and that how much a battery will degrade each year cannot be specified with certainty⁴⁷. Because all six conditions vary between fleets, this paper sets out the mechanism rather than a single cost of battery wear.

V2G adds energy throughput, and Lehtola's 2025 review concludes that the extra charge transfer shortens battery life⁴⁸. It finds, however, that scheduled charging might lengthen battery life. The net effect depends on the balance between the extra throughput and the scheduling. The review's highlights point to battery management, rather than new cell chemistry, as the route to longer life.

Because the extra throughput shortens battery life, the decision to export is commercial as well as technical: the grid service has to cover conversion losses and wear. Four constraints set the window within which a vehicle can export:

- **Vehicle:** minimum departure energy and owner availability
- **Battery:** limits on state of charge, temperature, power and throughput
- **Grid value:** services worth the battery use
- **Evidence:** measured battery health rather than an assumed degradation rate



Wireless charging and battery swapping bring constraints of their own

Where conductive charging transfers energy through a cable and connector, wireless power transfer removes the cable, and battery swapping replaces a discharged battery with a charged one. Each needs dedicated infrastructure, standards and commercial arrangements.

High-power wireless charging has specifications and demonstrations, not proof of deployment at scale

IEC PAS 61980-4:2025, a Publicly Available Specification, addresses stationary high-power wireless power transfer, including interoperability, safety and positioning⁴⁹. It also sets basic communication requirements where a system needs them. For dynamic transfer while the vehicle is moving, IEC PAS 61980-6:2025 sets requirements for the communication and activities of a dynamic system⁵⁰.

Two demonstrations have reached high power. In June 2024, Oak Ridge National Laboratory (ORNL) announced what it describes as the first 270 kW wireless power transfer to a light-duty EV⁵¹. The vehicle was a Porsche Taycan research vehicle, and the work with Volkswagen Group of America completed a US Department of Energy project. ORNL reports that the vehicle's receiver coil can achieve 8 to 10 times the power density of existing systems.

The second demonstration tested dynamic transfer, the case that IEC PAS 61980-6 addresses. In December 2025, Purdue University reported that a quarter-mile of Indiana highway had delivered 190 kW to an electric heavy goods vehicle at 65 mph⁵². At that speed the lorry crosses the section in about 14 seconds. If 190 kW were sustained for the whole crossing, the lorry would receive about 0.7 kWh, equivalent to 2.9 kWh per powered mile.



The standards and the two demonstrations show progress beyond low-power stationary use, but not that dynamic road charging is commercially mature at scale. Charging without a plug still reduces manual handling, and it may suit fixed-route or autonomous vehicles. Alignment, cost, efficiency, electromagnetic compatibility, road or site works and cross-vehicle interoperability, however, remain design trade-offs. High-power wireless charging is therefore an emerging option rather than a like-for-like replacement for conductive charging.

Battery swapping charges a pool of packs instead of a vehicle

Swapping separates energy replenishment from the time a vehicle occupies a bay. It works where vehicles and packs are standardised enough for automated exchange, and where a fleet or local market supports an inventory of charged packs.

OCPP 2.1 adds support for battery swap stations for two- and three-wheelers and other electric vehicles⁷. That lets a swap station be managed through the same protocol as a charger.

A swap site, however, still needs electrical capacity to recharge returned packs. It also needs pack identification, health data, thermal management, inventory control and commercial rules for ownership and degradation. With standardised packs and an inventory to manage, swapping therefore suits a fleet or a local market rather than mixed public traffic as a whole.

In both cases, a 2026 specification should include wireless charging or battery swapping only where the vehicles, the infrastructure and the operating model support it. It should also name the standard or demonstration relied on, so that the evidence behind the choice is on record. Either counts as progress rather than as proof of deployment at scale.



Specify the charging service, not only the hardware

Since the first edition in April 2025, public charging infrastructure has expanded and new AFIR requirements have taken effect. Five of the six communication standards in Table 7 have also had a new edition or amendment. The checklist below sets out what a specification should state after those changes. It takes the paper's three parts in order: scheduling power, keeping the communications path working and testing each function.

