



Return on Investment Calculation

Project deliverable D5.1



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2 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), Greater Munich Area (DE), 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.

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3 Report executive summary

Key words

Electric vehicles, smart charging, Vehicle-to-Anything, flexibility markets, return on investment, business case analysis, financial potential analysis, business model.

Summary



Figure 1. Use case locations

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), Greater Munich Area (DE), 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.

The *Return on Investment Calculation report (D5.1)* examines the business models of seven use cases in SCALE and attempts to compile actual and/or projected cost and revenue data to bring forth useable insights about the financial potential and viability of these use cases for future scalability. Return on investment calculations have been conducted for a majority of these use cases where concrete business models have been piloted and relevant useable data has been collected or simulated. For a certain number of these use cases that did not have a traditional investment-return focus, other types of analyses have been conducted instead to showcase insights relevant to optimising for other types of value creation outcomes, such as strategies to reduce grid fees or to assess the most beneficial charging strategies on a levelised cost of charging basis.

The seven use cases examined were:

- UC00 – We Drive Solar (Utrecht)

- UCA2 – LVN (Germany)
- UCB3 – Enedis (Toulouse)
- UCB4 – Chalmers (Gothenburg)
- UCC2 – VDL (Netherlands)
- UCC4 – Stedin (Netherlands)
- UCD1 – CURRENT (Oslo)

Due to the highly varied nature of the technical aims, business models and geographical contexts of the use cases within SCALE, common take aways from the analyses can be difficult to generalise – local market and use case specific context are key. With this strong caveat in mind, the following paragraphs attempt to summarise some common themes and insights from the return on investment focused analyses of the eight use cases.

Common themes

Smart Charging and V2G as Cost-Saving Levers

Across a range of different charging contexts (residential, workplace, shopping centres, shared mobility, commercial fleet operations, heavy duty passenger transport) smart charging and V1G consistently reduces costs by shifting demand to off-peak periods.

Vehicle-to-Grid (V2G) further enhances savings, sometimes converting charging costs into net revenues when combined with ancillary service markets (Chalmers, Stedin, WDS).

However, returns from both V1G and V2G are highly sensitive to market conditions: high price volatility (2022, 2023) yields strong profitability, while calmer years (2024) result in weak or negative ROI for projects with high investment costs in order to enable the V1G and V2G functionalities.

Importance of flexibility markets

Participation in frequency reserves (FCR/aFRR) or congestion management (GOPACS, NODES) appear to be a critical revenue driver for many of the business cases examined.

Some of the use cases (Chalmers, Stedin, WDS) show that without access to these services, V2G often struggles to outperform unidirectional smart charging.

CURRENT's Oslo case underlines that even simple V1G + spot price optimisation + local flexibility markets can deliver €10–15 extra value per charger/month—scalable without new investment (when assuming smart charging capable chargers are standard).

Investment Horizon and Equipment Costs

ROI outcomes improve significantly with longer investment horizons (7.5 years vs 5 years) as shown in the analyses of the Stedin, Enedis and WDS use cases.

As long as bidirectional chargers remain expensive, this will continue to put pressure on ROI viability under low-price conditions in the energy and ancillary services markets.

Future cost reductions in bidirectional chargers could materially improve viability.

Role of Regulation and Tariffs

National regulatory frameworks and the creation of new flexibility markets strongly shape value realisation:

- Germany (§14a EnWG) introduces mandatory controllability of large loads, with compensation modules that change optimal household choices (LEW).
- France: subscribed capacity limits and penalty fees create a plausible case for smart charging in depots (Enedis).
- Netherlands: congestion and balancing platforms (aFRR, GOPACS) provide important new revenue streams (Stedin, WDS).
- Norway: NODES platform allows trading of flexibility for V1G with minimal investment (CURRENT).

Operational Trade-offs and Risk Factors

Customer experience vs revenue: more aggressive flexibility participation risks leaving EVs undercharged (CURRENT, Stedin).

Uncertainty in revenues: Almost all business cases and revenue models assume perfect foresight or historical back-testing; real-world forecasting errors will likely reduce margins.

Battery degradation is only modelled in some cases (Chalmers, Stedin), generally showing limited but not negligible economic impact. However, access to battery degradation models validated by real world data is still a challenge.

Cross-cutting insights

- Smart charging is already economically justified across all cases.
- V2G has strong potential but fragile economics, hinging on market access (frequency/congestion markets), hardware costs, and electricity price volatility.
- Scale and long horizons matter: returns improve markedly with larger fleets, charger utilisation, or extended asset lifetimes.
- Policy and regulation are decisive: tariff design, double-taxation issues, and grid fee structures all heavily affect outcomes.
- Heavy-duty and depot contexts highlight grid capacity and reinforcement avoidance as key value drivers, often overshadowing direct market revenues.

In short:

Smart charging is a no-regret option today, V2G is promising but not broadly profitable yet, and success depends on regulatory frameworks, cost trajectories, and market volatility.

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4 List of abbreviations and acronyms

Acronym	Meaning
AC	Alternating Current
AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
aFRR	Automatic Frequency Restoration Reserve
BEMS	Building Energy Management System
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CCS	Combined Charging System
CEP	Clean Energy for all Europeans Package
CP	Charge Point
CPMS	Charging Point Management System
CPO	Charge Point Operator
DC	Direct Current
DSO	Distribution System Operator
EED	Energy Efficiency Directive
eMIP	eMobility Interoperation Protocol
EM	Energy Manager
EMS	Energy Management System
eMSP	e-Mobility Service Provider
EPBD	Energy Performance of Buildings Directive
ETD	Energy Taxation Directive
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserves
FSP	Flexibility Service Provider
GDPR	General Data Protection Regulation
GRI	Global Reporting Initiative
HEMS	Home Energy Management System

ISP	Imbalance Settlement Period
KPI	Key Performance Indicator
LDV	Light duty vehicle
mFRR	Manual Frequency Restoration Reserve
MWS	Megawatt Charging System
OCHP	Open Clearing House Protocol
OCPI	Open Charge Point Interface protocol
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OICP	Open InterCharge Protocol
OpenADR	Open Automated Demand Response
PKI	Public Key Infrastructure
PV	Photovoltaic
RED	Renewable Energy Directive
RTO	Research and Technology Organisation
SCALE	Smart Charging Alignment for Europe
SoC	State-of-Charge
TEN-T	Trans-European Transport Network
ToU	Time-of-Use
TSO	Transmission System Operator
VPP	Virtual Power Plant
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

5 Purpose of the deliverable

The Return on Investment Calculation report (D5.1) examines the business models of seven use cases in SCALE and attempts to compile actual and/or projected cost and revenue data to bring forth useable insights about the financial potential and viability of these use cases for future scalability.

It builds on earlier SCALE work packages, *D3.2 Use Case Evaluation Report*; and *D3.3 Business Case Analysis*.

A core purpose of the deliverable is to demonstrate in a transparent way, with metrics anchored in real data, plausible business models based on the use cases examined. In a majority of the use cases, concrete business models were either piloted or simulated, and return on investment calculations were able to be conducted to show the scale of the potential in relation to smart charging, V1G and/or V2G. In a small number of use cases, other financial analyses were employed instead of a return on investment approach, due to the context differing from that of a traditional business model with an upfront investment generating revenue over time.

Initially this report intended to cover eight use cases – two from each of the innovation clusters. However, due to both of the use cases from the Vehicle-to-Home innovation cluster being terminated during the use case setup phase, it was only possible in the time-frame remaining to conduct this work on one of the two replacement use cases. The deliverable was also delayed by five months due to a combination of factors, which include challenges obtaining real-world data and simulation results, staff sickness, and the desire to include the use case from LVN, who's delayed participation in SCALE resulted from the withdrawal of the earlier partners in the V2H innovation cluster.

6 Introduction

The rapid electrification of road transport is transforming not only how vehicles are powered, but also how they interact with the wider energy system. Electric vehicles represent both a new source of demand and, increasingly, a potential source of flexibility. Through smart charging (V1G) and bidirectional vehicle-to-grid technologies, EVs can shift consumption to off-peak periods, provide grid support, and in some cases even generate net revenue. These capabilities open opportunities for new business models, but also raise important questions about cost-effectiveness, scalability, and regulatory fit.

This report brings together seven case studies developed within the SCALE project, each examining the financial and operational potential of smart charging and V2G in different European contexts. The cases span a range of geographies, actors, and applications – and provides broad coverage of all four of the SCALE innovation clusters.

The included use cases are listed below under their respective innovation clusters.

Overarching use case

- (WDS, Utrecht) Bi-directional ecosystem via combined V2G service

Innovation cluster A: Smart home charging

- (LEW, Germany) Extension to V2G services enabling participation in energy market

Innovation cluster B: Smart charging at businesses & offices

- (Enedis, Toulous) Smart Charging in car dealer depot
- (Chalmers, Gothenburg) V2G chargers at office and residential buildings

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

- (VDL, Netherlands) Highway charging with local generation & storage
- (Stedin, Netherlands) Smart charging of light commercial vehicles

Innovation cluster D: Smart public charging

- (CURRENT, Oslo) Smart Charging and V2G for public in commercial and residential neighbourhood
- *WDS Utrecht use case is highly relevant to this innovation cluster, but also overarches several innovation clusters and has therefore been grouped into its own category.*

Together, these case studies provide a cross-sectional view of the emerging economics of EV flexibility in Europe. They show that while smart charging is already viable today, the pathway to profitable V2G requires careful alignment of technology costs, regulatory frameworks, and market design. The findings are intended not only to inform operators and policymakers, but also to support ongoing experimentation as Europe scales up the role of EVs in a decarbonised and ever more decentralised energy system.

7 Analyses of the selected use cases

We Drive Solar (Utrecht): Bi-directional ecosystem via combined V2G service

Background

We Drive Solar (WDS) is primarily a charge point developer and operator based in Utrecht, the Netherlands. WDS provides charging as a service to a number of customer segments (private, semi-public and public). Beyond just simple charging, they have developed and integrated smart charging solutions including bi-directional charging and power management with locally generated solar and load balancing. WDS chargers are used by both the general public in Utrecht as well as by WDS, a car-sharing service. WDS is the official charging partner for MyWheels in Utrecht.

MyWheels is the largest car-sharing platform in the Netherlands, offering a sustainable and flexible alternative to car ownership. MyWheels has grown into a nationwide network with thousands of cars across approximately 90 Dutch cities. MyWheels operates over 800 electric shared cars in Utrecht, making it the city with the highest density of MyWheels vehicles and users per capita in the Netherlands. They operate both free-floating (zone-based) and station-based cars in their fleet.

This study is based on the station-based portion of the V2G compatible EV fleet owned and operated by MyWheels. The station-based nature of this fleet means the vehicles are parked and returned to the same parking spot and WDS charger after each use-period by the customer. As such, the vehicles are always connected to their V2G charger and available for smart and V2G charging whenever they are not booked.

Approach

The business case of WDS examined in this financial potential analysis consists of WDS providing charging services as a CPO for the fleet of shared EVs managed by MyWheels. The business case is evaluated for the years 2025 and 2030, based on real-world data obtained during the SCALE project.

The result is an overview of the business case, presented in the form of Sankey diagrams, showing all the relevant revenue streams as well as operating expenses. These streams are modelled and quantified, based on collected data from the SCALE pilot. Key assumptions underlying the modelling are described below.

Based on these quantified revenue and operating expenses streams a calculation of the return on investment is also made.

Key assumptions and demarcation

The financial potential analysis is viewed from the perspective of WDS as CPO, the party that operates a fleet of V2G chargers. The chargers are used by MyWheels's station-based car-sharing fleet in Utrecht. The analysis focuses on the operation of those chargers only.

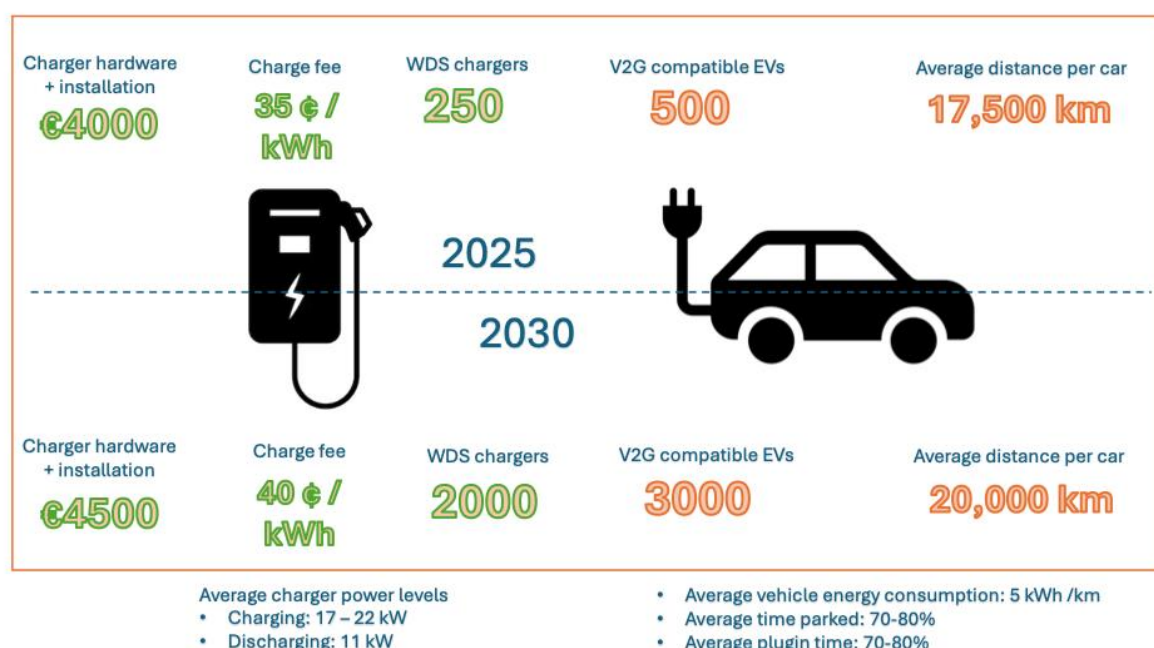
The operation of other WDS chargers in Utrecht used by the general public is not included in this analysis. Furthermore, the operation of the fleet of shared EVs, which is managed by MyWheels, is not in focus here.

The financial potential analysis would be different for future use cases and market segments such as chargers with company/lease cars, public chargers with private customers, or as private chargers at homes of EV customers.

The analysis is conducted for two periods, the calendar years 2025 and 2030. The subsection 'Key Numbers' below shows the different assumptions underlying the analysis for these two years.

The WDS chargers are assumed to have large scale V2G functionality in cooperation with MyWheels' fleet of V2G shared EVs. For those evaluation years, a number of assumptions are made concerning electricity market prices and benefits, the scale of operations and other inputs. Specifically, the 'aFRR benefits' and 'GOPACS benefits' flexibility markets are assumed to be operational in both 2025 and 2030 scenarios. Coupling to aFRR is being developed and tested through the Equigy platform in SCALE, and coupling to the congestion management platform GOPACS is similarly being developed and tested within the project ROBUST; both can be expected to be operational in 2025 or maybe 2026.

