CHARGE

Smart Charging Connections: Trials Learning and BaU Roll-Out

The Charge Project
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1. Document Issue Control

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2. Introduction

The Charge Project is designing and demonstrating innovative *Smart Charging Connection* (SCC) solutions for Electric Vehicle (EV) Charging. The SCC solutions provide EV Chargepoint developers with a greater range of connection options and accelerate the roll-out of public EV charging infrastructure.

2.1. Project Background

Through the Charge Project, SP Energy Networks (SPEN) is accelerating the process of planning and connecting EV charging infrastructure at the lowest cost to GB electricity customers. This is achieved by maximising the use of existing assets and deploying innovative approaches to the connection and management of EV uptake across the SP MANWEB licence area. The Charge Project combines learning from other EV charging projects with expertise from the world of transport planning. This learning is coupled with a targeted selection of innovative EV chargepoint connection trials for a range of practical situations.

The Charge Project merges the disciplines of transport planning and electricity network planning to create an overarching plan for how EV chargepoints will impact the network. This facilitates better planning of electricity networks and provides vital information for all sectors involved in helping the UK transition to low carbon transport.

The project uses driver behaviour and journey statistics to form a view of the demand draw from multiple EV chargepoint installations in various uses (for example, car park, forecourt, destination), in order to help the DNO assign more appropriate design values during the connection process.

The Charge Project includes three methods:

- **Method 1:** Strategic transport and network planning
- **Method 2:** Tactical solutions to support EV connections
- **Method 3:** Development of the 'ConnectMore' software tool

Smarter Grid Solutions (SGS) is responsible for Method 2, which designs and demonstrates Smart Charging Connection (SCC) solutions that enhance the flexibility of EV charging and support improved hosting of charging infrastructure without expensive reinforcement.

Previous phases of The Charge Project have defined a 'smart solutions toolbox' of flexible EV charging solutions, which is demonstrated through trials in subsequent phases of the project.

The Charge Project has consulted with stakeholders across the distribution networks and Electric Vehicle domain, using learning from this process to refine SCC offerings. This has established two forms of SCC:

- Customer-Led SCCs: in which the customer is responsible for managing EV chargepoint consumption against pre-agreed, fixed import limitations
- DNO-Led SCCs: in which the customer must manage EV chargepoint consumption against a varying import threshold that reflects prevailing network conditions

For each of the above SCCs, multiple forms of solution can be deployed, with varying degrees of complexity and capacity release across them.

2.2. Document Objectives and Structure

This document is targeted at a range of stakeholders, including EV Chargepoint Operators and Developers, DNOs and Ofgem. The objective is to report on the learning derived through the Successful Delivery Reward Criteria (SDRC) 6 project stage. SDRC 6 demonstrates the deployment of SCCs on network case studies through configuration and bench-testing of the SCC control solution in a laboratory simulation environment. This 'Virtual Trial' provides the rationale and benefits case for SCCs as an interim connection solution ahead of reinforcement and recommendations for establishing appropriate procedures, policies, and standards for business-as-usual deployment of SCCs.

This document presents learning from SDRC 6 through the following structure:

- Section 3 presents the findings and key learning from detailed study of historical datasets from public EV chargepoint infrastructure, providing an update to previously reported analysis of EV chargepoint datasets.
- Section 4 presents the design and test cases demonstrated through the Virtual Trials. Key learning from the design, configuration, commissioning, and operation of the SCC solution in the Virtual Trials laboratory environment is also presented.
- Section 5 presents key observations from the Cost-Benefit Analysis of each SCC scheme applied to a selected trial site. This provides detail on the value case for SCCs and highlights the suitability of different scheme types for different sites.
- Section 6 provides a summary of recommendations for revision of industry-wide standards to accommodate and reflect SCCs.
- Section 7 presents the summary of curtailment assessment best-practice methodology, including the value of curtailment assessment, required datasets, analysis methodology and outputs, assumptions, and limitations.

3. Chargepoint Data Analysis (Extended Datasets)

The Charge Project has accessed historical datasets of EV chargepoint utilisation, sourced from several Chargepoint Operators (CPOs) and representing sites across South Scotland and Northern England. The study of these datasets has improved understanding of EV chargepoint behaviours and informed the modelling of EV chargepoint operation in follow-on Virtual Trials and Desktop Assessments. Characteristics of EV chargepoint utilisation, such as duration, energy consumption during charging events, and total utilisation of EV chargepoints, are derived across the diverse types of chargepoints.

Understanding the typical utilisation levels of EV chargepoints is crucial to the subsequent evaluation of SCCs, the frequency and severity of constraint events, and the impact of constraint events on customers using an EV chargepoint site. This section details summary findings from the updated statistical review of the CPO datasets of chargepoint utilisation.

3.1. Source Datasets

EV chargepoint datasets were provided from five sources, detailing approximately 124,000 charging events across 211 chargepoint units. A summary of the data sources is provided in Table 1. A description of the specific information provided for each source is detailed in the following sections.

Source	Sites/ Chargepoints	EV Chargepoint Type	Dataset Start	Number of Charging Events
PACE – Lanarkshire, Scotland	23 sites; 68 chargepoints	Destination	August 2020 to June 2022	109,286
Q-Park – Yorkshire, Lancashire, and Merseyside	22 sites; 28 chargepoints	Destination	January 2020 to March 2021	1,792
Liverpool Lamppost Chargers	63 sites & chargepoints	Residential	January 2020 to December 2020 April 2021 to June 2021	1,417
Cheshire West & Chester Car Parks	7 sites; 15 chargepoints	Destination	September 2021 to June 2022	4,761
Warrington Council Car Parks	5 sites; 37 chargepoints	Destination	June 2020 to June 2022	6,899

Table 1: Summary of Available Datasets

The EV chargepoints within the datasets consist of *Destination* charging sites, with a smaller proportion from *On-Street Residential* charging sites. A universal dataset of EV charging events was derived from the diverse datasets, presenting the following information in a consistent format:

- **Source:** Detailing the original source of the event dataset
- **Site Unit:** A unique identifier for the chargepoint used during a charging event
- **Charging Type:** Whether the chargepoint type is Destination or On-Street Residential
- **Charge Event Start Date and Time:** The date and time the EV was connected to the chargepoint
- **Charge Event End Date and Time:** The date/time the EV disconnected from the chargepoint
- **Charge Duration:** The duration the EV was connected to the chargepoint during the charge event
- **Energy Consumption (kWh):** The total energy consumed by the EV within the charging event window
- **Average Charge Rate:** The average rate of charge across the full charging event

3.2. Summary Findings

Several key behaviours have been derived from statistical evaluation of the metrics available in the universal datasets of EV charging events. These are summarised as the following four factors:

- **Time of Events**: When charging events occur, namely, what time of day or year has the greatest demand for EV chargepoint usage
- **Duration:** The typical duration of EV connection to the chargepoint throughout a charging event
- **Energy Consumption:** How much energy is consumed across the range of typical charge events in the datasets
- **Per-site Utilisation:** The typical availability of EV chargepoints, such as the probability that the chargepoint is available for an EV connection or the number of chargepoint events per day

Observations from the study findings include the following (which are detailed further in following sections):

Time of Events

A high proportion of all charge events initiated during daytime hours, particularly 08.00 – 17.00. As most event data is related to *Destination* charging, there is strong correlation between chargepoint utilisation in these hours and the operational hours of destinations such as shopping centres, public transport park-and-ride sites, and leisure facilities.

In the case of *On-Street Residential charging*, the charging events tail into the evening, which is distinct from the abrupt decline observed in Destination charging after 17.00. This represents utilisation of On-Street Residential chargepoints in the evening, when commuting users return home from work.

Duration

The study of EV Charging Event Duration highlights a notable distinction in event duration between the *Destination* and *On-Street Residential* cases: Destination cases show the majority (over 80%) of charging events lasting under two hours, whereas the On-Street Residential cases reveal that over 45% of charging events last more than six hours. The behaviour of On-Street Residential charging is likely to reflect that of private domestic charging, which was not covered in this analysis. This observation may reflect behaviour in which once a user has connected to an *On-Street Residential* chargepoint, they may not disconnect until the next car journey, unlike behaviour at a Destination site, in which the car is disconnected when the user must continue their journey.

Most available datasets only highlight the window of EV connection to a chargepoint, rather than the period when the EV is actively drawing power from the chargepoint.

Most available datasets only highlight the window of EV connection to a chargepoint, rather than the period when the EV is actively drawing power from the chargepoint. In practice, during longer events the EV may reach full charge during the event, resulting in no electrical energy consumption at the chargepoint part of the charge window. This is a significant limitation when evaluating both EV user behaviour and assessing the grid import impacts of charging events across a time-series connection window.

A key recommendation is that CPO operational logging is configured to measure the distinction between the true 'charging window' and 'connection window' of a connected EV. Logging this information would facilitate more accurate study of the electrical demand impacts of EV charging events. Understanding the true charging window of connected EVs will be crucial for DNOs to understand likely diversity factors for public EV charging sites. This will allow more accurate, representative network designs that accommodate new connections effectively.

Energy Consumption

Across all chargepoint types, approximately 50% of charging events consume less than 20 kWh. This may relate to the nature of Destination charging or reflect that, in many cases of public chargepoint utilisation, EV users are merely 'topping up' charge.

In the case of *On-Street Residential*, a marginally higher percentage of charge events consume over 60 kWh (than with *Destination* charging). This may be related to the larger proportion of long-duration charging events in the case of On-Street Residential charging (as explained in Section 3.4).

Per-Site Utilisation

General trends suggest that chargepoint utilisation can follow two behaviours:

- High Frequency Events/Low Duration: in which the chargepoint experiences multiple low-duration (sub-hour) events throughout a day, most often observed at *Destination* charging sites.
- Low Frequency/High Duration: in which the chargepoint may only experience a single charge event throughout the day, but it is likely to be a minimum of two hours' duration. This is most often observed at *On-Street Residential* Charging sites.
- On average, higher levels of utilisation are shown across the PACE datasets than with most other data sources. This may reflect how PACE chargepoints are free for public use, whereas other chargepoints charge customers, potentially causing users to defer charging to the cheaper at-home periods.

Across the periods covered by the operational datasets, a considerable proportion of data was recorded during COVID-19 Lockdown, when utilisation of public chargepoints was lower than typically expected.

3.3. Data Analysis Outputs: Time of EV Connection Events

The timing of EV charging events is concerned with the initial moment of connection from the EV at the chargepoint. This illustrates the user demand for chargepoint availability at certain times of the day, and can also be used as a proxy to identify the period of peak/highest demand at the beginning of a charge event.

The start time of EV charging events are aggregated to half-hour windows, with the number of events in each window used to derive the following:

- Figure 1 illustrates the distribution of charge event start times across the day, derived from all data sources.
- Figure 2 illustrates the probability of charge event start times for each source of data.
- Figure 3 illustrates the breakdown in probability of charge event start times across *Destination* and *On-Street Residential* sites.

Figure 1 details the number of charging events that start during each half-hour window, broken down across the dataset sources.

Observations from the study of EV charging start times are:

- A significant trend shows charge events starting during daytime hours, particularly 08.00 – 17.00, as highlighted in Figure 1. As most event data is related to *Destination* charging, correlation is strong between chargepoint utilisation during these hours and the operational hours of destinations such as shopping centres, public transport park-and-ride sites, and leisure facilities.
- In the case of *On-Street Residential* charging, the charging events tail more significantly into the evening, rather than experiencing the more abrupt decline in Destination charging after 17.00. (See Figure 3.) This represents utilisation of on-street residential chargepoints in the evening when commuting users return home from work.
- The specific morning peak observed in the Warrington Town Centre dataset (Figure 2) reflects expected behaviour at such city-centre car park sites, where commuting users are likely to initiate charging events just prior to the working day.
- As highlighted by some source sites in Figure 2, those with smaller populations of charge events present higher levels of variation across charging start times. This factor is likely to affect the comparison between the *On-Street Residential* datasets, which reflects greater variation, as well as the smoother pattern observed in the *Destination* datasets (see Figure 3), which shows a significantly higher population of Destination events.

