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Integration of Electric Vehicles into Local Flexibility Markets

A Case Study of Electric Vehicle Aggregator Participation on a Swedish Local Flexibility Market

Master's thesis in Sustainable Energy Systems

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Abstract

Electric vehicles (EVs) are becoming increasingly widespread, transforming energy systems and presenting new opportunities and challenges. Beyond transportation, EVs can provide valuable services to the grid. Local flexibility markets (LFMs) allow electricity consumers and producers in specific regions to offer products that support local grid operation. This thesis explores the potential for EV integration in LFMs by identifying and reviewing operating European markets. The review finds that aggregated EV fleets are technically capable of participating in all studied markets. Additionally, a retrospective case study simulates EV aggregator participation in the Swedish LFM Effekthandel Väst during January 2025. Using a mixed-integer linear programming (MILP) model, the study minimizes charging costs for a fleet of 588 EVs under different scenarios. Results show significant cost reductions with V2G, particularly through a long-term availability contract, reducing cost by 56%. Without V2G, a capacity limitation contract offers the highest savings, reducing costs by up to 28%. In conclusion, the viability for EVs to participate in LFMs is greatly increased when bi-directional charging capabilities are available.

Keywords: Local Flexibility Markets, Electric Vehicles, Vehicle-to-Grid, Flexibility, Smart Charging

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Anna Oskarsson and Fredrik Berntsson, Gothenburg, June 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

ACER	European Union Agency for the Cooperation of Energy Regulators
CAPEX	Capital Expenditure
DSO	Distribution System Operator
EV	Electric Vechicle
FSP	Flexibility Service Provider
LFM	Local Flexibility Market
MILP	Mixed-Integer Linear Programming
OPEX	Operational Expenditure
SOC	State of Charge
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
V2X	Vehicle-to-Everything

Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

Indices

t	Index for time step
j	Index for electric vehicle

Sets

$\mathcal{T}$	Set of time steps (simulation/scheduling horizon)
$\mathcal{N}$	Set of EVs managed by the aggregator.
$\mathcal{N}_t^{Connect}$	Set of EVs connected at time t.
$\mathcal{T}_j^{Connect}$	Set of timesteps when an EV j is connected.
$\mathcal{T}_j^{Disconnect}$	Set of timesteps when an EV j is disconnected.

Parameters

Δt	hourly time discretization step (time interval)
$E_{\max}$	EV battery capacity
η_j^{ch}	Battery charging efficiency
η_j^{ds}	Battery discharging efficiency
P_t^{base}	Baseline power
$P_{\max}^{\text{ch}}$	Maximum charging power
$P_{\min}^{\text{ch}}$	Minimum charging power
$P_{\max}^{\text{ds}}$	Maximum discharging power
$P_{\min}^{\text{ds}}$	Minimum discharging power

$\pi_{t,j}^{\mathrm{sp}}$	Day-ahead spot price of electricity
$\pi_{t,j}^{\mathrm{gu}}$	Grid utilization cost
$\pi_{t,j}^{\mathrm{tax}}$	Energy tax
$\pi_{t}^{activation}$	Flexibility market price for activation
$\pi_{t}^{avaliability}$	Flexibility market price for availability
$\pi^{MaxUsage}$	Flexibility market price for MaxUsage
C^{minBid}	Minimum bid size of flexibility market
$SOC_{\mathrm{t,j}}^{\mathrm{des}}$	Desired State of charge at disconnection time
$SOC_{t,j}^{Connect}$	State of Charge at each time of connection of EV j.

Variables

$p_{t,j}^{ch}$	Charging power (in kW) delivered to EV j at time t.
$p_{t,j}^{dis}$	Discharging power (in kW) delivered from EV j at time t.
$B_{t,j}^{ch}$	Binary variable; 1 when EV j is charging at t.
$B_{t,j}^{ds}$	Binary variable; 1 when EV j is discharging at t.
B_{t}^{im}	Binary variable; 1 when fleet is net importing power at t.
B_{t}^{ex}	Binary variable; 1 when fleet is net exporting power at t.
$B_{t}^{\Delta P}$	Binary variable; 1 when deviation from baseline is greater than, or equal to minimum allowed bidding size.

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1

Introduction

As power systems worldwide transform into clean technologies and a higher share of electrification, the demands on power grids are increasing. Small-scale installations behind consumer meters such as photovoltaic panels, energy storage, and electric vehicles (EVs) are becoming increasingly widespread and are transforming our energy systems, introducing both new opportunities and challenges. Between 2019 and 2021, 167 GW of distributed photovoltaic systems were installed globally, with a combined peak output exceeding the peak consumption of France and Britain [1]. Accordingly, the transport sector is in transformation, with around 25% of the sold passenger cars in Europe being electric in 2023 [2, 3]. With a significant amount of cars charged at home, the energy consumption in local distribution grids is heavily increased. EVs can play a crucial role in addressing these challenges by offering services and energy products to the grid, beyond their traditional role as a means of transportation. By smart charging, i.e. controlling the EV charging, EVs can act in a demand-responsive way to mitigate grid stress. In addition, Vehicle-to-Grid (V2G), Vehicle-to-Home and Vehicle-to-Building technologies, with the collective name Vehicle-to-Everything (V2X), are becoming more widespread, enabling EVs to function not only as energy consumers but also, at times, as energy providers.

Local flexibility markets (LFMs) are markets where electricity consumers and producers within a geographic area offer to adjust their electricity demand or generation to support the operation of local electricity systems, typically to the local DSO [4]. The primary goal is to optimize the use of the existing grid infrastructure by distributing load more evenly and efficiently, to reduce or defer the need for costly grid reinforcements. The use of market-based mechanisms like LFMs and power tariffs is supported by the EU Electricity Directive 2019/944, which states that member states must provide the necessary regulatory framework to allow and incentivize DSOs to procure flexibility services, including congestion management in their areas [5]. In 2023, the European Union Agency for the Cooperation of Energy Regulators (ACER) informed that local markets have been implemented in less than a third of the member states. Legislative work or effective implementation of such markets is ongoing in an additional third of the Member States and in the remaining, the local markets are not implemented yet or the information on the status of such markets is unknown [4].

Given the increased significance of both EVs and LFMs in the evolving energy system, it is of growing relevance to understand how these two developments can be integrated and what the potential benefit of using EVs for flexibility services is.