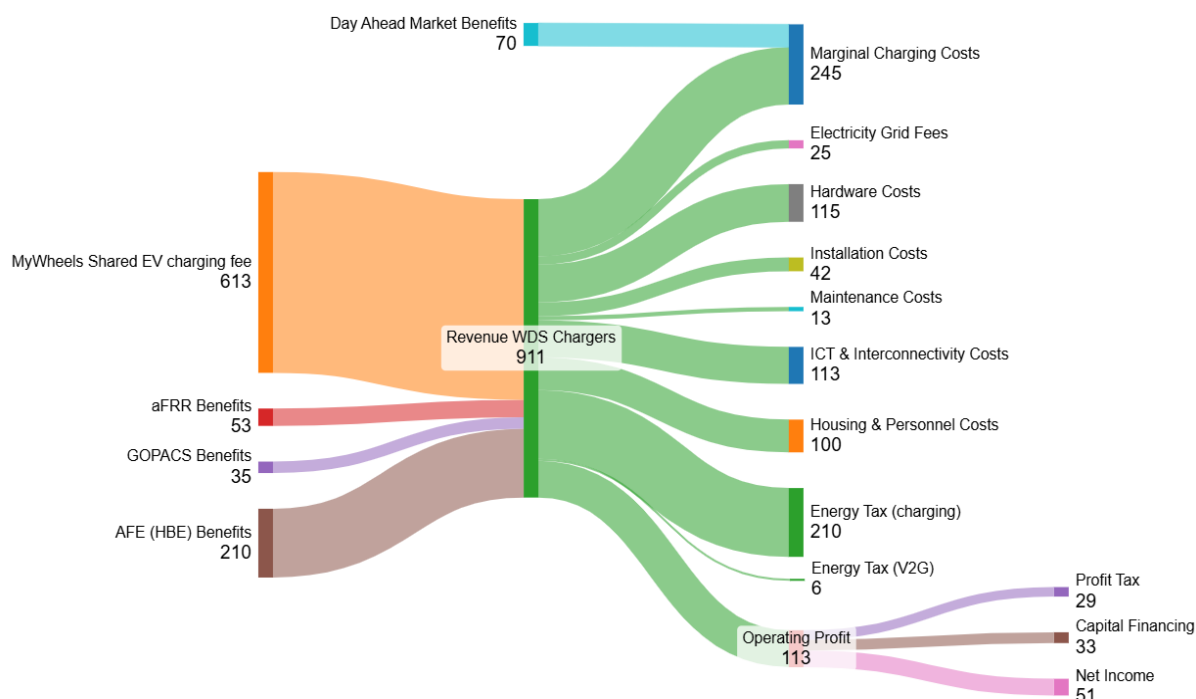
Key numbers



Assumptions	2025 Scenario	2030 Scenario
V2G charger costs (incl. installation)	€4000	€4500
# of chargers	250 (minority with V2G support)	2000 (majority with V2G support)
Power levels of chargers	17-22 kW charging 11kW discharging	
Charging fee	35 cents / kWh	40 cents / kWh
# MyWheels EVs (V2G compatible)	500	3000
Size of EV batteries	Variable	
Average EV distance travelled per year	17,500 km	20,000 km
Average energy consumption	5 kWh / km	
Average time parked at charger	70-80%	
Average time plugged in	70-80%	

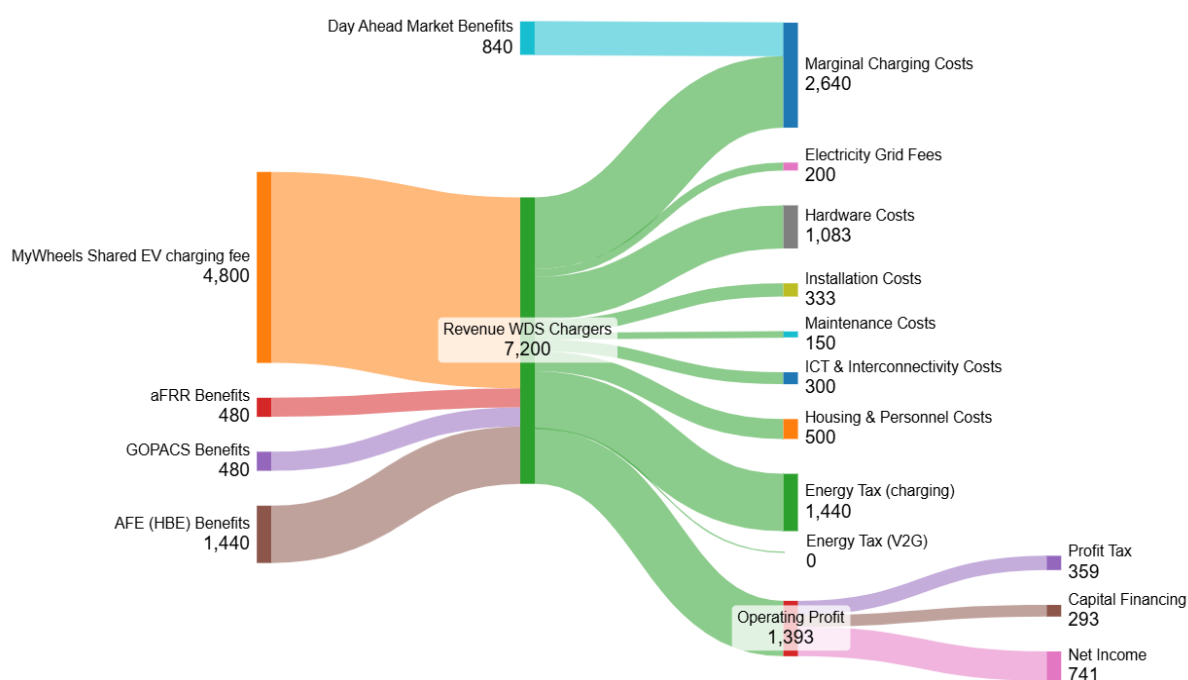
Result of analysis

Below is a Sankey representation of the business case calculated for 2025 and 2030 in the form of a Sankey diagram, with the units representing 1000 euros. Costs shown for hardware have been annualised and include depreciation costs. Detailed descriptions of the various value streams and the underlying assumptions related to them are provided in the table further below.



In 2025 with only 500 V2G compatible EVs and 250 bidirectional chargers, operating profit is low in this phase. Revenue largely depends on the MyWheels charging fee and AFE benefits, with smaller

contributions from providing services for frequency regulation (aFRR) congestion management (GOPACS). The cost of charging is also reduced by smart charging, optimised for the day ahead market – contributing to lower operating expenses on par with the value of aFRR and GOPACS combined. After charging costs, the other major cost components are hardware and installation costs of the chargers, energy tax and then overheads – such as the ICT systems, maintenance, housing and personnel costs. In this scenario, the operating profit still represents about 12.4% of revenue.



For 2030, with a six-fold larger fleet and eight-fold number of V2G chargers, leading to much higher V2G operability, the operating profit grows to 19.3% of revenue (from 12.4% in 2025). The diagram contains several elements for which the actual value will be highly-dependent on a number of factors that are hard to estimate at this time. This means that depending on those factors, charging fees to MyWheels may need to be higher or lower than estimated here, to arrive at a workable profit margin. In the scenario modelled here, a 5 euro cent increase in the charging fee from the 2025 scenario has been assumed – taking it from 35 euro cents per kWh to 40 euro cents per kWh.

In this scenario, most of the revenue and cost streams contribute almost proportionally the same as in the 2025 scenario- However economies of scale savings can be seen in the overhead costs, which only increase about four-fold compared to an eight-fold increase in revenue and most other operational costs. These savings are largely responsible for the increase in operating profit as a proportion of overall revenue.

Description of the value flows and assumptions

Mywheels Shared EV Charging Fee	The WDS chargers are assumed to charge MyWheels shared EVs. WDS receives charging fees from MyWheels, which in turn has income from the shared car users (not shown).
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aFRR Benefits	The chargers are assumed to deliver services to the aFRR balancing market and this describes the benefits to WDS. Coupling to aFRR is currently being developed and tested in SCALE. Utrecht University has evaluated aFRR benefits for smart charging and V2G charging of shared EVs based on historic usage patterns of the WDS/Mywheels shared EV fleet. The results are condensed into a simplified benefit assumption.
GOPACS Benefits	The chargers are assumed to deliver services to the Dutch congestion management platform GOPACS and this describes the benefits to WDS. Coupling to the GOPACS platform is similarly being developed and tested within the project ROBUST. The benefits are hard to predict, as currently the volumes on the GOPACS platforms are still small and prices very high and volatile. Simple assumptions on volume and prices have been used.
Day Ahead Market Benefits	WDS is already operating smart charging of its chargers steered by the Day Ahead Market and this describes the benefits to WDS. This benefit is fed into the Net Electricity Costs cost item as it presents itself as a price reduction as compared to non-smart charging.
Marginal Charging Costs	Net costs paid for electricity. Energy Tax is considered separately.
Alternative Fuel Units (AFE) benefits	The Alternative Fuel Units provide financial benefits for electricity generated in a sustainable way. Incomes vary strongly and are dependent on whether the electricity is generated locally or not. The average income is estimated for a mix of locally and non-locally produced sustainable electricity (which is the case for the WDS chargers).
Energy Tax (charging)	The Energy Tax in the Netherlands currently is 12 Eurocents per kWh.
Energy Tax (V2G)	At the moment, there is double Energy Tax for V2G kWh discharged (and delivered to third parties) which is taken into account for 2025. For large batteries, already there is no double taxation, but for V2G this still is being implemented in regulations. It is assumed that double taxation for V2G will not be in place by 2030.
Electricity Grid Fees	All electricity grid fees including possibly dynamic grid fees
Hardware Costs	All hardware costs and depreciation of the chargers.
Installation Costs	All installation costs
Maintenance Costs	All maintenance costs

ICT & Interconnectivity costs	All costs related to ICT backoffice, central control, financial settlement and connection to market platforms and other systems
Housing & Personnel costs	Costs made at WDS, including personnel costs for continuous innovation.
Operating Profit	Gross profit, from which capital financing and taxes still need to be deducted.
Capital Financing	Costs connected to capital financing of the chargers and installation
Taxes	All taxes for WDS connected to the operating profit of the chargers (excluding energy tax, see above)
Net Income	Net income after taxes and depreciation for WDS

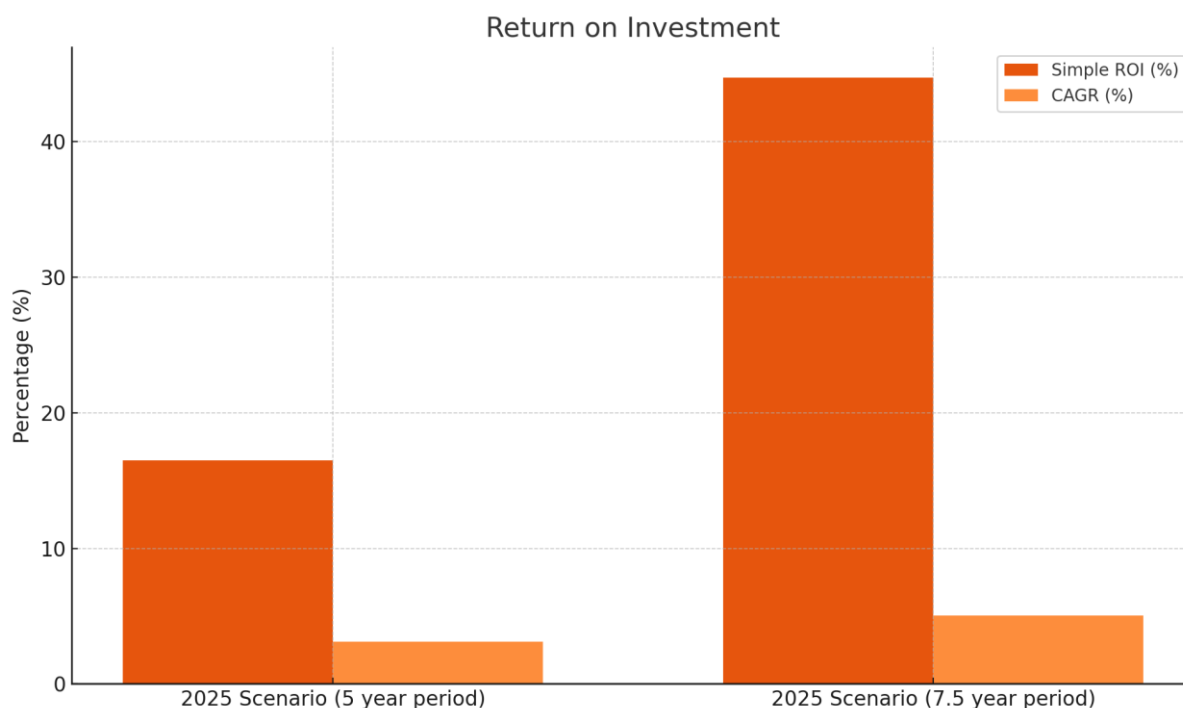
Return on investment calculation

A return on investment analysis is shown below for both the 2025 and 2030 scenarios. The two analyses conducted each assume that the revenue, costs and operating profits stay the same each year over the investment period. This approach was taken for simplicity and to enable the results to be easily interpreted. Given there are already many uncertainties and assumptions that underline the revenue and cost estimates, introducing additional assumptions around variations in income and expenses from year to year would potentially add complexity without increasing the overall accuracy of the ROI analysis. Nevertheless, the ROI analysis still can provide a valuable insight into the approximate magnitude of the returns that can be expected for such a business case.

Two investment periods were calculated, 5 years and 7.5 years. The initial investment amount consists of the cost of the charger hardware plus installation costs. Given that depreciation costs of the chargers are already factored into the operating expenses, in order to avoid double-counting the residual value of the charger hardware is assumed to be 100% of its initial value. Because no separate breakdown of the hardware and the installation components were given (i.e. only a combined hardware plus installation cost was provided) an assumption is made that 60% of the combined cost is due to the hardware component, while 40% is due to installation. Therefore, the residual value used in the ROI calculation is set at 60% of the initial investment.

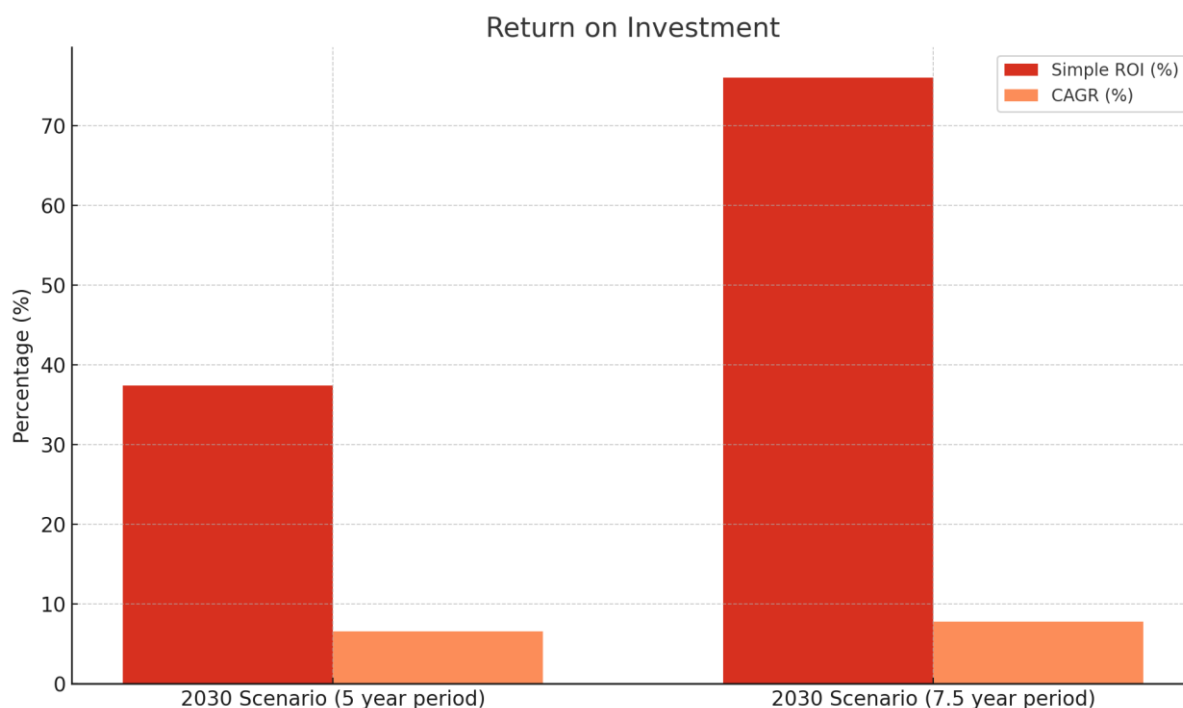
The diagrams below show the result of the 2025 and 2030 scenarios with 5-year and 7.5-year investment periods. This is followed by a table outlining the ROI inputs into the scenarios.

2025 Scenario



While both analyses based on the 5-year and 7.5-year time periods come out positive, the investment period makes a significant difference. In the 5-year ROI, the return is 16.5% but this grows to almost 45% just by extending the investment period by another 2.5 years. This indicates that the service life of the V2G chargers will play a crucial role in the ROI. When converting the ROI to a compounded annual growth rate (CAGR) we get 3.1% and 5.05% respectively for the two investment periods. While this sits below the typical range of 10-25% for corporate projects, and more in line with public sector projects of 4-10%, it is not surprising given that the 2025 scenario represents a pre-scaled up situation.

2030 Scenario



For the 2030 scenario there is an improved ROI for both investment periods calculated. For the 5 year period the ROI is 37.4% (compared to 16.5% for 2025 scenario) and for the 7.5 year period it is 76.1% (compared to 45% for 2025 scenario). The CAGR is also better, however with more marginal improvements, at 6.6% and 7.4% respectively. This indicates that the magnitude of returns for such a project still falls below typical expectations in the corporate world.

Discussion of results

The financial potential analysis and the return on investment calculations presented in this report provide a quantitative lens through which to evaluate the financial potential of large-scale deployment of V2G-capable chargers by We Drive Solar for their specific business case as a charging provider to a car-sharing fleet. The results from both the 2025 and 2030 scenarios highlight not only the current limitations but also the future potential for profitability as the scale of operations increases.

A key takeaway is the strong sensitivity of ROI to the investment period. Extending the assumed service life from five to 7.5 years significantly improves the ROI across both scenarios. This underscores the importance of asset durability and long-term operational planning. Furthermore, the analysis shows clear economies of scale in 2030, with higher revenues and only proportionally moderate increases in overhead costs, contributing to a more favorable ROI outlook.

While the calculated CAGR values (between 3.1% and 7.4%) may fall short of what is typically expected in private sector ventures, they remain in line with public infrastructure projects and early-stage clean tech investments. Importantly, the ROI in both year scenarios remain positive even under relatively conservative assumptions. This contrasts with many other early-phase sustainable technologies that often face prolonged periods of unprofitability.

