Lessons Learned Report

Project deliverable D3.4

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SCALE Introduction

SCALE (Smart Charging Alignment for Europe) is a three-year Horizon Europe project that explores and tests smart charging solutions for electric vehicles. It aims to advance smart charging and Vehicle-2-Grid (V2G) ecosystems to shape a new energy system wherein the flexibility of EV batteries' is harnessed. The project will test and validate a variety of smart charging and V2X solutions and services in 13 use cases in real-life demonstrations in 7 European contexts: Oslo (NO), Rotterdam/Utrecht (NL), Eindhoven (NL), Toulouse (FR), Budapest/Debrecen (HU) and Gothenburg (SE). Going further, project results, best practices, and lessons learned will be shared across EU cities, regions, and relevant e-mobility stakeholders. SCALE aims to create a system blueprint for user-centric smart charging and V2X for European cities and regions.

SCALE's consortium comprises 29 cutting-edge European e-mobility actors covering the entire smart charging and V2X value chain (equipment and charging manufacturers, flexibility service providers, research and knowledge partners, public authorities, consumer associations, etc.) It is led by ElaadNL, one of the world's leading knowledge and innovation centres in smart charging and charging infrastructure.

Purpose of the deliverable

The Lessons learned report (SCALE deliverable 3.4) is the fourth report of Work Package 3, led by FIER Sustainable Mobility. It builds on the earlier SCALE work package 3 Use case setup report (D3.1) (Christiaens et al., 2023), the use case evaluation report (D3.2) (Christiaens et al, . 2025) and Business Case analysis (D3.3) (Csukas et al, 2025) as well the work done in both Multi-actor Smart Charging & V2X System Architecture (D1.4) (Geerts et al., 2024) and Analysis of hard- and software requirements (D1.5) (Meersmans et al., 2023). The report evaluates lessons learned and from the use cases and innovation clusters underpinning SCALE according to a uniform methodology, extracting overarching conclusions to present on behalf of all use case leaders and SCALE.

Consistent with the D3.1 and D3.2 assessments of the lessons learned are done following the methodology introduced in the SCALE Stakeholder analysis (D1.2) (Langenhuizen et al., 2022), where Industry Value Chains were introduced. For each lessons learned, the use cases and the innovations clusters are reviewed to evaluate the key findings on the most relevant and actionable abstraction layer.

List of abbreviations and acronyms

Acronym	Meaning
AC	Alternating Current
AFIR	Alternative Fuels Infrastructure Regulation
aFRR	Automatic Frequency Restoration Reserve
BEMS	Building Energy Management System
BESS	Battery Energy Storage System
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CCS	Combined Charging System
CP	Charge Point
CPMS	Charging Point Management System
CPO	Charge Point Operator
DC	Direct Current
DSO	Distribution System Operator
EAFO	European Alternative Fuels Observatory
EM	Energy Manager
EMS	Energy Management System
eMSP	e-Mobility Service Provider
EPBD	Energy Performance of Buildings Directive
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserves
FSP	Flexibility Service Provider

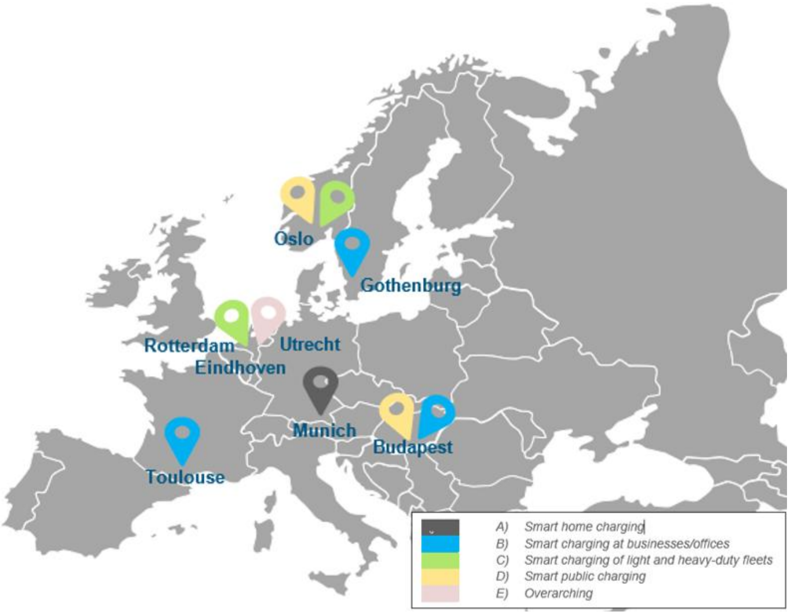
GDPR	General Data Protection Regulation
IC	Innovation Cluster
HEMS	Home Energy Management System
LDV	Light duty vehicle
OCPI	Open Charge Point Interface protocol
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
PV	Photovoltaic
SCALE	Smart Charging Alignment for Europe
SoC	State-of-Charge
ToU	Time-of-Use
TSO	Transmission System Operator
V1G	Vehicle-One-Grid
V2B	Vehicle-to-Business
V2D	Vehicle-to-Depot
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2P	Vehicle-to-Public
V2X	Vehicle-to-Everything

Report executive summary

Keywords

Electric vehicles, smart charging, Vehicle-to-Anything, flexibility markets, interoperability, Use cases, Control topology, System Architecture

Summary



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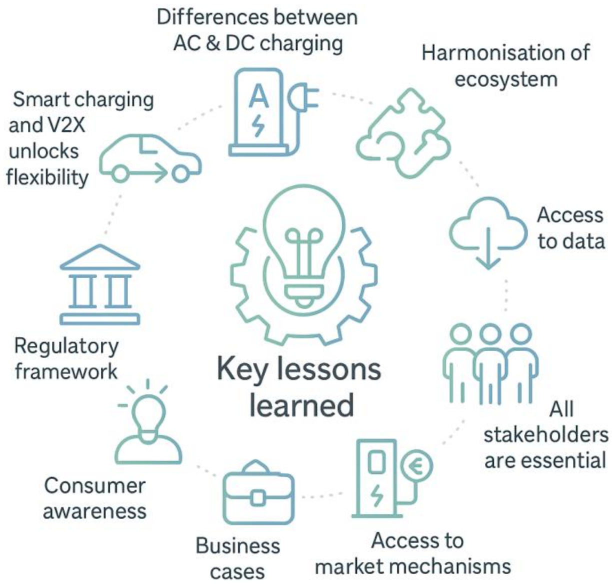
The *Lessons learned report* (SCALE deliverable 3.4) is the fourth and final report of the work done on the SCALE Use cases, and builds forth on the earlier SCALE work package 3 deliverables (D3.1 – D3.3). It provides an evaluation and key lessons learned per category of use cases, the innovation clusters. These are the (A) Smart home charging, (B) Smart charging at businesses/offices, (C) Smart charging of light and heavy-duty fleets, and (D) Smart public charging.

Consistent with the other deliverables in this work package, this report adopts the methodology and key concepts from the Industry Value Chains and System Architecture from other SCALE work. Looking at the Industry Value Chains 4 categories are distinguished; Charging infrastructure, Mobility services, Charging services and Energy services. From work done on system architecture the control topologies and communication protocols are introduced.

In the last three years each use case followed three phases: preparation & set-up, execution & monitoring, and quantitative and qualitative data gathering. As we reach the end of phase 3 it is now possible to assess, extrapolate and cross-examine the findings from the different use cases and this was largely carried out in D3.2 Use case evaluation (Christiaens et al., 2025). Repeating the same exercise on an innovation cluster level allows us to assess findings on yet a higher abstraction level.

The learnings on the individual use cases are provided in 9 key topics that are visible in the figure below.



The key conclusions that we can draw from these learnings are summarised in relation to the implementation and further upscaling of smart and bidirectional charging solutions.

Smarter charging

Advanced smart charging solutions, as piloted in the SCALE use cases, can unlock significantly more flexibility compared to the smart charging that is mainstream today. In order to untap this potential, these technologies need to become mainstream. From our SCALE learnings, key topics for scaling up towards advanced smart charging solutions can be summarised into two key topics:

(a) the business case; getting access to market mechanisms so that advanced smart charging aligns with the dynamic needs in the electricity system and results in revenues so that the end user (and other stakeholders in the value chain) are incentivized to participate. It is important to realise that there is a lot of uncertainty on the business case around smart charging. High degree of variance of pricing in existing markets and differences between countries adds to this complexity.

(b) the harmonisation in the ecosystem to allow the highly needed transfer of data and the control of assets. In the heart of the e-mobility domain this is primarily about the adoption and maturity of ISO15118, OCPP 2.X. The hardware of the equipment (BEVs and recharging points) need to be capable to support these standards. Retrofitting existing equipment is often not possible. Harmonisation in the energy domain can further add to the flexibility potential. Integrations to access smart meters, (H/B)EMS, energy storage systems, flexibility markets are currently often tailor made solutions. This makes implementations complex and costly resulting in barriers in many use cases to implement.

Bidirectional charging

Bidirectional charging can be seen as an add-on to advanced smart charging. It introduces more potential to offer flexibility in the electricity system, but is also faced with some additional challenges. These are;

(a) The business case; further to the above it is important to remove regulatory barriers like double taxation and feed-in tariffs that exist in some countries. These are prerequisites to a positive business case.
(b) Further to the harmonisation in the e-mobility ecosystem it's important that both vehicles and recharging points are hardware capable for bidirectional charging, support the latest standards (ISO15118-20, OCPP 2.1) and are software enabled to allow bidirectional charging. With the latter often not possible due to immaturities around interoperability, the possibility to remotely update to the latest protocols and enable bidirectional charging is probably the best viable option for these manufacturers today.
(c) Network code complexity for bidirectional charging present challenges for the implementation of V2X technologies. These challenges are primarily related to AC charging where typically the combination of the CP and EV needs to comply with these codes. As there are numerous configurations between EV and CP possible and since EVs can cross borders with implications on which national grid codes to comply to, there is a clear need to revisit the regulatory framework to allow V2X on full scale.

Knowing the complexity of implementing smart and bidirectional charging today, there are differences in this complexity from cluster to cluster. The table below provides an overview of these differences.

Continued efforts to upscale

At the present level of maturity on advanced smart charging and bidirectional charging it is clear that we're far from a fully open and interoperable ecosystem. There is a clear need to continue to upscale with implementations to further enhance the maturity level. By different implementations across a variety of use cases the different stakeholders can all make their contributions and progress together to overcome the addressed challenges of today.

From SCALE it is apparent that there are important differences between the innovation clusters. In certain clusters, commercially viable concepts on smart, but also on bidirectional charging already exist today. In the table below an overview of today's key challenges faced by smart and bidirectional charging are provided in relation to the 4 innovation clusters.