1.1 Objective and scope

In this report, the integration potential of EVs within LFMs is explored by identifying and analysing currently operating markets in Europe, with a focus on their design and key characteristics. This is to identify key factors influencing the analysis and decision-making in LFMs. A retrospective, scenario-based case study modelling the participation of EV aggregators in the LFM Effekthandel Väst in south-western Sweden during January 2025 is also conducted, which aims to explore potential earnings from participation. This is to evaluate the potential effect that V2G and bi-directional charging can bring in the context of LFMs, and to aid in aggregator strategy for participating in LFMs.
In line with this objective, the thesis seeks to answer the following research questions:

- What examples are there of operating local flexibility markets in Europe? (Q1)
- What are their key characteristics affecting EV integration? (Q2)
- How much can be earned from EV participation in a LFM? (Q3)

1.2 Limitations

Although LFMs are emerging worldwide, this study focuses exclusively on European examples, with a single case study conducted in a Swedish LFM. Consequently, the estimated revenue and market behaviour presented may not be representative of LFMs in other regions or under different regulatory and market conditions. Battery degradation costs have not been taken into consideration in the model, however, an efficiency factor is used to mitigate excessive discharging. The data set containing charging data that is the basis for the case study combines both home and public EV charging sessions to reflect a prospective scenario in which vehicles can participate in LFMs from multiple locations. This limits the applicability to current LFMs. Furthermore, this study restricts its analysis to applications that require slow charging, without exploring opportunities or constraints associated with fast charging.

2

Background

2.1 Power System Challenges

As electricity demand grows and distributed energy resources become more widespread, distribution grids face increasing loads. The adoption of EVs may contribute to electricity demand peaks that exceed the grid capacity resulting such as congestion and voltage issues in distribution grids. Voltage control aims to maintain voltage levels within specified limits, as exceeding these limits can cause higher losses in the grid, overloading of induction motors, and other types of electric equipment dysfunctions [6]. Congestion management ensures that electricity demand remains within the capacity of transmission and distribution lines or transformers. This capacity may be limited by physical factors, such as the thermal limits of grid equipment or the maximum power it can support, but can also be constrained by non-physical factors, such as contractual agreements that restrict the amount of power that can be transmitted [7]. Overloading the maximum capacity can be expensive for the DSO if the limit is set by a contractual agreement. Running equipment above its rated power can lead to a shorter lifespan of the equipment and, in the worst case, to damage or destruction, which also leads to increased cost for the DSO [6].

The traditional way to address the above-mentioned challenges is grid expansion, meaning to redimension the equipment for higher loads. Increased power system flexibility, meaning the ability to respond in a timely manner to variations in electricity supply and demand, makes up an alternative to grid reinforcement by utilizing the existing grid infrastructure more evenly, reducing peak loads [8].

2.2 V2G and Smart charging

EVs are increasingly recognized as viable assets for providing flexibility through smart charging and V2X. Smart charging can be described as charging when power is controlled, in contrast to charging with maximum power immediately as the car connects to a charger. Through V2X functionalities, electric vehicles have the possibility to dynamically shift between acting as a load on the grid and acting as energy storage, outputting power to the grid. This makes their capacity for flexibility even more significant, as the possibilities go beyond switching between charging and not charging, to being able to switch between charging and discharging, essentially doubling their degrees of flexibility. There are various concepts and definitions related to bi-directional charging, depending on the intended use of discharged energy. Vehicle-to-Home supplies power to a household, Vehicle-to-Load powers any external device or equipment, and V2G returns electricity to the power grid. These approaches are collectively referred to as Vehicle-to-Everything (V2X). For the purposes of this report, the term V2G is used and defined as the process by which an electric vehicle (EV) exports electricity, resulting in a net power flow from the vehicle back to the grid.

These functionalities can offer benefits such as peak shaving, increased self-consumption of photovoltaics, and provision of ancillary services. Studies show that EV charging can be optimized to reduce peak load and energy costs [9, 10, 11], and V2G capabilities can enhance the profitability of PV systems by increasing export flexibility [11]. From a system perspective, EVs have also been demonstrated to support electricity market services such as secondary frequency regulation [12].

From a technical perspective, compatibility between vehicles and V2G programs remains a challenge, and the overall maturity of V2X technologies is still low [13]. Surveys among Swedish EV owners indicate that user acceptance of V2X services is closely linked to the level of control users retain over charging and discharging processes. While economic benefits are not the primary motivator, non-financial values such as backup power and environmental concerns seem to influence users' willingness to participate [14]. Awareness of V2X capabilities remains limited among EV owners, and there are still concerns over battery degradation, long charging times, and the risk of insufficient charge when needed [13]. The report [15] concludes that many market participants face difficulties justifying a business case for smart charging and V2X, which leads to a chicken-and-egg problem where the benefits are not visible until the technology is widely adopted, and vice versa, that wide adoption requires clear benefits.

2.3 Local Flexibility Markets

LFMs offer a tool to manage the power system challenges described in section 2.1 alongside measures such as conditional grid agreements and power tariffs. Power tariffs are a solution where the consumer pays not only for the amount of energy used in a month but also pays a tariff proportional to the peak power consumption for the month. This incentivizes the consumer to distribute its power draw more evenly throughout the month, leading to lower peaks in the distribution grid, which makes grid planning and dimensioning easier. Conditional grid agreements, or non-firm grid agreements, are agreements made when a new consumer connects to the grid, with the condition that the DSO can disconnect the consumer when necessary, which could be in the event of overloading the grid [16].

A LFM is defined as a market where flexibility service providers (FSPs) offer products for local electricity system operator services [4]. The need for an LFM is driven by various factors across different geographic areas and grids, and the flexibility traded can be defined as either upward or downward flexibility. Upward flexibility means that the flexibility service provided involves demand turn-down or generation turn-up, while a downward flexibility involves generation turn-down or demand turn-up, to avoid curtailment of electric energy. The Local Constraint Market run by NESO in Scotland is mainly centred around the procurement of downward flexibility [17], while upward flexibility is traded in the Netherlands [18]. Low market liquidity and reliability are highlighted as main design challenges for LFM [19]. Learnings from pilot projects indicate that these issues reduce the predictability of revenue streams, discouraging continued or new participation [20, 21]. Since flexible assets adjust their output or consumption to meet flexibility demands, a standard usage profile must be established for each time interval, called a baseline. The baseline acts as this reference point and signifies the power consumption or production that a flexible asset would be expected to have if it was to not participate in the LFM. The deviation from a baseline signifies the amount of flexibility delivered.

2.4 Stakeholders in local flexibility markets

The following section provides a short description of the actors on LFMs and Figure 2.1 provides a schematic representation of the market participants and the interactions between them.

Flexibility Service Providers

An FSP is an actor that offers flexibility products and services in LFMs, the product being their flexible consumption and production of electricity. Examples of FSPs are large electricity consumers like industries, electricity producers such as CHP plants, and electricity prosumers, i.e. actors that both consume and produce electricity, and have the ability to adapt this demand or generation according to grid needs.