LEW (Germany): Extension to V2G services enabling participation in energy market

Background

LEW Verteilnetz (LVN) is the regional electricity distribution operator in Bavaria, Germany. As such, they are responsible for the construction, operation, and maintenance of electricity distribution networks - serving nearly 1 million residents in a network spanning Swabian Bavaria and parts of Upper Bavaria.

In this use case, LVN is examining the value of optimised self-consumption of residential PV systems in combination with smart (uni-directional) charging as well as bidirectional charging. In doing so, they are seeking to determine and optimise the costs and benefits for the end user – taking into account hardware, installation and operation costs, quantifying EV battery life and savings on energy costs.

An important part of this analysis is taking into account the interactions of smart home charging with the latest grid-orientated control requirements of the German legal framework - §14a of the German Energy Industry Act (EnWG).

According to §14a EnWG, systems with a capacity of more than 4.2 kW that are installed after January 1, 2024 must be controllable. Controllable consumption units include energy storage systems, heat pumps, charging points for electric vehicles, and space cooling systems. This allows the grid operator to temporarily reduce the power output when necessary to relieve stress on the grid. As a result, the secure integration of new consumption units is ensured, whilst overloading of the local grid is prevented.

While the grid-orientated control requirements are mandatory for all controllable consumption units with a capacity of more than 4.2 kW, customers are compensated in terms of reduced grid fees and/or cost of electricity. As part of this, customers must choose from a range of 'modules' which determine the structure of the compensation regime.

However, understanding the practical implications of these module choices can be complex – given they each include different upfront costs, equipment installation costs, and pricing structures for electricity tariffs on the one hand, and flat vs. variable compensation, on the other hand. As such, LVN has conducted a financial cost-benefit analysis to simplify the module choice for customers, and which also contributes to understanding the range of cost savings that smart-charging of EVs can result in under each of those choices.

Approach

A financial cost-benefit analysis was undertaken by LVN. This analysis compared a reference case (without the grid-orientated control remuneration regimes) against the costs and benefits of the remuneration regimes under each of the 3 modules.

The figure below provides a summary of the remuneration regimes under each of the modules.

Overview of the Grid Fee Reduction Modules in the LVN Grid Area

Module 1	Module 2	Module 3
Includes a grid fee reduction in the form of an annual flat-rate payment, which is credited to the customer's electricity bill as a cost reduction For Module 1, it is not required that the controllable consumption unit is connected to the power grid via a separate meter. The flat-rate amount may vary depending on the grid area. 2025 in the LVN network are : €111.25/year Billing is carried out on an annual basis.	Includes the reduction of the energy price to 40% of its original value (5.87 ct/kWh → 2.35 ct/kWh). This discount applies to every kilowatt-hour consumed by the controllable consumption unit, and the basic grid fee is also waived. Requirements: Module 2 requires a separate metering point for the controllable consumption unit.	Introduces a time-variable grid fee that changes depending on the time of day: • (HT) Peak tariff: 11.66 ct/kWh • (ST) Standard tariff: 5.87 ct/kWh • (NT) Off-peak tariff: 0.59 ct/kWh Customers are incentivized through a very low off-peak rate to shift their electricity consumption to periods with lower costs, thereby relieving the grid. Requirements: • Module 3 can only be selected in combination with billing Module 1. • A smart metering system is mandatory for billing under Module 3. • Additional fee for early installation: €57.28/year
Flat-rate remuneration	Percentage reduction	Variable grid fee

The cost-benefit analysis for each of these modules were then calculated for two different scenarios, with the first scenario being based on an annual consumption of 6000 kWh and the second scenario based on 8500 kWh. In both scenarios, the household consumption is held constant at 3500 kWh, but in the second scenario the EV consumption is increased from 2500 kWh to 5000 kWh – representing a high EV charging case.

The full assumptions underlying the cost-benefit analysis and scenarios are provided in the following section. This is followed by a section outlining the results and then a section discussing the findings.

Key assumptions and demarcation

The following diagrams (representing each of the two scenarios) outline the underlying assumptions for the reference case and the 3 modules. They take into account the specific structure of the remuneration regimes of each of the modules that customers must choose from when they have a 'controllable consumption unit' such as energy storage systems, heat pumps, charging points for electric vehicles, and space cooling systems. For each of the two scenarios, the overall total annual consumption is split between a household portion and an EV portion. While the household portion remains the same under both scenarios, the EV portion in the second scenario is doubled.

Total annual consumption = 6000 kWh

Parameter	Reference	Module 1	Module 2	Module 3
Annual consumption Household EV	3500 kWh 2500 kWh			
Flat-rate remuneration	-	111,25 €/year	-	111,25 €/year
Basic fee Variable price Meter 1	73 €/year 5,87 ct/kWh			73 €/year NT:0,59 ST:5,87 HT:11,66 (ct/kWh)
Basic fee Variable price Meter 2 (EV)	-	-	0,00 €/year 2,35 ct/kWh	-
Tariff shares – Optimized	-	-	-	NT: 40% ST: 50% HT: 10%
Tariff shares – Unoptimized	-	-	-	NT: 10% ST: 30% HT: 60%
One-time meter installation cost	-	-	mME: 79,93€	-
Meter operation cost	21,01 €/year	21,01 €/year	21,01 €/year (x2)	25,21 €/year

Total annual consumption = 8500 kWh

Parameter	Reference	Module 1	Module 2	Module 3
Annual consumption Household EV	3500 kWh 5000 kWh			
Flat-rate remuneration	-	111,25 €/year	-	111,25 €/year
Basic fee Variable price Meter 1	73 €/year 5,87 ct/kWh			73 €/year NT:0,59 ST:5,87 HT:11,66 (ct/kWh)
Basic fee Variable price Meter 2 (EV)	-	-	0,00 €/year 2,35 ct/kWh	-
Tariff shares – Optimized	-	-	-	NT: 40% ST: 50% HT: 10%
Tariff shares – Unoptimized	-	-	-	NT: 10% ST: 30% HT: 60%
One-time meter installation cost	-	-	mME: 79,93€	-
Meter operation cost	21,01 €/year	21,01 €/year	21,01 €/year (x2)	33,61 €/year

The time frame for the analysis is 6 years, from 2024 to 2030.

Another key assumption is that the grid costs will remain constant over this period.

It is worth noting that the financial cost analysis conducted by LVN focuses only on the grid fees for electricity supply, and does not take into account the other cost components such as procurement (i.e. what the retailer charges), taxes and levies.

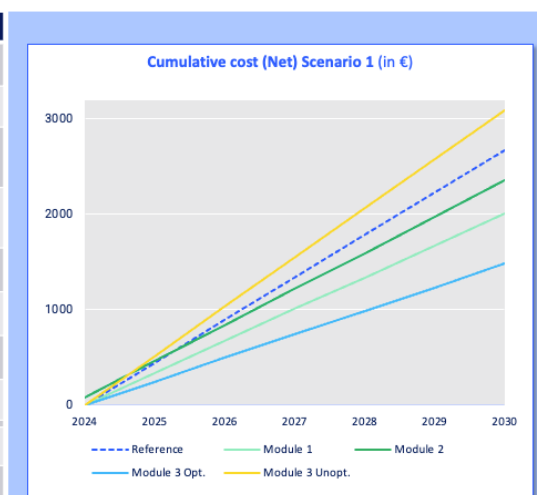
Result of analysis

The results of the financial cost-benefit analysis are summarised in the following two diagrams representing each of the scenarios.

Cost Simulation: Scenario 1

Total annual consumption = 6000 kWh

Parameter	Reference	Module 1	Module 2	Module 3
Annual consumption Household EV	3500 kWh 2500 kWh			
Flat-rate remuneration	-	111,25 €/year	-	111,25 €/year
Basic fee Variable price Meter 1	73 €/year 5,87 ct/kWh			73 €/year NT:0,59 ST:5,87 HT:11,66 (ct/kWh)
Basic fee Variable price Meter 2 (EV)	-	-	0,00 €/year 2,35 ct/kWh	-
Tariff shares – Optimized	-	-	-	NT: 40% ST: 50% HT: 10%
Tariff shares – Unoptimized	-	-	-	NT: 10% ST: 30% HT: 60%
One-time meter installation cost	-	-	mME: 79,93€	-
Meter operation cost	21,01 €/year	21,01 €/year	21,01 €/year (x2)	25,21 €/year
Total cost (Net)	446,21 €/year	334,96 €/year*	379,22 €/year	Unopt.: 515,92 €/year* Opt.: 247,18 €/year*



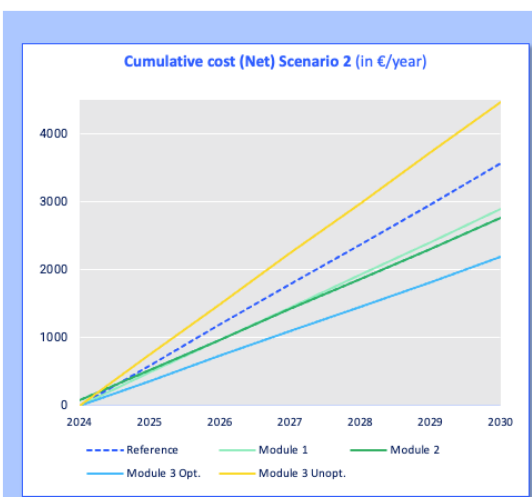
all values net | *Offset against Flat-rate remuneration | Use of a smart metering system is mandatory for operators of controllable consumption units (§14a EnWG)

3

Cost Simulation: Scenario 2

Total annual consumption = 8500 kWh

Parameter	Reference	Module 1	Module 2	Module 3
Annual consumption Household EV	3500 kWh 5000 kWh			
Flat-rate remuneration	-	111,25 €/year	-	111,25 €/year
Basic fee Variable price Meter 1	73 €/year 5,87 ct/kWh			
Basic fee Variable price Meter 2 (EV)	-	-	0,00 €/year 2,35 ct/kWh	-
Tariff shares – Optimized	-	-	-	NT: 40% ST: 50% HT: 10%
Tariff shares – Unoptimized	-	-	-	NT: 10% ST: 30% HT: 60%
One-time meter installation cost	-	-	mME: 79,93€	-
Meter operation cost	21,01 €/year	21,01 €/year	21,01 €/year (x2)	33,61 €/year
Total cost (Net)	592,96 €/year	481,71 €/year*	445,67 €/year	Unopt.: 744,72 €/year* Opt.: 364,05 €/year*



all values net | *Offset against Flat-rate remuneration | Use of a smart metering system is mandatory for operators of controllable consumption units (§14a EnWG)

4

The results for module 1 are the same in both scenarios – this is to be expected as it provides a flat-rate remuneration of €111,25 per year.

The results for module 2 are more mixed. It underperforms module 1 in the first scenario and performs marginally better than it in the second scenario. This suggests that in order to be seen as a better option than module 1, a user would need to have 5000 kWh or more of annual energy use from their controllable consumption unit. The upfront cost of the separate metering point for the controllable consumption unit (a requirement for being able to choose module 2) also contributes to a lower marginal benefit when compared to module 1.

The results for module 3 show a wide spread between the optimised and unoptimised cases – this is to be expected given the significant difference in cost between the off-peak and peak tariffs. By using only 10% of total daily consumption during peak tariff hours, and the rest spread equally between standard and off-peak hours, it is possible to save €200–€230 a year compared to the reference case. However, choosing module 3 also comes with the risk of resulting in the highest cost if loads are not optimised away from the peak tariff hours.

Discussion of results

An important preparatory step for designing and realising business models around smart charging, V1G and V2G is understanding the incentive structures of the electricity market, including particularly the local grid, and how this may interact with typical household and EV use of energy. This business case analysis has looked specifically at the latest grid-orientated control requirements of the German legal framework (§14a of the EnWG) and how the different remuneration options under that framework in the LVN grid area could impact grid fees for typical households with EV charging.

The financial cost-benefit done shows that for the typical household use cases covered by the two scenarios:

- Module 1 provides a stable and reliable cost advantage over the reference in both scenarios, making it a low-risk choice, especially at lower EV consumption levels.
- Module 2, while initially burdened by setup costs, becomes increasingly competitive over time. The benefit of Module 2 increases with a higher EV share of consumption, as the percentage discount then has a stronger effect.
- Module 3 strongly depends on optimisation. Low optimisation can result in the highest cost, even when compared to the reference case. However, strong optimisation can result in this module being the lowest cost.

Overall, Module 1 is the most robust short-term choice, Module 2 pays off at high EV consumption, and Module 3 offers the greatest long-term potential with consistent load shifting.

The implication that this analysis has for (unidirectional) smart charging is that the grid fee component of household energy use plus charging can be most significantly reduced under module 3 – but only if both charging and household energy are substantively optimised away from the peak tariff periods. Just optimising the EV load alone will likely not be enough to achieve the same magnitude of savings that were shown for the optimised case under Scenario 2. This suggests that there could be a useful role to play not only for smart charging, but for bidirectional vehicle-to-building applications.

However, it may be important to keep in mind that the financial cost-benefit analysis conducted here only takes into account local grid fees, and not the retail cost of electricity. For customers exposed to time-of-use tariffs, they may in some cases need to optimise between lower dynamic grid fees (under module 3) and lower ToU prices for the retail component of electricity – and this could result in modules 1 or 2 being a better option.

Further analysis could also potentially explore scenarios for multi-family dwellings with large amounts of onsite EV chargers.

Enedis (Toulouse): Smart Charging in car dealer depot

Background

Enedis, as the national Distribution System Operator in France, are looking at optimizing charging strategies within logisticians' depots to facilitate electric vehicle grid integration for the mass-scale future uptake of EVs. The main goal, from its perspective as a DSO, is to reduce the grid capacity, and thus the needed grid reinforcement. But as a whole, it is also to forecast how much power increase will be needed for similar sites (which are numerous in the territory) and prepare for a fair power increase at a proper localization.

This use case, conducted in Toulouse, takes place at a vehicle depot where the share of EVs in the fleet (currently composed mainly of light passenger internal combustion cars) is steadily increasing each year. This use case aims to analyze the existing on-site charging infrastructure and project the required power capacity for future scenarios, characterised by a significant increase in fleet electrification. Up to now, the number of EVs are manageable but as electrification of the car fleet is growing, there is a need to

understand how much power capacity will be requested in the mid-term (with and without smart charging options) for this use case.

The vehicle depot in Toulouse stores cars (light passenger vehicles and vans) temporarily before they are transported further to distribution sites, such as car dealerships – where they are subsequently sold or transferred over to new owners. The customers for storage services are either OEMs for new car storage or renting agencies for their fleet maintenance or renew.

For about 10 years the site has also accommodated EVs, which need to be charged before being delivered onwards. Onsite chargers are used by the staff to charge these vehicles from about 50% to 100% SOC before being delivered (the average in 2023 is about 10 to 30 EVs being charged per day). The EVs are driven to be parked next to the on-site chargers. For safety reasons it is recommended to charge only when employees are present. This means the EVs cannot currently be plugged in and left to charge after working hours, nor scheduled to charge during the evening.

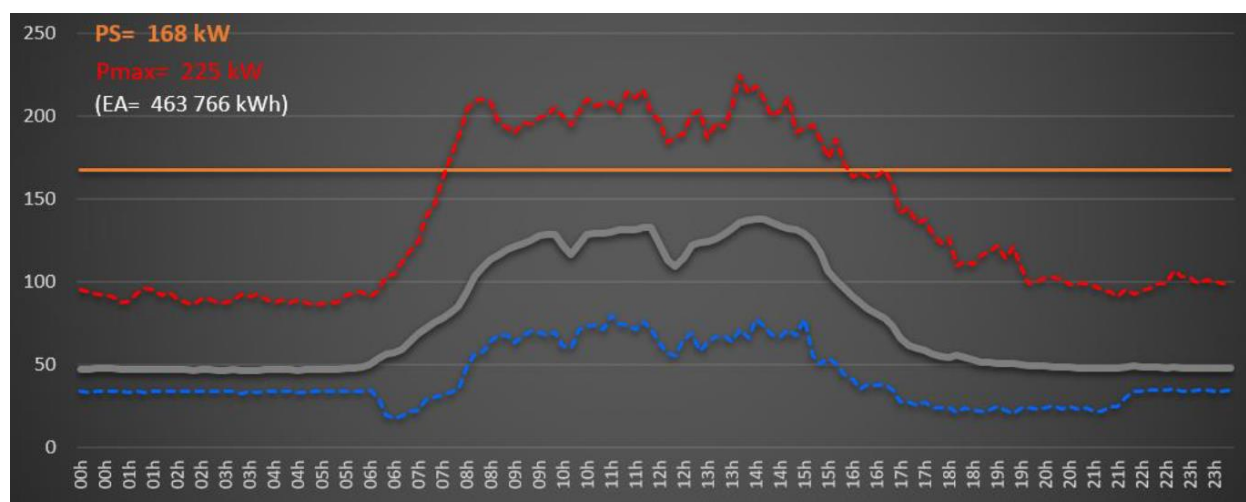
The current electricity contract is a fixed price contract, as this site does not usually consume by night nor on the weekends. Up to now, the share of EVs among the fleet has been quite low, so there has not yet been a significant benefit to shift to a time-of-use contract (ToU), as in the case of ToU the peak time prices are higher than the baseline fixed tariff.