Innovation Cluster	Immature interoperability	Stakeholder complexity	Network code complexity (V2X)
A: Smart home charging	+	+	+
B: Smart charging at businesses/ offices	-	-	- -
C: Smart charging of light and HD fleets	0	+	+
D: Smart public charging	- -	- -	- -

(++) not an issue <---> significant issue (- -)

Important to mention here is that all the key challenges are related to both smart - and bidirectional charging with the exception of the "network code complexity" which is a specific challenge on bidirectional charging. What can be concluded from the table is that barriers to implement advanced smart charging solutions in business and offices (IC-B) and for public charging (IC-D) faces higher challenges. It's also visible that there are "low hanging fruit" clusters such as home charging (IC-A) and to a lesser degree charging of light and heavy-duty fleets. This is also visible in some of the commercial solutions offered by OEMs today. These solutions are often closed setups with no or limited variance between the type of EV, CP and EMS to avoid interoperability issues. Nevertheless they have adopted the open standards, contribute to the learnings of its use and therefore to further mature it. Also these “low hanging fruit” clusters can serve as a stepping stone to learn from and improve the business cases around the various use cases in these innovations clusters. This is also likely to result in more momentum for the less progressive stakeholders to advance their efforts and take part in the smart charging and V2X ecosystem. Examples of these stakeholders include manufacturers of CPs or BEVs whom currently do not see a clear market for advanced smart charging and bidirectional charging.

For the innovation clusters B and D it is apparent that there are showstoppers hindering the commercial roll out today. More experimental pilots are needed or solutions have to be investigated in specific use cases with shared electric cars like in SCALE. Conducting those pilots creates momentum for more manufacturers and other stakeholders aim their efforts at maturing their technologies and unlock use cases in these innovations clusters.

For more detail on the methodological framework, key learnings, and the conclusions in full, we refer to the complete report in which these are provided.

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1. General Introduction to the report

SCALE aims to advance EV charging technology and facilitate the mass market uptake of smart charging and Vehicle-to-Everything (V2X) technology. To do this, 13 use cases are executed over 4 innovation clusters: (A) Smart home charging, (B) Smart charging at businesses/offices, (C) Smart charging of light and heavy-duty fleets, and (D) Smart public charging. In all 4 innovation clusters, smart charging and V2X technologies will be tested.

In SCALE, the process of setting up the use cases was spearheaded by the local use case leaders (see figure 1.) who were in turn cooperating with the other SCALE partners who are providing their expertise, services and hardware. Within SCALE, these activities were carried out in work package 3, led by FIER Sustainable Mobility. The cooperation between partners within SCALE is regular and sustained over the project: a necessary approach as most use cases are dependent on many different SCALE partners and other SCALE work packages.

Figure 1. Use case leaders and work package leader logos

To support this process, monthly meetings were attended by all use case leaders. In these meetings, the progress of the set-ups, encountered bottlenecks, available solutions, and other relevant aspects were discussed. With work package overarching activities being addressed in follow-up meetings as needed. Besides the WP3 structure, there were many bilateral exchanges among the use case leaders and other SCALE partners to further support the development of individual use cases and ensure that all objectives were attained.

In the process of setting up and executing the use cases many findings came to light. Next to providing the key lessons from the SCALE use cases, the Lessons learned report (D3.4) will adopt a specific focus on how these learnings relate to the innovation clusters. This results in the conclusions on how to upscale smart and bidirectional charging across these 4 clusters.

The report is composed of 4 parts, beginning with the overall context of the project, and the applied conceptual framework employed throughout WP3 and most of SCALE and as described in chapter 2. Chapter 3 provides an overview of the key lessons learned on the use cases as well as on the innovation cluster level. In practice this means identifying key findings from the use cases and comparing how these weigh up against each other on an innovation cluster level. The report concludes with chapter 4 which reflects on this report's findings at the highest level of abstraction.

2. Methodology and key concepts

Following the methodology introduced in the SCALE *Stakeholder analysis (D1.2)* (Langenhuizen et al., 2022), where Industry Value Chains were introduced. The four identified industry value chains are defined as Charging infrastructure, Mobility services, Charging services and Energy services as visualised in Figure 2. The benefits of organising the smart charging and vehicle-to-everything (V2X) ecosystem into different industry value chains are to analyse and understand different market models and processes within the ecosystem.

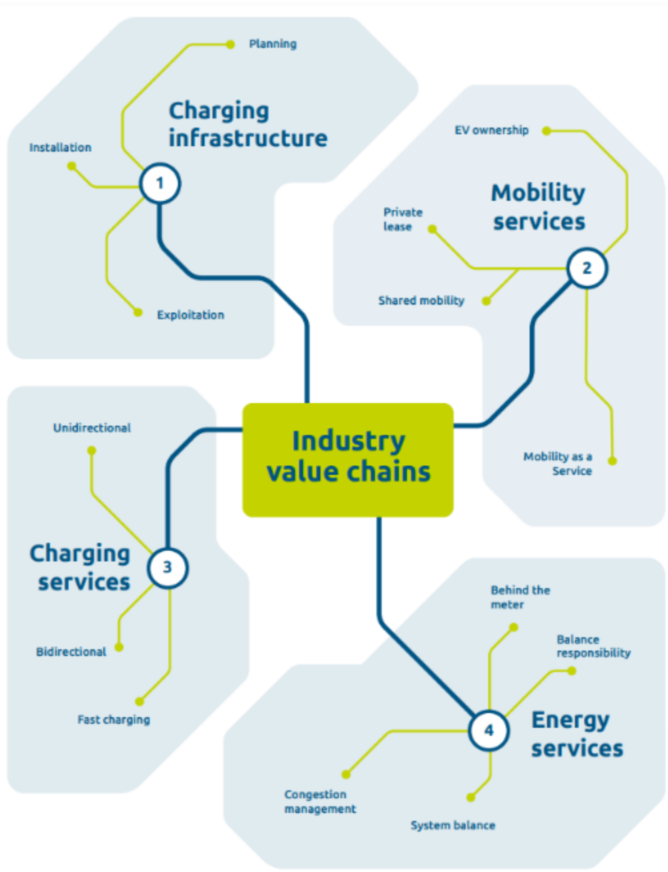

Figure 2. Industry value chains

In the following sections, a description is included per relevant industry value chain. By using the industry value chains to describe the use cases being evaluated, a comprehensive picture can be given of them.

2.1 Mobility services

Mobility can be offered to end users in different ways. As already written in the *Stakeholder analysis* of SCALE *(D1.2)* (Langenhuizen et al., 2022), the paradigm is shifting from only ownership of vehicles to other mobility services. In SCALE there are different varieties of mobility services in the use cases. The mobility services used in SCALE are private cars, shared cars (business-to-business and business-to-consumer, and leasing cars (company cars). One of the SCALE goals is to better understand the impact of different mobility services on the smart charging and V2X potential, e.g. the intentions of the explicit placement of shared cars in some use cases is that these are always connected to a charger when not in use, they are owned by a central professional organisation instead of by many individuals, and that their usage pattern is known from the reservation system. Mobility services are thus essential to unlocking the key findings that can, in the longer term, contribute to mass market uptake of smart charging and V2X technology. It is foreseen that these factors strongly enlarge the potential per car and cause car sharing systems to have an important position in scaling-up of V2X operation of e-cars. The same is true, to a lesser degree, for leased cars. In the car sharing context there are benefits to implement smart and bidirectional charging solutions. Important reasons for this are the possibility to operate within a controlled environment as well as the configuration between vehicles, charge points and the CPMS. Furthermore, the data on the mobility requirements can be made available through the car sharing platform.

2.2 Charging services

With the development of smart charging and V2X services within SCALE, the impact that charging of EVs has on the electricity grid is drastically reduced. As described in the SCALE *Stakeholder analysis (D1.2)* (Langenhuizen et al., 2022), 3 charging services can be distinguished: 1) unidirectional charging, 2) bidirectional charging, and 3) instant fast charging. In the context of the 4 innovation clusters the unidirectional and bidirectional charging services are most relevant. These are explained in this section.

Unidirectional charging

Unidirectional charging means that the power is only flowing from the grid into the vehicle, this is the most well-known charging service today. Most of the currently available charging services are unidirectional. However, within this charging service, there is an important distinction to be made, between *smart charging* and *uncontrolled charging*. Uncontrolled charging stations can only deliver full power, at the request of the EV, and cannot be managed. With charging stations that have smart charging functionalities the power level can be controlled. This way, EV charging can become part of the solution instead of the problem, e.g. EV charging can be initiated or maximised when there is an abundance of renewable energy and can be stopped or reduced when there is high energy demand or there is congestion on the electricity grid. This way the charging sessions are contributing to a more stable electricity grid.

Within smart charging, there are different levels of control. The first, and often already available manner of smart charging, is charging stations controlled being reduced in power when the maximum power on the grid connection is reached. This is a very effective way of smart charging, but it doesn’t take any other factors into account than the measurements at the grid connection. Within SCALE, the use cases go further than this: additional data sources are used to manage and optimise the charging sessions. More on this will be described in the paragraph §2.3 on the Energy services.

Bidirectional charging

Bidirectional charging, as the term implies, means that power can flow into the car, but also from the car back to other electricity consumers. In this situation, the battery of the vehicle is being used to store energy that can be used at a later moment. The energy can flow back to several destinations, in Vehicle-to-Home (V2H), Vehicle-to-Depot (V2D), Vehicle-to-Business (V2B), or Vehicle-to-Grid (V2G). We see that many of the Energy Services that are described under §2.3 can be done both uni- and bidirectionally, where the latter has the potential to create higher added value and minimise the need for grid reinforcements.

2.3 Energy services

In the combination of mobility and charging services, different energy services can be provided using the batteries in electric vehicles in a smart way. In SCALE, Energy services are divided into 4 categories: 1) local behind-the-meter optimization, 2) balance responsibility, 3) system balance, and 4) congestion management. Per category, different energy services can be identified and in this section of the report they are introduced.

Most energy services can make use of unidirectional or bidirectional charging services. The main difference is that with energy services going via bidirectional charging the potential that can be offered to the grid is larger than with unidirectional charging. For instance, executing the energy service *Optimize photovoltaic (PV) self-consumption* aims to increase the use of generated power from a PV installation. With unidirectional charging, you can charge the EV when the PV installation is producing power and stop or reduce charging if there is no PV power generation. In this way, you are executing this energy service because you are optimizing the PV consumption. When using bidirectional charging with the same energy service, the EV can offer more value. In this situation, you can charge the EV when the PV installation is generating power whilst in turn providing power to a home or other buildings whilst there is no PV power generation (for instance, at night), and then charge the EV again the next day.

Local behind-the-meter optimization

Local behind-the-meter optimization is, as the name suggests, done without power going back to the grid. All the optimization, whether it is unidirectional (smart charging) or bidirectional (V2X), is taking place behind the meter at a home, office building, or other location. The optimisation is typically controlled by the site owner and the typical strategies are defined as follows.