Market Operator

Transactions on the LFMs are most often procured and solicited through a digital market platform provided by a market operator. Via the market platform, the operator matches the supply and demand of local flexibility, and also executes and validates the trade. In the case of LFMs, the buyer of flexibility is most often a DSO while the sellers are FSPs.

Distribution System Operator

A DSO is the party that is responsible for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity, as well as the short- and real-time operation of the distribution grid. This responsibility also includes operating, ensuring the maintenance of, and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems [5]. In LFMs, the DSO acts as the buyer of flexibility from FSPs.

Aggregator

A third party, known as an aggregator, can combine and control resources from multiple flexible assets to act as a single FSP. The aggregator's role is to consolidate these smaller resources into a single entity for participation in the LFM.

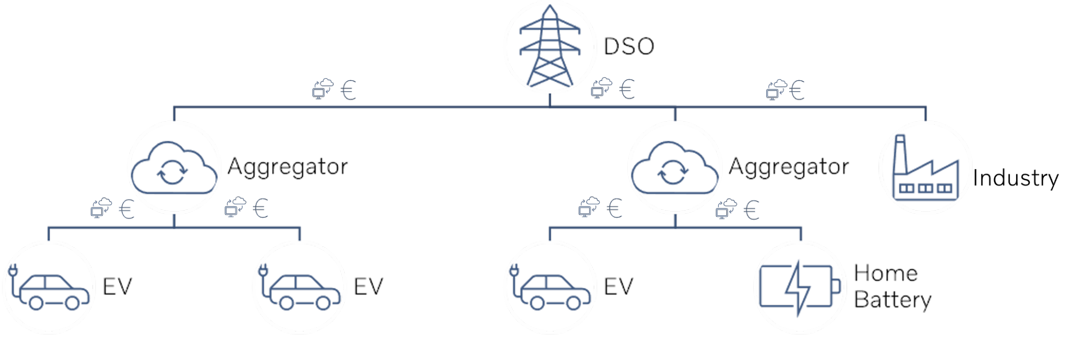


Figure 2.1: Schematic overview of actors and transactions on an LFM.

3

Methodology

This chapter describes the methodology of this study. The initial phase of the work included a mapping of existing markets. This review led onto a deeper review of a subset of existing markets and selection of a market for a case study which included a charge scheduling simulation. This simulation models the charging of a fleet of EVs. A flow chart of the methodology is shown in Figure 3.1.

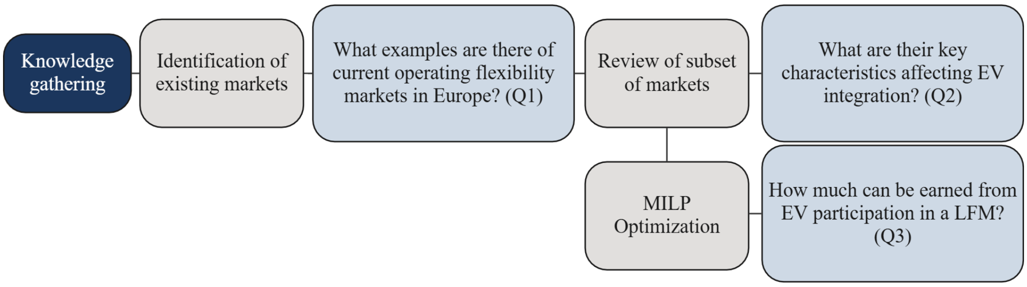


Figure 3.1: Flow chart summarizing the methodology.

3.1 Market mapping

To answer research questions Q1 and Q2, a review of current flexibility markets has been conducted by reviewing publicly available materials from relevant stakeholders, including white papers and related scientific publications. This resulted in a list of market operators and pilot projects mentioned in these sources. Each of the identified projects was then examined through online searches, including company websites and press releases to determine whether the project was still active, had concluded, or had evolved into a different form. For the markets found to be currently operating, their main characteristics were reviewed by examining information on the respective companies' websites. For some specific details that were not available online, direct contact was made with the companies via email or meetings.

3.2 Optimization Model

A mixed-integer linear programming (MILP) approach was used to represent both binary decisions, such as participation in flexibility markets and continuous variables, including charging power and state of charge (SOC). The optimization problem was coded in Python with Pyomo as the modeling interface and was solved using the Gurobi solver. A similar approach has notably been used in [22] to optimize the

V2G scheduling of an EV, while also accounting for battery degradation.

The objective function is:

$$f = \text{minCost}^{Agg} \tag{3.1}$$

where

$$\text{Cost}^{Agg} = \text{Cost}^{\text{ch}} - \text{REV}^{\text{sp}} - \text{REV}^{\text{LFM}} \tag{3.2}$$

The objective function is used to minimize the cost of energy for all aggregated cars in a fleet. The Cost^{ch} is the cost of purchased electricity for charging, REV^{sp} is the spot market revenue earned from selling electricity through V2G and REV^{LFM} is revenue earned from the LFM. The Cost^{ch} and REV^{sp} are defined as:

$$\text{Cost}^{\text{ch}} = \sum_{t\in\mathcal{T}}\sum_{j\in\mathcal{N}} \left(\left(\pi^{\text{sp}}_{t,j} + \pi^{\text{gu}}_{t,j} + \pi^{\text{tax}}_{t,j}\right) p^{\text{ch}}_{t,j}\right) \Delta t \tag{3.3}$$

$$\text{REV}^{\text{sp}} = \sum_{t\in\mathcal{T}}\sum_{j\in\mathcal{N}} \left(\left(\pi^{\text{sp}}_{t,j} + \pi^{\text{tax}}_{t,j}\right) p^{\text{dis}}_{t,j}\right) \Delta t \tag{3.4}$$