Schedule power within the grid connection

Since connection capacity, dwell time, storage and each vehicle's need set the useful charging rate, a specification should state:

- **The duty cycle and energy need:** dwell time, required energy, simultaneous demand and departure times, set against the site's grid connection
- **Energy planned with operations:** a lower site peak that still leaves every vehicle with its departure energy
- **The site variables:** energy demand, electrical capacity, and operational, commercial and digital use
- **Storage and load management:** the job each has at peak, set against its losses, battery cycling and the limits of the connection

Give services that cannot wait a path through an independent core

A second path through the same operator core shares that core's failures. Which services need a path through an independent core depends on what an outage puts at risk. For the communications path, a specification should state:

- **Downtime exposure:** for each charging setting, the driver payments at risk in each hour of outage from the chargers' power, utilisation and tariff; the cost of lost vehicle availability at a depot; the chargers behind each shared dependency; and the frequency and duration of outages in the estate's own incident records
- **Regulation in scope:** the duties the service has to meet, including reliability measured from reported status, open data, payment roaming, contactless payment and a staffed helpline

- **Offline behaviour:** what each charger does when its communications, the payment provider or the management platform is unavailable, and the OCPP settings that apply while the platform cannot be reached
- **The resilience tier:** access diversity or core independence for each service, with the operator cores named or stated as separate, the component that takes the switching decision and the failure policy that triggers a switch
- **Protection on both paths:** private encrypted routing, and a second path that carries the charger's TLS connection to the same platform endpoint
- **The site link at hubs and depots:** the number of active connections it combines, and any satellite or fixed-line path that depends on no cellular network
- **Profile management:** how changes of SIM subscription, eSIM profile and mobile operator are made across the estate, and whether eSIM profile management is aligned with SGP.32
- **The estate over its lifecycle:** how and when each charger returns to its preferred path after an outage, and any modem that still falls back to 2G, with a plan for its replacement
- **Evidence from each layer:** charger, router and platform telemetry that traces a failed session to its source, session success measured alongside reported status, and a statement of the design that covers each failure in Table 6

Test each function before relying on it

A protocol label does not show which edition or which features a charger supports, and only testing shows that vehicle, charger and back office work together. A specification should therefore name what each function relies on and ask for evidence that it works:

- **Protocol editions:** the OCPP, ISO 15118 and OCPI functions required, by version, part, edition, amendment and errata
- **Interoperability testing:** evidence that the vehicle, charger and back-office functions relied on work together
- **Bidirectional operation, where planned:** the vehicles' availability, the battery limits and the grid value that justify export
- **Wireless charging or battery swapping, where considered:** the standard or demonstration relied on, and the fleet or vehicle type it serves



CSL supplies both paths as one managed service

A charger's rating, signal strength, reported status or protocol label cannot show on its own what a charging service will deliver. Each layer of the power, control and communications chain therefore needs its own evidence.

CSL manages the communications layer of that chain. In a compatible charger, rSIM technology provides both paths, through two independent multi-network roaming profiles that reach the platform through separate operator cores. A CSL DualSIM Router configured for core independence also provides both cellular paths, whether it is installed in a single charger or serves a multi-charger site. Both approaches enable compatible chargers to reconnect through an independent operator core and resume remote authorisation and payment, provided the alternative path and supporting services remain available. To discuss a resilient communications design for a charging estate, contact sales@csl-group.com.



References

Obligations, statistics and standards are cited to the bodies that publish them, and the interpretation also draws on peer-reviewed literature. CSL's own publications are cited only for CSL's architecture, products, illustrative model and published positions.