Approach

This financial potential analysis is based on 2023 consumption data from the vehicle depot, combined with simulation results conducted for the scenario of 250 EV additional EVs being charged at the site per day.

The consumption data from the site was provided by the site owner from its point of delivery – this data therefore covers electricity for the full site load, including maintenance machines, heat, and EV charging sessions. Charging session data for one whole week (of approximately 30 EVs per day) was provided separately and used as a basis for disaggregating charging electricity consumption from overall site consumption for the whole year.

The figure below shows the minimum, the maximum and average on-site electricity consumption over a workday (including EV charging sessions during work hours) for the whole year (2023).



The orange line represents the subscribed power contract, the red line represents the maximum used power, the grey line represents the average used power, and the blue line represents the minimum used power. The power from charging has not been disaggregated in the figure, but can be seen in the figures under the forecast scenario.

The forecast scenario simulates the 2023 case based on actual collected site data with an additional 250 EVs (on top of the 30) that needs to be charged per day. The simulation has been run for both direct charging during work hours (representing the existing practice at the site) and smart charging that also utilises off-peak (after-work) hours.

Key assumptions and demarcation

The modelling for the forecast scenario is based on a mix of chargers of 7,4kW and 22kW. The model adds chargers and stops when the targeted SOC (100%) is satisfied for all EVs. The initial SOC is randomly modelled.

In this scenario, 198 charging points were required for smart charging compared to 139 for dumb charging.

The modelling optimises for reducing peak power loads under the subscribed power limit, where possible, and takes into account other site loads apart from charging.

The variable component of the electricity tariff used in the modeling are taken from the French residential tariff – as commercial and industry tariff rates are considered commercial-in-confidence information and were not provided for this project.

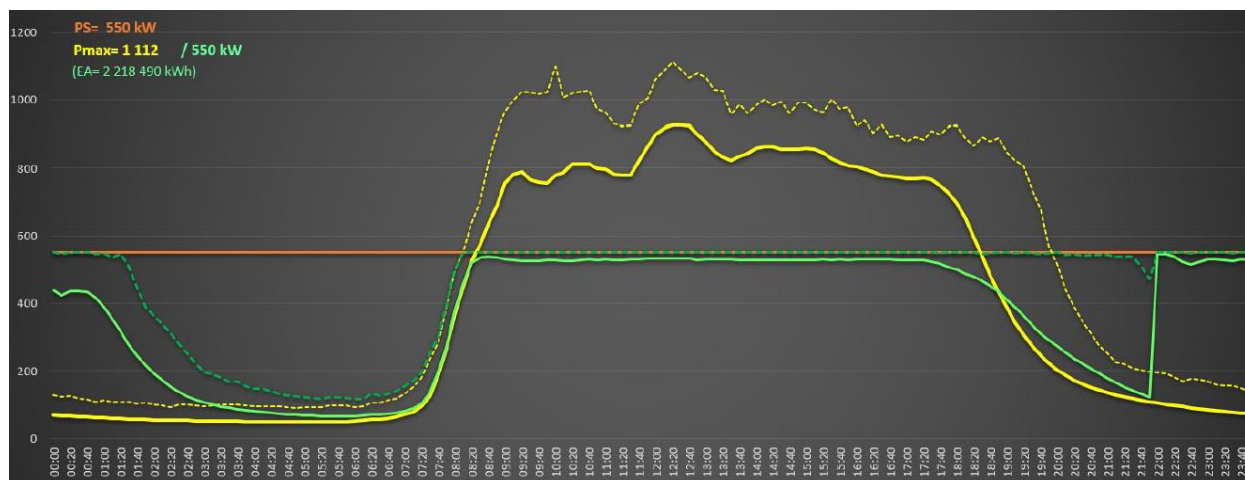
The following rates were used:

- Peak winter: 18,29 c€/kWh
- Off-peak winter: 10,29 c€/kWh
- Peak summer: 9,05 c€/kWh
- Off-peak summer: 4,67 c€/kWh

Result of analysis

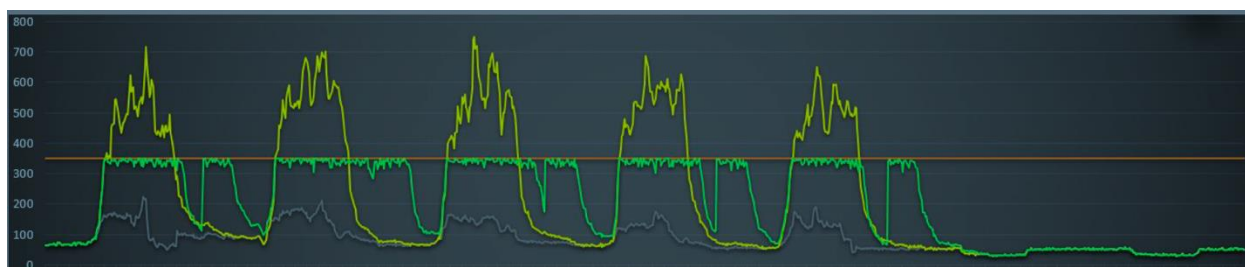
Simulation results indicate that utilizing off-peak charging periods (both day and night) reduces the required power capacity by approximately 50% (see green lines in the figures below), compared to maintaining charging exclusively during daytime hours (yellow line).

The solid green and yellow lines represent the yearly average, whereas the dotted lines represent the maximum values experienced over the year. The orange line represents the subscribed power limit, above which penalty fees can be incurred per kW of electricity used.



The figure shows that in the 250+ EV scenario using direct charging during work hours only, a significant amount of the electricity consumed from the site will occur above the subscribed power limit – thus incurring significant costs from penalty fees. However, by shifting towards a smart charging regime in conjunction with allowing charging to occur outside of work hours, essentially all electricity from the site can be kept under the subscribed power limit.

The figure below shows the variation of these averages during a week in December 2023.



While variation in the power usage of the site is seen between the different days of the week under the direct charging regime, power levels are still consistently kept under the subscribed power limit when smart charging and charging outside workhours is implemented.

When the variable tariff rates were applied to the simulated electricity usage of the site over the year, the smart charging regime with charging outside workhours is shown to save €19,487 in annual energy costs compared to the direct charging regime within workhours. This is predominantly driven by the shifting of charging away from the peak day tariff to the off-peak tariff, with an additional small proportion due to a reduction in the amount of penalty fees paid for peak consumption above the subscribed power limit.

Return on investment calculation

Based on the results of the simulation for the 250+ EV scenario presented above, a calculation of the return on investment has been made with the direct charging strategy as the base case. In this scenario, 198 charging points were required for smart charging compared to 139 for dumb charging – a difference of 59 charging points. With the exception in their numerical difference, the charging points used for both smart and dumb charging are in all other respects the same hardware with the same installation setup.

The base case is compared against the smart charging regime with charging outside of workhours. Given that the smart charging regime in this use case will require an additional 59 chargers to be installed on the site, the investment cost is taken to be the cost of installing these additional chargers. Two scenarios for this investment cost have been analysed, with one assuming that each additional charger will cost €1000, and the other assuming €1500 per charger. Furthermore, for each of these two scenarios, investment periods of 5 years and 7.5 years were considered, providing a total of 4 scenarios based on the following assumptions:

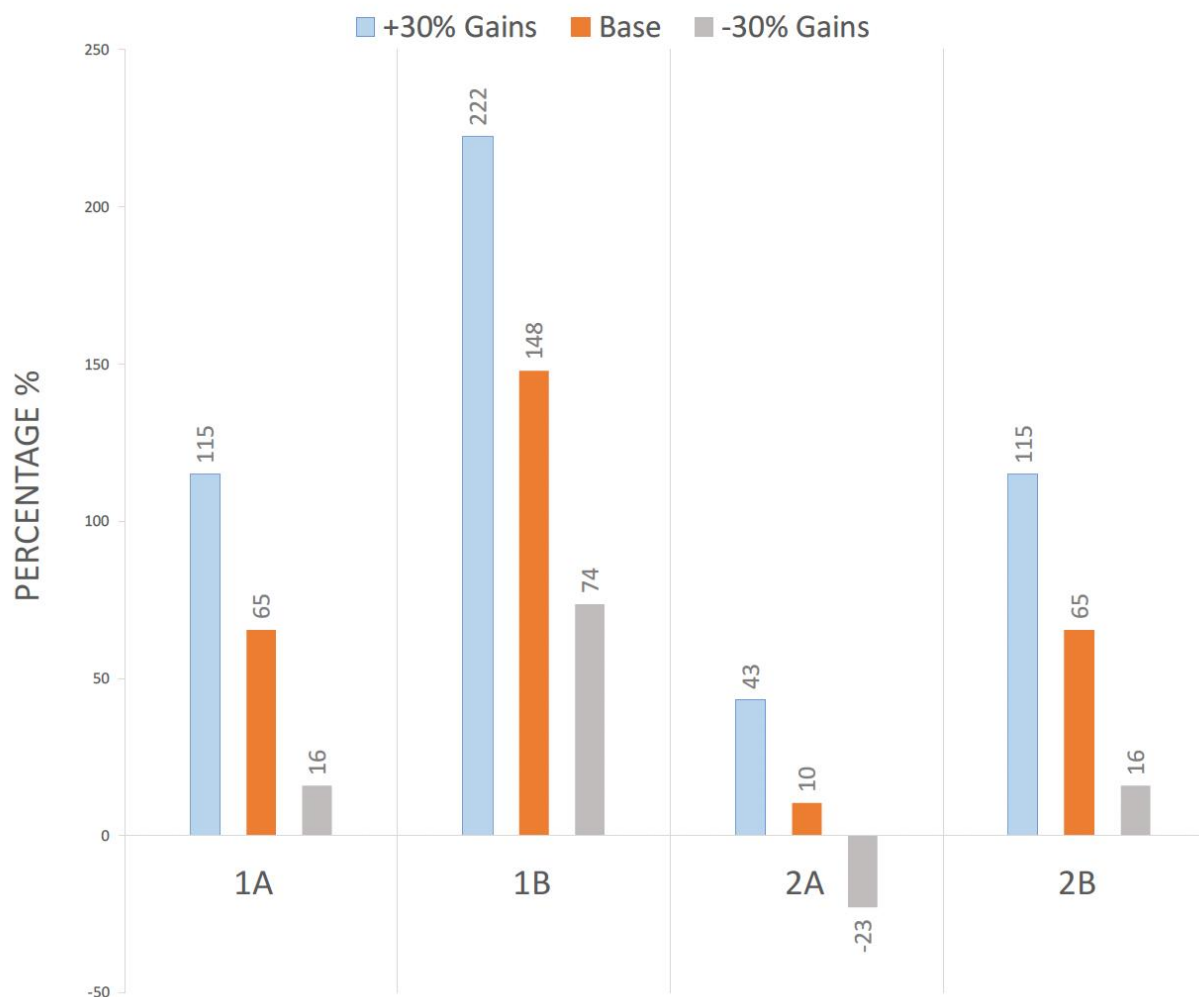
ROI Scenario 1a - Investment period: 5 years - Cost per charger: €1000	ROI Scenario 1b - Investment period: 7.5 years - Cost per charger: €1000
ROI Scenario 2a - Investment period: 5 years - Cost per charger: €1500	ROI Scenario 2a - Investment period: 7.5 years - Cost per charger: €1500
Common assumptions: - Cost per charger includes all costs associated with charger purchase and installation - The chargers are assumed to have zero investment value at the end of the investment period - The total investment cost is the cost per charger multiplied by 59 – as this is the additional amount of chargers needed for the smart charging use-case. - The investment provides an annual return of €19,500 – corresponding to the savings in charging costs from smart charging. Sensitivity considerations: +/- 30% in the annual return of €19,500 (+30% gives €25,350 -30% gives €13,650)	

Based on the financial potential analysis showing the €19,500 in annual savings from switching from the direct charging during workhours regime to the smart charging including outside workhours, the smart charging regime can be considered as an investment that gives an annual return of €19,500.

As an additional sensitivity analysis, a +/- 30% factor has been applied to the annual return and is shown alongside the ROI results calculated for each of the 4 scenarios.

With the above assumptions in place, we calculated a range of ROIs ranging from -23% in the worst case to 222% in the best case. These are shown in the diagram below.

ROI SCENARIOS + SENSITIVITY



As can be expected, a low initial investment cost (i.e. charger purchase and installation) has a major impact on the return on investment. As the per unit charger purchase and installation price reaches €1500, the ROI over a 5-year time horizon risks becoming negative if the annual savings from smart charging drops by 10% or more. Another insight that can be drawn is that by extending the time horizon 50% (from 5 years to 7.5 years) the ROI can be doubled. Therefore, emphasizing that the longevity and reliability of the chargers could be an important consideration to take into account. Given a 7.5 year investment time horizon, the ROI in the high initial investment cost scenario (2b) is still positive at 16% even if the predicted €19,500 annual savings from smart charging drops by 30%. We should bear in mind that if smart charging option is chosen (with larger number of chargers), there will be less need for labor, as EVs will not be moved several times. Some additional savings in labor costs are also expected, however not included in this analysis.

Discussion of results

This analysis explores the financial implications of transitioning from a direct charging strategy during work hours to a smart charging regime that also utilises off-peak periods at a vehicle depot in Toulouse where EVs are charged before final delivery to the customer (car dealerships and other vehicle distribution sites). The findings demonstrate that with the smart charging regime, significant reductions in peak power loads and annual energy costs can be achieved – even under a large-scale electrification scenario involving 250 additional EVs charged daily.

One of the most critical insights is that smart charging not only reduces electricity costs by taking advantage of off-peak tariffs but also plays a key role in reducing peak consumption above the subscribed power threshold – thereby also reducing penalty fees associated with exceeding contracted grid capacity. The simulation showed that, under the smart charging configuration, nearly all electricity consumption can be kept below the subscribed power limit—an outcome that is not achievable under the current direct charging during workhours setup.

From a return on investment perspective, the analysis focused on the marginal cost of implementing smart charging: the installation of 59 additional chargers. ROI values ranged widely depending on two main factors—initial investment cost and investment horizon. In the most optimistic case (low charger cost and 7.5-year period), ROI reached 222%. Only in the most pessimistic case (high charger cost, 5-year horizon and -30% annual savings) did ROI fall negative (-23%).

Another important observation is that extending the investment horizon from 5 years to 7.5 years consistently improved ROI outcomes, often doubling the return. This highlights the importance of charger longevity and system durability in achieving financial viability. Furthermore, potential savings from reduced labor – due to decreased need for manual EV relocation during the day – were not included in this analysis but could further improve the overall return.

In light of these results, smart charging presents a strong case for such vehicles depots with growing EV fleets – especially when combined with operational changes that allow for off-peak charging to be scheduled outside standard workhours. While initial hardware investments can pose a barrier, the savings potential in both energy and avoided grid reinforcement costs makes smart charging a cost-effective strategy aligned with both DSO goals and depot operator needs.

Chalmers (Gothenburg): V2G chargers at office and residential buildings

Background

The use case centres around a test site located at Chalmers University Campus in Gothenburg, Sweden. The test site consists of two locations situated close to one another.

The first is HSB Living Lab, a smart residential building equipped with rooftop solar PV, stationary battery energy storage, and some controllable loads. An AC charger from chargepoint manufacturer CTEK was installed at this living lab to test the modified backend to enable the possibility to send negative values in the charge profile using OCPP1.6. The charger was also added into the existing building's EMS to assess the potential gain from smart charging and V2G.

The second location in the test site is at the power system lab of the division of electrical power engineering. At this site, a Ferroamps DC charger was connected to the power system lab to demonstrate bidirectional charging using a Polestar 2 electric vehicle.

The main goals of this use case were the following:

- To increase the self-consumption of the on-site solar PV through V1G and V2G technology. Since the demonstrations were conducted during the autumn and winter the PV production did never exceed the demand of the building during the evaluation phase. Instead, the demonstration was focused on reducing the charge cost and peak demand.
- Reduction of the electricity bills for the building. This was also set as the objective function of the optimization algorithm used. In this scenario, the EV was charged at off-peak time when the electricity price was low and discharged to the building at peak times when the electricity price was high.
- Reduction of peak power. By incorporating power tariffs into the objective function the peak load was also reduced by the optimization algorithm.
- Modelling battery degradation of the EV's battery for discharging through V2G. Battery aging variables were incorporated in the cost function in order to determine if it is economic to discharge the EV and how it would affect the optimal charge/discharge pattern of an EV.

The demonstrations were conducted following a modification of the ISO standard 15118-2 as a first step towards a full integration of the 15118-20 standard for the V2G communication.

While this particular use case is not integrated into a commercial business setting, the results from the demonstration, and modelling conducted as a result of it, provides some valuable quantitative insights for analysing the financial potential of V2B and V2H in a local Swedish context.

Approach

The financial potential analysis is based on a series of simulation results looking at the charging costs of various combinations of V2X charging scenarios, conducted by Chalmers.

The simulations themselves were based on a mix of real-world historic data and synthetic data. The house electricity demand data is real historical demand data from a building, the vehicle usage is simulated based on statistical data and the electricity prices are real historical spot prices from the day-ahead market.