The index t refers to an hourly time step within the set $\mathcal{T}$, which spans all hours in a given month. The index j represents an individual vehicle in the fleet, and $\mathcal{N}$ is the set of all vehicles. The $\pi^{\text{sp}}_{t,j}$ is the day-ahead spot price of electricity, $\pi^{\text{gu}}_{t,j}$ is the grid utilization cost, consisting of an electricity transmission fee per kWh and $\pi^{\text{tax}}_{t,j}$ is the energy tax. The variables $p^{\text{ch}}_{t,j}$ and $p^{\text{dis}}_{t,j}$ describe the charging and discharging power of EV j at time t. This means that when the EV discharges, the power is sold to the grid at the spot market price. The revenue added from LFM participation is calculated as:

$$\text{REV}^{\text{LFM}} = \sum_{t\in\mathcal{T}} \left(\pi^{\text{LFM}}_{t} \cdot \Delta P^{\text{LFM}}_{t}\right) \Delta t \tag{3.5}$$

$$\Delta P^{\text{LFM}}_{t} = \begin{cases} 0, & \text{if } \sum\limits_{j\in\mathcal{N}} p^{ch}_{t,j} - \sum\limits_{j\in\mathcal{N}} p^{ds}_{t,j} \geq P^{\text{base}}_{t} \\ P^{base}_{t} - \left(\sum_{j\in\mathcal{N}} p^{ch}_{t,j} - \sum_{j\in\mathcal{N}} p^{ds}_{t,j}\right), & \text{if } \sum\limits_{j\in\mathcal{N}} p^{ch}_{t,j} - \sum\limits_{j\in\mathcal{N}} p^{ds}_{t,j} < P^{\text{base}}_{t} \end{cases} \tag{3.6}$$

where the parameter π^{LFM}_{t} is the compensation for LFM market participation and $\Delta P^{\text{LFM}}_{t}$ represents the deviation from the baseline consumption for all cars in the fleet. P^{base}_{t} is a series of baseline fleet energy consumption at time t.

The market has a minimum capacity requirement for flexibility bids, denoted as C^{minBid}. The binary variable $b^{\Delta P}_{t}$ is equal to one only when ΔP^{LFM}_{t} is greater than C^{minBid}, described in Equations 3.7 and 3.8 below.

$$\Delta P^{LFM}_{t} \geq C^{\text{minBid}} \cdot B^{\Delta P}_{t} \qquad \forall\, t \tag{3.7}$$

$$\Delta P^{LFM}_{t} \leq C^{\text{minBid}} + M \cdot B^{\Delta P}_{t} \qquad \forall\, t \tag{3.8}$$

The EV battery power is characterized by the expressions below. The battery can not charge and discharge simultaneously, which is defined in the constraints 3.9, 3.10

and 3.11 where the binary variable $B^{ch}_{t,j}$ is equal to one when EV j is charging, and vice versa.

$$b^{ch}_{t,j} + b^{ds}_{t,j} \leq 1 \tag{3.9}$$

$$b^{ch}_{t,j} \cdot P^{\text{ch}}_{\text{min}} \leq p^{ch}_{t,j} \leq b^{ch}_{t,j} \cdot P^{\text{ch}}_{\text{max}} \tag{3.10}$$

$$b^{ds}_{t,j} \cdot P^{\text{ds}}_{\text{min}} \leq p^{ds}_{t,j} \leq b^{ds}_{t,j} \cdot P^{\text{ds}}_{\text{max}} \tag{3.11}$$

The state of charge at every time t is calculated by using the state of charge in the previous time step, the efficiency η^{ch}, the battery capacity E^{max}_j, and the charging power and the discharging power at time t. This is expressed in Equation 3.12.

$$SOC_{t,j} = SOC_{t-1,j} + \eta^{\text{ch}} \frac{P^{\text{ch}}_{t,j} \Delta t}{E^{max}_j} - \frac{P^{\text{ds}}_{t,j} \Delta t}{\eta^{\text{ds}} \cdot E^{max}_j} \tag{3.12}$$

$\mathcal{T}^{Connect}_j$ is a set containing the times of connection for every EV. The state of charge of EV j is assigned the value $SOC^{Connect}_{t,j}$ $\forall t \in \mathcal{T}^{Connect}_j$, which is a parameter specific to every $t \in \mathcal{T}^{Connect}_j$. The charging and discharging of the car is controlled only in the time steps between connection and disconnection, which is expressed in Equation 3.13.

$$b^{\text{ch ds}}_{t,j} = 0 \quad \text{if } t = 0 \text{ or } t \notin [t^{\text{Connect}}, t^{\text{Disconnect}}] \tag{3.13}$$

where $b^{\text{ch}}_{t,j}$ is the charging status of EV j at time t, and $[t^{\text{Connect}}, t^{\text{Disconnect}}]$ represents the valid connection time intervals.

The net power import, P^{im}_t, and net power export, P^{ex}_t, are given by the net difference between the total charging, $\sum_{j \in \mathcal{N}} p^{ch}_{t,j}$, and discharging, $\sum_{j \in \mathcal{N}} p^{ds}_{t,j}$ throughout the entire EV fleet, expressed by the power balance equation below. The binary variables B_{im} and B_{ex} ensure that the fleet is not importing and exporting at the same time.

$$\sum_{j \in \mathcal{N}} p^{ch}_{t,j} - P^{im}_t \cdot B^{im}_t = \sum_{j \in \mathcal{N}} p^{ds}_{t,j} - P^{ex}_t \cdot B^{ex}_t \tag{3.14}$$

$$B^{im}_t + B^{ex}_t \leq 1 \tag{3.15}$$

The SOC is kept equal to or greater than the desired SOC at all times of disconnection, expressed in Equation 3.16. The $SOC^{des}_{t,j}$ is a parameter specific to every $t \in \mathcal{T}^{disconnect}_j$, given by historical data. This ensures that all EVs reach at least the SOC of disconnection given in the data.

$$SOC_{t,j} \geq SOC^{\text{des}}_{\text{t,j}} \quad \forall t \in \mathcal{T}^{tDisconnect}_{\text{j}} \tag{3.16}$$

3.3 Case study specifications

The study explores the participation in LFM Effekthandel Väst through its three product types, called ShortFlex, LongFlex and MaxUsage. The products are further described below in section 3.3.1 and summarized in Table A.1. An EV fleet is simulated to participate in Effekthandel Väst through all three products using smart charging, either with or without V2G-technology, resulting in six different setups, plus two reference cases for participation. For the rest of this thesis, these will be referred to as smart charging and V2G, even though smart charging is included in the V2G cases. Three different scenarios of flexibility demand from the DSO, meaning different numbers of flexibility asset activations, are also compared, showing how much cost savings can be achieved during a high, medium and low flexibility demand. Figure 3.2 describes the inputs and outputs of the simulation.