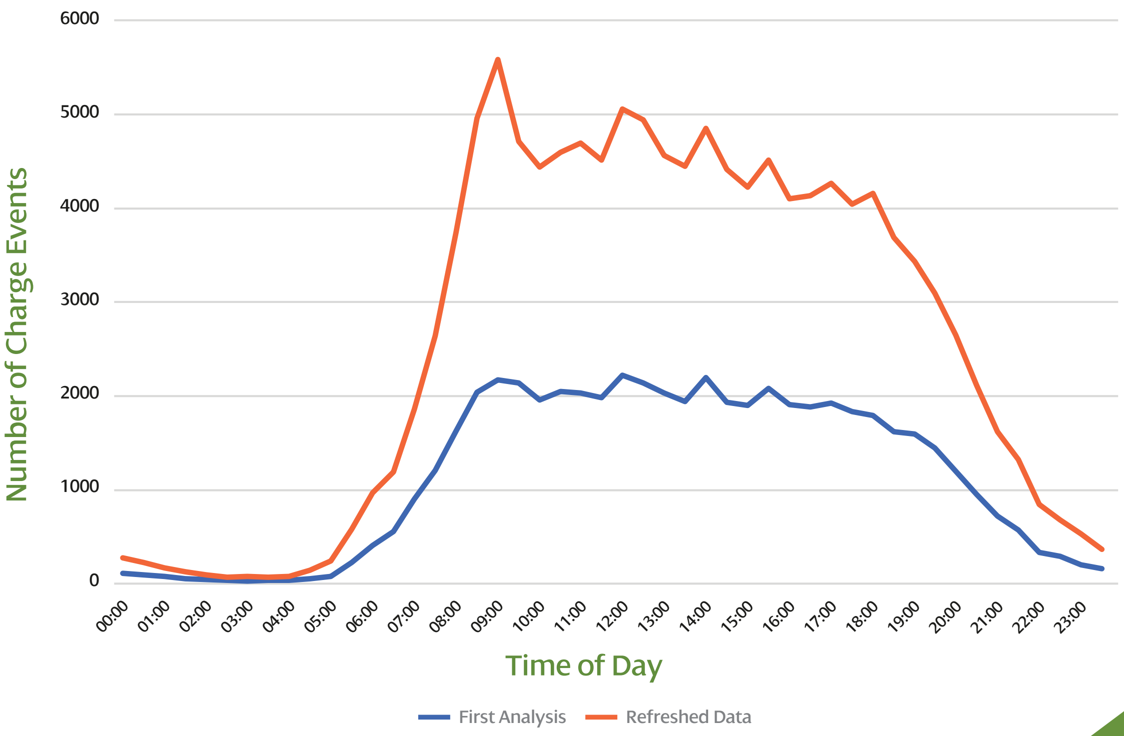

Figure 1: Charging Event Start Time: Number of Charging Events (All Data)

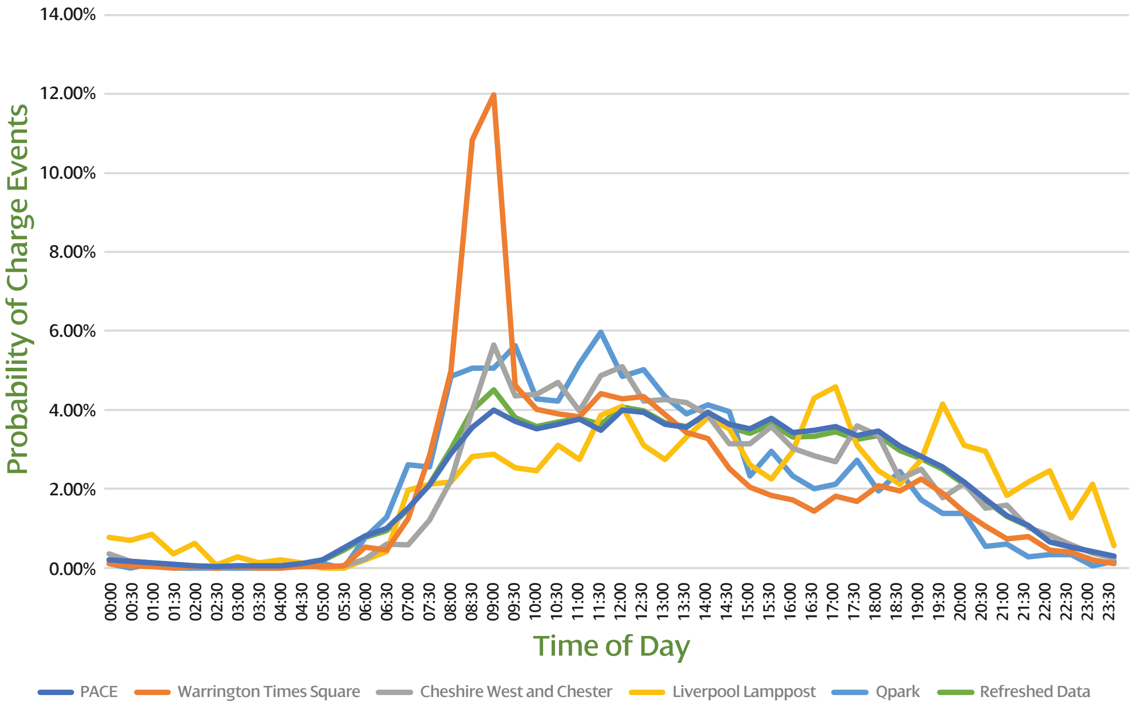

Figure 2: Charging Event Start Time: Probability of Charging Events per Source

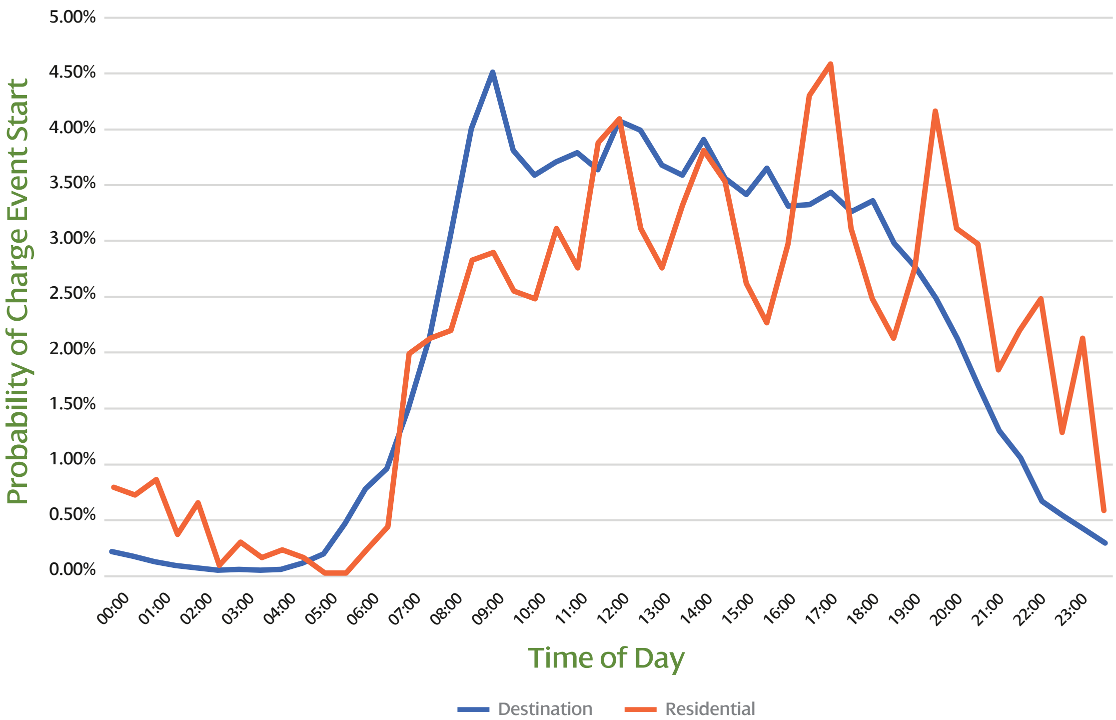

Figure 3: Charging Event Start Time: Probability of Charging Events per Chargepoint Type

3.4. Data Analysis Outputs: Charging Event Duration

Like the start time of EV charging events, the duration of events reflects a key factor in user behaviour. The study of event duration assists with understanding the utilisation levels of different chargepoint types and associations between utilisation and number of users.

Although the Charging Event Duration metric describes the period during which an EV is plugged into a chargepoint, in practice, the EV may reach full charge during longer events, resulting in no electrical energy consumption at the chargepoint during the charge window. Improvement in collection of CPO operational datasets to distinguish between the true 'charging window' and 'connection window' would allow more accurate study of the electrical demand impacts of EV charging events.

The duration of individual EV charging events is grouped into windows of event duration, for which the following is presented:

- Figure 4 illustrates the probability of charge events lasting for different duration levels, broken by each of the data sources.
- Figure 5 illustrates the probability distribution of charge event duration levels across *Destination* and *Residential On-Street* sites.

The key observations from the study of EV Charging Event Duration are that there is a notable distinction in event duration between Destination and On-Street Residential cases: Destination cases show the majority (over 80%) of charging events lasting under two hours, whereas On-Street Residential cases reveal that 45% of charging events last over six hours. This observation may reflect behaviour in which, once a user has connected to an On-Street Residential chargepoint, they may not disconnect until the next car journey, unlike behaviour at a Destination site, in which the car is disconnected when the user must continue their journey.

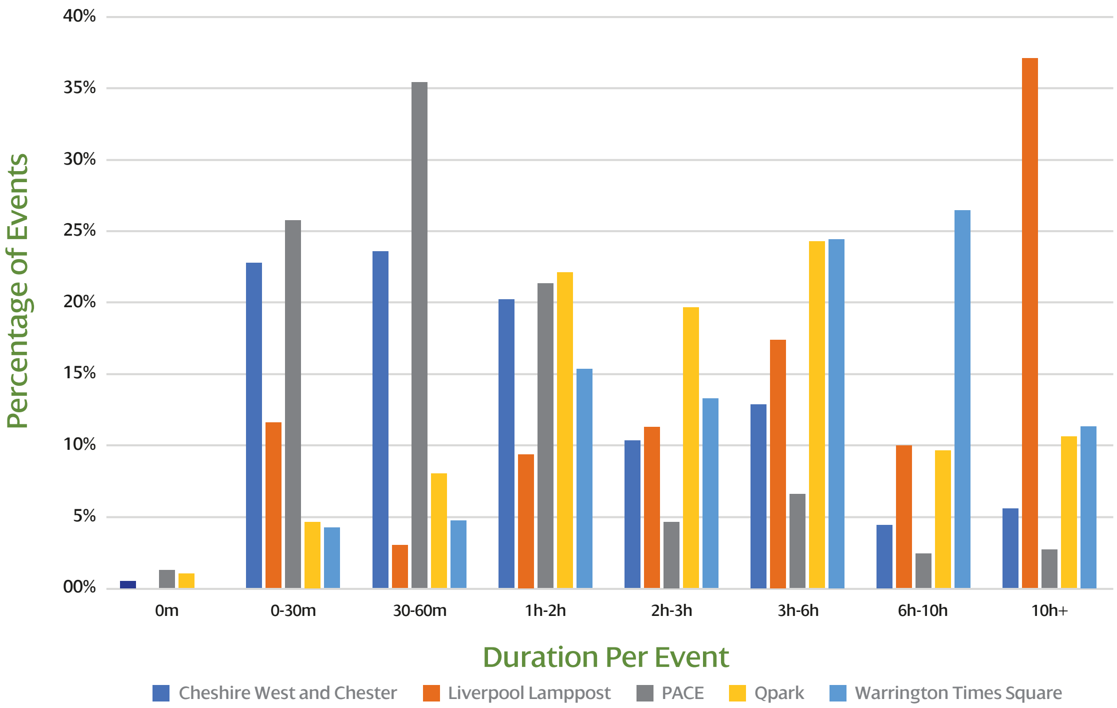

Figure 4: Charging Event Duration: Probability per Data Source

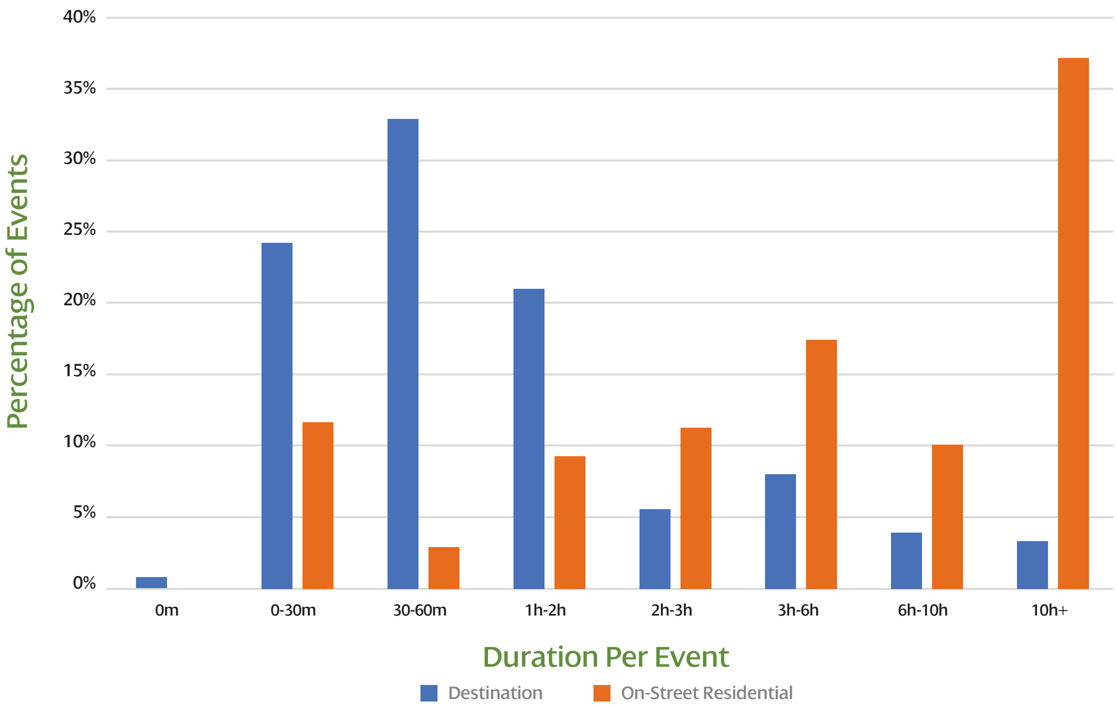

Figure 5: Charging Event Duration: Probability per Chargepoint Type

3.5. Data Analysis Outputs: Energy Consumption

Analysing the energy consumed at a chargepoint assists with understanding the links between customer behaviour, EV chargepoint utilisation levels, and types of EV chargepoint.