Two reference years were used for the simulations, 2022 and 2024. The reason for this is both 2022 and 2023 exhibited historically high price volatility, whereas 2024 was more in line with historical trends. So choosing 2022 and 2024 provides a useful overview of how these two varying scenarios can affect the financial outcome.

The results are shown in terms of the total annual cost of charging for each charging scenario.

The charging scenarios are described in the following table.

Scenario	Description
Direct Charging (Direct)	Charging the EV up to 90% SOC as quickly as possible when plugged in. Used as the base case for comparison. The simulated EV drives 18,974 km/year with a typical home-to-work pattern.
Smart Charging (SC)	Optimises EV charging by adjusting power, timing, and duration based on real-time factors like electricity prices, grid load, and renewable energy. Enables off-peak and solar-based charging.
Vehicle-to-Grid (V2G)	Enables bidirectional energy flow between EV and grid. Supports grid during high demand by discharging energy. In this study, V2G excludes FCR capabilities but includes smart charging.
Frequency Containment Reserve-N (FCR)	A service that maintains grid frequency (e.g., 50 Hz) by balancing supply and demand. EVs with V2G can quickly charge/discharge in response to grid signals. Only FCR-N market considered here.
House Load (HouseLoad)	The household's annual electricity usage excluding EV charging, totaling 15,452 kWh. The optimization model aligns EV charging with household demand to reduce peaks and avoid high costs.
Photovoltaics (PV)	Solar panels generating electricity. Integration with SC, V2G, or FCR lets EVs charge using solar when beneficial. 4,629 kWh solar energy is available annually in the simulation.
Simulation Year (year)	Simulations used electricity and FCR prices from 2022 and 2024. For late 2024, price data from Nov–Dec 2023 was used due to the simulation being run in winter 2024.

Based on the results from the simulations of these scenarios, a calculation of the return on investment is also made with the direct charging scenario as the base case. The base case is then compared against the smart charging and V2G scenarios, where the investment cost of the smart and bidirectional chargers are considered.

Key assumptions and demarcation

The financial potential analysis is based on the simulations described above, which are viewed from the perspective of a single vehicle charging from a building (residential or business). The only investment costs factored into this analysis are the relative costs of the different types of chargers. Other investments, such as the building energy management system (which is necessary for some of the scenarios), have not been

calculated – since these were already preexisting on the test site. Potential overhead costs that would come into play when scaling such a V2G system beyond one vehicle in a demonstration setting to a larger commercial setting (such as maintenance, personnel, IT connectivity and software licensing costs) are also not considered. The savings calculated also do not take into account the crucial role that any aggregators may play in a real world scenario, and the market power that these aggregators will have to demand a percentage of the realisable revenues. Indeed, the results of the analysis is probably more relevant for aggregators, as they will likely be the ones trading directly in the energy markets, realizing the revenues, and determining how much of it to share with the EV user.

A key assumption underlying this analysis is having perfect knowledge about both the behaviour of the day-ahead spot market and the FCR market. This is due to the use of historical data for the simulations, which are based on optimization algorithms. Using such algorithms in the real world for predicted prices would typically yield lower cost savings due to uncertainty and inherent risks.

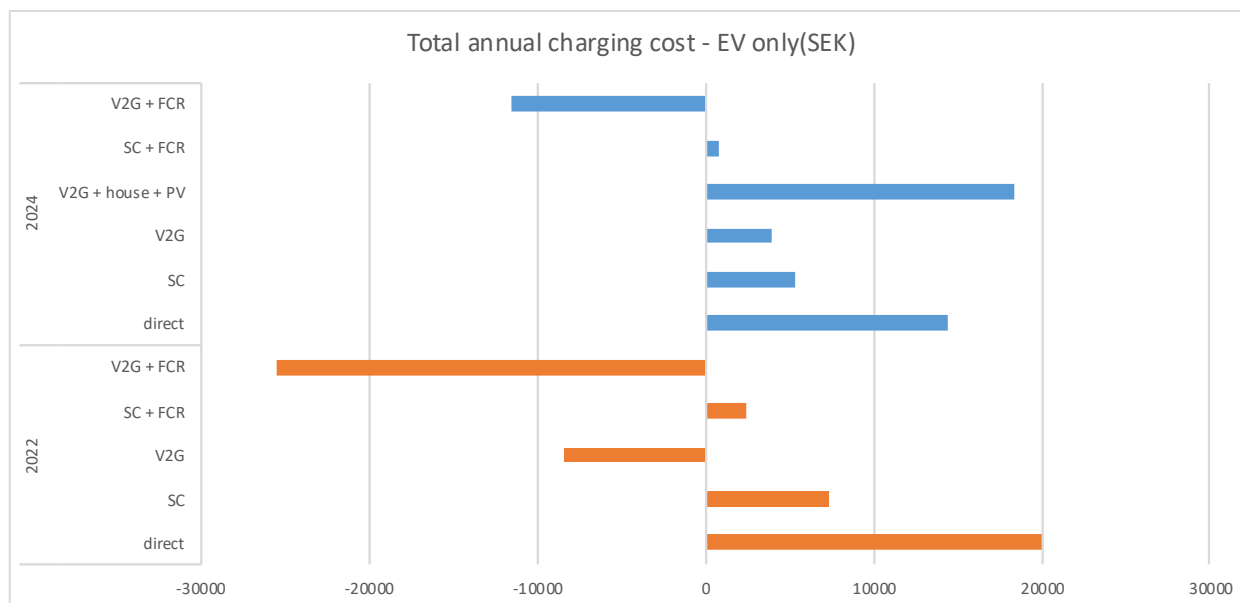
Another assumption is for the electricity costs in the direct charging scenario. This has been calculated based on the day-ahead spot market price, consistent with the same approach taken for the other scenarios. However, it should be noted that most household electricity customers in Sweden, including the Gothenburg area, commonly have electricity contracts where the prices are fixed on a day-to-day basis – only shifting from month to month to reflect the expected average cost of electricity over that period. The choice to adopt the approach of the calculations based on the spot price is to more accurately reflect the cost of the electricity use to the system as a whole, since that cost has to be paid for by other actors in the energy system (such as electricity retailers and other energy users). This however may mean that the calculated cost comparisons between the direct charging scenario with the smart and V2G scenarios may not be as high in reality from the perspective of the average EV user's wallet.

The simulation results also did not consider any differences in the charging and discharging efficiency between AC and DC bidirectional charging in the scenarios.

Furthermore, the results conducted in the simulations were presented in two sets, with one set showing the EV only case and the other set showing a 'house plus EV' case. The reason for including these cases is that the peak power tariff impacts the potential savings compared to the case when only considering the EV charging. Tariff data from Göteborg Energi was used in the simulations. Minor differences in the results were seen between the two sets of cases when it came to the absolute savings. Given this, only the results from the EV only case will be discussed in detail below.

Result of analysis

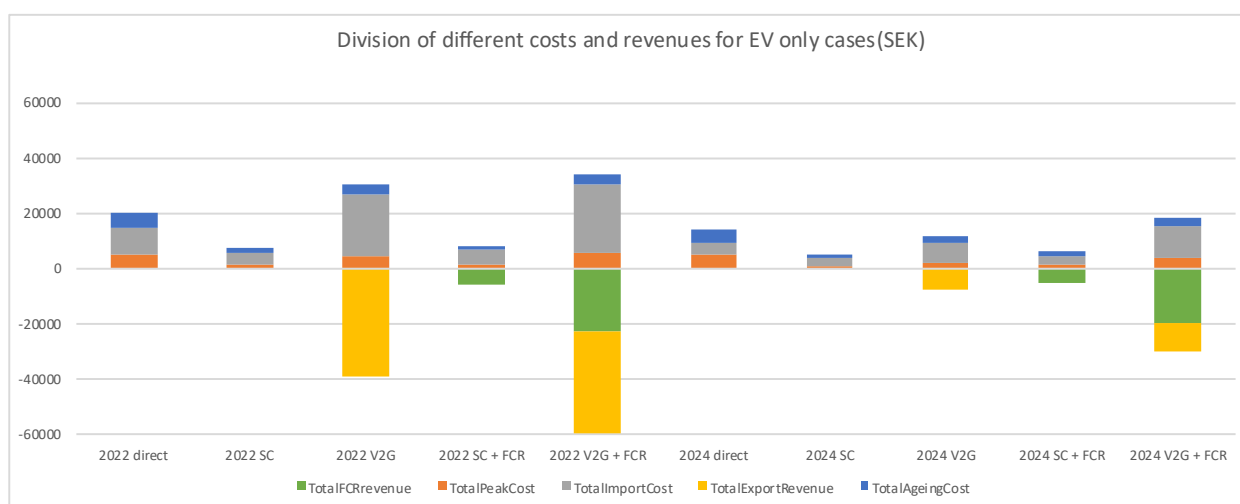
The analyses below show the cost for an EV owner to charge their vehicle in each of the simulated years under the range of scenarios described above. Configurations with FCR and V2G flexibility enabled substantial cost reductions, with some scenarios showing negative costs due to revenue from energy exports and FCR participation.



The comparison of results highlights significant changes in electricity costs and the impact of flexibility measures between 2022 and 2024. In 2022, the implementation of flexibility measures such as V2G and FCR demonstrated dramatic reductions in annual EV charging costs. Notably, V2G achieved a 141,8% reduction compared to direct charging, and the combination of V2G+FCR led to an impressive 227,5% reduction – effectively generating a substantial net revenue rather than cost. This indicates the strong financial advantage of flexibility measures in a higher-cost environment like 2022.

In 2024, while the absolute costs have decreased due to lower electricity prices, the relative benefits of these flexibility measures are less pronounced. FCR+V2G still achieves the largest cost reduction when compared to direct charging. However, the V2G setup shows a much smaller reduction of 72,6%, reflecting a diminished impact of V2G when electricity prices are less volatile.

The diagram below provides a breakdown of the different costs and revenue streams contributing to the net results above.



This breakdown allows us to see that while flexibility measures remain beneficial in both years, their relative cost-saving potential is more pronounced during periods of higher electricity prices, as seen in 2022. In 2024, with reduced electricity prices and price volatility, the reliance on grid-support measures such as FCR plays a greater role in achieving meaningful cost reduction.

The following table provides a summary of the cost reductions of the different charging scenarios when compared against the direct charging scenario. The units for costs are denoted in SEK, representing the Swedish currency.

Annual Cost Reduction and Absolute Cost

Year	Charging Strategy	EV Only (% Reduction)	EV Only (Cost, SEK)	House + EV (% Reduction)	House + EV (Cost, SEK)
2022	Direct	0.0%	19,998	0.0%	59,617
	Smart Charging (SC)	63.4%	7,319	21.4%	46,859
	Vehicle-to-Grid (V2G)	141.8%	-8,359	48.4%	30,762
	SC + Frequency Reserve	88.1%	2,380	29.8%	41,851
	V2G + Frequency Reserve	227.5%	-25,497	77.2%	13,593
2024	Direct	0.0%	14,376	0.0%	33,115
	Smart Charging (SC)	63.0%	5,319	27.3%	24,075
	Vehicle-to-Grid (V2G)	72.6%	3,939	32.4%	22,386
	SC + Frequency Reserve	94.7%	762	41.4%	19,405
	V2G + Frequency Reserve	180.7%	-11,601	79.9%	6,656

As the cost reduction exceeds 100%, the absolute cost of charging is shown as a negative number – representing the transition from a cost to a source of income. This is exhibited by the V2G + FFR scenarios in both years, as well as the V2G only scenario in 2022.

The relatively smaller percentage reductions for the ‘house plus EV’ set of charging scenarios are almost entirely due to the effect of including the cost of household electricity supply into the total before calculating the percentages. Despite this, the amount of absolute savings for each scenario under both the ‘EV only’ and ‘house plus EV’ sets, when compared against direct charging, are almost exactly the same – in some cases being slightly larger in the ‘house plus EV’ set.

Return on investment calculation

For the ROI calculation, two different investment costs are considered:

- A DC charger costing 100,000 SEK (inclusive of installation costs)
- An AC charger costing 15,000 SEK (inclusive of installation costs)

The DC charger is assumed for the V2G scenarios, whereas the AC charger is assumed for the direct charging and smart charging scenarios.

Two alternative revenues were also considered for the ROI calculation:

- Revenue as the difference between the V2G scenarios (with and without frequency reserve) and the direct charging scenario
- Revenue as the difference between the V2G scenarios (with and without frequency reserve) and the corresponding smart charging scenarios (with and without frequency reserve).

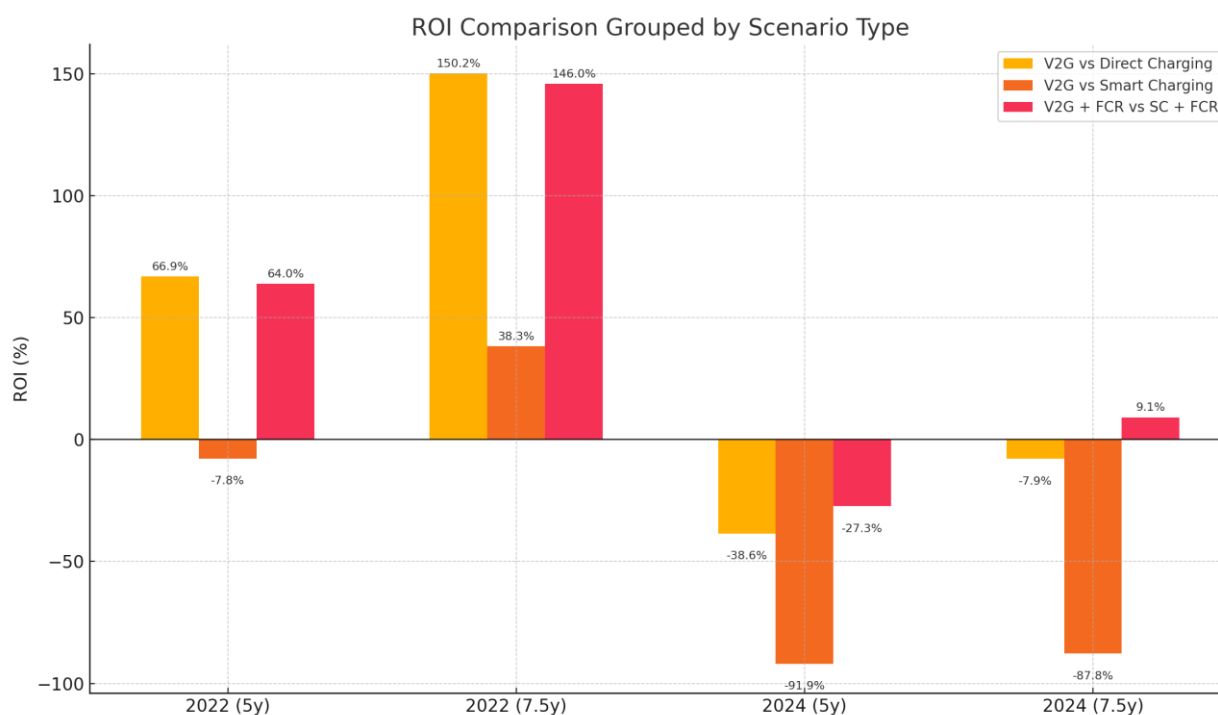
As each ROI case compares a V2G scenario with either a direct charging or smart charging scenario, this results in the investment cost used in all the ROI cases being the difference between the cost of the DC charger and the AC charger – giving a figure of 85,000 SEK.

The ROI calculation was also conducted for both years of the simulation – 2022 and 2024.

The investment period was set at 5 and 7.5 years. In all cases, the residual value of the investment at the end of the investment period is assumed to be zero.

For all the ROI cases the revenue is assumed to be the same for each year of the investment period. So for the ROI based on 2022 revenue, the revenue figure from 2022 is used for each year of the 5 and 7.5 year analyses – likewise for 2024. As a separate sensitivity analysis, a ROI is also calculated where one-third of the years use revenue figures from 2022 and two-third of the years use revenue from 2024. The purpose of this is to visualise how such a split between the two years would affect the ROI, given the large differences between the 2022 and 2024 only results.

The diagram below shows all the results of the ROI calculation for the different cases – with the sensitivity analysis at the end.