- [1] International Energy Agency (IEA). *Global EV Outlook 2026: Outlook for electric mobility*. Paris: IEA, 20 May 2026. Licence: CC BY 4.0. <https://www.iea.org/reports/global-ev-outlook-2026/outlook-for-electric-mobility-chap-9-11>
- [2] *The Public Charge Point Regulations 2023* (SI 2023 No. 1168). Made 2 November 2023; in force 24 November 2023. <https://www.legislation.gov.uk/uksi/2023/1168/contents/made>
- [3] Office for Zero Emission Vehicles and Department for Transport. *Public Charge Point Regulations 2023 guidance*. Published 24 November 2023; updated 21 October 2024. <https://www.gov.uk/government/publications/the-public-charge-point-regulations-2023-guidance/public-charge-point-regulations-2023-guidance>
- [4] Powell, B. and Johnson, C. *Impact of Electric Vehicle Charging Station Reliability, Resilience, and Location on Electric Vehicle Adoption*. Technical Report NREL/TP-5R00-89896. Golden, CO: National Renewable Energy Laboratory, August 2024. Table 4 and page 9. <https://www.nrel.gov/docs/fy24osti/89896.pdf>
- [5] CSL Group. *Electric vehicles and EV charging reliability: frequently asked questions*. 23 July 2026, accessed 11 October 2026. <https://www.csl-group.com/blogs/electric-vehicles-and-ev-charging-reliability-frequently-asked-questions/>
- [6] Thurston, S. *ChargeX Prescribed Testing Program at CharIN November 2024 Testival: Outcomes and Future Recommendations*. ANL/TAPS-25/4. Argonne National Laboratory, May 2025. Pages iv, 15 and 17. https://inl.gov/content/uploads/2024/01/ChargeX_Prescribed-Testing-Program-at-CharIN-Nov2024-Testival.pdf
- [7] Open Charge Alliance. *OCPP 2.1 is now available!* 23 January 2025. <https://openchargealliance.org/ocpp-2-1-is-now-available/>
- [8] International Organization for Standardization. *ISO 15118-20:2022, Road vehicles: Vehicle to grid communication interface, Part 20: 2nd generation network layer and application layer requirements*. Published April 2022. <https://www.iso.org/standard/77845.html>
- [9] CSL Group. *The Transition to Electric Vehicles, Article 3: EV Charging, Power Delivery Systems and Smart Grid Infrastructure*. Version 1.09, April 2025. Landing page, accessed 11 October 2026. https://www2.csl-group.com/EV_charging_smart_power_infrastructure
- [10] Department for Transport. *Public electric vehicle charging infrastructure statistics: 1 July 2026*. Published 27 August 2026. <https://www.gov.uk/government/statistics/electric-vehicle-charging-infrastructure-statistics-1-july-2026/public-electric-vehicle-charging-infrastructure-statistics-1-july-2026>
- [11] European Alternative Fuels Observatory (European Commission). *EAFO Data Update & News Flash September 2026*. Published 21 September 2026; preliminary EU27 data for August 2026. <https://alternative-fuels-observatory.ec.europa.eu/general-information/news/eafo-data-update-news-flash-september-2026>
- [12] Open Charge Alliance. *New editions of the OCPP 2.1 and 2.0.1 now available!* 4 December 2025. <https://openchargealliance.org/new-editions-of-the-ocpp-2-1-and-2-0-1-now-available/>
- [13] International Electrotechnical Commission. *IEC 63584-210:2026, Open Charge Point Protocol 2.1*. Second edition, published 22 September 2026; replaces IEC 63584-210:2025. <https://webstore.iec.ch/en/publication/111422>
- [14] International Organization for Standardization. *ISO 15118-20:2022/Amd 1:2026, Amendment 1: AC DER service, MCS service, and improved security concept*. Published July 2026. <https://www.iso.org/standard/87920.html>
- [15] Department for Energy Security and Net Zero. *Clean flexibility roadmap: July 2026 update* (accessible webpage). Updated 13 July 2026. <https://www.gov.uk/government/publications/clean-flexibility-roadmap/clean-flexibility-roadmap-july-2026-update-accessible-webpage>
- [16] International Energy Agency (IEA). *Global EV Outlook 2026: Electric vehicle charging*. Paris: IEA, 20 May 2026. Licence: CC BY 4.0. <https://www.iea.org/reports/global-ev-outlook-2026/electric-vehicle-charging-chap-6-and-10>
- [17] Department for Transport. *Electric vehicle public charging infrastructure statistics: January 2026*. Published 26 February 2026. <https://www.gov.uk/government/statistics/electric-vehicle-public-charging-infrastructure-statistics-january-2026/electric-vehicle-public-charging-infrastructure-statistics-january-2026>
- [18] Mohan, A., Pal, K. and Meena, H. K. Comprehensive review of electric vehicle charging infrastructure: Technologies, standards, and smart energy management. *Future Batteries* 10 (2026), 100177. <https://doi.org/10.1016/j.fub.2026.100177>
- [19] European Parliament and Council of the European Union. *Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure*. OJ L 234, 22 September 2023. Consolidated text of 8 January 2026, as amended by Commission Delegated Regulations (EU) 2025/656 and (EU) 2025/671. <https://eur-lex.europa.eu/eli/reg/2023/1804/2026-01-08/eng>
- [20] *The Electric Vehicles (Smart Charge Points) Regulations 2021* (SI 2021 No. 1467). Made 15 December 2021; in force 30 June 2022. <https://www.legislation.gov.uk/uksi/2021/1467/contents/made>
- [21] Department for Energy Security and Net Zero, Office for Zero Emission Vehicles and Office for Product Safety and Standards. *Regulations: electric vehicle smart charge points*. Published 3 February 2022; updated 23 April 2024. <https://www.gov.uk/guidance/regulations-electric-vehicle-smart-charge-points>