Energy service	Description
Increase self-consumption of on-site renewable energy	When a consumer has rooftop solar with a feed-in tariff different from the supply tariff, value can be created by maximizing the consumption of locally generated solar.
Reduce demand charges	When a consumer is exposed to capacity related charges (€/kW over a period), such demand charges can be reduced by applying peak shaving.
Time-of-Use shifting	When a consumer is subject to time varying electricity prices in the form of static ToU, dynamic pricing, critical peak pricing, etc., value can be generated by avoiding exposure to high prices of behind-the meter consumption.
Provide back-up power	When a grid outage is detected, the vehicle can provide back-up power to the household.

In front of the meter services

The three energy services which are not behind the meter are de-facto all in front of the meter and need to be briefly explained in order to complete the full landscape of activities considered in the use cases and, thus, innovation clusters. The simplest market mechanism, is the feed-in incentive for V2G, which can provide financial benefits for vehicles that return energy to the grid. Other more advanced examples are explained in the following table.

Energy service	Description
Balance responsibility	On the electricity grid, supply and demand need to be balanced: the same amount of energy needs to be generated as the energy that is used. The responsibility for matching supply and demand lies with the Balance Responsibility Party (BRP), which is, on many occasions, the energy supplier. Underneath, there are energy services associated with balance responsibility. With a single car being typically too small of an asset to provide these services, aggregation of these assets is needed for them to participate as BRP.
System balance	For a stable electricity grid, the system balance is important. To achieve system balance, the electricity grid needs to maintain a stable frequency of 50 hertz. A Balance Service Provider (BSP) provides this balancing service to the Transmission System Operator (TSO). EVs can be an example of assets that are used to provide the service. With smart charging electric vehicles can only be used as a demand asset, it can only take power from the grid. With V2G, the electric vehicles can also be used as supplying assets. With a single car being typically too small of an asset to provide these services, aggregation of these assets is needed. Underneath are the energy services associated with system balance.
Congestion management	Congestion management energy services can be aimed at preventing and resolving grid congestion. As described in the SCALE *Stakeholder analysis (D1.2)* (Langenhuizen et al., 2022), congestion management is typically needed on occasions when certain parts of the distribution system risk getting overloaded or congested.

2.4 System architecture

Beyond the building blocks introduced in the industry value chain, the evaluation framework also builds forth on the work done in SCALE task 1.4 on the system architecture. SCALE tested several applications of smart charging and V2X charging solutions. The goal of the different solutions, over different mobility services, charging services, and energy services is to ensure that electric vehicles are not a strain on the grid, but rather can support the grid and reduce the need for grid reinforcement. To use EV charging sessions to reduce the grid impact, EVs and charge points need to be able to work together as well as with many other systems that make up the smart charging and V2X ecosystem. Also, these subsystems need to be interoperable in order to be ready for upscaling for mass deployment. Herein lies a great challenge: the system architectures of these ecosystems are not yet fully developed and aligned among the different stakeholders in the ecosystem. For the complete overview of the SCALE protocols and standards we refer to the SCALE *Analysis of hard- and software requirements (D1.5)* (Meersmans et al., 2023). To have the ecosystem fully cooperating and communicating, a sound system architecture is necessary. This consists of all the actors involved, the roles of these actors, the communication protocols used, and the energy services provided. There is no one-size-fits all system architecture as every situation can have key differences leading to other choices in the system architecture. However, there are certain important aspects which are universal, or at least recommended.

In the setup and execution of the use cases the system architecture has been a central focus and further elaborated on in SCALE deliverable 1.4 *Smart charging and V2X system architecture* (Geerts et al., 2024) and for each of the use cases the system architecture is provided in the D3.1, with updates on the control topology and protocols is provided in D3.2.

Control topology

The control topology means the way of controlling a charging session and which actor is doing the actual controlling of the charging session. There are three control topologies that can be distinguished in SCALE: the car manufacturer (OEM), the Charge Point Operator (CPO), or the Energy Manager (EM). Each of these control topologies has a control system which is able to control the asset. There is no good or bad choice, but the choice for a control topology does have implications for the rest of the system architecture and data requirements. For example, the actors that need to be involved and the communication protocols that can be used.

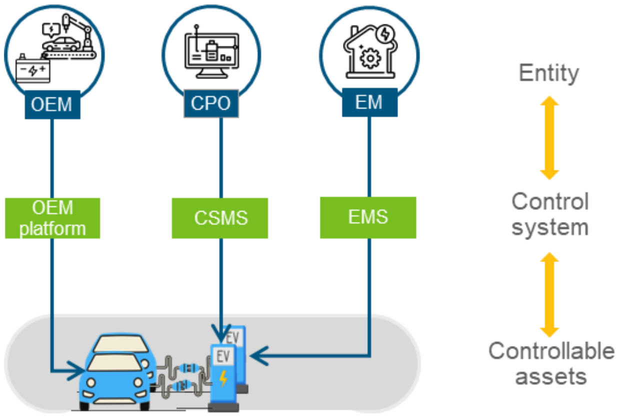

Figure 3. Control topologies

Communication protocols

In *chapter 3 & 4* of the SCALE *Analysis of hard- and software requirements (D1.5)* (Meersmans et al., 2023) a very detailed description of all the necessary hard- and software requirements for the electric vehicle, the charging station, and the Charge Point Operator (CPO) is given. This is very relevant and necessary input to the work done on the system architecture. Important protocols to be included in the system architecture are Open Charge Point Protocol (OCPP) and Open Charge Point Interface (OCPI). The latest or soon to be released protocol versions of OCPP & OCPI allow for most desired outcomes to be achieved by a V2X ecosystem. With regards to EV- Charging Station communication, the current dominant protocol for both AC charging is IEC 61851.

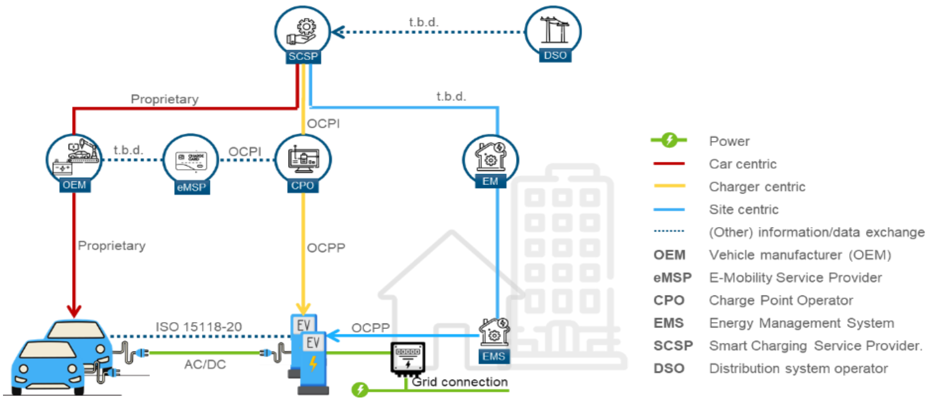

Figure 4. Example architecture on communication protocols

This protocol is not considered future proof due to several reasons such as lack of support for bidirectional charging and an inability to exchange information between the EV and charging station for smart charging purposes such as present State-of-Charge (SoC) of the EV battery. The bidirectional communication capabilities that ISO 15118-20 offers in addition to IEC 61851 would close most of the gaps related to the desired system outcome for the communication between the EV and the charging station.

Figure 3 shows an example of a representation of the communication protocols as part of the system architecture. This system architecture is merely a representation of the potential actors in the system architecture of a use case with recommended communication protocols. Per use case, the system architecture will differ highly. That said, this is not the definitive system architecture: it serves as an example to be built upon.

3. Concepts of innovations clusters

Within SCALE, innovation clusters (ICs) are defined as groupings of use cases serving a similar segment of business, society or end-customer. Two core benefits of grouping the use cases into aggregated groups are discussed in this section. Firstly, it supports the identification of best practices and standardisation opportunities for particular target groups. And this, even in the cluster itself if one underlying use case is facing a somewhat different challenge. Secondly, faster comparisons can be achieved between diverse operational activities in terms of maturity and best practices; allowing for best practices to be carried over or prescribed to a different innovation cluster. In contrast, the Utrecht use case (*#00: Bi-directional ecosystem via combined V2G service*) overarches several innovation clusters and does not specifically fit to one single cluster as it operates across several business segments. The below table provides the overview between the relation of use cases and innovation clusters. In the map the geographical dispersion of the use cases in the innovation clusters is given.