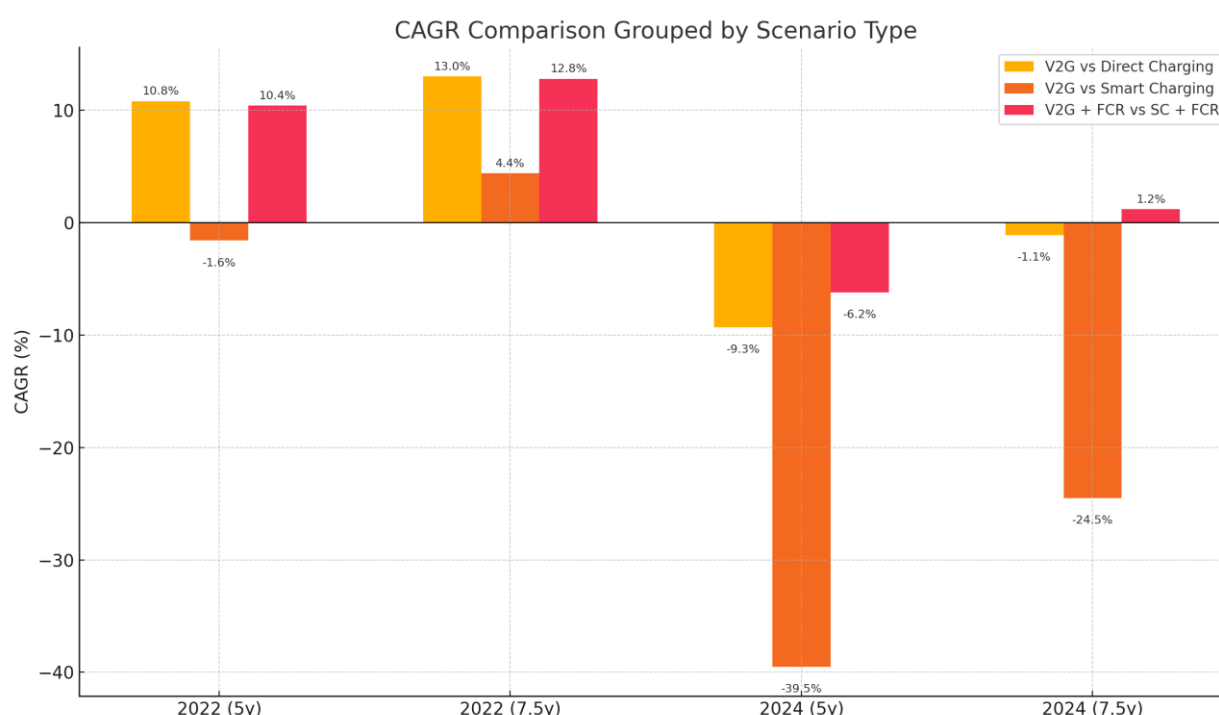


The ROI results show a very strong difference between cases based on the different simulation years. In the 2022 case, almost all scenarios show very positive ROI results, with the exception of the 5 year

investment period for the V2G vs Smart Charging scenario. This reinforces previous research and modelling which indicate that a majority of the benefits of V2G when compared against direct charging can be achieved through smart charging. However, once frequency services are included in the ROI, V2G is shown to achieve significantly much higher returns even when compared to smart charging with frequency services. This is a potentially novel finding.

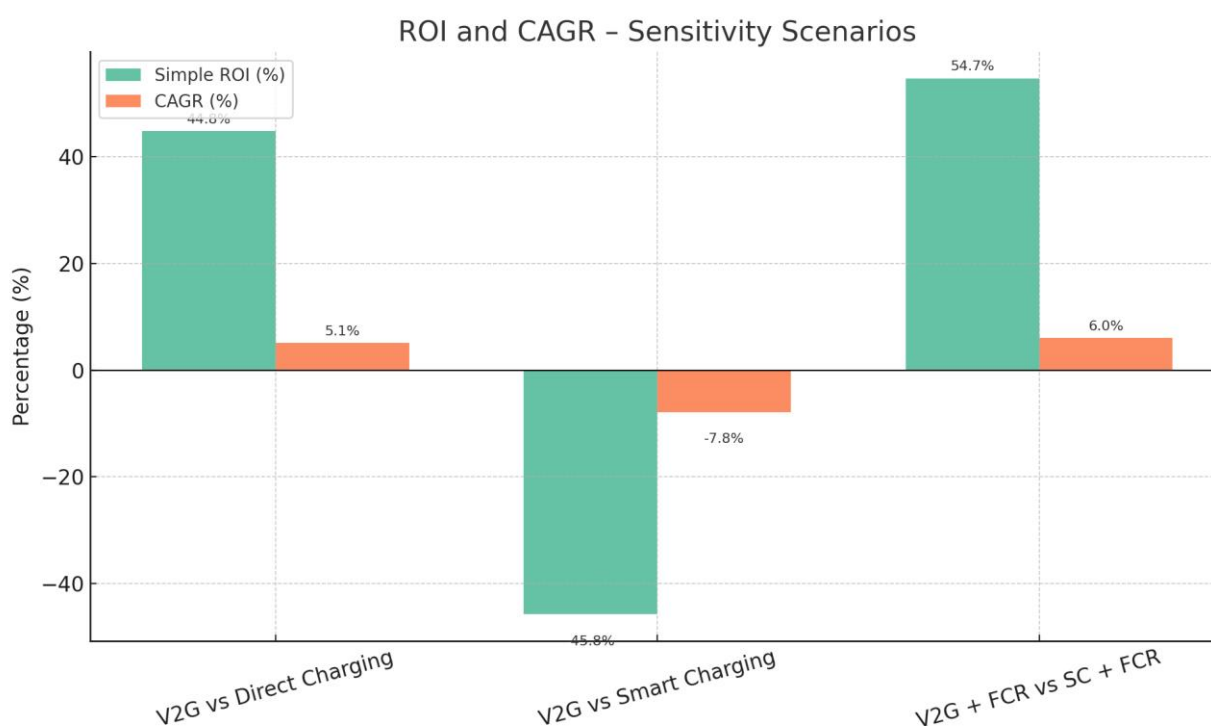
For the ROI calculations based on the 2024 simulations, the ROI results are completely different – with almost all the scenarios showing strong negative returns. This indicates the volatility of V2G revenues and its dependence on two factors – market conditions in the electricity and grid services markets, as well as the initial investment cost. If the assumption is correct that market conditions in 2022 (and 2023) were outliers, and that the market conditions in 2024 reflects more of a ‘return to the norm’, then this suggests a challenging ROI environment for V2G given the assumption that an investment cost of 85,000 sek for a bi-directional DC charger is necessary.

The diagram below shows the same ROI results presented as compounded annual growth rates (CAGR).



When seen in the context of CAGR, in most of the scenarios based on the 2022 simulations, V2G provides a reasonable commercial rate of return at 10% or above. The only exception is when it is compared against smart charging, where neither V2G nor smart charging are involved in providing frequency services. In the case of the 2024 simulations, CAGR is negative which is expected given the ROI results discussed above.

The final diagram below shows the results of the sensitivity analysis for a 7.5 year investment period, where revenue from five of those years are based on the 2024 simulations and revenue from the remaining 2.5 years are based on the 2022 simulations.



The ROI results from the sensitivity analysis shows that returns from the V2G versus direct charging scenario and the V2G with frequency services scenario in the range of 5.1% CAGR and 6% CAGR respectively, which is in line with the expected returns seen for public investment and early-phase sustainable technologies. However it is important to keep in mind that it can be difficult to predict how the electricity and grid services markets will evolve over time, as these may be affected by many other technologies and factors.

Discussion of results

The financial potential analysis from this use case presents a comparative analysis of EV charging costs and return on investment across multiple configurations, focusing on the role of flexibility measures such as V2G energy trading and frequency containment reserve. The results demonstrate that enabling these flexibility options can lead to substantial cost reductions for EV owners, especially in periods of high electricity prices.

In 2022, scenarios with V2G and FCR delivered the most significant cost reductions, with V2G alone reducing annual charging costs by over 140% relative to direct charging, and the V2G + FCR configuration achieving a 227.5% reduction – effectively turning costs into revenue. However, in 2024, due to lower electricity prices and reduced volatility, the financial impact of V2G alone was much smaller. In this context, the inclusion of grid-support services such as FCR became more critical to maintaining cost benefits.

ROI calculations were conducted by comparing the added investment cost of a bidirectional DC charger (85,000 SEK more than a standard AC charger) against the revenue benefits of V2G configurations versus direct charging and smart charging configurations. The analysis used annual revenue estimates based on the 2022 and 2024 simulations, as well as a blended sensitivity scenario combining both years. Results were calculated for both 5-year and 7.5-year investment periods.

The ROI outcomes reflect the broader market dynamics. In 2022-based scenarios, most configurations yielded positive returns—particularly when frequency services were included. Notably, V2G with FCR outperformed even smart charging configurations that also included FCR. In contrast, the 2024-based ROI calculations resulted in predominantly negative returns, indicating that profitability is highly sensitive to market conditions and the initial investment cost of the charger.

When expressed as compounded annual growth rate (CAGR), the 2022 scenarios often reached or exceeded 10%, making them commercially viable in that context. However, 2024 scenarios consistently showed negative CAGR values, reinforcing the risk of investing in V2G without favorable market conditions.

A final sensitivity analysis, which used a revenue blend from both years, revealed more moderate outcomes. V2G compared to direct charging or smart charging with FCR achieved CAGR values around 5–6%, aligning with typical returns for public sector or early-phase sustainable investments. Nonetheless, the long-term viability of V2G as a business model remains heavily dependent on future developments in energy markets and technology cost trends for DC bidirectional chargers.

Another possible way forward, which was not considered in this analysis, is AC bidirectional chargers with much lower relative investment costs. Even if the cost of the AC bidirectional charger is two times more expensive than a regular AC charger, the results from this analysis shows that a positive return should be achievable for V2G with FCR services even within the first year.

VDL (Netherlands): Highway charging with local generation & storage

Background

VDL is a bus and coach OEM based in Valkenswaard, Netherlands. The company designs, develops, produces, sells, and services a broad range of buses and coaches, including public transport buses, touring vehicles and chassis modules.

The use case centres around a simulation model developed to investigate the necessary and optimal charging infrastructure to support the electrification of the long-haul passenger transport vehicles (primarily coaches) by minimizing the grid peak load and taking advantage of opportunity charging regimes.

The goal of the use case was to obtain an optimal setup of a highway charging station based on location constraints in order to supply sufficient amount of charging power compliant to the needs of the long-haul vehicle operators by performing simulations.

Approach

The implemented charging schedule is based on typical coach driver schedules for day and overnight driving and the charger powers. Smart charging is not considered, as this is not applicable due to the nature of stop time of the vehicles. Based on this demand, the optimal setup is obtained from the simulation model, which estimates the optimal BESS capacity, grid connection and allows optimal operation in terms of operational costs.

The fixed predefined charging booking schedule is based on customer expectations, namely the resting times of the drivers and therefore the charging slots are pre-booked and defined. To complete the simulation, this booking schedule is fixed during the simulation time and therefore no dynamic booking services have been implemented. The charging booking schedule can easily be adapted to a different schedule.

VDL has summarised the results of the analysis into a table which shows the levelised cost of various capital and operational expenses over the lifetime of different vehicle-fuel combinations. While these results are not detailed enough to enable a return on investment calculation to be conducted, they nevertheless provide a basis for which some interesting analysis and key takeaways can be discussed.

Key assumptions and demarcation

Physical implementation was limited due to the BESS not being operational within this project. Additional limitations are that there are no e-coaches in the market. The performance of e-coaches will be very different from the current diesel fleets and is therefore unknown. As a result, it is an assumption that the energy infrastructure around the highway charging hub can be modelled for this use case.

Whilst the model can be used to size the components of the energy network while minimizing the grid energy and grid peak power costs heavy duty highway charging infrastructure is currently not existing and as such there was no reference case to be considered. However, VDL have investigated a relation between the investment costs of energy network components (solar and BESS), the grid power connection costs and energy prices.

In the energy model no ad hoc charging is considered. All charging events (time and energy demand) in the model are defined. Pre booking is assumed to be essential. Customer route information was not available, so many assumptions were made on the charging stop frequency and duration.

Result of analysis

The result of the modelling and analysis conducted by VDL has been condensed into the table below, which shows the levelized cost of various capital and operational expenses over the lifetime of different vehicle-fuel combinations. The costs shown are annualised and built on various assumptions which will be further discussed below.

Vehicle		12m	12m	12m	12m	12m-TR
		Diesel	Battery BE	Battery OC	Hydrogen	Hydrogen
Fuel					10 Euro/kg	10 Euro/kg
Fuel price						
Battery capacity					20kWh	20kWh
Extra cost RE						
Energy costs	Euro/km	€ 0,40	€ 0,13	€ 0,13	€ 0,73	€ 0,73
Vehicle costs	Euro/km	€ 0,29	€ 0,39	€ 0,41	€ 0,44	€ 0,42
Energy storage costs	Euro/km	€ 0,00	€ 0,19	€ 0,16	€ 0,03	€ 0,02
FC costs	Euro/km	€ 0,00	€ 0,00	€ 0,00	€ 0,33	€ 0,33
Maintenance costs	Euro/km	€ 0,20	€ 0,39	€ 0,26	€ 0,56	€ 0,56
Total	Euro/km	€ 0,89	€ 1,09	€ 0,96	€ 2,09	€ 2,06
Total	%	100%	123%	109%	235%	232%
					235% Today EU	232% Today EU-TR
Driver costs		€ 40,00 Euro/hours			1.000 hours/year	

The reference scenario is for a fleet of ten 12m diesel coaches. This is compared against similar fleets of battery electric coaches, with the column 'Battery BE' representing coaches with larger batteries (320 kWh usable capacity) and utilising a depot-only charging strategy (at the end point of a coach line) over a 6-hour period. While the column 'Battery OC' represents coaches with smaller batteries (170 kWh usable capacity) charging a mix of depot and opportunistically at highway charging sites –15-20 minutes of enroute charging during stops for every 3 hours of driving. Figures for hydrogen bus scenarios are also shown in the table, however analysis of these are outside the scope of this report.

Other assumptions are:

- 'Energy costs' – electricity costs are assumed to be based on a fixed price contract at 0,10€ per kWh.
- 'Energy storage costs' – refers to the cost of supplementing the charging stations with stationary battery storage systems to reduce peak loads to an optimal level after considering the cost of the storage system and potential savings from reduced grid costs. This is slightly higher for the 'Battery BE' scenario which requires 500 kW peak power at the depot, compared to 360 kW peak power at the highway opportunity chargers.
- 'Maintenance costs' – refers to both the cost of maintenance for the vehicles themselves as well as for the charging stations. For the 'Battery BE' scenario this includes the assumption that a battery replacement will be needed at 480,000 km, (based on NMC battery chemistry). Whereas in the 'Battery OC' scenario no battery replacement is assumed due to the battery chemistry being based on LTO (Lithium-Titanate Oxide). The remainder of the added maintenance cost that is seen in both the electric bus scenarios vis-à-vis the diesel bus scenario is due to maintenance of the

charging and stationary battery infrastructure as the maintenance costs for diesel re-fuelling infrastructure is not taken into account.

- Driver costs under all scenarios are kept consistent, as the scenarios are designed around not requiring any changes in driver or route schedules.

As a result of the assumptions, the levelled cost of both the 'Battery BE' and 'Battery OC' scenarios in the modelling are shown to be higher than the diesel reference scenario, despite energy costs being substantially lower. For the 'Battery BE' scenario this is 23% higher and for the 'Battery OC' scenario it is 9% higher.

Discussion of results

On the surface, the results of the simulation show a substantive cost gap of 23% between the diesel coach reference scenario and a battery electric scenario (coupled with a depot-only charging strategy), and a marginal gap of 9% when the reference scenario is compared with the opportunity charging scenario. This would seem to indicate that from a purely cost-centred perspective, electric coaches are still not yet competitive against diesel coaches when the fleet owner and operator are also responsible for financing and maintaining the necessary charging infrastructure.

However, the results and the assumptions which underline them offers a few additional insights. The simulated 'cost gap' between the reference diesel scenario and the depot-only charging scenario almost completely disappears if the assumptions regarding the battery replacement and the maintenance cost of the charging infrastructure are nullified. If maintenance costs for these two scenarios are the same, then the depot-only charging scenario would only be 0,01€ more expensive to operate per kilometre. A similar result could also be reached for the opportunity charging scenario if the maintenance costs were held to be the same as that for the diesel scenario.

Battery technology is improving at a rapid rate, and the need for battery replacements even in aggressive use-cases such as long-distance transport (with heavy usage and regular high-powered charging) is coming into question. This could suggest that a reality where electric coaches in the 'Battery BE' scenario will no longer need to assume a battery replacement during the operational lifetime of the vehicle could be within reach in the near-term.

Likewise, charging equipment have also seen improvements in uptime and reduced maintenance demands in recent years – with EVSE providers releasing weather-proof and high-cycle charger systems designed for rugged and high-use environments (Phihong, n.d.) – while predictive maintenance and remote diagnostics functions are also being increasingly integrated into charging infrastructure (Ampcontrol, n.d.). These trends suggest that maintenance costs of fast chargers are likely to continue to fall.

Regarding maintenance of the vehicles themselves, a comparative analysis of bus technologies from the International Climate Initiative (IKI, 2023) noted that "During the market ramp up we are currently seeing that maintenance costs are reported to be similar [between electric and diesel buses] as there are currently fewer spare parts available and not all mechanics are skilled well enough to repair electric buses." (IKI, 2023). However, the report also projects that "In the long run BEBs are expected to be more reliable than the ICE counterparts due to having fewer moving parts inside the vehicle."

In summary, should projections for falling maintenance costs of charging infrastructure and the buses themselves be realised, as well as improvements in battery technology doing away with the need for a

battery replacement within the operational lifetime of a bus, then electric coaches in both the modelled charging scenarios should achieve cost-parity with the diesel reference case. Further potential reductions in the purchasing cost of the vehicles themselves, as well as the cost of procuring and operating stationary energy storage systems, will help electric coaches achieve a levelised cost per kilometre that is even lower than diesel coaches.