References

- [22] ChargeX Consortium. *Customer-Focused Key Performance Indicators for Electric Vehicle Charging: Implementation Guide*. INL/RPT-24-77389, Revision 1. Idaho National Laboratory, 31 December 2024, revised 10 January 2025. Page 13. https://inl.gov/content/uploads/2024/03/ChargeX-report_KPI-Implementation-Guide_Dec2024.pdf
- [23] J.D. Power. *2026 U.S. Electric Vehicle Experience (EVX) Public Charging Study*. Press release, 12 August 2026. <https://www.jdpower.com/business/press-releases/2026-u-s-electric-vehicle-experience-evx-public-charging-study/>
- [24] EVRoaming Foundation. *Open Charge Point Interface (OCPI)*. Web page, accessed 11 October 2026. <https://evroaming.org/ocpi/>
- [25] Ofcom. *Ofcom investigates BT and Three following mobile network outages*. 15 December 2025. Cases CW/01331/12/25 and CW/01330/12/25. <https://www.ofcom.org.uk/phones-and-broadband/telecoms-infrastructure/ofcom-investigates-bt-and-three-following-mobile-network-outages>
- [26] Technology Audit Partners. *Findings Report on the July 8th Telstra Outage*. 24 August 2026. Pages 2 and 4. Accessed 11 October 2026. <https://www.telstra.com.au/content/dam/tcom/dynamic-media-projects/luke-campbell/TAP-Findings-for-Telstra-Outage.pdf>
- [27] HM Revenue and Customs. *Revenue and Customs Brief 4 (2026): VAT liability of supplies of electricity from public electric vehicle charge points*. Published 12 May 2026. <https://www.gov.uk/government/publications/revenue-and-customs-brief-4-2026-vat-liability-of-supplies-of-electricity-from-public-electric-vehicle-charge-points/vat-liability-of-supplies-of-electricity-from-public-electric-vehicle-charge-points>
- [28] Green Finance Institute and Zapmap. *Demystifying Utilisation: 2026 Update*. May 2026. Page 5, table of average energy-based utilisation, Q4 2025 column, and note 3. Listed on the Green Finance Institute's Transport page, accessed 11 October 2026. <https://www.greenfinanceinstitute.com/programmes/cdr/t/>. Report file, as linked from that page: <https://www.greenfinanceinstitute.com/wp-content/uploads/2026/07/Demystifying-Utilisation-2026-Update.pdf>
- [29] Zapmap. *Zapmap Price Index*. Web page, updated 7 October 2026, accessed 11 October 2026. <https://www.zapmap.com/ev-stats/charging-price-index>
- [30] CSL Group. *Critical Connectivity FAQs: IoT SIMs, rSIM, routers, VoiceLink and sector solutions*. 3 July 2026. <https://www.csl-group.com/blogs/critical-connectivity-faqs-iot-sims-rsim-routers-sector-solutions/>
- [31] CSL Group. *CSL Outpost*. Product page, accessed 11 October 2026. <https://www.csl-group.com/solutions/csl-outpost/>
- [32] CSL Group. *CSL Outpost*. Support page, accessed 11 October 2026. <https://www.csl-group.com/support/csl-outpost/>
- [33] CSL Group. *How CSL delivers eSIM management together with rSIM resilience*. 3 September 2026. <https://www.csl-group.com/blogs/how-csl-delivers-esim-management-together-with-rsim-resilience/>