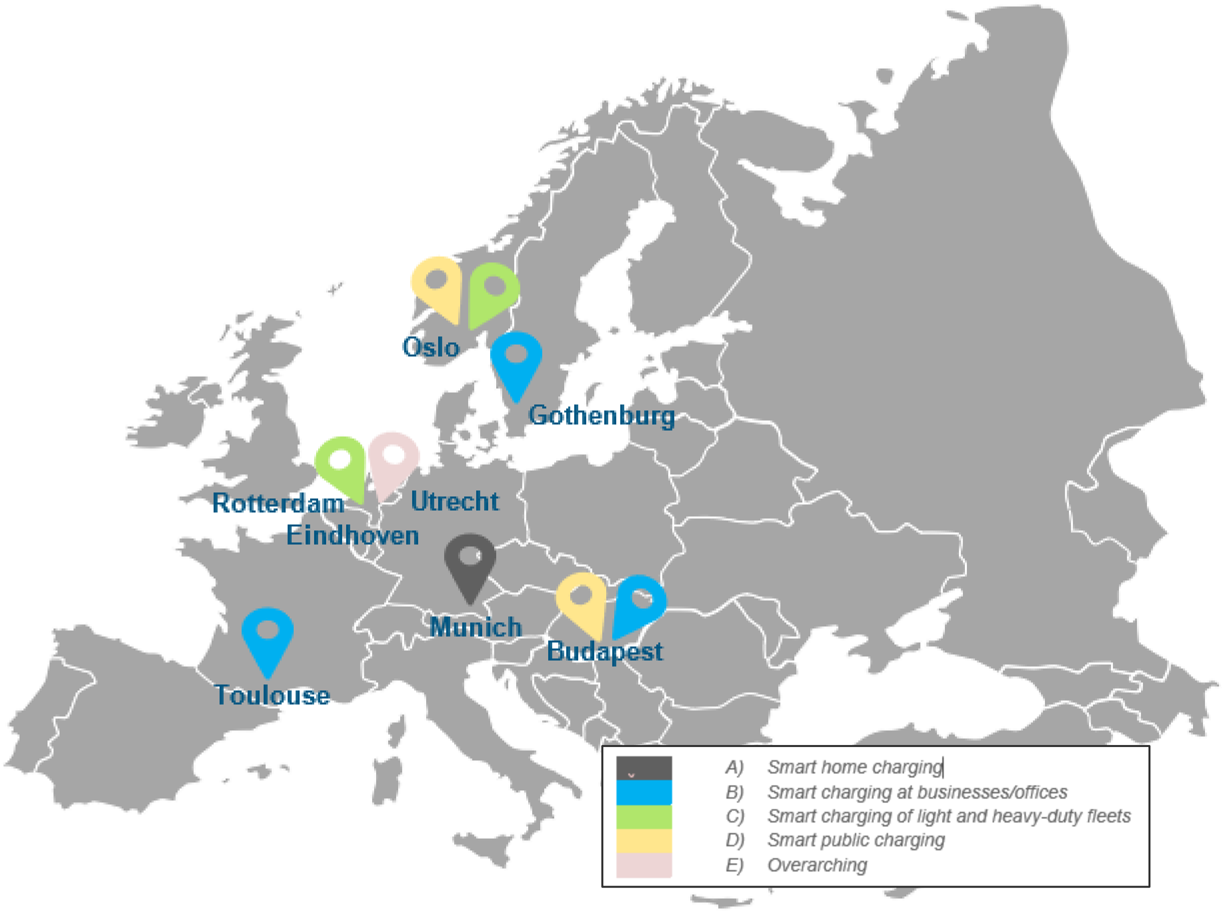

Figure 5. Map of innovations clusters per city

3.1 Innovation cluster A: Smart home charging

In this innovation cluster the smart and V2X charging is done in the context of the home. In practice, the innovation cluster is characterised by a user-owned or leased EV with a primary goal of providing mobility to the end user. The EVs are mostly charged on the home's driveway with an AC charger with the vehicle typically plugged-in overnight but charging can happen any time of the day.

Reasons for end users to adopt smart or V2X charging can be to lower the GHG impact of driving EVs or to lower the costs of charging. This can be done by maximising the self-consumption of solar power, or charging when (dynamic) electricity prices are most optimal or when there are other financial triggers.

Looking at the end user of this IC it is know that 44% of the European BEV drivers know what vehicle-to-grid (V2G) is and 68% are interested in buying a V2G-capable vehicle. The most important criteria to eventually buy a V2G compatible BEV are being able to use the battery of the V2G capable BEV to power their home (e.g., for heating, appliances, etc.) and having a similar purchase price to their current BEV (EAFO Consumer Monitor, 2023). Therefore, offering important potential for smart charging and V2X functionalities. Utilizing smart charging and V2X can, in this Innovation Cluster (IC), increase the uptake of EVs (through cost benefits, improved asset utilization and ease of use), as well as increasing the utilization of locally produced renewable energy (e.g. through self-consumption of the generated solar power) thus lowering grid-dependency. Important criteria for the adoption of smart and V2X is to reduce costs and creating a high-quality user experience to ensure high participation throughout society. The availability of plug and play EV, recharging station and (H)EMS that always work seamlessly with each other are important in this regard.

The two use cases in the Smart home charging innovation cluster were terminated during the use case setup phase. As a consequence, it was not possible to fully develop and test scenarios, thereby making use case evaluations impossible. In practice thus the execution part of the Sono Motors use cases, A1 and A2 from Munich, are not included in this report. However, there are still many lessons from the broader experiences of SCALE to report on this IC. These are partly derived from other innovation clusters by projecting them on the context of Smart Home Charging. Other lessons where shared through knowledge sharing among SCALE partners on their experiences with Smart Home Charging.

3.2 Innovation cluster B: Smart charging at businesses/offices

This innovation cluster focusses on smart charging and V2X in the context of business and offices. In this cluster the employees charge their vehicles at the office or customers change their vehicles close to the business or shopping areas. What is important for the EV user is that there is sufficient range for commuting or business travel. This scenario represents potential for smart charging and V2X services because of the central control of charging, relatively long stationary times and across the board a higher uptake of EVs in company fleets. For the business and/or building owner the key incentive to adopt smart and V2X charging can be to lower the GHG impact of employees driving EVs or to reducing costs through self-generation and self-consumption as well as demand charge reduction. As a result, increasing the use of locally generated renewable energy and lowers the peak loads on the grid.

Vehicles in this cluster are represented private and lease cars operated by individuals (e.g. company staff or customers of a shop). Within the cluster there also shared cars associated to a shared office business model. Charging happens mostly by an AC charger with a vehicle typically plugged-in Monday to Friday during the working hours and the plug rate can be high if user is encouraged by their employer or site owner. With regulatory drivers such as the EU Energy Performance of Buildings Directive (EPBD), the volume of charging at businesses/offices can be expected to grow.

The charging of the BEVs is part of the business which offers potential to combine the smart and bidirectional charging with the overall "Building Energy Management" to achieve the full potential of local behind the meter optimization. Systems in this cluster tend to be integrated and connected to a (B)EMS which can support optimised decision making. Energy assets other than the EVs that are part of the buildings can be solar panels, HVAC system, energy meters, and energy storage devices. With bidirectional charging the BEV can in addition to this be utilised as an energy storage device and adding additional flexibility to the overall energy management.

Within SCALE we've carried out 4 pilots within this innovation cluster as outlined in the table below.

Innovation Cluster	**B: Smart charging at businesses/ offices**			
Use case	B1	B2	B3	B4
Use case leader	DBH	Emobility Solutions	Enedis	Chalmers
City & country	Debrecen (Hungary)	Budapest (Hungary)	Toulouse (France)	Gothenburg (Sweden)

3.3 Innovation cluster C: Smart charging of light and heavy-duty fleets

In this innovation cluster smart charging and V2X takes place in the context of light and heavy-duty fleets, typically located at depots. Heavy duty vehicles require larger batteries and thus longer charging times and/or charging at higher capacities. Because these are often commercially operated vehicles, their utilization rate (effective time for which they are on the road) is important.

Vehicles in this clusters are typically LCV and HDVs operated by fleet owners (e.g. logistics companies, bus operators or service companies) with scheduled activities. The heavier vehicles are predominantly charged with DC charge points, for the LCV this can also be through AC charging. Another characteristic of the cluster is that it concerns fleets of EVs often with some level of uniformity between the vehicles. In addition the combined charging power is much higher than in the previous clusters. Moreover, the fleet operator is typically owner of the energy assets, pays electricity bills and is also in a position to optimally steer drivers and end users of the vehicles are part of the business operations.

The characteristics of the charging offer good potential for proving flexibility with a high degree certainly when EVs are at the depot and end users usually operate in highly automated data driven processes. This has the potential to offer high degree on the plannability of the charging, hence increasing the potential to provide flexibility. Driven by regulation such as "fit for 55" mandating 45% decline in CO2 emissions from the sector, for instance Regulation (EU) 2019/1242 for HDV emissions, the cluster is expected to grow in the coming years.

Important drivers for fleet owners to implement smart and V2X charging solutions are to minimise capacity demand charges, and cost of charging, and to reduce the environmental impact of electric driving by maximizing self-consumption of solar power.

Within SCALE 4 pilots are executed within this innovation cluster as outlined in the table below.

Innovation Cluster	**C: Smart charging of light and heavy-duty fleets**			
Use case number	C1	C2	C3	C4
Use case leader	Current	VDL	VDL	ELAAD
City & country	Lørenskog (Norway)	Valkenswaard (Netherlands)	Eindhoven (Netherlands)	Rotterdam (Netherlands)

3.4 Innovation cluster D: Smart public charging

In this innovation cluster, charging is taking place at public locations and charging typically happens in urban areas where charging at homes is often not possible. The charge point of these public areas are operated by Charge Point Operators (CPOs) and accessible by the EV drivers by making use of a charge card in order to process the payments for the charging session through the eMSP. The EV drivers need to charge their EVs at these charge points and typically want to charge overnight of during the day. Costs of charging are important for the EV driver, as well as the hassle free charging experience. Typically the vehicles are connected to chargers for longer than necessary durations. This provides opportunities for smart charging to plan the charge sessions in a way that avoids peaks in the electricity network. This type of public charging happens mostly by AC chargers.

Important in this cluster is the role of CPO’s who often needing to operate in highly complex multi-year concession models with charging infrastructure managed in public/private partnerships. Additionally, EV and charge point manufacturers, as well as grid operators play a central role in the ecosystem. The importance of the cluster cannot be overstated due to the high volumes of CPs in many cities and projected growth in combination with AFIR regulation. This translates to predictability of the flexibility offer on regional levels being high.

Smart charging and V2X services can make big impacts through the large amount of available parked EVs. SCALE will implement and test ecosystems of smart charging and V2X that will help municipalities and parking operators to manage energy demand, relieve local congestion, and support in reducing peak loads. Also, the call for a ‘right to plug’ in apartments and non-residential buildings increase the importance of charging infrastructure capable of reducing the need for grid reinforcements. Out of scope of this cluster is fast charging services at urban nodes such DC fast charging or motorway fast chargers.

Within SCALE we've carried out 2 pilots within this innovation cluster as outlined in the table below.

Innovation Cluster	D: Smart public charging	
Use case number	D1	D2
Use case leader	Current	Emobility Solutions
City & country	Oslo (Norway)	Budapest (Hungary)

3.5 Innovation cluster 00: Overarching

Because the Utrecht use case overarches several innovation clusters and does not specifically fit to one single cluster, it is described separately. Applicable charging scenarios are: congestion management, grid balancing (via aFRR), demand charge reduction, time-of-use price arbitrage, maximized feed-in of renewables and virtual power plant.

Innovation Cluster	00: Innovation cluster overarching use case
Use case number	00
Use case leader	We Drive Solar
City & country	Utrecht (Netherlands)

4. Lessons learned

In the last three years each use cases followed three phases: preparation & set-up, execution & monitoring, and quantitative and qualitative data gathering. As we reach the end of phase 3 it is now possible to assess, extrapolate and cross-examine the findings from the different use cases and this was largely carried out in D3.2 Use case evaluation (Christiaens et al., 2025). Repeating the same exercise on an innovation cluster level allows us to assess findings on yet a higher abstraction level. In this way, for each lessons learned the use cases and the innovations clusters are considered: evaluating key findings on the most relevant and actionable abstraction layer.

This chapter is composed of 9 sections that all build forth on the earlier SCALE work package 3 deliverables, namely D3.1 Use case setup report (Christiaens et al., 2023), D3.2 Use case evaluation (Christiaens et al., 2025) and D3.3 Business case analysis.