The energy consumption within individual EV charging events is aggregated into blocks of kWh consumption across the event. Energy consumption at a chargepoint is influenced by not only the chargepoint rating, but also the type of EV (which dictates both rate of charge and battery capacity), the starting state of charge of the EV, and the duration of the charging event. Figure 6 illustrates the probability distribution of charge event consumption derived from all data sources.

Observations from the study of consumption during EV charging events are:

- Across all chargepoint types, approximately 50% of charging events consume less than 20 kWh. This may relate to the short-term nature of user parking at Destination spaces or reflect that, in many cases of public chargepoint utilisation, EV users are merely 'topping up' charge rather than requiring an essential recharge of the EV battery.
- In the case of *On-Street Residential*, a marginally higher percentage of charge events consume over 60 kWh (when compared to *Destination* charging). This may be related to the larger proportion of long-duration charging events in the case of On-Street Residential charging, as noted in Section 3.4.

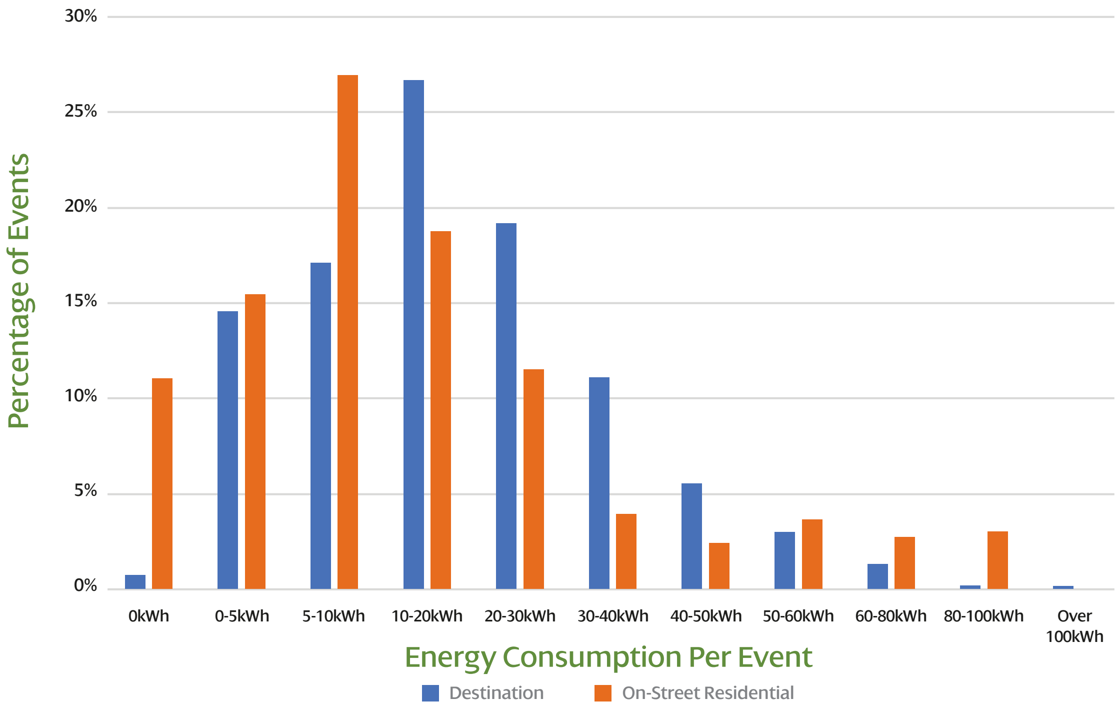

Figure 6: Charging Event Consumption: Probability per Chargepoint Type

3.6. Data Analysis Outputs: Per-Chargepoint Utilisation

Utilisation metrics are derived on a per-chargepoint basis, in which for each chargepoint, the following metrics are derived:

- The **average number of charge events per day**: calculated as the total number of charging events at the chargepoint divided by the total number of chargepoint operational days
- The **average duration of charging events**: calculated as the total duration of charging events at the chargepoint divided by the total duration of chargepoint operation

In the calculation of both metrics, the operational window for each chargepoint is derived as the period between the start of its earliest charging event and the completion of its latest charging event. It is possible that less-utilised chargepoints may have been operational for longer periods in the study window. However, without clear information on per-chargepoint dates of data collection, the applied approach provides the most representative and consistent method for deriving chargepoint operational windows. Similarly, information about chargepoint downtime was not available to incorporate into the utilisation calculations.

Figure 7 presents a plot of the above metrics for each chargepoint, in which the chargepoints are colour-coded to reflect source datasets. Table 2 details average utilisation of chargepoints across each source dataset. Observations from the per-chargepoint metrics are:

- Aside from a small number of outliers, the PACE Destination charging dataset is the only source dataset that returns more than one average number of charging events per day. Where a chargepoint sees more than one event per day, the average event duration is most often below one hour.
- Conversely, the Liverpool Lamppost On-Street Residential chargepoints return a higher average duration of charging event, albeit all chargepoints see less than one charge event per day. The long-duration charge events reduce the overall availability.
- General trends suggest that chargepoint utilisation can follow two behaviours:
  - High Frequency Events/Low Duration: in which the chargepoint experiences multiple low-duration (sub-hour) events throughout a day
  - Low Frequency/High Duration: in which the chargepoint may only experience a single charge event throughout the day, but it is likely to be a minimum of two hours.
- Levels of utilisation are higher across the PACE datasets than most other data sources. This may reflect how PACE chargepoints are free for public use, whereas other chargepoints charge customers, potentially causing users to defer charging to the cheaper at-home period.

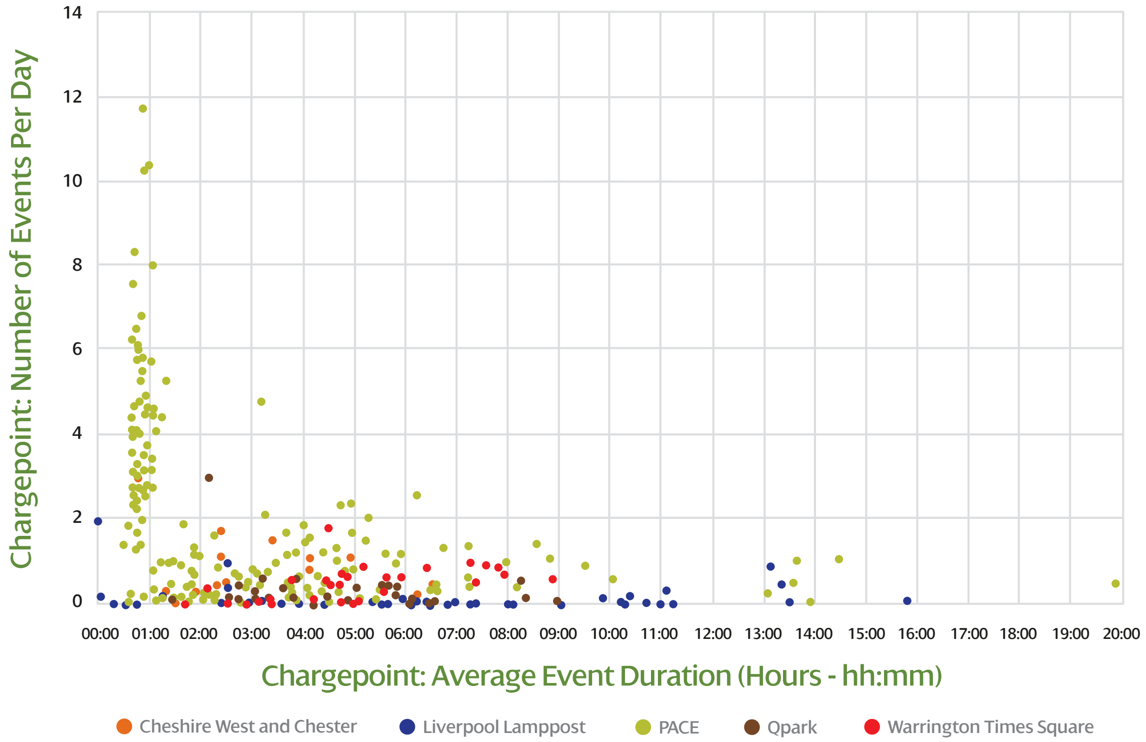

Figure 7: Mapping the Average Event Duration and Number of Events Per Day to Each Chargepoint

Source Data	Average Chargepoint Utilisation
Cheshire West and Chester	10.8%
Liverpool Lamp-post	3.6%
PACE	16.0%
Q-Park	6.0%
Warrington Times Square	14.7%
Total	12.6%

Table 2: Per-Chargepoint Average Utilisation

4. VIRTUAL TRIAL: OUTPUTS AND LEARNING

The *Virtual Trials* demonstrate delivery of the Distribution Network Operator (DNO) SCC solutions across a variety of use cases, both validating the DNO control technology and providing a practical illustration of chargepoint demand curtailment across different scenarios.

The *Virtual Trials* were delivered under the re-scoping of The Charge Project following challenges to establishing suitable conditions for the project physical trials. The *Virtual Trials* implemented a DER Management System (DERMS) solution, with trial objectives summarised in Figure 8.

The following section highlights the key learning derived from the *Virtual Trials*, highlighting the findings from the study of site curtailment across different case studies and sharing learning from implementation and testing of the SCC control systems.

Establish Study Environment for Simulation of SCC Deployment

- Specify requirements for study of SCC deployment to estimate frequency of constraint and resultant curtailment actions
- Establish and demonstrate a recommended methodology and best practice for delivery of SCC Curtailment Study that can be rolled out by other DNOs

Study Curtailment of Smart Charging Connections (SCCs) in Different Deployment Scenarios

- Establish varied network cases and EV/SCC scenarios that reflect the diversity of potential deployment cases
- For each case, study SCC operation and approximate curtailment of EV chargepoint events
- Explore levels of capacity released between different SCC solutions

Establish Standardised Approximate Curtailment Ranges For Different SCC Deployment Scenarios

- From study scenarios, identify standardised combinations of SCC deployment and network cases
- Approximate ranges of curtailment to be expected at EV chargepoints when SCCs deployed to standardised network cases

Figure 8: Virtual Trials Objectives

4.1. Overview: Virtual Trials Test Environment

The Virtual Trials explore an architectural implementation of the DERMS control infrastructure that enables SCC schemes. The SCC types studied and their respective Virtual Trials implementation architectures are defined below.

4.1.1. CLM – Customer Load Management

The 'Customer Load Management' (CLM) SCC scheme uses a local ANM DERMS controller to dynamically manage the CPO site load within the DNO-contracted limits. The CLM SCC concept is summarised in Figure 9.