- [34] CSL Group. *What is SGP.32?* Resource page, updated 10 September 2026. <https://www.csl-group.com/resources/what-is-sgp-32/>
- [35] Ofcom. *Switching off the UK's 2G and 3G mobile networks: what you need to know*. First published 6 March 2024; updated 10 August 2026. <https://www.ofcom.org.uk/phones-telecoms-and-internet/advice-for-consumers/advice/3g-switch-off>
- [36] Open Charge Alliance. *OCPP Security Operations Guide*. Version 2.0, September 2026. Sections 4.2 and 4.3. https://openchargealliance.org/wp-content/uploads/2026/01/ocpp_security_operations_guide-v2.pdf
- [37] Open Charge Alliance. *OCPP 2.1, Edition 2, Part 2: Specification*. 3 December 2025. Sections C 1.3 to 1.5 and E 1.3; use cases C10, C13, C15 and E04; Referenced Components and Variables 2.3.3, 2.5.1, 2.5.2, 2.6.1 and 2.6.3. Download page, accessed 11 October 2026. <https://openchargealliance.org/my-oca/ocpp/>
- [38] SAE International. *SAE J3400_202409, North American Charging System (NACS) for Electric Vehicles*. Recommended Practice, revised 30 September 2024. https://saemobilus.sae.org/standards/j3400_202409-north-american-charging-system-nacs-electric-vehicles
- [39] International Electrotechnical Commission. *IEC 62196-3:2026, Plugs, socket-outlets, vehicle connectors and vehicle inlets: Conductive charging of electric vehicles, Part 3: Dimensional compatibility requirements for DC and AC/DC pin and contact-tube vehicle couplers*. Published 23 April 2026; corrected version August 2026. <https://webstore.iec.ch/en/publication/86314>
- [40] International Electrotechnical Commission. *IEC 61851-23:2023, Electric vehicle conductive charging system, Part 23: DC electric vehicle supply equipment*. Published 13 December 2023. <https://webstore.iec.ch/en/publication/32973>
- [41] International Electrotechnical Commission. *IEC TS 63379:2026, Vehicle connector, vehicle inlet and cable assembly for megawatt DC charging*. Technical Specification, edition 1.0. Published 28 January 2026. <https://webstore.iec.ch/en/publication/67975>
- [42] International Electrotechnical Commission. *IEC 61851-23-3:2026, Electric vehicle conductive charging system, Part 23-3: DC electric vehicle supply equipment, Megawatt charging systems*. Edition 1.0. Published 21 August 2026. <https://webstore.iec.ch/en/publication/69016>
- [43] International Electrotechnical Commission. *IEC 63584-201:2026, Open Charge Point Protocol 2.01*, based on OCPP 2.0.1; replaces IEC 63584:2024. Published 18 September 2026. <https://webstore.iec.ch/en/publication/111418>
- [44] EVRoaming Foundation. *Open Charge Point Interface (OCPI) 2.3.0, edition 2: Version history*. 18 June 2026. https://github.com/ocpi/ocpi/blob/2.3.0/release/core/version_history.asciidoc