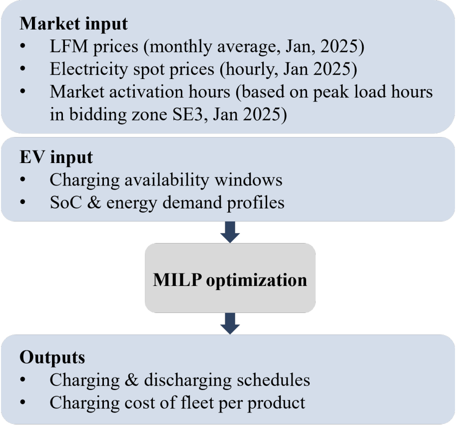


Figure 3.2: Flow chart of inputs and outputs in MILP optimization

3.3.1 Market Participation

Participation through ShortFlex means that the aggregator voluntarily places hourly bids, responding to tenders from the DSO. The demand for flexibility on Effekthandel Väst is in general the highest between 07:00-11:00 and 16:00-20:00 (Personal communication, Lisa Holgersson, Göteborg Energi, April 2025). For the case study, only these times are considered as market hours. At each time t, the bid size corresponds to the deviation of the actual power import from the baseline, i.e. the deviation from the power import in the reference case without any flexibility market participation. The compensation is received only if the asset is activated, and the π_t^{LFM} is therefore equal to $\pi_t^{activation}$, as shown in Equation 3.17. It is assumed that the aggregator always places bids corresponding to its available flexibility capacity, as long as the desired SOC of connected cars is met.

The LongFlex product involves that the aggregator enters contractual agreements to place ShortFlex bids during specific time windows. Compensation for availability is always given, regardless of whether the asset is activated by the flexibility buyer or not. If activated, availability payments are added to the activation revenues, as shown in Equation 3.17. For LongFlex participation through Smart Charge, the maximum possible availability compensation for the EV fleet is explored, given the baseline power. The aggregator is assumed to place an availability bid corresponding to the total amount of available flexibility at each timestep, which is equal to the power consumption in the baseline case. This means that in practice, an activation of the bid would require all charging to stop for the activated hour. Since LongFlex bids often specify one recurring capacity for a set period, an aggregator cannot place this bid under realistic circumstances without complete knowledge of future connections and disconnections. Instead, the calculation results in the maximum theoretical potential for LongFlex participation.

On the other hand, for V2G, the participation strategy for availability compensation consists of the aggregator placing a bid of constant capacity for all times. This corresponds to the maximum discharge capacity at the hour with the lowest amount of connected cars. This means that the aggregator assumes that all connected cars can be switched to discharge at their maximum discharge power at any time, and the LongFlex bid consists of the total discharge capacity of the fleet at the time when the least amount of cars are connected. This results in a relatively optimistic LongFlex bid, similar to the smart charge case.

$$\pi_t^{\text{LFM}} = \begin{cases} \pi^{activation}, & \text{for} \quad \text{ShortFlex} \\ \pi_t^{activation} + \pi_t^{avaliability}, & \text{for} \quad \text{LongFlex} \\ \pi^{MaxUsage}, & \text{for} \quad \text{MaxUsage} \end{cases} \tag{3.17}$$

The key difference in the MaxUsage simulation compared to ShortFlex and LongFlex is the baseline used and the flexibility remuneration mechanism. MaxUsage is a contract signed before the season starts, where the FSP offers a power cap on their capacity between certain times.

The possible time frame for MaxUsage is 7:00-9:00 and 16:00-19:00 (Personal communication, Lisa Holgersson, Göteborg Energi, April 2025). For MaxUsage, the baseline calculation does not rely on historical power demand. Instead, flexibility is provided by limiting the power consumption below a predetermined level, here called C_t^{cap}, that is based on the maximum capacity at every time step. This maximum capacity, C_t^{max}, is equivalent to the charging capacity used if all connected EVs were to charge at their maximum capacity at time t. The relations between the two are described below in Equations 3.18 and 3.19.
The baseline power P_t^{base} for ShortFlex and LongFlex is instead set to C_t^{max}, and the contract imposes a predefined cap on the power demand. Equation 3.6 is therefore changed to equation 3.20. The capacity restriction is set to 50% for both smart charge and V2G, and the aggregator is not paid equivalent to how much below baseline it consumes for the hour, but rather if it stays under C_t^{cap} .

$$C_t^{max} = \sum_{j \in \mathcal{N}_t^{Connect}} P_j^{max} \tag{3.18}$$

$$C_t^{cap} = C_t^{max} \cdot 0.5 \tag{3.19}$$

$$\Delta P_t^{\mathrm{LFM}} = \begin{cases} 0, & \text{if } \sum_{j\in\mathcal{N}} p_{t,j}^{ch} - \sum_{j\in\mathcal{N}} p_{t,j}^{ds} \geq C_t^{\max} \\ C_t^{\max} - C_t^{cap}, & \text{if } \sum_{j\in\mathcal{N}} p_{t,j}^{ch} - \sum_{j\in\mathcal{N}} p_{t,j}^{ds} < C_t^{\max} \end{cases} \tag{3.20}$$

The market pricing mechanism is pay-as-bid for ShortFlex and LongFlex, meaning that the final price is always equal to the bid placed. For MaxUsage, the price is fixed at a level set by the DSO. In the simulation, instead of various individual bids at different price levels, the average prices for the respective products are used. A comprehensive table of the different participation strategies through ShortFlex, LongFlex, and MaxUsage by smart charging and V2G can be found in Table A.7 in Appendix A.

3.3.2 LFM Activation scenarios

January 2025 consists of 23 weekdays; within these 23 weekdays, there are in total 184 hours that occur on Effekthandel Väst's market hours. Since the exact activation hours, meaning hours when the flexibility is needed, are not publicly available, it is assumed that activations in Effekthandel Väst occur in the peak load hours of the bidding zone SE3, in which Gothenburg is located. Three different scenarios for market activations have been used to simulate different flexibility demands. These are listed below.

- High flex demand scenario, (Flexibility assets activated 46 hours out of the 184 possible market hours.)
- Mid flex demand (Flexibility activated 23 hours out of the 184 possible market hours.)
- Low flex demand (Flexibility activated 12 hours out of the 184 possible market hours.)

The top load hours for the SE3 bidding area, with the top load hours are shown in Figure 3.3. The activations take place during weekdays on Effekthandel Väst market hours, meaning some peak load hours on weekdays or outside these time windows are not included.