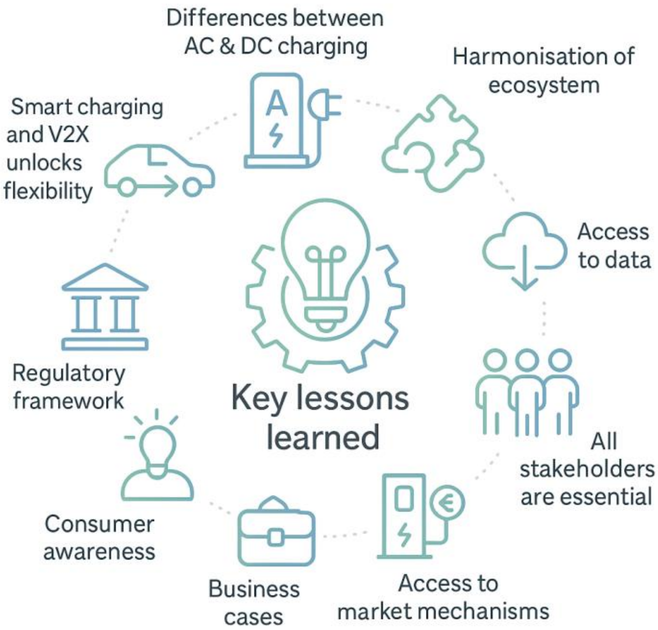

Figure 6. Key lessons learned for the SCALE pilots

With the exception of 3.9 each of the topics in this chapter start with the findings as highlighted in the D3.2 report aimed at the use case learnings. Subsequently, any relations of relevant part of these findings to innovations clusters level is explained.

4.1. Smart charging and V2X unlocks flexibility

Use case learnings

Within the use cases of SCALE significant progress has been made in the development, testing, and simulation of various smart charging (V1G) and V2X solutions. The use cases have demonstrated considerable potential in unlocking flexibility in energy systems. In particular, the use cases for both smart charging and V2G have shown promising results in contributing to grid balancing across a broad range of energy services. The use of data sources for e.g. planning the mobility requirements, PV production forecast and many other sources can greatly contribute to the flexibility potential of BEVs. Another contributing factor is the integration of additional assets in the flexibility mix, such as a BESS.

The adoption of ISO 15118-2 / 20 and OCPP 2.x standards can further enhance the capabilities of smart charging solutions, providing the foundation for more advanced systems that can unlock even greater flexibility. Besides smarter charging solutions, V2X capabilities of EV and charging infrastructure can further increase the potential to offer additional flexibility and contribute even more effectively to grid stability and optimization.

Across a wide-range of the use cases there have been validated opportunities to efficiently charge vehicles optimising existing connection sizes and reducing grid dependency. Across innovation clusters, partners have reduced grid dependency, connection sizes and peak KW levels with a range of local behind-the-meter optimization strategies. In other words, significant gains have been demonstrated using smart charging and these gains are the foundations for overall smarter charging strategies as is explored in the following sections on innovation cluster learnings.

Innovation cluster learnings

Local behind-the-meter optimization

With the development of smart charging and V2X services within SCALE, the impact that charging of EVs has on the electricity grid is drastically reduced. EV charging can be initiated or maximised when there is an abundance of renewable energy and can be stopped or reduced when there to prevent exceeding grid connection power limits or when there is congestion on the electricity grid. This way the charging sessions are contributing to a more stable electricity grid.

Most energy services can make use of unidirectional or bidirectional charging services. The main difference is that with energy services going via bidirectional charging the potential that can be offered to the grid is larger than with unidirectional charging. More advanced market mechanisms also play a crucial role in optimizing the economic potential of smart charging and V2X technologies. Moreover, holding great potential in unlocking access to balancing and congestion management markets for EVs.

Innovation Cluster	Assessment and lessons learned on 'Local behind-the-meter optimization'
A: Smart home charging	Predominantly optimising PV use, ToU etc behind the meter Within the innovation cluster the charging of the BEV is part of the home which offers potential to combine the smart and bidirectional charging with the overall "Home Energy Management System" (HEMS). In doing so the home owner can optimise the use of self-generated solar power, charge when overall home power use is low, and/or charge when electricity prices are low. With bidirectional charging the BEV can in addition to this be utilised as an energy storage device enhancing the flexibility of the BEV. To achieve the full potential of local behind the meter optimization integration with the smart meter, energy storage device, heat pump and other energy assets is important. Also, information on the EV user's mobility requirement and solar power forecast is key.
B: Smart charging at businesses/ offices	Predominantly optimising PV use, ToU etc behind the meter In many ways this is similar to the characteristics of IC-A, important differences are; (a) Charging of the BEV is part of the business which offers potential to combine the smart and bidirectional charging with the overall Building Energy Management System (BEMS). In doing so the building owner can optimise charging (b) the size of the operation is typically significantly larger, justifying the investments required in the complex integrations that are needed to execute the relevant optimisations.
C: Smart charging of light and heavy-duty fleets	Predominantly optimising PV use, ToU etc behind the meter In many ways this is similar to the characteristics of IC-A and IC-B, important differences are; (a) the size of the operation is typically significantly larger in terms of power consumption and charging capacities (b) the characteristics of the charging have better potential to offer high degree of flexibility, justifying the investments needed in the complex integrations needed to do the optimisations.
D: Smart public charging	With CPs in this IC-D predominantly directly connected to the electricity network, there is limited potential for behind the meter optimisations.

In front of the meter services

Opposed to “Behind the meter services”, the concept of “In front of the meter services” has been introduced as a range of different flexibility services to maintain and balance the electricity system. See the below table on the relation between these services and the different innovation clusters.

Innovation Cluster	Assessment and lessons learned on ' In front of the meter services'
A: Smart home charging	<u>Potential to tap into flex markets</u> Many flexibility markets are limited to large consumers or suppliers. Participation by users in this segment requires an aggregator. This role can be fulfilled by the EV OEMs, energy company, or new market players.
B: Smart charging at businesses/ offices	<u>Potential to tap into flex markets</u> Same as IC-A, however there is additional complexity as the EV user is not the same as building owner, control is more complex.
C: Smart charging of light and heavy-duty fleets	<u>Potential to tap into flex markets</u> For large fleet owners there is good potential to participate in flexibility markets directly or through an aggregator depending of the size of the operation.
D: Smart public charging	<u>High potential to tap into flexibility markets</u> With CPOs controlling large volumes of CPs there is good potential to aggregate these assets and provide flexibility services. The role of the user(s) and its mobility needs are important to consider here as they need to be motivated to participate in these markets. In some of the SCALE use cases the he user(s) and its mobility needs were known through the car sharing platform offering valuable input for providing these energy services.

4.2. Differences between AC & DC charging

Central to SCALE's objective is to draw conclusions on how different hardware components, with a big emphasis on charge points, can optimally contribute to the smart charging and V2X potential of the different services identified. In SCALE, differences have been identified in the implementation of smart charging and V2X solutions across use cases. Moreover, a prerequisite for various forms of smart and bidirectional charging is the rolling out of ISO 15118. However, both vehicle and charge point manufacturers are faced with challenges rolling out the protocol. To some extent also for this reason, the availability of V2X capable chargers and vehicles has proven to be a bottleneck experience within several use cases.

Use case learnings

At present, DC charging faces fewer barriers to the implementation of advanced smart charging solutions. One of the key advantages of DC charging is that ISO 15118-2 is already well-established and mainstream, enabling easier integration of advanced functionalities. Additionally, and in relation to bidirectional charging, since the generator is located within the charging point and is not mobile, the *grid* code issue - typically associated with AC charging – is less of a challenge in the case of DC charging systems.

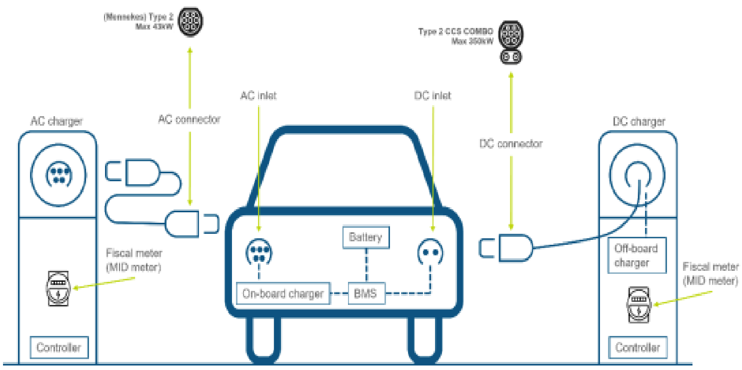

Figure 7. Differences between AC & DC charging

On the other hand, AC charging is seen to have a higher potential to provide flexibility on the long run, despite its current limitations. The installed base of charging infrastructure within the EU is predominantly AC and most vehicles are equipped with onboard chargers, making it a widely accessible and an established technology. Furthermore, the inherent characteristics of AC charging offer greater opportunities for providing grid flexibility, particularly in terms of managing energy flow and optimizing usage based on system needs.

While DC charging is currently more suited to smart - and bidirectional charging and advanced smart functionalities, AC charging holds significant promise for future scalability and flexibility, especially as the technology continues to evolve. What's more, all findings from both technical and operational perspectives indicate that both charging methods can coexist and fulfil complementary roles.

Knowing the present-day differences between AC and DC charging, it is important to note that they should not be seen as competing technologies for smart charging and V2X solutions. Both technologies can coexist for charging different vehicle types in different power ranges and in different use cases.

Innovation cluster learnings

The learnings in terms of innovation clusters focuses on the current dominant methods of charging per innovation cluster and their interactions with the relevant activities and known challenges.

Innovation Cluster	Assessment and lessons learned on 'Differences between AC & DC charging'
A: Smart home charging	Predominantly AC charging, slow DC charging is also possible. Offers potential for flexibility.
B: Smart charging at businesses/ offices	Predominantly AC charging, which offers potential for flexibility
C: Smart charging of light and heavy-duty fleets	Predominantly DC charging for HDV, also AC charging for LDVs. Both offer potential for flexibility. DC charging faces fewer barriers to the implementation; ISO 15118-2 is already well-established and mainstream standard, enabling easier integration of advanced functionalities. Also, grid code issues are far less problematic in the case of DC charging systems.
D: Smart public charging	Predominantly AC charging, also DC for fast of HDV charging. AC charging offers highest potential for long-term flexibility and grid management potential.

4.3 Harmonisation of ecosystem

Use case learnings

As concluded earlier in this chapter, it is demonstrated that ISO15118-2 & 20 and also the OCPP2.x can unlock more flexibility. Looking at the SCALE use cases, the implementation of ISO15118-20 and OCPP2.x in both EV and CP are still in an early stage. Although important steps are being made, to which SCALE contributed, we cannot speak of a truly interoperable ecosystem with these standards. Existing implementations on ISO15118-20 are in pilot phase or have a closed setup where there is only a single combination between EV, CP and EMS or CPMS. An example of the latter is the innovative bidirectional Renault-5 vehicle that is currently commercially offered together with the Mobilize solution for Vehicle-to-Home (V2H).