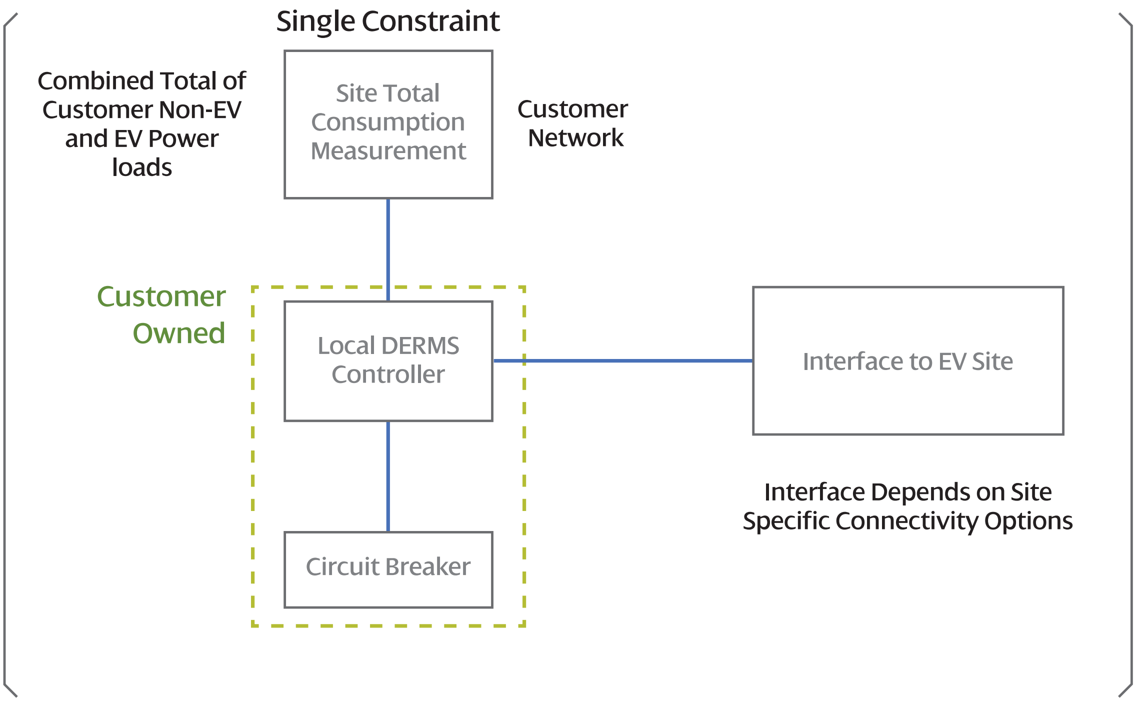

Figure 9: Smart Charging Scheme – CLM

4.1.2. LMC – Locally Managed Connection

The 'Locally Managed Connection' (LMC) DNO-Led SCC scheme uses a local DERMS controller to dynamically manage the CPO site against the real-time demand headroom observed at a single DNO network constraint. The load is controlled in real time to ensure the DNO Measurement Point remains within safe limits. The LMC SCC concept is summarised in Figure 10.

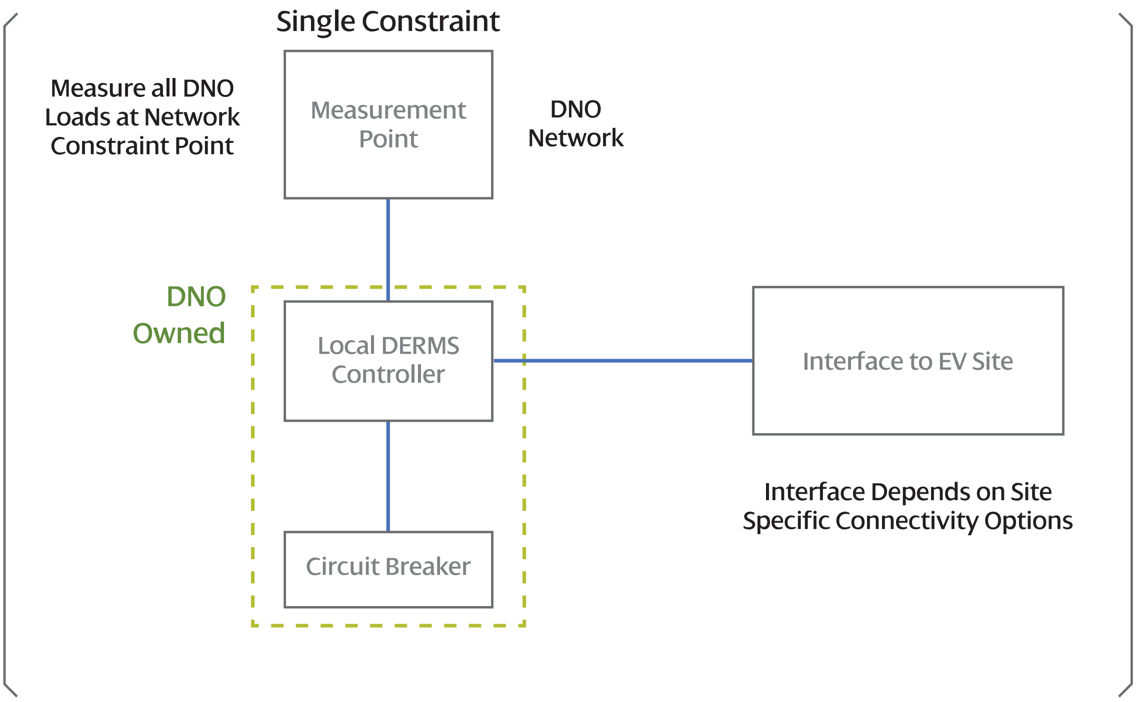

Figure 10: Smart Charging Scheme – LMC

4.1.3. CMC – Centrally Managed Connection

The 'Centrally Managed Connection' (CMC) DNO-Led SCC scheme manages multiple CPO sites, deploying a local DERMS controller at each CPO site to dynamically manage all CPO sites against multiple DNO network constraints. All CPO sites are controlled to ensure that the loading across all DNO Measurement Points remains within the prescribed safe limit. The CMC SCC concept is summarised in Figure 11.

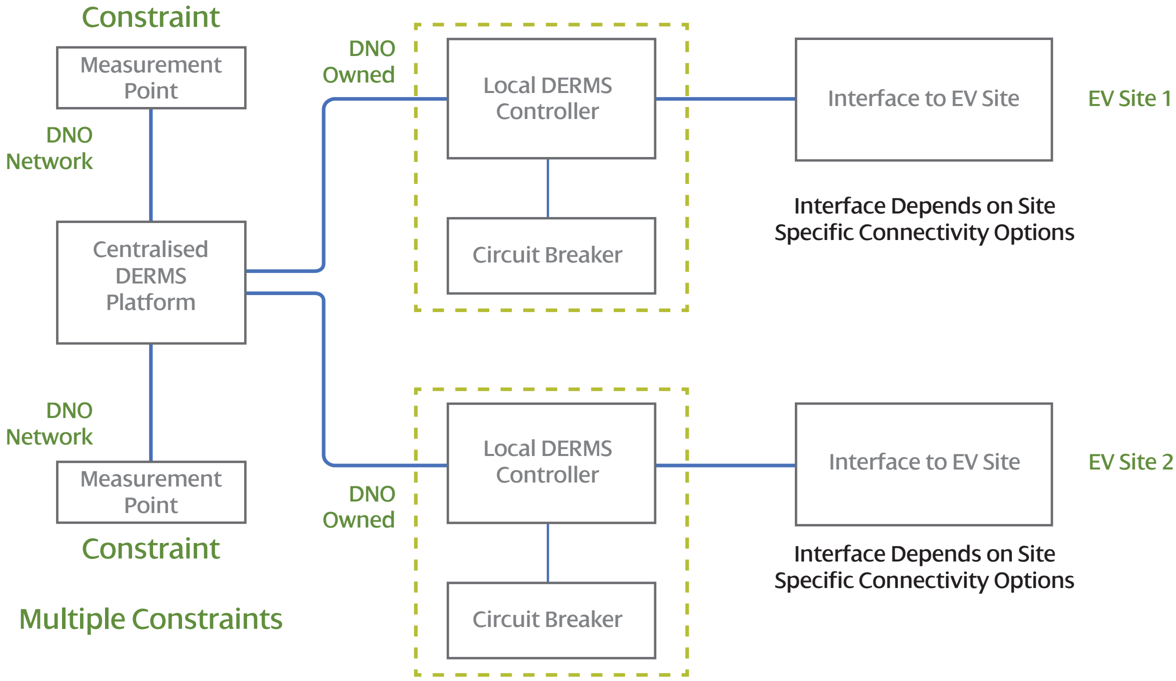

Figure 11: Smart Charging Scheme – CMC

4.1.4. LMC/CLM SCC Virtual Trials Implementation

The implementation architecture for the Virtual Trials of LMC/CLM SCC schemes, using the SGS Element Grid local DERMS controller device, is presented in Figure 12.

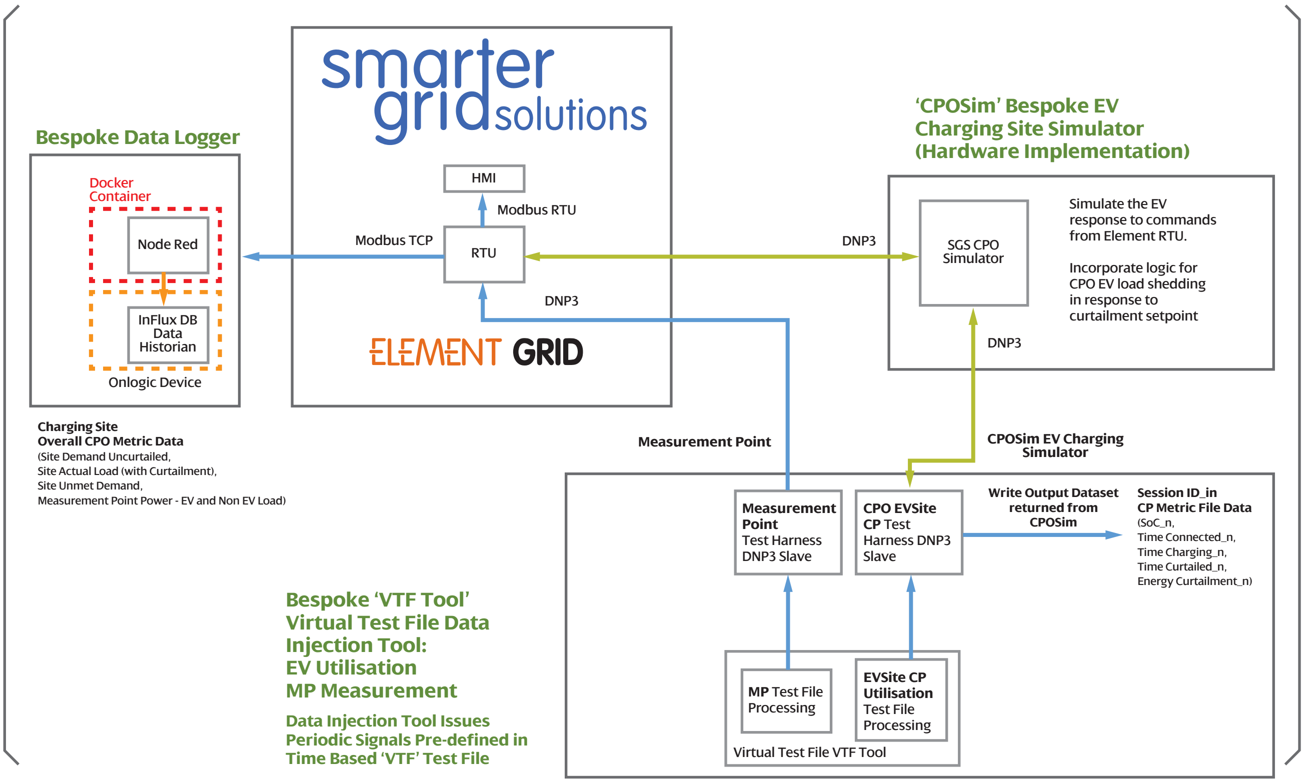

Figure 12: LMC/CLM SCC Scheme Architecture

The *Element Grid* local controller processes the single input Measurement Point dataset of constraint loading, identifying cases of constraint and the necessary demand curtailment setpoint for the CPO site. Under constraint conditions, the *Element Grid* issues a CPO curtailment setpoint to the 'CPOSim' application, which models the demand reduction response of the CPO site to the setpoint. Trial operational data is logged to an archive database for post-trial analysis of SCC operation and CPO charging behaviour.

4.1.5. CMC SCC Virtual Trials Implementation

The implementation architecture for the *Virtual Trials* of CMC SCC schemes, utilising the SGS Strata Grid centralised DERMS platform, is presented in Figure 13. In the *Virtual Trials*, the *Strata Grid* processes the input Measurement Point datasets of constraint loading, identifying cases of constraint across all Measurement Points, as well as the necessary demand curtailment setpoints for all CPO sites under control. Under constraint conditions, the *Strata Grid* issues a CPO demand reduction setpoint to the 'CPOSim' application, which models the demand reduction response of the CPO sites under control. Trial operational data is logged to an archive database stored on the *Strata Grid* for post-trial analysis of SCC operation and CPO charging behaviour.