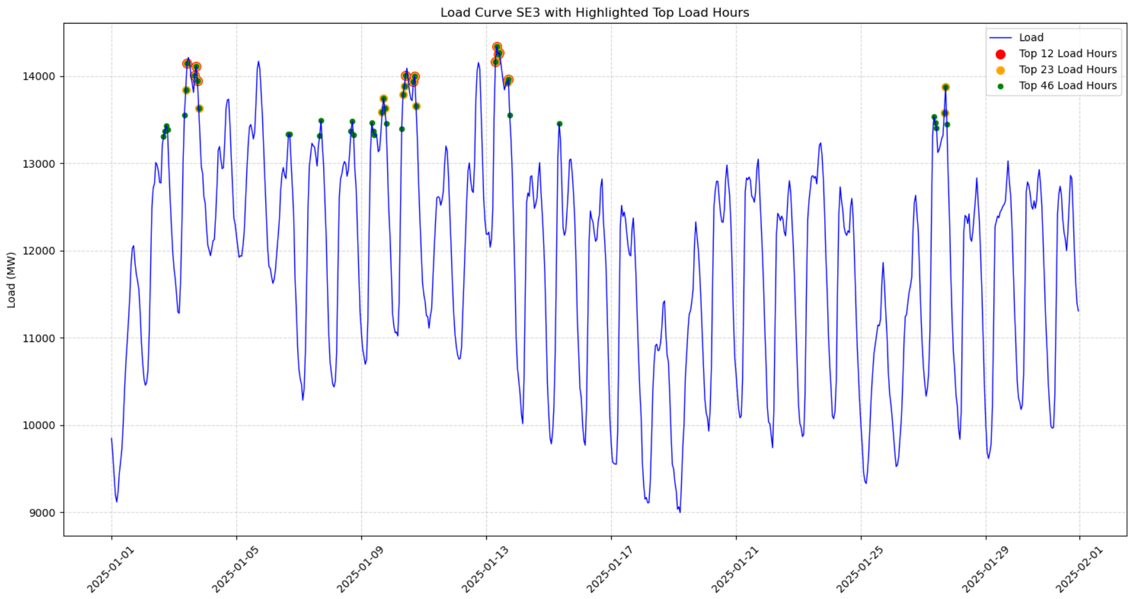


Figure 3.3: Load curve in SE3 bidding zone with marked top load hours occurring on weekdays between 07:00-11:00 and 16:00-20:00.

3.3.3 Input data

A dataset including times and SOC for connection and disconnection for 588 vehicles in January of 2025 is used to represent the regular charging behavior of the fleet. Except for removing faulty and incomplete data points, all charging sessions for the month were included, meaning that both home charging and public charging. An example of two charging sessions for one EV is shown in Table 3.1. All cars are assumed to be disconnected at the start and end of the simulation. As described in section 3.2, the connection and disconnection SOC is to be kept as in the input data, meaning that the optimal participation strategy is explored, under the condition that the user experience with regard to the SOC is not affected.

Table 3.1: Example of Charging Session data for one EV. The car connects at 20% and disconnects at 50% SOC in the first session. The next time the car connects, it has 36% SOC and disconnects the next morning with 90 % SOC.

ConnectTimestamp	DisconnectTimestamp	ConnectSOC	DisconnectSOC
2025-01-12 19:33	2025-01-12 23:10	20	50
2025-01-19 20:34	2025-01-20 07:13	36	90

Figure 3.4 shows the average number of connected cars, highlighting market hours. Data for the spot price is gathered from the ENTSO-E transparency platform, shown in Figure 3.5, and the flexibility prices are adapted from the NODES market platform [23]. Optimization parameters are listed in Table 3.2. For simplicity, all EVs are assumed to have identical characteristics, a 78 kWh battery, 11 kW maximum (dis)charging power, and 93% efficiency. In reality, this varies depending on car manufacturer, model, and other specifications.

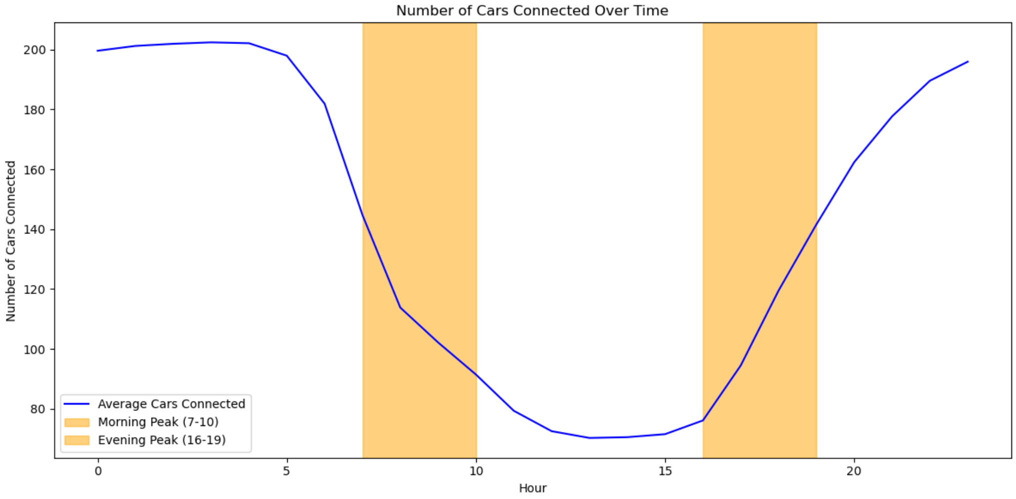


Figure 3.4: Average number of connected cars during January 2025 in dataset

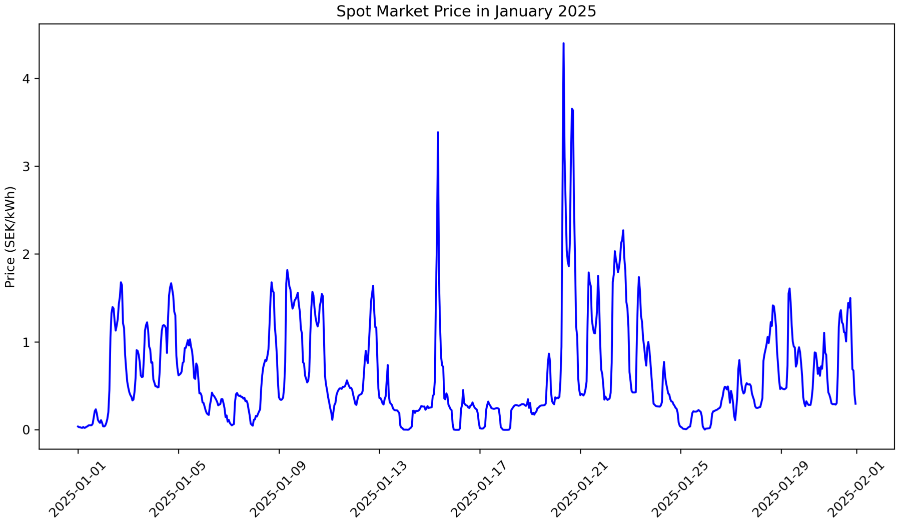


Figure 3.5: Spot Price of electricity in bidding zone SE3 in January 2025

Table 3.2: Parameters used in the optimization

Parameter	**Value**
EV battery capacity E^{max}	78 kWh
Maximum charging power $P_{\text{max}}^{\text{ch}}$	11 kW
Maximum discharging power $P_{\text{max}}^{\text{ds}}$	11 kW
Charging efficiency η^{ch}	0.93
Discharging efficiency η^{ds}	0.93
Average activation price $\pi_t^{\text{activation}}$	2.5 SEK/kWh [24]
Availability price $\pi_t^{\text{availability}}$	0.216 SEK/kWh [24]
MaxUsage price π^{MU}	1.0 SEK/kWh [24]
Grid utilization cost $\pi_{t,j}^{\text{gu}}$	0.25 SEK/kWh [25]
Energy tax $\pi_{t,j}^{\text{tax}}$	0.548 75 SEK/kWh [25]

4

Review of Existing LFMs

This chapter presents qualitative results from reviewing current LFMs. Currently operating LFM projects are identified and presented in section 4.1, followed by a comparison between four different markets operating at the market platforms NODES, Switch, Piclo and Epex Localflex in Norway, Sweden and UK. The market operators are first briefly described in section 4.2, then their products, requirements, and baseline calculations are described and compared in Sections 4.3.1, 4.3.2, and 4.3.3.