At this stage, it is premature to consider the core of the charging ecosystem (EV, CP and CPMS) fully interoperable with these standards. For broader adoption and seamless integration, additional implementations across the ecosystem are necessary. Furthermore, extensive interoperability testing is required to ensure that diverse components can effectively communicate and function together.

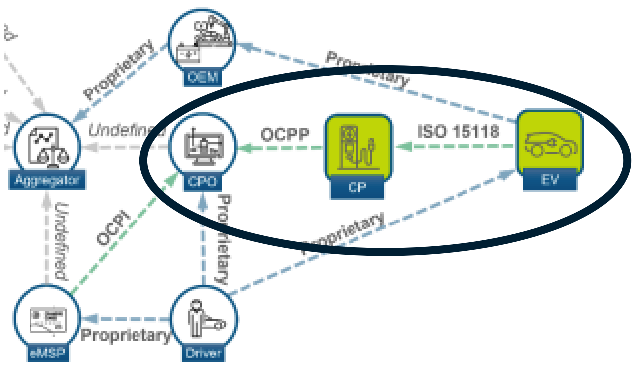

Figure 8. Charging ecosystem

While the interoperability between EV, CP and CPMS is essential and at the core of smart charging solutions, harmonisation must extend beyond these communication standards to also include the energy domain, such as electricity meters, BESS, EMS, DSO, and TSO.

In the use cases, facing the same challenges, the need for a dedicated “system integrator” to navigate the complexity involved in integrating subsystems and performing energy management optimisations appeared important. This proved a great help to ensure the successful deployment of the various smart solutions.

Further harmonisation of these standards in the ecosystem would reduce the dependency on system integrators and enable the faster scaling up and roll-out of smart charging and V2X solutions. Achieving this harmonisation is essential to fully harness the flexibility potential of EVs and optimise their contribution to energy management and grid stability.

Innovation cluster learnings

Harmonisation in e-mobility domain (between CP and EMS or CPMS)

As concluded earlier, we cannot speak of a truly interoperable ecosystem. Looking at the different innovation clusters there are different levels on how this impacts the introduction of solutions in the innovation clusters.

Innovation Cluster	Assessment and lessons learned on 'Harmonisation in e-mobility domain'
A: Smart home charging	Low dependency on interoperability maturity The smart charging and bidirectional charging interoperability complexity does not exist whenever there is a single configuration between the EV, CP and CPMS. There are already examples in the market where the complete setup is offered as a concept by the EV OEM or by a third party This means that for Smart home charging the interoperability challenge can be overcome. Eventually, for widespread adoption it is important to work towards an open and fully interoperable ecosystem where all EV, CP and CPMS configurations work with each other.
B: Smart charging at businesses/ offices	Medium to high dependency on interoperability maturity In this innovation cluster there is high variety between the EVs charging at the location. This creates high variety and possibly unknown configurations in particular between the EV & CP.
C: Smart charging of light and heavy-duty fleets	Low to medium dependency on interoperability maturity The smart charging and bidirectional charging interoperability complexity does not exist whenever there is a single configuration between the EV, CP and CPMS. In this innovation cluster the smart charging and bidirectional charging functionalities can be limited when there is a limited number of configurations between the EV & CP. In addition, for HDV charging the existing standards (CCS - ISO15118-2) is already mature, allowing higher degree of smart charging functionalities today. Eventually, for widespread upscaling it is important to work towards an open and fully interoperable ecosystem that incorporates the latest standards and where all EV, CP and CPMS configurations work with each other.
D: Smart public charging	High dependency on interoperability maturity In this innovation cluster there is high variety between the EVs charging at the location. This creates high variety and unknown configurations in particular between the EV & CP. This means that there is a high dependency on a mature and interoperable ecosystem to achieve seamless smart and bidirectional charging. In SCALE we have seen lower complexity in smart public charging in car sharing use cases. In these situations the smart and bidirectional charging is enabled and possible for certain groups of EVs in the shared car fleet that have been extensively tested for these functionalities.

Harmonisation in energy domain

From the SCALE experience there are different ways of how the charging is controlled and what the control devices, energy assets, and data sources are to optimise the energy management. In the below table an overview of the typical items per innovation cluster is provided.

As key learning it is clear that making the integrations between the various sources and systems in the energy domain is not straightforward. There still is a world to win in terms of harmonisation in the energy domain for both behind the meter (typically IC-A/B/C) and in front of the meter (typically IC-D). From SCALE it is apparent that for the more advanced optimalisations there is the need for a system integrator with capabilities to connect these different subsystem and to create the optimalisations. In the real world, to justify the upfront investment for this service, there needs to be a positive business case. This is only possible where the revenues are sufficiently high, something that typically works best for the larger power consumer that you typically find in IC-C.

Innovation Cluster	Assessment and lessons learned on 'Harmonisation in energy domain'	
A: Smart home charging	*Control*	EV driver controls the charge through EV or CP Home owners or tenants control the smart charging based on their inputs (schedules, target SoC, use of renewables, grid costs, etc.)
	Integrations	(H)EMS, E-meter, PV system, PV forecast, Mobility requirements
B: Smart charging at businesses/ offices	*Control*	Both control through the CPO and EMS occur in this situation Business owner control the smart charging based on their inputs (schedules, target SoC, use of renewables, grid costs etc.)
	Integrations	(B)EMS, E-meter, PV system, PV forecast, Mobility requirements
C: Smart charging of light and heavy-duty fleets	*Control*	Predominantly control through the EMS Business owner control the smart charging based on their inputs (schedules, target SoC, use of renewables, grid costs etc.)
	Integrations	EMS, E-meter, PV system, PV forecast, Mobility requirements (planning software)
D: Smart public charging	*Control*	Predominantly control through the CPO role Depending on the service offering, a combination of user input and CPO logic is expected to determine the smart charging outcome. User opt-in is however needed and not guaranteed so full optimisation is not necessarily a given. Economic incentives assumed to be needed to stimulate adoption and manual data sharing from end-users.
	Integrations	CPs are predominantly connected to the grid directly. Direct communication with CPO who controls the charge sessions. Interfacing with an eMSP and further upstream in the electricity system with actors such as the DSO, TSO, BRP, etc.

4.4 Access to data

Access to data has the potential to enable smarter charging and therefore increase flexibility.

Use case learnings

As concluded also in the SCALE report Specifications and IT Use-Case definition for V2X services (D2.2) (Sautreau,& Meersmans, J, 2023) there is a clear need for data from various sources within both the mobility and energy domain. Moreover, there is a great variety in data requirements in relation to the targeted charge optimisation to execute one or more energy services. See figure 7 for an overview of some key data streams.

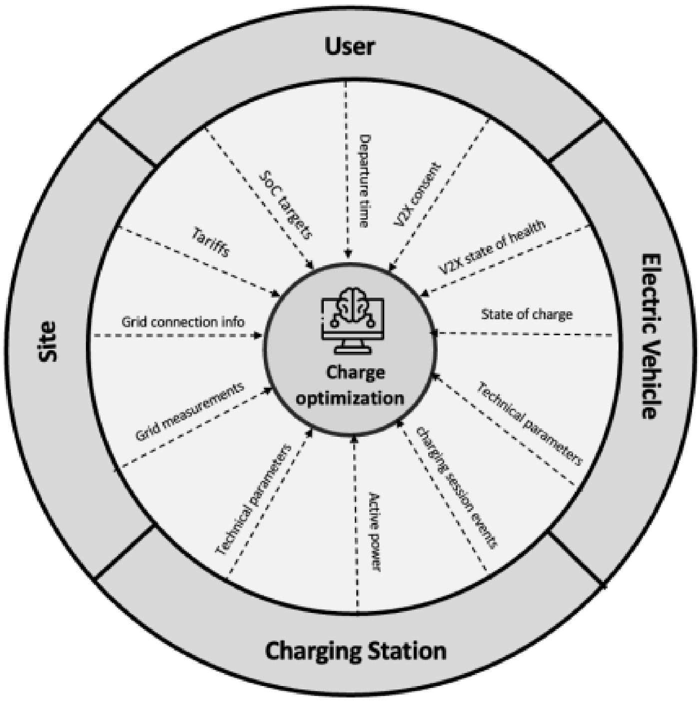

Figure 9. Data requirements for charge optimisation

A clear distinction can be made here between 'in front' and 'behind' the meter energy services. Data quality also proved to be an important aspect as the provision of certain energy services required faster and more frequent and/or more accurate data to operate optimally. Of particular relevance, load request predictability plays a key role. Data on the mobility requirement targets such as the SoC at the planned departure time can be used to optimise the charging profiles of the vehicles. This increases the potential role of electric vehicles in grid balancing and behind the meter optimization and can enhance the business case.

In practice however, a general concern in getting access to data comes from the GDPR regulation which requires authorisation to access data or anonymised data. Additionally, getting access to data often means cooperation with one or more stakeholders which often have limited incentive to do so. With the SCALE partners having a clear objective to cooperate and exchange data, this topic is expected to be a more dominant boundary outside of the project and in a 'real-world' environment.

No other relations between the learnings of "access to data" and the innovation clusters have been identified that are not explained elsewhere in this chapter.

4.5 All stakeholders are essential

Use case learnings

As experienced by many of the use case leaders whilst implementing their use cases, there is a clear need for participation of all stakeholders in the ecosystem. Activation of these stakeholders is key to further upscaling and goes beyond data exchanges alone; failure to do so can inhibit the full adoption and benefits of all relevant smart charging and V2X solutions.

Core of ecosystem

There are diverse levels of importance between stakeholder involvement to implement and further scale up smart charging and V2X solutions. Key stakeholders in the ecosystem are the EV and CP manufacturers as well as the grid operators. Activation of these stakeholders is key to further scaling up. Besides activation of these stakeholders, challenges faced by manufacturers such as grid code compliance for V2X, and the need for better harmonisation and interoperability should also be accounted for in the run up to mass deployment.

As with many lessons learned, the situation varies vastly between use case and innovation cluster. However, the common ground is the need for cooperation with one or more stakeholder which often has limited incentive to do so. In order to achieve full potential, a clear objective to cooperate and exchange relevant data across the ecosystem is needed.

Location specific

Across the use cases a variety of location specific stakeholders have been identified that impact the implementation and execution of smart charging solutions. Asset ownership, whether it is in the form of a single family home, multi-tenant office building or industrial site, is an essential differentiator in the complexity of this stakeholder environment. In the simplest form the location owner is the same stakeholder as the EV operator and the one paying the electricity bill. Experience from the use cases indicated that in many pilots there are many additional location specific stakeholder that need to cooperate in order to have permission to install charging equipment, get access to data streams, etc. In short, the more stakeholders there are with different interests, the more complex alignment becomes. Experiences from the use cases show that installing the required equipment in 3rd party locations can lead to two challenges:
(i) It is difficult to get permission of building owners as they are not necessary aware or supportive
(ii) business cases are subject to risk as the timeframes needed to align with the rental period do not per se correspond with expected life-span of materials or investments.