Stedin (Netherlands): Smart charging of light commercial vehicles

Background

Stedin is one of the major grid operators in the Netherlands responsible for managing the electricity and gas networks in the densely populated Randstad area, which includes significant urban centres such as Rotterdam, The Hague, and Utrecht. The use case focuses on Stedin's fleet of commercial service vehicles in its operational area, with concentrated charging around Rotterdam where the fleet primarily charge using the public charging infrastructure.

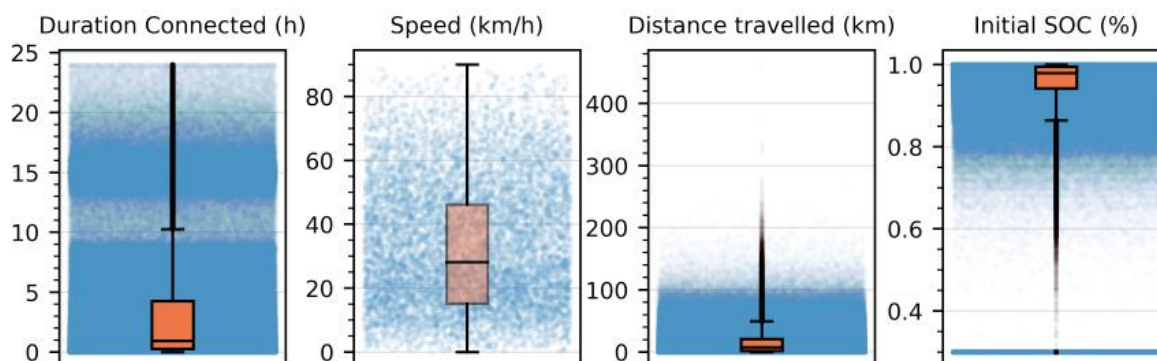
Since 2017, Stedin has been actively working on electrifying its fleet of service vehicles as part of its broader sustainability goals – this includes transitioning their vehicles to EVs. The total Stedin fleet is 2200 vehicles, of which 800 are light-duty vehicles for their engineers. Electrification of these vehicles is occurring in line with the normal depreciation of the vehicles.

Approach

This financial potential analysis is based on simulations done as part of the Stedin use case. Out of Stedin's total fleet of 2200 vehicles, driving and charging data from 2023 for 1735 vehicles was collected, after filtering for data errors. The data was then used to simulate different charging strategies as well as participation in flexibility markets. As well as the driving and charging data, the simulation also uses electricity price data from the same year.

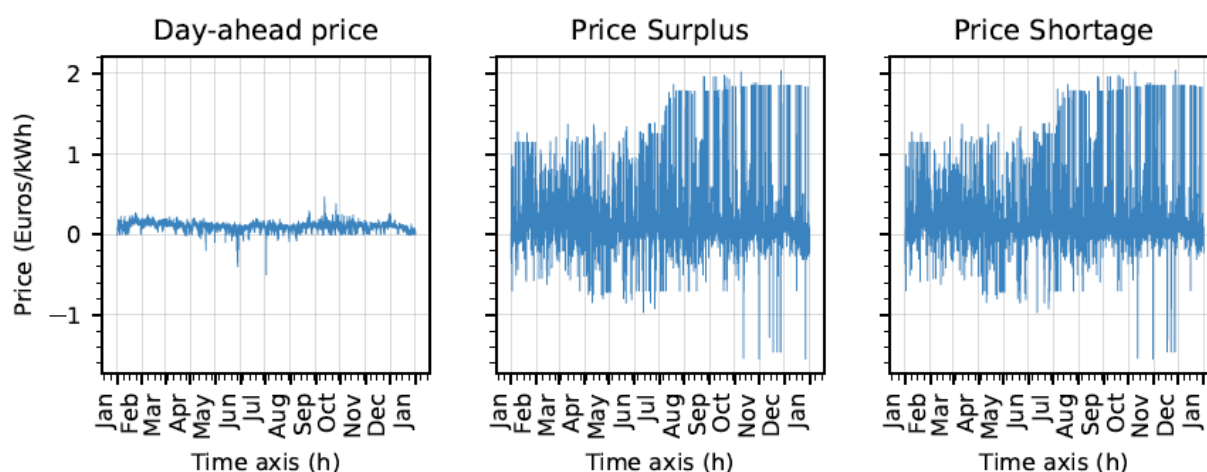
Based on the driving patterns of the vehicles (including the duration of charging stops and their range needs), appropriate charging schedules were drawn up, which were later used in an optimisation framework. Charging is assumed to occur at public AC chargepoints, which is in line with the current practice of vehicles in the fleet that have already been electrified.

The figure below shows the variation of the charging and vehicle behaviour statistics within Stedin's EV fleet.



Duration connected refers to the total expected time a van remains connected to a chargepoint. Distance travelled and speed pertain to the trip made just before connecting to the chargepoint, while the initial SoC corresponds to the state of charge at the moment of connection.

The electricity price data (prices used to simulate day-ahead market trading and aFRR) for the year 2023 used in the simulation is shown in the figure below.



Price surplus and price shortage refer to the imbalance prices that a hypothetical aggregator pays or receives based on the regulation state during aFRR trading. In the Dutch system, balancing energy is activated based on real-time grid needs, and market participants (like aggregators) may be paid or penalised depending on how their actual energy profile aligns with the system needs.

Using these data, simulations were run for five different charging strategies:

- **Business-as-usual** (charging directly when the vehicle is plugged in)
- **Cost-optimised unidirectional** (charging based on the day-ahead market)
- **Cost-optimised + aFRR unidirectional** (charging based on the day-ahead-market plus participation in the aFRR market)
- **Cost-optimised bidirectional** (charging based on day-ahead market with V2G trading)
- **Cost-optimised bidirectional + aFRR** (charging based on the day-ahead-market with V2G trading plus participation in the aFRR market)

The results of the simulation gives the charging cost for each of the strategies, as well as a breakdown of the cost components including the amount of revenue gained from aFRR participation.

Based on these results, a calculation of the return on investment is also made with the direct charging scenario as the base case. The base case is then compared against the bidirectional charging strategies, where the investment cost of the bidirectional chargers are taken into account for 5 and 7.5 year investment periods. To provide additional insights, the unidirectional smart charging strategies will also be compared against the bidirectional strategies.

Key assumptions and demarcation

The financial potential analysis is based on the simulations described above, which include several key assumptions in its modelling approach:

- All EVS meet their charging demand
- Perfect foresight with respect to arrival and departure time is assumed.
- No perfect foresight in market prices is assumed in the ancillary service market models
- V2G functions are assumed to be available (in both the vehicles and public chargers) for the provision of ancillary services, to get insight into the maximum potential

For the return on investment analysis, the only investment costs factored in are the relative costs of the different types of chargers. Other investments, such as potential overhead costs that would come into play when scaling such a V2G system beyond one vehicle in a demonstration setting to a larger commercial setting (such as maintenance, personnel, IT connectivity and software licensing costs) have not been considered.

Another key assumption is that the hypothetical aggregator (or chargepoint operator) utilises a time-of-use electricity contract that is based on the day-ahead spot market prices.

Result of analysis

Based on the presented model, more than 1.1 million individual charging sessions were independently optimised under various charging strategies for both unidirectional and bidirectional charging. The results were later analysed both on a per-EV basis and in aggregate form.

The table below shows the yearly costs for different simulated charging strategies and market participation schemes, evaluated for the given fleet of EVs over the year 2023.

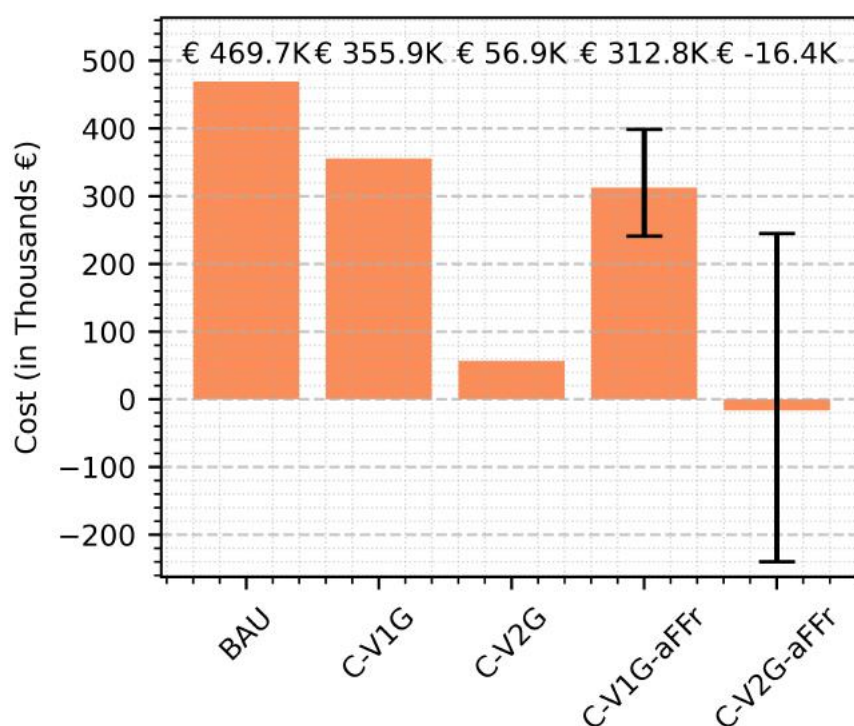
Strategy	Tag	Cost (Euros)	% Change from BAU	Error Range (Euros)
Business-as-usual	BAU	470k	0	N/A
Cost optimised (unidirectional)	C-V1G	356k	-24	N/A
Cost optimised + aFRR (unidirectional)	C-V1G-aFRR	313k	-33	72k–87k
Cost optimised (bidirectional)	C-V2G	57k	-88	N/A
Cost optimised + aFRR (bidirectional)	C-V2G-aFRR	-16k	-104	224k–262k

The business-as-usual (BAU) scenario, where EVs are charged immediately upon plugging in, results in the highest cost (€469 700 for the 2023 year) due to uncoordinated charging during expensive peak-price hours.

Cost-optimised unidirectional charging (C-V1G) significantly reduces this cost by 24.2% by shifting charging sessions to cheaper off-peak periods in the day-ahead market. The bidirectional variant without aFRR participation (C-V2G) provides an even larger reduction of 87.9%, primarily by leveraging the flexibility of Vehicle-to-Grid (V2G) technology. This allows the fleet to not only shift charging but also to export energy back to the grid during high-price periods, effectively turning the EVs into decentralised storage assets. Currently in this analysis there is no tax levy on bidirectional charging or accountability for battery charging/ discharging cycles, hence the actual realisation of profits might be lower.

Further reductions are observed when the fleet participates in the aFRR market. C-V1G-aFRR achieves a 33.4% cost reduction compared to BAU, while C-V2G-aFRR results in a net revenue (i.e., negative cost), reducing the total cost by more than 100%. The added benefit in these cases arises from the ability to respond to real-time imbalance prices during regulation states of 1 or -1, exploiting price deviations from the day-ahead forecast.

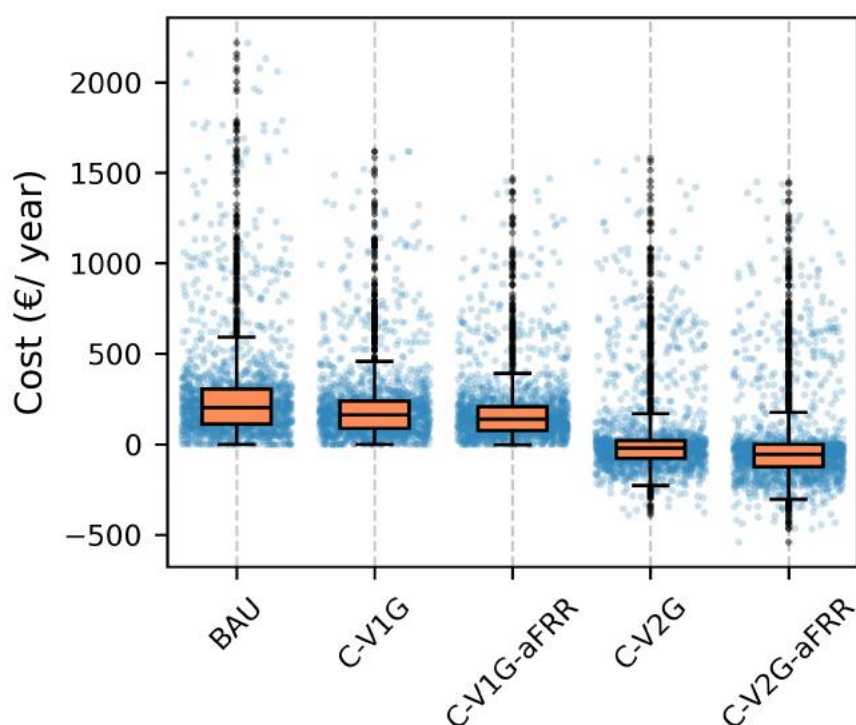
One important factor to consider when simulating scenarios involving participation in the aFRR market are ‘price thresholds’. The diagram below shows the error bars which represent the variation in outcomes for the two aFRR scenarios across the different price thresholds.



When participating in aFRR, the participant responds to real-time signals from the grid. However, the participant will only choose to offer these services when the aFRR price exceeds a certain threshold above the cut-even price point — this is called the price threshold. Choosing the right threshold is critical given that hypothetical CPO is also trying to optimise for the lowest price of charging in the day-ahead market. For example, if the CPO selects a low aFRR threshold and later the day-ahead prices drop significantly, they might miss out on the opportunity to charge at lower costs and earn more profit. In other words, setting the threshold poorly can lead to opportunity costs or reduced profitability.

Accurately modeling this behavior is challenging due to the uncertainty in future prices. To address this, instead of trying to model the optimal threshold directly, various price threshold scenarios were simulated. For each scenario, the maximum, minimum, and average charging costs were recorded. This provided a clearer picture of the potential outcomes across different thresholds and allowed for a more data-driven assessment of risk and opportunity.

The diagrams above present the annual cost for each strategy for the total EV fleet of 1735 vehicles. The following diagram below presents the cost across the different scenarios on a per EV basis instead.



The BAU case shows a wide spread, with a high median and many outliers above €1000/year, highlighting the inefficiencies of unoptimised charging.

Optimised strategies not only reduce median costs but also significantly narrow the interquartile range. This suggests more consistent savings across the fleet, making cost-optimised charging a more equitable and predictable approach.

C-V2G and C-V2G-aFRR in particular show a shift in the cost distribution toward negative values for a notable fraction of EVs. This reflects successful exploitation of both price arbitrage and ancillary service opportunities, especially for EVs with long connection durations and high flexibility.

Interestingly, some cost outliers remain even under optimised strategies. These typically correspond to EVs with shorter connection durations or those charging during hours of flat price signals, where optimisation has limited leverage. For bidirectional cases, the effectiveness of V2G also depends on technical constraints such as maximum discharge power and battery degradation limits, which were conservatively modelled in this study.

Return on investment calculation

Based on the results of the financial potential analysis presented above, a calculation of the return on investment has been made with the direct charging strategy as the base case. The base case is compared against the bidirectional charging strategies (on a whole of fleet basis for the 1735 vehicles simulated), where the investment cost of bidirectional chargers are taken into account for 5 and 7.5 year investment periods.

The investment cost per bidirectional charger is assumed to be €4000, inclusive of hardware and installation costs – aligning with the assumptions made in the We Drive Solar use case. To keep the calculations conservative, no investment cost is assumed for the unidirectional chargers, meaning that the investment cost for the bidirectional chargers used can be understood as the premium that a CPO would pay for installing bidirectional chargers over standard, unidirectional chargers.