4.1 Market Mapping

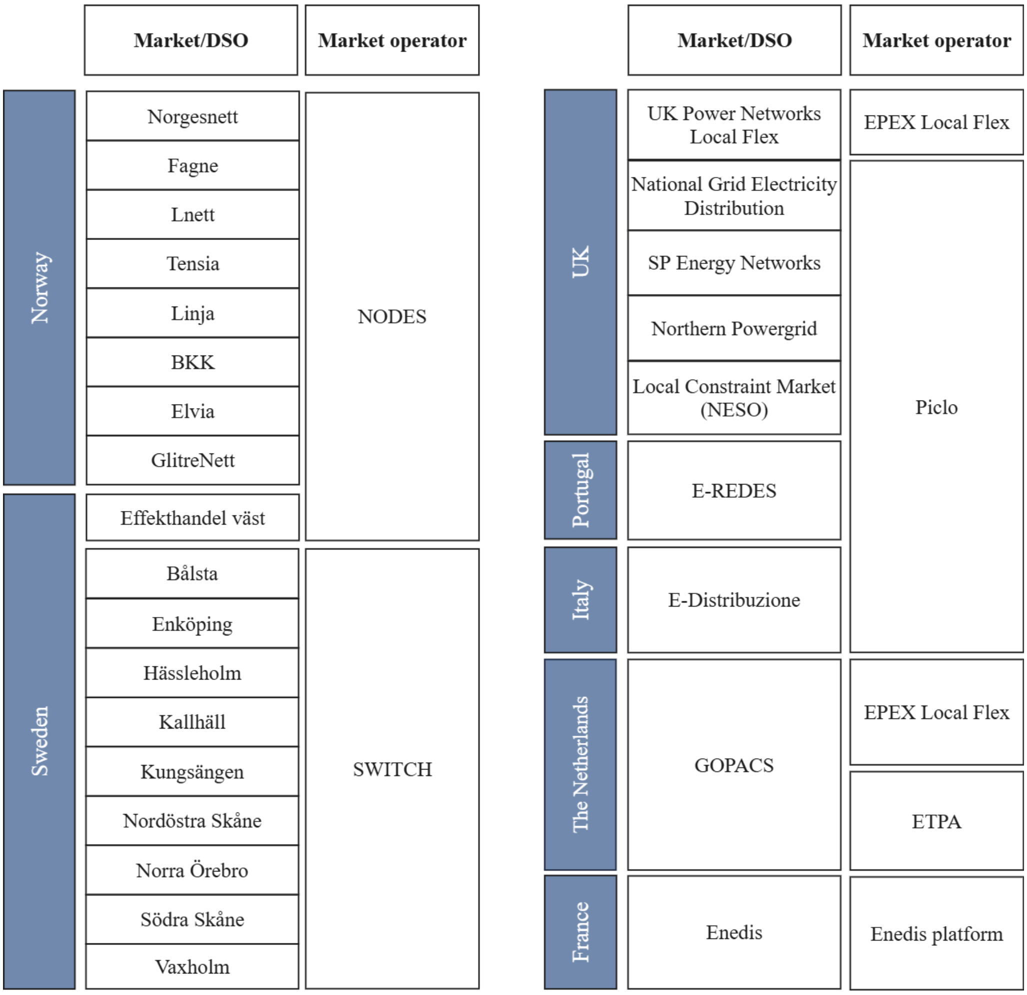
During the last 10 years, several pilot projects have been launched for LFMs in Europe. EU's research and innovation programme, Horizon 2020 (2014-2020), has funded several research projects on the topic, and there are also examples of projects initiated by grid operators or independent companies. The 2022 report [26] reviews key initiatives aimed at developing LFMs, including NorFlex (Norway), Enera Flexmarkt (Germany), IntraFlex (UK), GOPACS (Netherlands), GB flexibility tenders via Piclo Flex (UK), Enedis flexibility tenders (France), and Sthlmflex (Sweden). The report [27] from 2022 maps LFM projects in Sweden and identifies Coordinet, with pilots in Uppsala, Jämtland/Västernorrland, Gotland, and Skåne, Sthlmflex in Stockholm, and Effekthandel Väst in Gothenburg in Sweden. The report also brings up examples of European markets and lists NorFlex, Smart Senja (Norway), IntraFlex, Coordinet, Piclo Flex, Enedis, and GOPACS. In [28] from 2023, ongoing or recent LFM projects are reviewed, and the projects in question are Nodes, EPEX Local Flex, GOPACS, and Piclo Flex. In summary, the current states of these markets/projects are the following:

- NorFlex has transitioned into the currently operating market EuroFlex, including eight Norweigan DSOs [29].
- Enera remained a pilot and was discontinued in 2020 [26]. The operator behind Enera, EPEX Spot, has launched the EPEX Local Flex platform, which is active in the UK and integrated with GOPACS in the Netherlands [30].
- IntraFlex, launched by Western Power Distribution on the NODES platform ended in 2021. Western Power Distribution has since been acquired by National Grid Electricity Distribution, which now procures flexibility services through Piclo Flex [31].
- GOPACS, Piclo Flex, and Enedis flexibility tenders are currently operating.

- Sthlmflex, originally a pilot project, was extended through the winter of 2023/2024 but was discontinued thereafter [32].
- Effekthandel Väst is operating at the NODES platform in the Gothenburg region, Sweden.
- The Coordinet projects in Uppsala, Jämtland/Västernorrland, Gotland, and Skåne have all ended [33, 20]. However, the DSO E.on, which developed the market platform Switch for the project, has since opened several markets in Sweden using the platform, shown in Table 4.1 [34].
- Smart Senja is a local project on the sparsely populated island Senja in northern Norway running until 2026 [35].