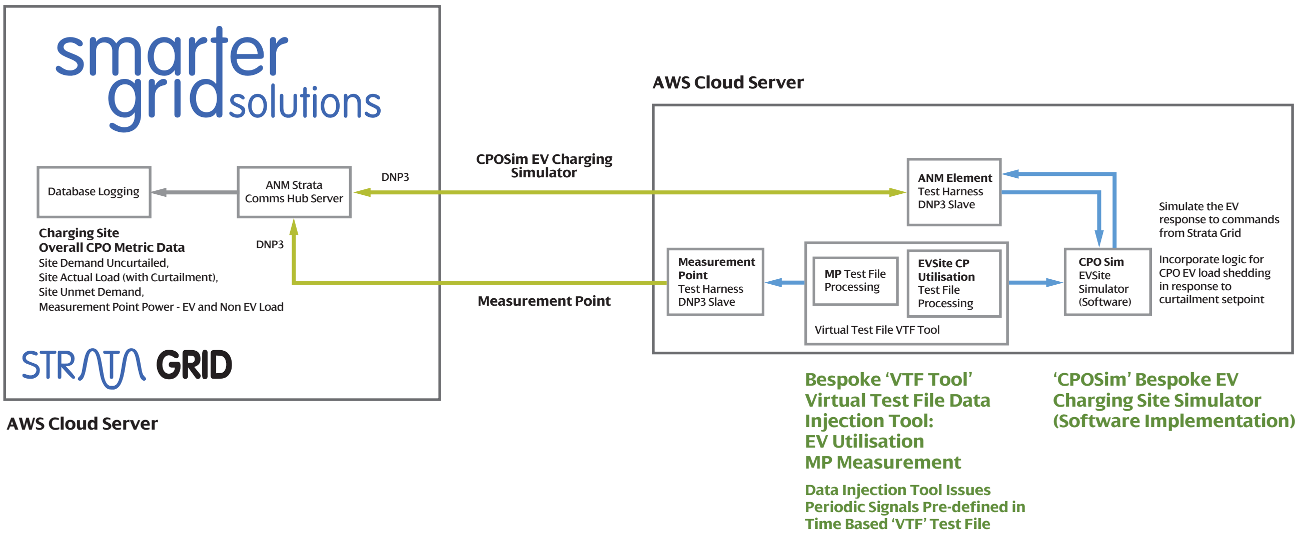

Figure 13: CMC SCC Scheme Architecture

4.2. SCC Solutions Under Trial and Observed Curtailment

The *Virtual Trials* studied a variety of network cases of public charging infrastructure connection: *On-Street Residential*, *Destination* and *En Route*. Each study case simulated network loading behaviour and CPO demand curtailment in real time across one week. The following network cases were explored:

- **Sandbach Destination:** a series of three Destination 500 kVA EV chargepoint sites at car park locations in the town of Sandbach. This network case allows study of CLM, LMC and CMC schemes.
- **Edge Lane En Route:** an En Route 6.3 MVA EV chargepoint site located in Liverpool. This network case allows study of LMC and CLM schemes.
- **Hoole Residential:** a series of five residential 150 kVA EV clusters connecting to LV networks in the Hoole area. This network case allows study of LMC and CMC schemes.
- **Sandbach En Route:** an En Route 7 MVA EV chargepoint site located on the outskirts of Sandbach. This network case allows study of CLM and CMC schemes.

Each of the above network locations has enabled study of multiple scenarios, with varying EV chargepoint utilisation, background demand profiles, and SCCs applied.

4.3. Trial Observations: Comparison of Capacity Release Across Sites and Varying EV Charging Type

Detailed outputs from each of the study scenarios are provided in the document 200713-44C *Virtual Trial Final Report*. The levels of curtailment experienced by EV chargepoint sites vary across the different network cases, EV charging types and scenario configurations. For each of the study sites, summary observations and results are captured below.

Table 3 presents, for each study case, the total percentage of energy that is not be delivered to EVs across planned charge events due to network constraint. This metric indicates the impact of network constraints on chargepoint utilisation and provides a basis for CPOs to understand the value case for choosing a particular SCC.

- **Sandbach Destination – Westfields:** Across all study scenarios for the Westfields EV site, the DNO-Led SCCs present significantly more capacity for EV chargepoints than the Customer-Led equivalent. This is reflected in Table 3, in which the DNO solutions result in lower levels of unmet energy due to curtailment.
- **Edge Lane En Route:** The Customer-Led SCC trial considers management of 350 kW chargepoints (6.3 MW capacity) against the real firm connection limit of 3 MVA. Although it has not been studied, under this case, the site would likely benefit marginally from a DNO-Led SCC. For the DNO-Led SCC trial, real network constraints were modelled, resulting in different thresholds compared to the CLM case. This study shows how significant demand from EV charging (above the CLM limit) results in less than 20% site curtailment.

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- **Hoole Residential – Panton Road:** The case studies for the Hoole Residential EV site is focused on DNO-Led SCC solutions. Across all study scenarios for the Hoole Residential EV site, the LMC SCC presents more capacity for EV chargepoints than the CMC equivalent.
- **Sandbach En Route:** Across all study scenarios for the Sandbach En Route EV site, the DNO-Led SCCs present significantly more capacity for EV chargepoints than the Customer-Led equivalent. This is reflected in Table 3, in which the DNO-Led CMC solution manages real-time capacity whilst avoiding curtailment, and there is insufficient firm capacity for a CLM. With no firm capacity available, the CLM case returns full curtailment; hence, zero energy is delivered to the EVs connected to the charging points.

En Route sites typically experience shorter-duration EV connection and charging sessions, which makes them more sensitive to curtailment events. As a result, EVs charging at En Route sites may not charge to the desired level in the requested connection time during constraint events.

Destination sites witness a smaller number of charging sessions, albeit each session is typically a longer connection duration. This typically provides a sufficient connection period for the charging sessions at Destination sites to complete following short full- or partial-curtailment events.

Residential sites typically have the longest connection and charging times since the chargepoint types are low power (7 kW or 22 kW, typically) and charging often occurs overnight. Charging behaviour is typically from early evening into the overnight period, so deferring charging from the peak demand evening period to the overnight period alleviates curtailment and ensures a full charge event.

Output Metric	Scheme		
	CLM 2030	LMC 2030	CMC 2030
Sandbach Destination (Secondary Sub Constraint)	39.4%	4.1%	Not Applicable
Sandbach Destination (Primary Sub Constraint)	100%[1]	Not Applicable	5.79%
Edge Lane En Route (Secondary Sub Constraint)	10.61%	Not Performed	Not
Edge Lane En Route (Primary Sub Constraint)	Not Performed	16.51%	Not
Hoole Residential	Not Performed	32.74%	38.1%
Sandbach En Route	100%	Not Performed	0%

Table 3: Trial Sites Unmet Energy Metrics

1. 100% undelivered energy reflects a case in which there is no firm headroom, and thus a CLM solution cannot be deployed.

4.4. Trial Observations: Impact of Chargepoint Utilisation

To critically study the effects of the sites under curtailment, scenarios of higher EV chargepoint consumption were modelled to allow comparison with the standard baseline EV consumption profiles. For this study, the number of charging sessions is scaled by a factor of three, resulting in three times the levels of energy consumption.

Initial study of the Edge Lane En Route EV Site used a consumption dataset that, whilst representative of over-installation of chargepoints, did not exceed the firm CLM limit. Thus, chargepoints were replaced with 350 kW rapid chargers, which doubled the site capacity.

The increased consumption scenarios experienced more than a threefold increase in curtailment at the study sites, and more than a 10% increase in average charging durations due to curtailment-based charging delay. This indicates that the limited headroom availability for future growth scenarios would adversely impact sites if reinforcement were not delivered.

Site	Pre-Constraint EV Consumption (MWh)	Unmet Energy (%)
Sandbach Destination – Westfields	4.8	4.1%
	12.9	31.5%
Edge Lane En Route (with Rapid 350 kW Charging Points)	71.2	5.5%
	214.2	16.5%

Table 4: LMC Scenario Result: LMC 2030

4.5. Virtual Trials Learning

This section summarises the areas of practical learning derived from implementation of the SCC scheme architectures, system performance testing of the various physical components of the *Virtual Trials,* and evolution of the functional tests to deliver the desired simulation performance output metrics.

4.5.1. Solution Interfaces

The communications interfaces between the DNO DERMS infrastructure and the CPO charging site Back Office Management System must adopt common standards and allow secure and affordable communications infrastructure. The interface to CPO Back Office Systems may be hardwired or used via the cloud, depending on the infrastructure deployed at the CPO site. Where a hardwired connection is not required or feasible, a remote REST API-based interface must be specified.

4.5.1.1. CPO Sites with Local Control Systems

CPO sites with local, on-site control systems must interface with the SGS *Element Grid* local controller over an appropriate industrial control-standard, ethernet-based, wired protocol such as DNP3 or Modbus TCP. This is the preferred means of communication between the DNO DERMS infrastructure and CPO.

4.5.1.2. CPO Sites Without Local Control Systems

CPO sites without an industrial control-standard protocol interface require an alternative means of communication between ANM DER Management Systems and CPO Back Office Management Systems. The *Virtual Trials* investigated the suitability of existing chargepoint communications standards. However, there is either minimal adoption from CPOs or insufficient remote-control capabilities beyond interfacing with individual chargepoints. Hence, the preferred option for ANM DERMS interfacing to CPO Back Office Management Systems (where a local control system interface is not available) is via a bespoke Charge Project-defined REST API server interface.

The REST API interface must be tailored to meet the specific smart-charging requirements of SCC solutions. The REST API server must be hosted on the CPO Back Office Management System, with the DNO DERMS API client interfacing to the CPO server. The CPO Back Office owners are responsible for implementing the REST API server based on a DNO-supplied specification. Defining a bespoke 'smart charge' endpoint interface provides flexibility, as the signals can be exchanged to meet the needs of SCC solutions.

4.5.2. ANM Control of EV Sites

The *Virtual Trials* provided practical learning from tuning the *Element Grid* and *Strata Grid* DERMS configuration and observing the subsequent impact on the control response between the power flows across network constraints, the DNO DERMS-issued control signals, and the response from the CPO charging site.

Initial studies in the *Virtual Trials* observed continual curtailment/release cycles from the DERMS control system, which reflected that the control configuration parameters were assigned values that did not lead to stable control operations.

It is crucial that the settings for SCC control solutions consider stability and introduce sufficient thresholds, dead-bands, and timers that add stability to the control actions.

The need for control system stability is balanced with a requirement to ensure that sufficiently fast-acting escalating control actions are taken in cases when fast-ramping changes in network loading occur. This is achieved in the *Virtual Trials* through introduction of an emergence 'trip' threshold, which, once exceeded, sends a signal to the CPO to immediately disconnect chargepoints to bring the network into a safe state. Following a trip action, the DERMS infrastructure brings the EVs back into service gradually, maintaining network security.

The DERMS control system configuration must balance the fast-acting control against the need for system stability. It is proposed that initial configurations must be reviewed following a period of operation, allowing refinement of the configuration based upon observed operational behaviours.

5. COST-BENEFIT ANALYSIS

Successful deployment of SCCs requires an understanding of the value case delivered to EV chargepoint developers through the new connection options. The key value case for developers is delivered through reduced time for connection of new developments, allowing connection ahead of the reinforcement that provides customers with a firm, unconstrained connection. The extent of the value delivered is also affected by the interim capacity release through SCCs, with additional capacity released by the more complex DNO-Led SCCs when compared to CLM options.

5.1.1. Impact of Access Significant Code Review on SCC Benefits Case

The Access Significant Code Review (Access-SCR), effective as of 1st April 2023, dictates that new demand connections will not directly pay for upstream reinforcement triggered by their connection (connections up to the High-Cost Cap of £1,720/kVA). This decision reduces the costs and risks for energy asset developers that would have previously had to pay for their contribution to wider network constraints.

Successful deployment of SCCs requires an understanding of the value case delivered to EV chargepoint developers through the new connection options.

The Access-SCR changes benefit EV chargepoint developers and alter the value case of SCCs. Under the previous connection charging regime, SCCs offered customers the opportunity to both accelerate connection timescales (by connecting ahead of reinforcement) and reducing connection cost (by avoiding upstream reinforcement). Following implementation of Access-SCR, EV chargepoint developers will benefit from accelerated connection through an SCC connection, where the SCC connection provides an interim solution ahead of reinforcement. For developers, the value of SCCs as an interim connection solution is significant, as the time to reinforce may be many years for larger sites seeking connection.

5.1.2. CBA Approach

The objective of this Cost-Benefit Analysis (CBA) is to approximate the value to EV charging infrastructure developers because of deploying SCC solutions. The CBA calculates the value to developers of deploying smart solutions and facilitating accelerated connection ahead of standard network reinforcement.

5.1.2.1. Understanding Firm Connection Timescales

For each study case, a 'traditional connection' baseline model establishes the delay in connection due to enabling reinforcement necessary to facilitate a firm customer connection. This provides the traditional connection scenario, highlighting the delay in connection timescales if the EV chargepoint developer waits for a firm connection. For example, if reinforcement work was due for completion in 2025/26, an SCC could accelerate connection for up to a three-year operational window. The traditional connection baseline helps illustrate the total period of 'gained' site operation compared to the base case of waiting for reinforcement and firm connection.

5.1.2.2. Approximating SCC-Enabled Value of Accelerated Connection

The value of SCC deployment is approximated through estimation of the revenue and profit achieved by a CPO in the years of operation facilitated by accelerated grid connection. CPOs derive direct revenue from the kWh energy delivered to connected EVs during charge events. Therefore, revenue can be directly attributed to kWh consumption at the site. It is assumed that a fixed profit margin (5–10%) is derived from each unit of kWh-based revenue.

An SCC may result in occasional curtailment of site import; therefore, a pre-reinforcement consumption value must be used when deriving site revenues. The estimates of site consumption (with SCC-related curtailment) are taken from the Desktop Trial analysis.

5.1.2.3. Cost of SCC

The customer costs for implementing an SCC relate to the enabling infrastructure that facilitates the SCC.