References

- [45] International Electrotechnical Commission. *IEC 63110-1:2022, Protocol for management of electric vehicles charging and discharging infrastructures, Part 1: Basic definitions, use cases and architectures*. Published 29 July 2022. <https://webstore.iec.ch/en/publication/60000>
- [46] Li, Y., Wang, K., Feng, X., Guo, D., Gao, X., Mou, D., Wu, Y. and Yang, S. Battery-electric vehicle-charging station-power grid synergies: A technical roadmap from vehicle to grid. *eTransportation* 28 (2026), 100569. <https://doi.org/10.1016/j.etrans.2026.100569>
- [47] Leijon, J. Charging strategies and battery ageing for electric vehicles: A review. *Energy Strategy Reviews* 57 (2025), 101641. <https://doi.org/10.1016/j.esr.2025.101641>
- [48] Lehtola, T. Vehicle-to-grid applications and battery cycle aging: A review. *Renewable and Sustainable Energy Reviews* 208 (2025), 115013. <https://doi.org/10.1016/j.rser.2024.115013>
- [49] International Electrotechnical Commission. *IEC PAS 61980-4:2025, Electric vehicle wireless power transfer (WPT) systems, Part 4: Interoperability and safety of high-power wireless power transfer (H-WPT) for electric vehicles*. Published 25 November 2025. <https://webstore.iec.ch/en/publication/67337>
- [50] International Electrotechnical Commission. *IEC PAS 61980-6:2025, Electric vehicle wireless power transfer (WPT) systems, Part 6: Specific requirements for magnetic field dynamic power transfer (MF-D-WPT) system communication and activities*. Published 31 March 2025. <https://webstore.iec.ch/en/publication/68093>
- [51] Oak Ridge National Laboratory. *Polyphase wireless power transfer system achieves 270-kilowatt charge, sets another world record for electric light-duty passenger vehicles*. News release, 18 June 2024. <https://www.ornl.gov/news/polyphase-wireless-power-transfer-system-achieves-270-kilowatt-charge-sets-another-world>
- [52] Purdue University. *First highway segment in U.S. wirelessly charges electric heavy-duty truck while driving*. News release, 3 December 2025. <https://www.purdue.edu/newsroom/2025/Q4/first-highway-segment-in-u-s-wirelessly-charges-electric-heavy-duty-truck-while-driving>



The Transition to Electric Vehicles

This paper is Article 3 of the four in the series, and the first of the four to appear in a second edition. The links for Articles 1, 2 and 4 open their first editions, published in 2025.

Article 1, first edition, 2025

EV driving behaviours and their implications for telematics and road safety

Article 3, second edition, 2026

EV charging, power delivery systems and smart grid infrastructure

Article 2, first edition, 2025

EV commercial fleet transitions: the challenges for heavy goods vehicles and rapid charging infrastructure

Article 4, first edition, 2025

The future of telematics: the roles of AI and machine learning in driver assistance, EVs and autonomous vehicles

General enquiries

sales@csl-group.com

[csl-group.com](https://www.csl-group.com)

This publication

The Transition to Electric Vehicles, Article 3. Second edition, version 2.99, October 2026. Evidence is cited as it stood on 11 October 2026.

CSL Group holds editorial responsibility for this publication, which is general technical information rather than legal, electrical design, financial or investment advice. Project specifications should be checked against current standards, network requirements, regulation and site conditions.

© 2026 CSL Group. All rights reserved. rSIM, CSL DualCore, CSL DualSIM and Critical Connectivity are registered trademarks of CSL Group Ltd. The CSL mark is a trademark of CSL Group. Other names are the property of their respective owners and are used for identification only.