Innovation cluster learnings

In the following three sections, different aspects of stakeholder engagement and interaction are identified on the level of the innovation clusters.

Innovation Cluster	Assessment and lessons learned on 'Stakeholder environment'
A: Smart home charging	Ranges from low to medium complexity - Relatively low number of location specific stakeholders. In today's market predominant situation is that Home owner = EV driver = paying electricity bill. This is different when homes are rented or in case of implementations in multi-tenant buildings (where power lies with home owner associations). - Strong dependency on available DSO market mechanisms e.g. dynamic tariffs for the business case and/or; - Strong dependency on OEMs offer (Small scale implementation with little to no possibility to invest in tailor-made solutions)
B: Smart charging at businesses/ offices	Ranges from low to medium complexity with some similarities IC-A - There is higher location specific stakeholder complexity as the driver is typically not the one owing the building or paying the electricity bill. - This complexity impacts the ability to commit to long-term infrastructure investments or even get permission to execute them. - Implementations are typically of larger scale slightly increasing the justification for investments in tail made solutions
C: Smart charging of light and heavy-duty fleets	Ranges from low to medium complexity with some similarity to IC-B - Implementations are typically of larger scale which may provide justification for investments in tailor made solutions - Larger scale in energy flows results higher degree of access to market mechanisms, in particular with HDV fleets
D: Smart public charging	Higher degree of complexity due to more stakeholders - Charging infrastructure is often handled in private / public partnerships in multi-year concession models. - CPOs control the charge points / car users the BEV. Both need to align their interests on the smart charging strategy. - The public nature of the charging implies that there is no control on who is charging at the charge point. - Primarily suitable for in front of the meter services. There is an important role for the stakeholders in the energy domain such as grid operators. - EV and charge point manufacturers, as well as grid operators play a central role in the ecosystem.

4.6 Access to market mechanisms

Use case learnings

More advanced market mechanisms also play a crucial role in optimizing the economic potential of smart charging and V2X technologies. As seen in the use cases, access to energy market mechanisms is essential for the profitability of smart charging and V2X solutions; the ability to participate in these mechanisms enables EVs to contribute effectively to balance the grid and capture value from various energy services. In Scale the following market mechanism were piloted and divided in to 4 categories:

1. **Local behind-the-meter optimization** involving strategies such as considering capacity tariffs and dynamic pricing to reduce energy costs and improve system efficiency.
2. **Balance responsibility** in spot markets, where EVs can participate in real-time energy balancing.
3. **System balancing**, with services like FCR and aFFR to help stabilize grid operations.
4. **Congestion management** solutions, such as GOPACS in the Netherlands, that support grid operators in managing energy distribution and prevent bottlenecks.

Importantly, market mechanisms should address the specific needs of grid operators or Balance Responsible Parties (BRPs), which can vary significantly from country to country. Additionally, these mechanisms must be adaptable, and adapted, to local regulations and requirements. Furthermore, the role of aggregators holds great potential in unlocking access to balancing and congestion management markets for EVs, with doing so increasing the potential for profitability of the smart charging and V2X solutions.

No other relations between the learnings of “Access to market mechanisms” and the innovation clusters have been identified that are not explained elsewhere in this chapter.

4.7 Consumer awareness

Use case learnings

The end consumer plays an integral role in the adoption of smart charging and V2X solutions. A clear demand for these technologies is important for its uptake. That said, consumers need to understand the benefits of the technology whilst also clearly understanding the added value of, for example, V2H use case which would enrich the conversation. A good insight in e.g. the financial wins is complex to grasp and currently missing. In addition, the biggest concern consumers have when looking at all the countries’ combined survey results is battery degradation (Aarvold Rastad, Sommerset Busengdal, & Hiep, 2023) as concluded in the SCALE report on consumer behaviour v2 (D1.1). Many recent publications on this topic suggest that the impact of bidirectional charging on battery degradation, when managed carefully, is limited. More effort is needed to increase consumer’s awareness on the impact of bidirectional charging in relation to battery life.

Innovation cluster learnings

Innovation clusters where consumers are particularly relevant are IC-A, IC-B and IC-D and these stand to benefit the most from increased consumer awareness to driver adoption. Indeed, many recent publications on this topic suggest that the impact of bidirectional charging on battery degradation, when managed carefully, is limited. Effectively, controlled bidirectional charging does not necessarily lead to significantly accelerated battery wear. Moreover, a study focusing on state-of-charge pre-conditioning strategies demonstrates how carefully managing charging profiles in V2G operations can even reduce battery degradation, providing a pathway for more sustainable bidirectional charging. (T. M. N. Bui, 2021)

Additional learnings on user experiences will be reported in the D4.4 report of SCALE.

4.8 Regulatory framework

Use case learnings

The current regulatory framework presents several challenges hindering mass deployment of smart charging and V2X technologies. One of the primary obstacles is the existing regulation on grid codes which is limiting the widespread integration of bidirectional charging systems into the energy grid. To unlock the full potential of these technologies, regulatory updates and harmonization are needed to address these barriers.

Additionally, the issue of double taxation is a significant concern in some countries that must be resolved to enhance the business case for V2G solutions. Without clear regulatory guidelines on tax treatment, operators and consumers may face limited financial incentives that eventually impact the profitability and scalability of these systems.

Feed-in tariffs are also essential to promote the adoption of V2G as they provide an important financial incentive for consumers to participate in energy markets by returning energy to the grid. As with the double taxation issues, it is also important to note that with respect to feed-in tariffs there are different national policies across the EU member states on how to deal with these in the context of bidirectional charging of EVs.

Lastly, there is a need for regulatory frameworks that open up more markets and reduce barriers to access flexibility services. By making it easier for electric vehicles to participate in flexibility markets and by offering services such as balancing and congestion management, regulators can foster greater integration of smart charging and V2G technologies, hereby contributing to more flexible, efficient, and sustainable energy systems.

Innovation cluster learnings

Compliance to network codes for bidirectional charging

For compliance to network codes for bidirectional charging differences have been identified amongst the innovation clusters. The current regulatory framework includes network codes for electricity generators that feed in power to the electricity system. These codes differ from country to country and present challenges for the implementation of V2X technologies.

These challenges are primarily related to AC charging where typically the combination of the CP and EV need s to comply with the network codes. As there are numerous configurations between EV and CP possible and since EVs can cross borders with implications on which grid codes to comply to, there is a clear need to revisit the regulatory framework to allow V2X on full scale.

Knowing the complexity of dealing with bidirectional charging today, there are differences in this complexity from cluster to cluster. The below provides an overview of these differences.

Innovation Cluster	Assessment and lessons learned on 'Compliance to network codes for bidirectional charging'
A: Smart home charging	Low complexity Closed setup, compliance possible
B: Smart charging at businesses/ offices	High complexity Variance in setup, compliance impossible today
C: Smart charging of light and heavy-duty fleets	Low complexity Closed setup, compliance possible
D: Smart public charging	High complexity Variance in setup, compliance impossible today In SCALE we have seen lower complexity in smart public charging in electric car sharing use cases. In these situations, the bidirectional charging is possible for certain groups of EVs in the shared car fleet that have been extensively tested for these functionalities.

4.9 Key findings from the business case analysis of V2X technologies

The business cases of V2X technologies are influenced by a complex interplay of country-specific conditions, market regulations, electricity pricing, and stakeholder cost-benefit distribution. This section distils key findings from the SCALE V2X use cases, emphasizing business model scalability, financial viability, and critical enablers for V2G adoption.

Business case viability is highly country-dependent

The financial attractiveness of V2X business models is heavily influenced by country-specific conditions, as electricity market structures, grid fees, regulatory environments, and available incentives differ significantly across Europe. In markets with high electricity price volatility, such as the Netherlands and Sweden, the feasibility of Smart and Bidirectional Charging participation becomes unpredictable due to fluctuating revenues from price arbitrage of dynamic electricity prices and grid services. The presence of clear and unified, and supportive grid codes, along with well-defined aggregator regulations, plays a crucial role in shaping the market potential of Smart and bidirectional charging business models. Without proper policy alignment, opportunities for vehicle-grid integration can be limited or financially unviable. Additionally, national policies on dynamic pricing, congestion management, and grid access for flexibility service providers are essential in ensuring that Smart and bidirectional services remain a financially attractive and scalable solution. The varying levels of regulatory support across different countries highlight the need for tailored business models that adapt to the specific market conditions of each region, which might not be suitable for smaller business actors.

Electricity price volatility directly affects V2G business case feasibility

The viability of Smart and bidirectional charging as a cost-saving and revenue-generating solution is closely tied to the volatility of electricity prices. Findings from Stedin's 2022 pilot in the Netherlands revealed a significant variation in Smart and bidirectional charging savings per electric light commercial vehicle, ranging from €1,080 per year in 2022 to a maximum of only €410 in 2021. This variation was driven entirely by fluctuating electricity market conditions. Dynamic pricing, while essential for maximizing potential revenues from grid services such as frequency regulation and peak shaving, also introduces financial uncertainty for fleet operators and energy aggregators. The unpredictability of energy prices complicates long-term financial planning, making it challenging for businesses to commit to Smart and bidirectional charging investments with confidence. To ensure a stable business case, market structures must evolve to offer more predictable compensation mechanisms for flexibility services, reducing exposure to extreme price fluctuations.

Vehicle battery size and charging power are key cost-saving enablers

The potential for Smart and bidirectional charging cost savings and revenue generation is directly linked to the size of vehicle batteries (and therefore the types of vehicles) and the power capacity of charging infrastructure. Larger battery capacities enable vehicles to store and discharge greater amounts of energy, allowing for increased participation in energy markets and greater cost savings from optimized charging schedules. High charging power is equally important, as it allows for faster energy transactions, making bidirectional charging more responsive to grid needs and enabling higher revenues from frequency regulation services. The VDL Eindhoven use case demonstrated that heavy-duty electric vehicles have an inherently stronger business case for Smart and bidirectional charging due to their large battery sizes and higher per-session revenue potential, making investment in bidirectional chargers financially more viable. Additionally, fleet-scale Smart and bidirectional charging participation presents a more stable and attractive business model than individual consumer participation, as aggregated vehicle capacity can provide a more predictable and valuable service to the grid, improving financial returns for both fleet operators and flexibility providers.