In the case of DNO-Led SCCs, there must be control infrastructure on the DNO side of the customer meter (on-site), additional network measurement infrastructure, and in the case of Centrally Managed Constraint SCCs, centralised control infrastructure.

An SCC may result in occasional curtailment of site import; therefore, a pre-reinforcement consumption value must be used when deriving site revenues.

Following application of the Access-SCR changes to connection charging, only the sole-use assets related to a connection will cost the customer. The cost of monitoring and control infrastructure on the wider network will therefore be socialised across all customers. The connecting customer will only pay for the control infrastructure deployed on the DNO side of the customer meter on-site.

In the case of Customer-Led SCCs, the customer must deploy control infrastructure behind the meter to coordinate consumption across all EV chargepoints.

These customer costs are included in the Cost-Benefit Evaluation model, representing the SCC costs that must be offset by profit gains from accelerated network connection.

5.1.2.4. Cost-Benefit Evaluation

The Cost-Benefit Evaluation assesses the value of accelerated connection (additional profit from earlier site operation) and offsets this against the cost of SCC implementation borne by the customer.

The value of accelerated connection is derived through the improvement on connection timescales when compared to the firm equivalent.

Once the Costs and Revenues associated with SCC implementation are understood on an annual basis, it is feasible to approximate the point at which the additional profits exceed the underlying cost of the SCC. This point (in months or years) is the required duration of SCC operation prior to reinforcement that triggers profit for the development and signals a net benefit to SCC implementation.

5.1.2.1. Cost-Benefit Analysis Observations

The CBA derives several observations that indicate the value case of SCCs and some of the sensitivities that cause the impact of SCCs to vary between deployments.

The analysis has identified that, where sufficient headroom is available, deployment of Customer-Led SCCs has a shorter payback, as the SCC infrastructure costs are predicted to be lower than the more complex DNO-Led SCCs, as shown in Figure 14. However, with DNO-Led SCCs presenting greater capacity release, DNO-Led SCCs eventually overtake Customer-Led SCCs in value. This is shown in the Westfield and CBC Offices cases, in which DNO-Led SCCs deliver higher longer-term profits. The EV chargepoint developer must assess whether this trade-off between the two SCC types occurs prior to the reinforcement that provides a firm connection.

Sandbach is predicted to have significant capacity congestion at the primary substations – hence the justification for transformer upgrades. Despite this recommendation, there is a clear value case for DNO-Led SCCs to enable profitable operation ahead of reinforcement. Insufficient firm headroom at the primary transformers eliminates the possibility of CLM deployment, as there is no Authorised Supply Capacity (ASC) for the EV chargepoint site to operate within, as shown in Figure 15.

In all 5% and 10% profit cases of DNO-Led SCC solutions, the developer receives value for connecting ahead of the three-year reinforcement timescale. Where sites have higher utilisation, the value to the developer increases and the payback period decreases.

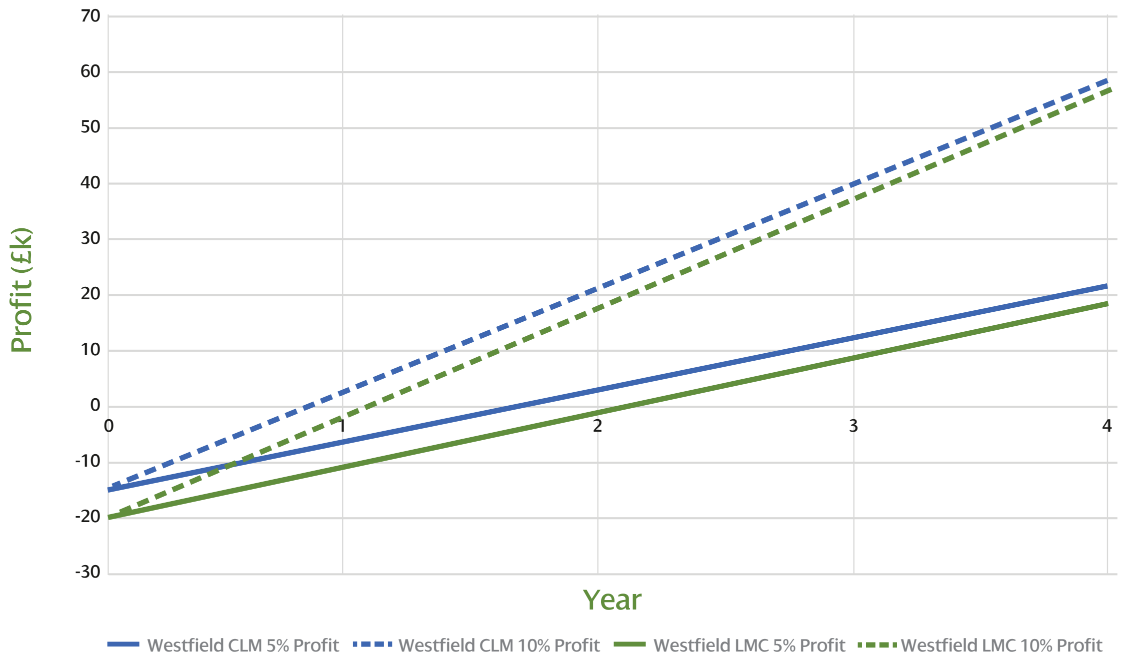

Figure 14: Payback Period for Westfield's EV Chargepoint for CLM and LMC SCCs (Distribution Substation Constraint)

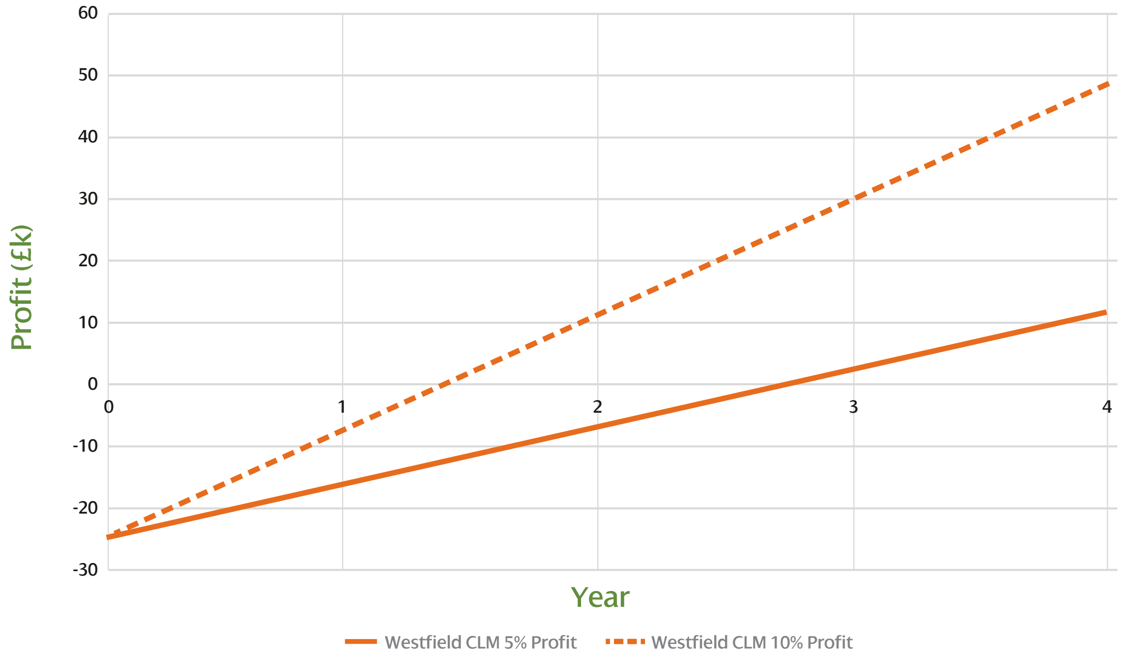

Figure 15: Payback Period for Westfield's EV Chargepoint for CMC SCCs (Primary Substation Constraint)

6. DNO PROCESS AND WIDER INDUSTRY POLICY REVIEW

A review of relevant DNO processes has identified the updates to the customer connection process that will facilitate SCC implementation as a business-as-usual solution. A review of wider industry standards has assessed the requirement for updating and refinement to incorporate SCC implementation. A review of wider industry standards has identified that, with SCC as a demand-side flexibility function, there is little requirement for updating of standards to facilitate SCC roll-out.

6.1. Integration of SCCs to the Customer Connection Process

As network congestion is forecasted to grow with the accelerated uptake of electric vehicles and heat pumps, SCCs are a growing need as an interim solution ahead of network reinforcement. Flexible Connections are already part of the existing DNO connection process for generator customers. Therefore, there is precedent and a reference point for introduction of SCCs as a connection solution for EV chargepoint developers.

Figure 16 outlines the steps required to achieve an SCC. The following sections provide commentary on the key DNO and EV *Chargepoint Developer* actions in each stage of the process.

Conventional Firm Connection Application

EV Chargepoint Developer Action: the EV Chargepoint Developer completes the site design activities, identifying the site boundary and requirements for site-import capacity. The new demand connection application is submitted to the DNO.

DNO Action: the DNO Planning Engineer initially delivers a conventional firm connection design for the proposed demand site. The firm connection design identifies a suitable Point of Connection (PoC) on the existing DNO network, the new infrastructure required between the customer site and the PoC, and the existing infrastructure that must be reinforced to enable the new connection.

The DNO Planning Engineer identifies the connection costs that must be met by the EV Chargepoint Developer to facilitate the new connection. The DNO Planning Engineer estimates the timescales for completion of all enabling works, including any necessary reinforcement, establishing an estimated energisation date for the new connection. The details of the connection design, enabling works, costs, and timescales for connection are documented in a Connection Offer issued to the EV chargepoint.

Initial Feasibility Consideration of SCCs

EV Chargepoint Developer Action: If the *firm* connection timescales are deemed excessive, the EV Chargepoint Developer may express a wish to explore SCC as an alternative to accelerate connection timescales. The EV Chargepoint Developer issues an SCC request to the DNO.

The DNO Planning Engineer identifies the connection costs that must be met by the EV Chargepoint Developer to facilitate the new connection.

DNO Action: The DNO Planning Engineer identifies whether any firm capacity below the initial desired site capacity can be facilitated. If so, the DNO Planning Engineer presents the alternative ASC as an option for a Customer-Led SCC.

The DNO Planning Engineer identifies the enabling reinforcement that is causing the extended connection timescale and whether an SCC would allow flexible connection whilst awaiting the enabling reinforcement. If an SCC is a feasible option to manage the constraint in interim timescales, the DNO Planning Engineer informs the EV Chargepoint Developer that an SCC is feasible and can be explored further. As of January 2023, any design work related to the SCC would sit outside the Standard Licence Conditions' (SLC) Guaranteed timescales[2] to issue a quotation, unless the DNO had a clear business case, as this goes beyond the standard recognised connection offering. Following implementation of the Access Significant Code Review (SCR), SCCs may qualify as *Curtailable Connections* and therefore require study and specification within the SLC Guaranteed timescales.

2. Standard Licence Conditions 15A Guidance Document 2010. Available at: https://www.ofgem.gov.uk/publications/standard-licence-condition-15a-guidance-document

SCC Constraint Study and Updated Connection Offer

EV Chargepoint Developer Action: If the EV Chargepoint Developer wishes to progress an SCC, the DNO is notified as such, specifying whether a Customer-Led SCC or DNO-Led SCC is to be offered.

DNO Action: The DNO Planning Engineer identifies the alternative interim connection design required for commissioning of the site and flexible management of network constraints until the enabling reinforcement is completed and the site achieves a firm connection.

If a DNO-Led SCC is to be explored, the DNO Planning Engineer performs a Curtailment Study to estimate the level of curtailment the site will experience when managing grid constraints. The Curtailment Study approximates the frequency and severity of grid constraints over a typical year of operation, identifying the required reduction in import capacity for the customer site on a half-hourly basis across the study year.

If a DNO-Led SCC is to be explored, the DNO Planning Engineer performs a Curtailment Study to estimate the level of curtailment the site will experience when managing grid constraints.

The updated connection design, commissioning timescales, and curtailment estimate are all documented in an updated Connection Offer, which details the cost and timescales for SCC-based connection.

EV Chargepoint Developer Action: At this point, the EV Chargepoint Developer may wish to perform further analysis on the output from the DNO curtailment assessment. This would involve aligning the anticipated consumption profile of the EV site against the post-constraint import envelope provided by the DNO curtailment assessment study. The EV Chargepoint Developer must decide to accept or reject the SCC Connection Offer.