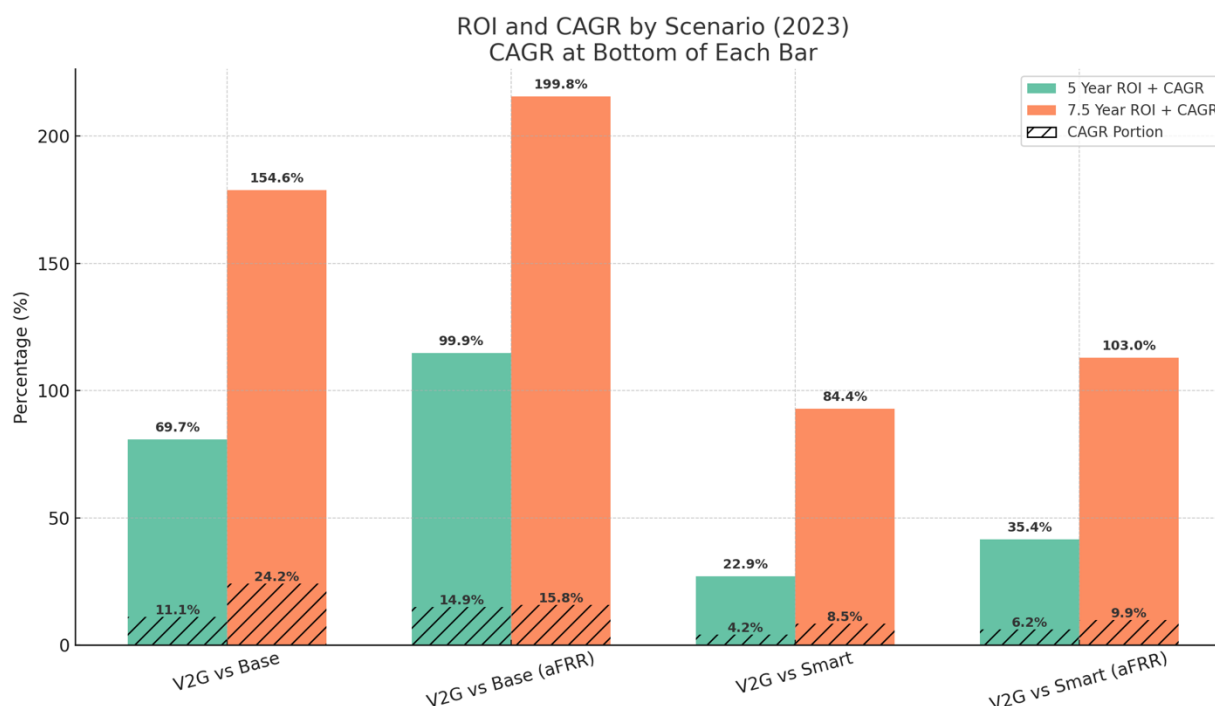
One uncertainty in this use case is the number of public chargers that is used by Stedin's fleet. As discussed previously, charging is assumed to occur at public AC chargepoints, in line with the current practice of vehicles in Stedin's fleet that have already been electrified. However, it is not known how many unique chargepoints are used by these vehicles in the greater Rotterdam area (Rijnmond region). Given this, we have estimated the average EV density per chargepoint in the Rijnmond region using publicly available data showing 14,431 public chargepoints (Electromaps, 2025); population of 1.49 million for Groot-Rijnmond region in 2023 (Data Commons, n.d.); 1 million plug-in EVs in the Netherlands as of 2025 (Statistics Netherlands, 2025). This results in estimated plug-in EVs in Groot-Rijnmond (as a proportion of national population and EV count) to be 82,300 EVs, providing an EV density per chargepoint figure of 5.7 EVs per chargepoint. Using this figure as a basis for Stedin's simulated fleet of 1735 vehicles, we get 304 chargepoints.

This specific ROI analysis is therefore conducted from the perspective of a hypothetical CPO operating 304 public chargepoints, with Stedin's fleet of 1735 vehicles as its only customer. In reality, the chargepoints, being public in nature, will have other users and income streams – which means that the ROIs conducted should be considered to be conservative in nature.

The cost of charging for the different charging strategies are incurred by the CPO, and these are taken from the results of the simulations in the financial potential analysis discussed above. Revenue for the CPO in the ROI analysis is hence considered to be the delta in charging costs it can expect between the bidirectional charging strategies and the base case charging, as this represents the potential savings it can expect in the cost of charging. For this, the median cost of charging for the bidirectional charging strategies will be used. Actual commercial charging fees are not considered in this analysis.

To provide additional insights, the unidirectional smart charging strategies will also be compared against the bidirectional strategies. It is assumed that the unidirectional smart charging strategies will utilise the same type of chargers as in the base case strategy, as smart charging compatible chargers are already common place in the charging market.

The diagram below shows the results of the ROI analysis for all the scenarios considered.



Three main findings appear evident from the analysis results. The first is that the investment period has the most significant impact on the overall ROI. By extending the investment period from a 5 year horizon to a 7.5 year horizon, the simple ROI can be doubled in the V2G vs Base scenarios – while in the V2G vs Smart Charging scenarios the simple ROI increases even more to between 3-4 times, depending on whether aFRR is included. The effect is more muted on a CAGR basis, but still significantly increased in most scenarios.

The second main finding is that the inclusion of participation in the frequency markets (aFRR) is also significantly beneficial in both the V2G vs Base and V2G vs Smart Charging scenarios – increasing the simple ROI in the 5 year investment period by approximately 50% for both scenarios. However, this seems to have a slightly negative effect on a CAGR basis for V2G vs Base scenario with the 7.5 investment period.

The third main finding is that ROI drops quite significantly when V2G is compared against Smart Charging, as opposed to direct charging in the base case. However, this is unsurprising given that smart charging is already understood as a proven way to reduce charging costs. The important takeaway is therefore that even when V2G is compared against smart charging, we see a positive ROI in both scenarios with and without aFRR. In particular, with aFRR we see a CAGR of nearly 10% for the 7.5 year investment horizon, which brings it in line with the typical expected rate of return for projects in the commercial sector.

Discussion of results

This analysis assessed the financial performance of various EV charging strategies under the operational context of Stedin's commercial fleet, focusing particularly on the return on investment for bidirectional (V2G) charging infrastructure. Building on over 1.1 million simulated charging sessions using real-world fleet and market data, the results reveal clear trends in how different configurations affect both annual cost outcomes and long-term investment viability.

The key insight from the ROI analysis is the strong influence of investment horizon and grid services participation on financial returns. Comparing V2G to direct charging (base case), simple ROI values ranged from ~70% over five years to more than 150% over 7.5 years. The inclusion of aFRR services further improved these figures, pushing simple ROI to nearly 200% for the 7.5-year investment period. These gains demonstrate the importance of both exploiting energy price arbitrage via V2G and accessing ancillary service revenue streams in real-time grid markets.

However, when the benchmark shifts from direct charging to smart unidirectional charging, the ROI results become more modest. This reflects the fact that smart charging—already widely available and requiring no additional hardware investment—captures a significant share of the cost-saving potential by shifting demand to low-price periods. Even so, the bidirectional scenarios with aFRR still achieved strong returns, with a 7.5-year CAGR of ~10%, suggesting commercial viability even when compared to intelligent unidirectional alternatives.

Another important observation is the impact of the investment period on returns. For nearly all configurations, extending the horizon from five to 7.5 years resulted in a 2–4× improvement in simple ROI. While CAGR values are less dramatically affected, they too increase significantly—underscoring the value of taking a longer-term view when evaluating the business case for V2G infrastructure.

Unlike analyses in some of the other use cases examined in this deliverable which shows a considerable year-to-year variation (e.g., 2022 vs. 2024), this use case is based on a single year (2023) and reflects relatively high variability in electricity price conditions – which are advantageous to V2G and aFRR trading. As such, the ROI figures presented here may be potentially more favourable than the historical norm seen in the years prior to 2022. However, the results assume a conservatively high hardware and installation cost for the bidirectional DC chargers (€4000 premium above each unidirectional charger unit). Should bidirectional AC charging solutions become viable at lower price points, the ROI figures could improve further—especially for configurations that include frequency market participation.

Overall, the analysis reinforces that while V2G alone can offer strong returns when compared to direct charging, its incremental value over smart charging depends heavily on access to grid services such as aFRR and having a longer investment time horizon (i.e. from 5 years to 7.5 years). As the flexibility value stack becomes more fragmented and competitive, aggregators and chargepoint operators will need to carefully design their offerings (for example by setting an appropriate aFRR price threshold) to capture both energy and grid-service revenue in order to justify the additional infrastructure investment.

CURRENT (Oslo): Smart Charging and V2G for public in commercial and residential neighbourhood

Background

CURRENT is a Norwegian Charge Point Management System (CPMS) providing services to charge point operators across a range of charging applications, such as residential, workplace, commercial and municipal public charging.

In this use case, CURRENT, acts as the CPMS for a location owner 'Mustad Eiendom' on a site in Oslo that is part business park and part shopping mall. The use case focuses on how smart charging and the offering of flexibility through V1G can be implemented in real-world scenarios to deliver mutual benefits for

energy stakeholders, charging operators, and EV drivers. The following paragraph describes the roles of the main stakeholders in this use case.

As the site owner, Mustad Eindom is responsible for the physical chargers and the electricity contract. CURRENT acts as the CPO, CPMS and Flexibility Operator on behalf of Mustad Eindom, managing the intelligent charging operations and receiving a fee per charger per month. CURRENT enables the location owner to tap into the flexibility market through NODES, an independent marketplace and technology provider for trading electricity flexibility. Through NODES, flexibility providers can be compensated for providing an availability based-contract (called a reservation) for ensuring that they can deliver flexibility during a specific time window, should the need arise. Flexibility providers are also additionally compensated for the actual use of that flexibility when called upon (called an activation).

The business model for CURRENT explored in this case study is hence to use smart charging in conjunction with V1G to unlock value from both flex trading and optimizing charging to spot/day-ahead prices. Consequently, Current can capture some of this value by increasing the fee charged to the location owner, with the location owner capturing the remaining value.

Approach

This financial potential analysis is based on real life data collected from the charge sessions of 179 chargers on the use case site over the month of January, 2025. This charging data was compared against historical data for the same month from NODES as well as the day ahead spot market price for electricity for the region. From this, CURRENT were able to calculate the potential revenue from trading on the NODES platform, as well as the potential savings from optimizing smart charging on the day ahead market compared to charging on a fixed price electricity contract.

Unlike in many of the other use cases with V1G, the flexibility being traded on the NODES platform is not for frequency regulation services, but rather for participants in the energy market who have missed their energy market predictions. While frequency regulation services were not considered as part of this use case, it could potentially form part of the value stack in the future.

The business model being examined by this use case of using smart charging in conjunction with V1G flexibility services takes place using the site owner's existing smart chargers. Therefore no further capital investments are needed to unlock the additional value calculated. Given this, a return on investment calculation has not been carried out – as there is no additional investment needed in order to scale this business model to other similar use cases.

Key assumptions and demarcation

The financial potential analysis is based on the real-life data from the charging sessions, spot market and NODES flex platform described in the section above. However, since this data is based on the month of January 2025, it may not be reflective of the value that could be captured in other months of the year, nor may it be generalizable to market conditions in future years.

Some additional key limitations should be acknowledged:

- Perfect foresight with respect to optimizing for the spot price and providing flex services to the NODES platform is assumed.
- The amount of value that can be unlocked is closely tied to the level of utilization of the EV chargers (i.e. increase in future utilization of the chargers will likely increase the potential value, while decreases in future utilization will likely have the opposite effect)
- The location owner sets the parameters on how active they would like to be on the flex market; a more active approach can mean increased revenue; however this comes also at the increased risk of EV charging customers receiving less charge than they expected – affecting satisfaction levels.
- The analysis was conducted in the local Norwegian currency (NOK) and converted to Euros (€) for simplicity and comparability in this report. As such, currency fluctuations should be taken into account.

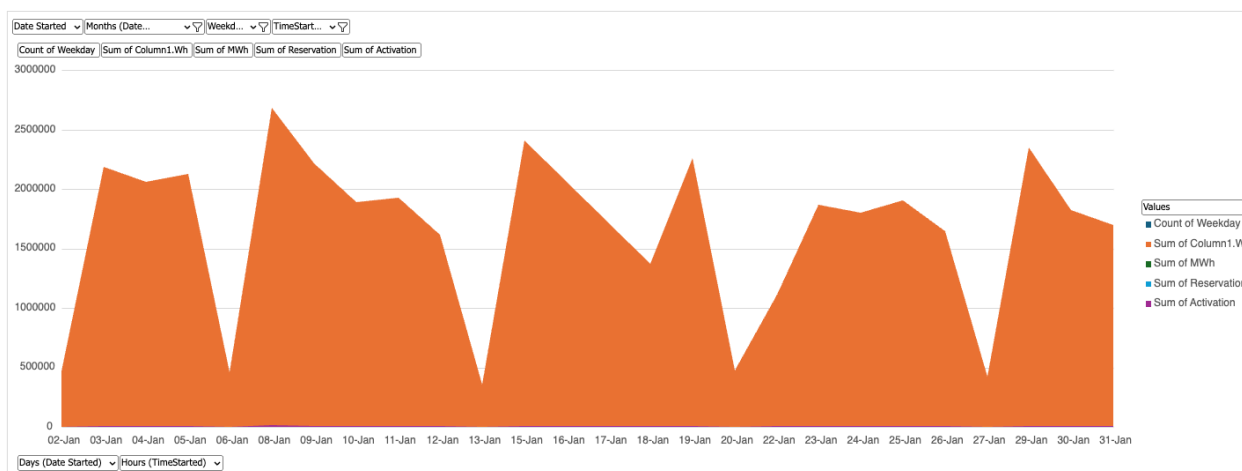
Result of analysis

The result of the analysis conducted by CURRENT shows that additional value of €10-15 per charger per month for this specific site could be achieved. This additional value comes from two separate value streams connected to the NODES flex market and from shifting from a fixed electricity contract to a day-ahead/spot market contract with smart charging optimization. The €10-15 calculated can be broken down as follows:

- ~34 NOK per charger per month from NODES LongFlex (reservations) value stream
- ~69 NOK per charger per month from NODES ShortFlex (activations) value stream

Switching from a fixed-price to a dynamic energy pricing model increases revenue by ~10%, which accounts for the remainder of the €10-15 per charger per month value that can be unlocked with this business model.

The figure below shows the modelled amount of watt hours that the vehicle fleet in this use case could have provided to the NODES platform (in terms of activations) for the month of January 2025, based on the real charging data collected.



The sharp dips in the figure align with the weekends of the month, where due to the commercial nature of the site, charger utilization often falls dramatically. This indicates that in more mixed-use settings (for example, car parks with a more balanced residential profile) revenue potential could be possibly higher or at least more evenly spread throughout the week.

Discussion of results

The financial potential analysis for this use case demonstrates how smart charging combined with V1G flexibility services can unlock measurable additional value without requiring further capital investment. By leveraging the existing charging infrastructure at Mustad Eiendom's site, CURRENT can optimise charging schedules to take advantage of day-ahead price variations and participate in the NODES flexibility market, generating incremental revenue that can be shared between the site owner and the CPMS.

The analysis shows that €10–15 per charger per month can be achieved at this location under the January 2025 market conditions, with approximately two-thirds of the value coming from the NODES LongFlex and ShortFlex services. LongFlex payments (for reservations) provide a predictable baseline revenue stream, while ShortFlex activations introduce a more variable but potentially higher-value component. The remaining one-third of the value comes from optimizing charging schedules to exploit lower spot market prices compared to a fixed-rate electricity contract.

While the monetary value per charger may appear modest, the lack of incremental investment required significantly enhances the attractiveness of this model. The scalability potential is high: deploying this approach across multiple sites with similar utilization patterns could deliver a substantial aggregate benefit. However, it is important to note that the financial returns are highly sensitive to charger utilization levels and the frequency of flexibility activations, both of which are dependent on local demand and market conditions.

Several operational considerations also emerge. Participation in flexibility markets inherently involves balancing commercial benefits with customer experience. A more aggressive approach to flex provision could increase revenues but risks delivering less-than-expected charging to EV drivers. Conversely, a more conservative approach prioritizing customer satisfaction may limit the value captured. The analysis assumes perfect foresight in scheduling, which is not achievable in real-world operations; future deployments should account for forecasting errors and market volatility.

Finally, while frequency regulation services were not part of this study, they could present an additional value stream in future iterations of the business model. Integrating multiple flexibility markets into a single operational strategy could further diversify and stabilise revenues, particularly in periods when spot market spreads or activation volumes are low.

Overall, this use case illustrates that even in the absence of new infrastructure investment, CPMS providers and site owners can generate meaningful returns by aligning smart charging operations with emerging flexibility markets. The model's validation in Oslo suggests that similar business parks, shopping centres, or mixed-use sites across Norway – and potentially in other liberalised energy markets – could replicate these results, provided that utilisation and market access conditions are favourable.

8 References

Ampcontrol. (n.d.). How to avoid EV charger downtime with a reliable charging management system. Retrieved September 2025, from <https://www.ampcontrol.io/post/how-to-avoid-ev-charger-downtime-with-a-reliable-charging-management-system>

Data Commons. (n.d.). Homepage. Retrieved April 2025, from <https://datacommons.org/>

Electromaps. (2025). Charging stations in the Netherlands. Retrieved March 2025, from <https://www.electromaps.com/en/charging-stations/netherlands>

International Climate Initiative (IKI). (n.d.). Comparative analysis of bus technologies for fleet renewal. Retrieved June 2025, from <https://www.international-climate-initiative.com/en/iki-media/publication/comparative-analysis-of-bus-technologies-for-fleet-renewal-new64c918518fcbb765275133>

Phihong. (n.d.). EV charging station solutions: How OEMs can engineer rugged, high-uptime chargers for public and commercial use. Retrieved September 2025, from <https://www.phihong.com/ev-charging-station-solutions-how-oems-can-engineer-rugged-high-uptime-chargers-for-public-and-commercial-use>

Statistics Netherlands (CBS). (2025). More than 1 million plug-in cars in the Netherlands. Retrieved March 2025, from <https://www.cbs.nl/en-gb/news/2025/22/more-than-1-million-plug-in-cars-in-the-netherlands>