Benefits and costs are distributed unevenly among stakeholders

The financial implications of Smart and bidirectional charging technologies do not impact all stakeholders equally. Some entities bear a disproportionate share of the costs, while others benefit significantly without direct investment. The Chalmers Smart and bidirectional charging use case highlighted these disparities. Among the major cost bearers, electric vehicle drivers face higher upfront vehicle costs and perceived uncertainties regarding battery degradation, while battery manufacturers are impacted by increased battery cycling, requiring them to adapt warranty frameworks to address potential wear and tear. BEV manufacturers also face financial challenges, as integrating bidirectional charging capabilities into their vehicles requires additional investment in both hardware and software development. Mixed impact stakeholders, such as charge point operators, may see potential service revenues from managing Smart and bidirectional charging infrastructure but also face increased costs due to the need for specialized charging hardware. Site owners benefit from optimized energy costs but must bear the upfront installation expenses. On the other hand, major beneficiaries such as transmission system operators, energy suppliers, and distribution system operators profit significantly from Smart and bidirectional charging enabled grid balancing and peak load reduction without being responsible for substantial capital investments. These disparities underscore the need for equitable cost-sharing models to ensure fair distribution of financial benefits and risks among all involved stakeholders.

Table 1 - Insights from D3.3 Business Case Analysis in the SCALE project indicate (Case study B4 – Gothenburg)

Major Cost Bearers	Mixed Impact Stakeholders	Major Beneficiaries

• **Electric Vehicle Driver** • **Battery Manufacturer** • **EV Manufacturer**	• **Charge Point Operator** • **Charge Point Manufacturer** • **Site Owner**	• **Transmission System Operator** • **Distribution System Operator** • **Energy Supplier**

Non-monetary gains play a role in business case justification

Beyond direct financial returns, Smart and bidirectional charging technologies offer several societal benefits that contribute to the overall justification for investment in vehicle-grid integration. In urban areas with grid congestion, Smart and bidirectional charging can play a critical role in reducing waiting lists for grid connections, helping to free up capacity for important public institutions such as schools, hospitals, and emergency services. This impact goes beyond financial metrics and contributes to overall energy security and resilience. Additionally, sustainability benefits such as reduced CO_2 emissions and increased self-consumption of renewable energy create further incentives for adopting Smart and bidirectional charging technologies. These environmental and social advantages can support the case for regulatory incentives and corporate ESG-driven investments, reinforcing the long-term viability of Smart and bidirectional charging solutions. As policymakers and market actors consider the future of smart charging, these broader benefits should be integrated into decision-making frameworks to ensure a comprehensive evaluation of the true value of V2G beyond immediate financial returns.

Business case analysis conclusions and recommendations

The business case for Smart and bidirectional charging is highly dependent on regulatory frameworks, market conditions, and stakeholder alignment. While the technology holds significant promise for cost savings, revenue generation, and grid stability, its success relies on favourable policy conditions, well-designed pricing mechanisms, and equitable benefit distribution.

Electricity price volatility remains a key challenge, highlighting the need for stable compensation mechanisms for grid services. Larger vehicle batteries and higher charging power enhance Smart and bidirectional charging profitability, making fleet-scale participation more attractive than individual ownership models.

Finally, beyond financial considerations, the societal and environmental benefits of Smart and bidirectional charging play an essential role in justifying its adoption, reinforcing the need for policy support and regulatory alignment. The lessons from SCALE's business case analysis highlight the importance of a structured, country-specific approach to Smart and bidirectional charging implementation, ensuring that the technology delivers both financial and societal value in the transition toward a more flexible and sustainable energy system.

5. Conclusions

5.1 General conclusions

Smarter charging

Advanced smart charging solutions, as piloted in the SCALE use cases, can unlock significantly more flexibility compared to the smart charging that is mainstream today. In order to untap this potential, these technologies need to become mainstream. From our SCALE learnings, key topics for scaling up towards advanced smart charging solutions can be summarised into two key topics:

(c) the **business case**; getting access to market mechanisms so that advanced smart charging aligns with the dynamic needs in the electricity system and results in revenues so that the end user (and other stakeholders in the value chain) are incentivized to participate. It is important to realise that there is a lot of uncertainty on the business case around smart charging. High degree of variance of pricing in existing markets and differences between countries adds to this complexity.

(d) the **harmonisation** in the ecosystem to allow the highly needed transfer of data and the control of assets. In the heart of the e-mobility domain this is primarily about the adoption and maturity of ISO15118, OCPP 2.X. The hardware of the equipment (BEVs and recharging points) need to be capable to support these standards. Retrofitting existing equipment is often not possible. Harmonisation in the energy domain can further add to the flexibility potential. Integrations to access smart meters, (H/B)EMS, energy storage systems, flexibility markets are currently often tailor made solutions. This makes implementations complex and costly resulting in barriers in many use cases to implement.

Bidirectional charging

Bidirectional charging can be seen as an add-on to advanced smart charging. It introduces more potential to offer flexibility in the electricity system, but is also faced with some additional challenges. These are;

(d) The **business case**; further to the above it is important to remove regulatory barriers like double taxation and feed-in tariffs that exist in some countries. These are prerequisites to a positive business case.

(e) Further to the **harmonisation** in the e-mobility ecosystem it's important that both vehicles and recharging points are hardware capable for bidirectional charging, support the latest standards (ISO15118-20, OCPP 2.1) and are software enabled to allow bidirectional charging. With the latter often not possible due to immaturities around interoperability, the possibility to remotely update to the latest protocols and enable bidirectional charging is probably the best viable option for these manufacturers today.

(f) **Network code** complexity for bidirectional charging present challenges for the implementation of V2X technologies. These challenges are primarily related to AC charging where typically the combination of the CP and EV needs to comply with these codes. As there are numerous configurations between EV and CP possible and since EVs can cross borders with implications on which national grid codes to comply to, there is a clear need to revisit the regulatory framework to allow V2X on full scale.

Knowing the complexity of implementing smart and bidirectional charging today, there are differences in this complexity from cluster to cluster. The below provides an overview of these differences.

5.2 Continued efforts to upscale

At the present level of maturity on advanced smart charging and bidirectional charging it is clear that we're far from a fully open and interoperable ecosystem. There is a clear need to continue to upscale with implementations to further enhance the maturity level. By different implementations across a variety of use cases the different stakeholders can all make their contributions and progress together to overcome the addressed challenges of today.

From SCALE and the previous chapter it is apparent that there are important differences between the innovation clusters. In certain clusters, commercially viable concepts on smart, but also on bidirectional charging already exist today. In the table below an overview of today's key challenges faced by smart and bidirectional charging are provided in relation to the 4 innovation clusters.

Innovation Cluster	Immature interoperability	Stakeholder complexity	Network code complexity (V2X)
A: Smart home charging	+	+	+
B: Smart charging at businesses/ offices	-	-	- -
C: Smart charging of light and HD fleets	0	+	+
D: Smart public charging	- -	- -	- -

(++) not an issue <---> significant issue (- -)

Important to mention here is that all the key challenges are related to both smart - and bidirectional charging with the exception of the "network code complexity" which is on bidirectional charging. What can be concluded from the table is that barriers to implement advanced smart charging solutions in business and offices (IC-B) and for public charging (IC-D) faces higher challenges. It's also visible that there are "low hanging fruit" clusters such as home charging (IC-A) and to a lesser degree charging of light and heavy-duty fleets. This is also visible in some of the commercial solutions offered by OEMs today. These solutions are often closed setups with no or limited variance between the type of EV, CP and EMS to avoid interoperability issues. Nevertheless they have adopted the open standards, contribute to the learnings of its use and therefore to further mature it. Also these "low hanging fruit" clusters can serve as a stepping stone to learn from and improve the business cases around the various use cases in these innovations clusters. This is also likely to result in more momentum for the less progressive stakeholders to advance their efforts and take part in the smart charging and V2X ecosystem. Examples of these stakeholders include manufacturers of CPs or BEVs whom currently do not see a clear market for advanced smart charging and bidirectional charging.

For the innovation clusters B and D it is apparent that there are showstoppers hindering the commercial roll out today. More experimental pilots are needed or solutions have to be investigated in specific use cases with shared electric cars like in SCALE. Conducting those pilots creates momentum for more manufacturers and other stakeholders aim their efforts at maturing their technologies and unlock use cases in these innovations clusters.

5.3 Closing remarks

In this SCALE Lessons learned reports (D3.4) the focus has been on the learnings of the use cases and overarching innovation clusters, extracted from the knowledge and results from the earlier deliverables from this work package (D3.2 and D3.3). It also incorporates learnings that we can draw from previous SCALE reports and many WP3 meetings and workshops with the full SCALE team on related topics.

For more details on specific topics as an outcome of the SCALE pilots we refer to the upcoming SCALE deliverables that will be available soon. Centred on assessment and monitoring framework activities, upcoming reports from work package 4 will, amongst other, continue the SCALE work on training materials and shed light on impact assessment results of each use case in the following deliverables: Report on Energy, Social and Environmental Impact assessment (D4.3), Usability and User Experience Assessment (D4.4) & Training material and assessment (D4.5). Additional to the business model deliverable (D3.3) there will be a ROI calculation from work package 5 (D5.1) that gives a financial insight in the business models from the use cases.
Finally, in addressing the systems models, protocols and legal & policy recommendations, the following upcoming SCALE reports are also recommended: System model (D5.2), Legal & policy recommendations (D5.3) and Standards and protocols gap analysis (D5.5).

6. Bibliography

Aarvold Rastad, A., Sommerset Busengdal, H., & Hiep, E. (2023). *Report on consumer behaviour version 2.* SCALE Project deliverable D1.1.

Arias-Gaviria, J., & al., e. (2021). The Chicken and the Egg Dilemma for Charging Infrastructure and Electric Vehicle. *International Association for Energy Economics*.

Christiaens et al. (2023). *Use case setup report - SCALE Project deliverable D3.1.*

Christiaens et al. (2025). *Use case evaluation report - SCALE Project deliverable D3.2.*

Csukas et al. (2025). *Business Case analysis - SCALE Project deliverable D3.3.*

European Commission. (2023). *Housing in Europe – 2023 edition*. Retrieved from https://ec.europa.eu/eurostat/web/interactive-publications/housing-2023#how-we-live

Geerts et al. (2024). *Multi-actor Smart Charging & V2X System Architecture - SCALE Project deliverable D1.4.*

German Federal Ministry for Economic Affairs and Climate Action, B. (2024, January). *German Federal Ministry for Economic Affairs and Climate Action.* Retrieved from https://www.bmwk.de/Redaktion/DE/Downloads/P-R/coalition-of-the-willing-on-bidirectional-charging-en.pdf?__blob=publicationFile&v=8

Langenhuizen et al. (2022). *Stakeholder analysis – SCALE Project deliverable D1.2.*

Meersmans et al. (2023). *Analysis of hard- and software requirements - SCALE Project deliverable 1.5.*

Sautreau, J, & Meersmans, J. (2023). *Specifications and IT Use Case definition for V2X Services - SCALE Project deliverable D2.2.*

T. M. N. Bui, M. S. (2021). *A Study of Reduced Battery Degradation Through State-of-Charge Pre-Conditioning for Vehicle-to-Grid Operations.* IEEE Access, vol. 9, pp. 155871-155896.

7. List of figures