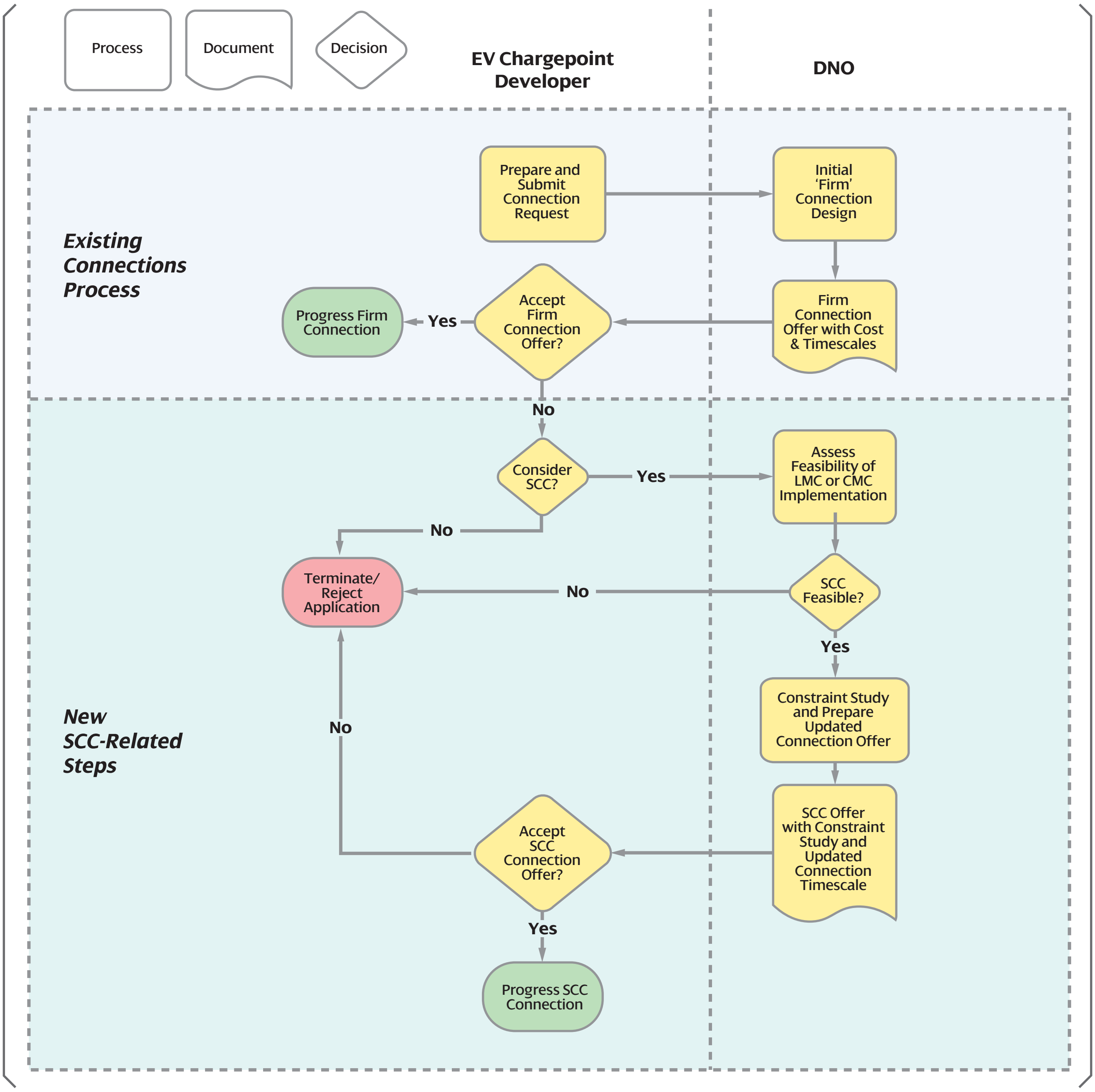

Figure 16: Overview of SCC Connections Process

6.2. SCC Impacts Wider Industry Standards and Policies

Industry-wide policies relevant to the introduction of SCCs have been identified. These are:

- Engineering Recommendation P2, Issue 7 (P2/7) (Energy Networks Association, 2019)
- Engineering Recommendation G100, Issue 2 (Energy Networks Association, 2022)

Both are explored in the following sections, highlighting the areas of relevance for SCCs.

6.2.1. Engineering Recommendation P2, Issue 7 (P2/7)

Engineering Recommendation (ER) P2/7 defines the Security of Supply standard. The policy recommends the levels of grid infrastructure redundancy that must be in place for supplying increasing increments of demand.

Implementation of SCCs is relevant for P2/7 as it introduces a new form of flexible, manageable demand to the system. Flexible demand is reflected through Demand-Side Response (DSR) in P2/7, which assigns this type of demand a security contribution. The supporting documentation (Energy Networks Association, 2019) states that when DSR is specified in the Connection Offer as a non-firm connection, *'activation of the DSR scheme is equivalent to restoration of demand'*. The implication is that non-firm demand need not contribute towards the calculation of group demand if, under network constraint conditions, it can be curtailed.

Therefore, SCCs fall under the description of non-firm connections in the context of P2/7, which allows connection beyond the firm capacity defined by the standard, recognising that the demand level will be kept within firm limits under constraint and contingency conditions.

No revisions of this document are required in relation to introduction of SCCs.

6.2.2. Engineering Recommendation G100, Issue 2 (G100/2)

Engineering Recommendation G100, Issue 2 details the 'Technical Requirements for Customers' Export and Import Limitation Schemes'. Previously dedicated to solely export limitation schemes, Issue 2 now also includes requirements for import limitation schemes.

Meeting G100 requirements is a critical feature of any customer control system deployed as a CLM Customer-Led SCC solution. The CLM solution must manage a behind-the-meter load behind a lower-capacity grid connection, and thus falls under the jurisdiction of G100.

In the case of CLM SCCs, the customer must deploy equipment that meets the requirements as specified by G100, Issue 2.

In the case of DNO-Led SCCs, in which real-time constraint management is deployed, the connection arrangements can be described as a *'flexible connection'* (G100 terminology). In these cases, there is no explicit requirement for a customer's behind-the-meter controller to meet G100 requirements, but it may be specified. DNO-Led SCCs deploy failsafe and escalating control actions as features of the DNO control infrastructure, which supersede any requirement for behind-the-meter alignment with G100.

In the case of DNO-Led SCCs (Locally Managed Constraint and Centrally Managed Constraint), there is no requirement for customer equipment to meet the G100, Issue 2 requirements.

7. CURTAILMENT ASSESSMENT BEST PRACTICE

Curtailment studies of SCCs allow both DNO Engineers and CPOs to approximate the restriction in capacity that EV chargepoint sites experience under the smart-charging alternative to reinforcement. However, implementation of SCC curtailment studies requires changes to the process followed by DNO Engineers, as well as the supporting design documents. The following sections present the overall objectives, high-level implementation methodology, and desired outputs from SCC curtailment studies.

7.1. Assessment Objectives

Whilst SCCs may result in occasional curtailment of EV chargepoint energy consumption, typical import profiles of EV chargepoints do not reflect 100% utilisation. This, alongside the diversity introduced when several chargepoints are available at a single site, mean an EV may only have rare occasions of import curtailment. This variable capacity needs to be quantified to give developers confidence in financing and operating new EV charging sites.

The overall objective of estimating likely curtailment of EV chargepoint import is consistent across both the DNO Planning Engineer (who performs the study) and the EV CPO. However, the motivations are distinct between both parties:

- The DNO Planning Engineer must perform the study to evaluate the network impacts of a DNO-Led SCC: how often the network nears constraint conditions and the frequency and severity of EV control actions to avoid constraints.
- DNOs will be required to give a fixed maximum curtailment value, which, if exceeded, will result in compensation from the DNO to the EV operator as laid out in the Significant Code Review.
- The EV CPO must indicate curtailment to enable evaluation of commercial impacts and inform the decision to proceed with an SCC or consider the *firm* connection equivalent.

7.2. Curtailment Study Data Requirements

DNO EV curtailment studies may require different study types depending on the connection site complexity and desired PoC to the network. For simple, DNO-Led SCC studies, a spreadsheet-based assessment may be sufficient to give an indication of curtailment. However, for sites where more complex DNO-Led SCCs must be applied, a full load-flow simulation of the wider network may be required. Complex DNO-Led SCC cases include those for which the EV Point of Connection is on a meshed network, multiple constraints exist, or multiple EV charging sites are operating as a coordinated scheme.

In the case of DNO-Led SCCs, the DNO requires the following details to establish a comprehensive Curtailment Study:

- A representative network model allows the constraint locations to be identified. Constraint locations are the network assets, such as a feeder or transformer, that are at risk of overload due to the new EV chargepoint connection.
- Capacity limits must be identified at each constraint location.
- Sensitivity factors must be derived such that power flows from EV charging sites are correctly apportioned to the constrained locations on the network.
- Half-hourly time-series profiles of network demand, or pre-EV power flow across constraint locations, are needed as input to the Curtailment Study.
- Where multiple EV chargepoint sites exist, half-hourly time-series profiles are needed of anticipated EV import at each site.

7.3. Curtailment Study Methodology

The SCC Curtailment Study applies the input information and datasets described in Section 7.2 and follows a methodology like that applied to flexible generator export constraint management cases.

The Curtailment Study methodology can take the form of a spreadsheet-based analysis or utilise a load-flow simulation. The steps in these methods are shown in Figure 17 and Figure 18, respectively. The figures show the curtailment process flow required at each timestep (t) until the iterative loop reaches the full simulation period (T).

The spreadsheet-based analysis method is the less computationally intensive process. However, it is limited to a simplified approximation of network loading conditions and SCC-based actions. In cases in which achieving a sufficiently accurate approximation of network loading is impossible through spreadsheet-based study, load-flow simulation must be performed to estimate network loading levels. Load-flow estimation is recommended in cases consisting of:

- Multiple network constraints under SCC management: where power flow must be approximated across more than one network location
- Meshed/interconnected network topology: where the approximation of power flow on network assets is not a linear calculation and not sufficiently accurate through spreadsheet-based calculation
- Voltage-drop constraints: where the SCC is required to manage undervoltage conditions and the voltage profile must be approximated

In the case of a load flow-based study, automation scripting must be used to run time-series sequential studies and simulate the SCC control system operation, in order to observe the overloads and undervoltage at constraint locations and apply the necessary curtailment actions. In load-flow simulation packages such as IPSA or PowerFactory (both used by SPEN), this can be achieved through use of automation scripts in the Python programming language.

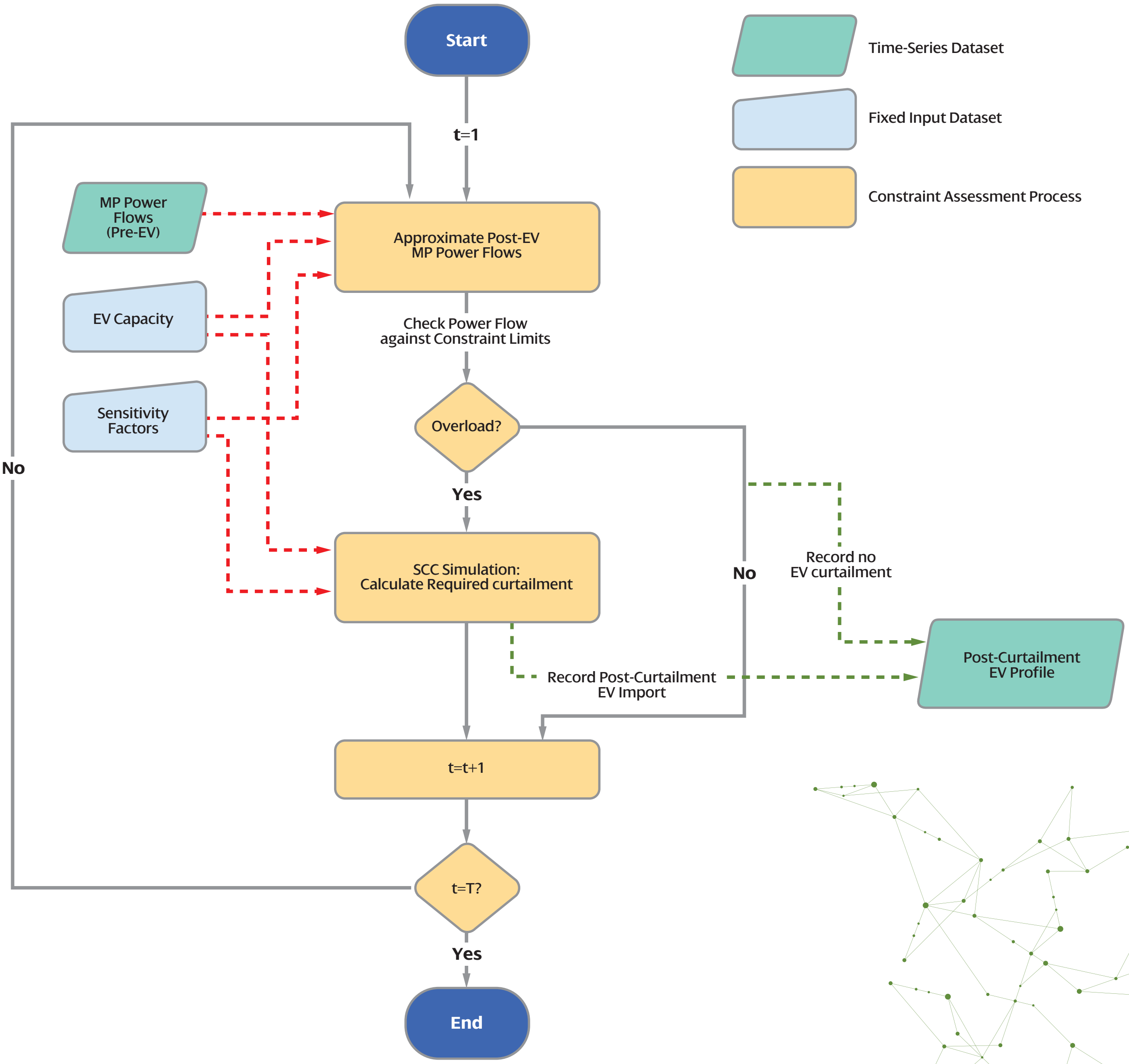

Figure 17: Spreadsheet-Based Curtailment Methodology

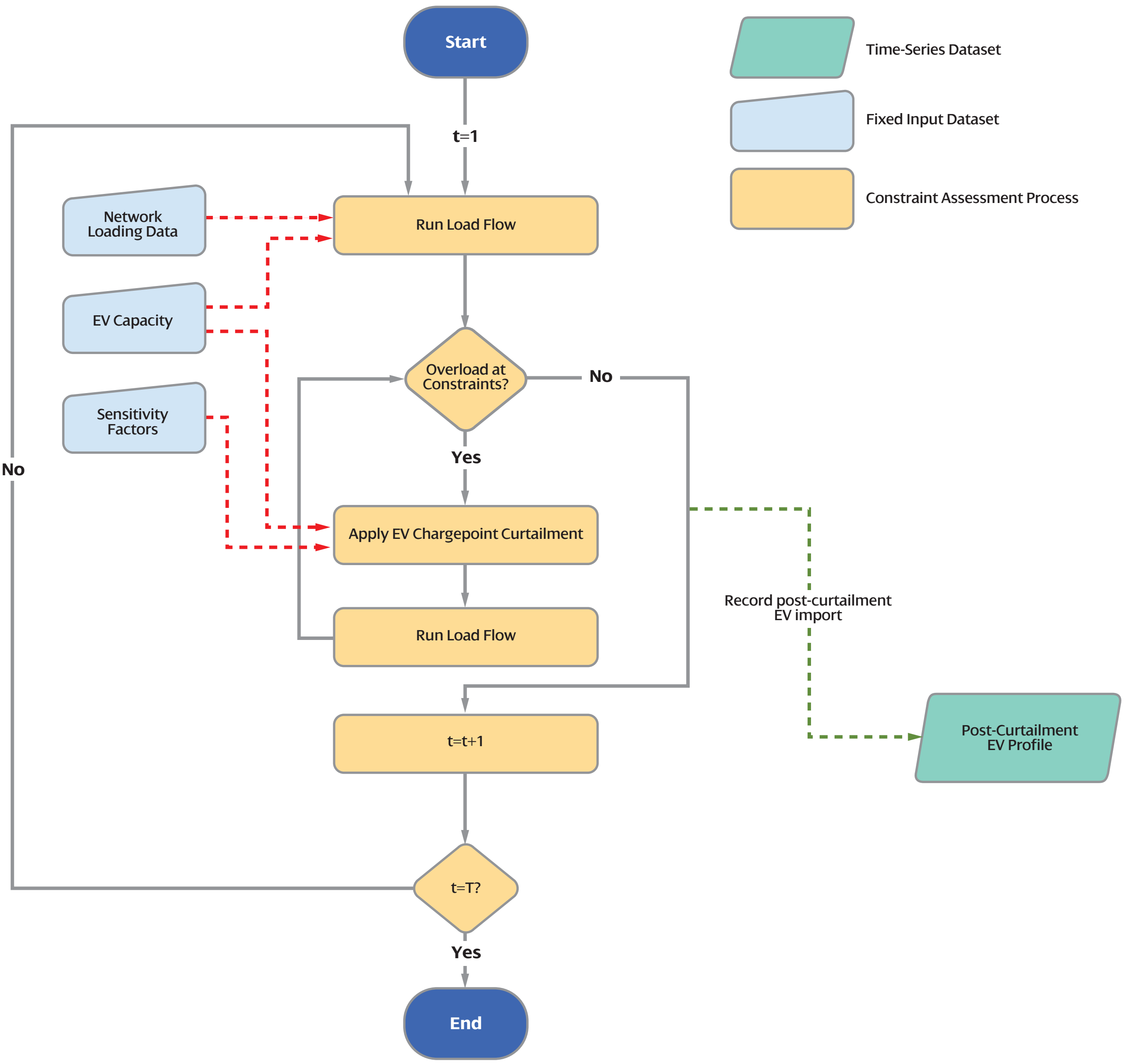

Figure 18: Load-Flow Simulation Methodology

7.4. Curtailment Study Outputs

Curtailment studies require an understanding of the local network, the available capacity, and historical datasets, and therefore must be delivered in-house by DNO Engineers as part of the connection process. DNO design engineers do not typically undertake time-series studies, only worst-case peak demand studies to deliver Connection Offers within the Guaranteed Standards timescales. It is therefore expected that these studies will be performed within the normal Guaranteed Standards timescales.

Outputs of the study are delivered to the customer prior to making decisions on progressing with a connection. DNO design/planning engineers are expected to perform the studies once connection design is completed (for example, identified site Point of Connection, rated capacity of development).

Curtailment studies provide a range of observation metrics as outputs. For each chargepoint, the studies quantify:

- The half-hourly curtailment profile of the site over a full year
- The percentage (%) of time that the site is unconstrained vs. constrained
- The instantaneous peak curtailment observed, measured in kW/MW
- The percentage (%) of energy import availability when constrained (vs. the 100% unconstrained equivalent)

The graphical presentation of Curtailment Study outputs is helpful in providing appropriate data visualisation for interpretation of study findings. Examples of graphical outputs are presented in Figure 19 to Figure 21, which provide a monthly breakdown of curtailment across a year in both energy and percentage values. This helps developers understand how the network capacity headroom varies and seasonal demand characteristics impact charging across the year.

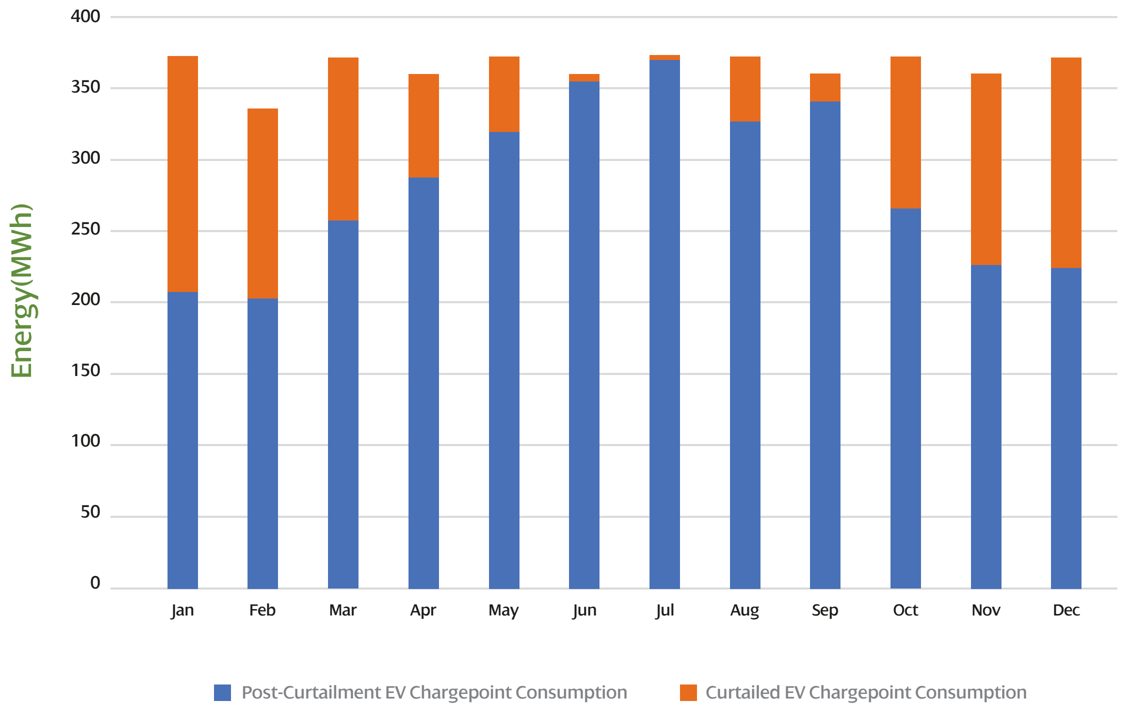

Figure 19: Monthly Breakdown of Constraint Impact (MWh)

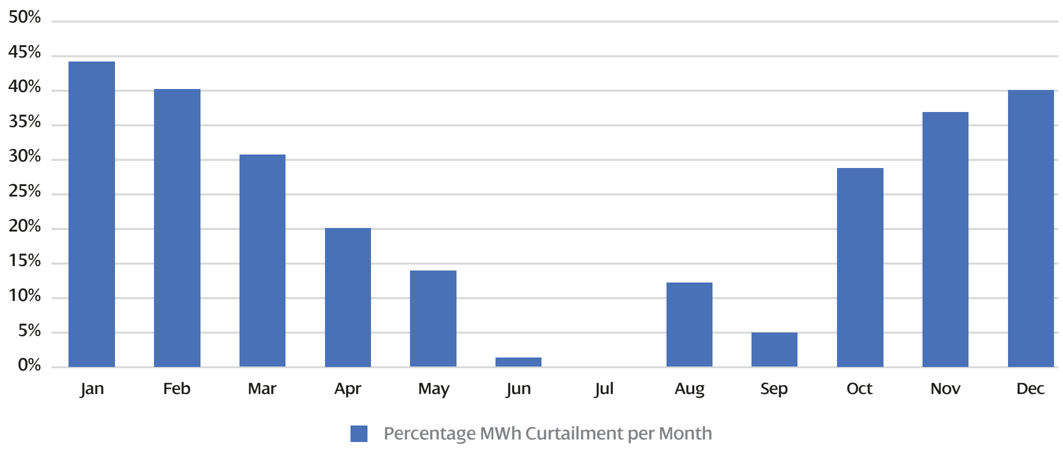

Figure 20: Monthly Breakdown of Constraint Impact (Energy Unavailability)

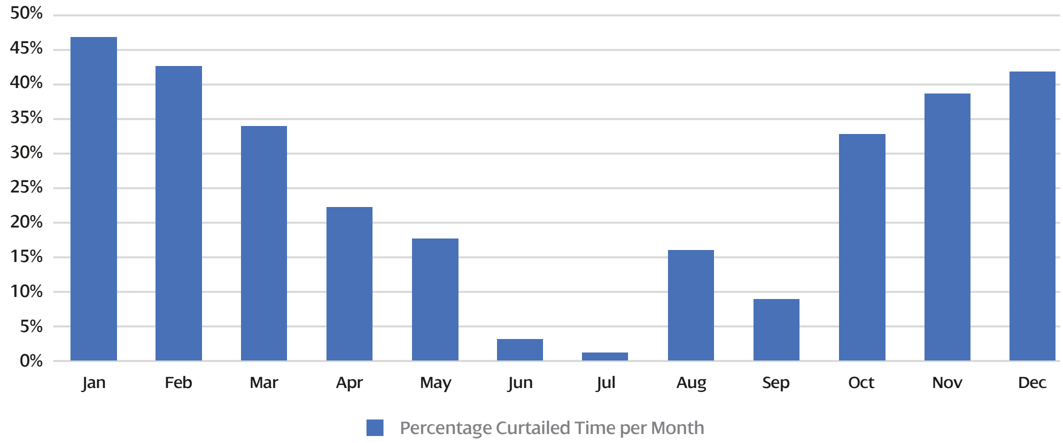

Figure 21: Monthly Breakdown of Constraint Impact (Time Unavailability)

Tabular metrics should also be presented for each case, as the example shows in Table 5. These metrics enable EV developers to determine the impact on charging revenue and charging disruption.

The example metrics for the same Destination charging site are shown in Table 5 and interpreted as follows:

- The site experiences an estimated **Site Curtailment** of 994 MWh across a year. This is lost from the uncurtailed equivalent available site import of 4,380 MWh, and is a 22.7% reduction. This reflects a **Percentage Energy Import Available** of 77.3%.
- The site is subject to constraint, and is thus experiencing some form of curtailment, across 2,204 hours during the year. This results in a **Constraint Time Per Year** of 25.2%.
- The estimated maximum (worst-case) reduction in site import is 0.5 MW, which means full curtailment of site import under the worst-case condition.

Output Metric	Value
Site Curtailment	994 MWh (22.7%)
Percentage Constraint Time Per Year	25.2%
Peak Observed Curtailment	0.5 MW
Percentage Energy Import Available	77.3%

Table 5: Sample Output Metrics for EV Curtailment