A visual summary of the identified markets is provided in Figure 4.1.

Table 4.1: Overview of currently operating LFMs in Europe



	Market/DSO	Market operator
Norway	Norgesnett	NODES
	Fagne	
	Lnett	
	Tensia	
	Linja	
	BKK	
	Elvia	
	GlitreNett	
Sweden	Effekthandel väst	
	Bålsta	SWITCH
	Enköping	
	Hässleholm	
	Kallhäll	
	Kungsängen	
	Nordöstra Skåne	
	Norra Örebro	
	Södra Skåne	
	Vaxholm	

	Market/DSO	Market operator
UK	UK Power Networks Local Flex	EPEX Local Flex
	National Grid Electricity Distribution	Piclo
	SP Energy Networks	
	Northern Powergrid	
	Local Constraint Market (NESO)	
Portugal	E-REDES	
Italy	E-Distribuzione	
The Netherlands	GOPACS	EPEX Local Flex ETPA
France	Enedis	Enedis platform

4.2 Market operators

Several of the markets share technical platforms and market operator, which often results in similar design principles and market mechanisms across different regions. The review focuses on the platforms NODES, Switch, Epex Local Flex and Piclo

Flex, introduced below. As mentioned, some of the platforms are used in markets in several countries. For this analysis, only markets in Norway, Sweden and the UK are considered.

4.2.1 NODES

NODES was started as a common project between Norwegian Adger Energi, (now Å Energi) and Nord Pool. In Norway, the NorFlex pilot was initiated by Å Energi in collaboration with the national TSO Statnett and NODES. This pilot formed the basis for EuroFlex, a national-scale market that includes eight Norwegian DSOs [29, 36]. In Sweden, NODES operates Effekthandel Väst in the Gothenburg region [23]. The markets on the Swedish and Norwegian markets are only open during winter, and generation turn up or demand turn down is traded [24]. NODES also operates an LFM in Belgium as well as a pilot market in Finland [37, 38].

4.2.2 Epex Localflex

Epex Localflex was initially implemented as part of the Enera project in 2017 by the power market operator Epex Spot. Epex Localflex is currently used by UK Power Networks to operate flexibility markets in London, the South East, and the East of England [28]. The flexibility traded is in both directions up and down, meaning that the flexibility traded is both upwards and downwards adjustments for both generation and demand [39]. Epex Localflex is also one of the two trading platforms connected to GOPACS in The Netherlands [40].

4.2.3 Switch

Switch was developed during the CoordiNet project by DSO E.on in Sweden, and E.on now operates multiple LFMs in its distribution grids using the platform. During the 2023–2024 season, active markets included Södra Skåne, Hässleholm, Vaxholm, and Bålsta. For the winter of 2024–2025, additional markets have been launched in Enköping, Kallhäll, Kungsängen, North-Eastern Skåne, and Norra Örebro [34]. The market operates from November to March and enables the trade of generation turn-up or demand turn-down flexibility [41].

4.2.4 Piclo flex

Piclo was launched by an independent software company and now facilitates markets in the UK, Ireland, Portugal, and Italy. Within the UK, the Piclo platform is used by the DSOs National Grid Electricity Distribution, SP Energy Networks, Northern Powergrid and the TSO NESO with their Local Constraint Market, designed to tackle the thermal constraint across the Scottish transmission boundaries. Piclo Flex operates markets that are open also during summer, where also demand turn up and generation turn down is traded [17].

4.3 Market Characteristics

In this section, the main characteristics of the markets presented in section 4.2 are outlined. This includes the different products traded on the platforms, their participation requirements, and baseline methodologies.

4.3.1 Products

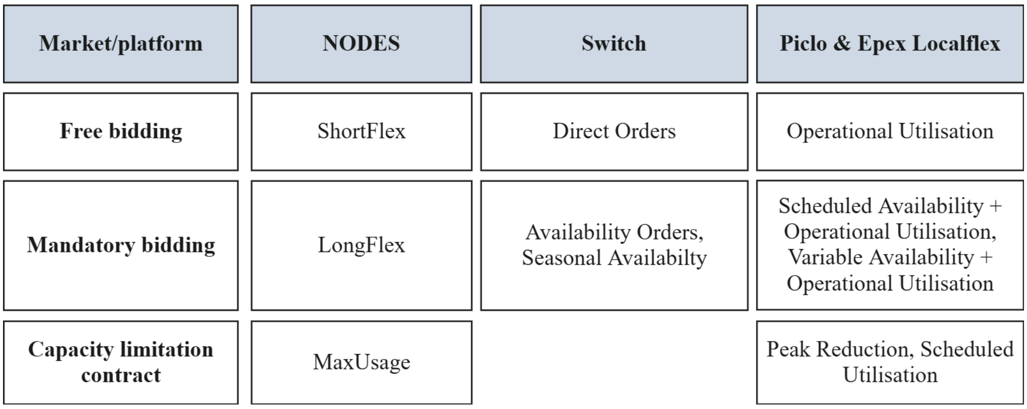
The flexibility services on the market platform are defined as different products, specifying the bidding time frame and remuneration mechanisms. As described in section 3.3, there are three products offered on NODES: ShortFlex, LongFlex, and MaxUsage, as summarized in Table A.1. ShortFlex are free bids, and payment is received if the asset is activated. LongFlex is a longer-term obligation to place ShortFlex bids during pre-agreed hours requested by the DSO, and MaxUsage is a capacity limiting contract, where the FSP commits to keep electricity demand below a pre-agreed cap.

The Switch platform in Sweden offers three products: Direct Orders, Availability Orders, and Seasonal Availability. These are summarized in Figure A.2. Similarly to NODES, trade is initiated by the DSO through a tendering process, after which FSPs may place bids on the platform. Direct orders are similar to ShortFlex and are only compensated upon activation. FSPs propose their activation price, and the lowest bid is selected (pay-as-bid). The times of bidding and activation notification vary between NODES and Switch, and are both shown in Table A.4 and A.5.

Similarly to LongFlex, Availability Orders provide compensation for being available to deliver flexibility, and potentially also for activation if the asset is used. Seasonal Availability contracts have no equivalent on NODES, and are contracts where the FSPs commit to being available on weekdays from 7:00–11:00 and 16:00–20:00 during December to February. The availability compensation is fixed at 192,000 SEK/MW for most regions and 320,000 SEK/MW in the Södra Skåne market for the 2024–2025 season. Activation follows the same schedule and compensation as for Direct Orders [41]. Notably, Direct Orders were never traded on any of the markets at Switch during the season of 2024-2025. Instead, the large majority of the trade consisted of Availability Orders [42].

In the UK, the trade association Energy Networks Association has established an industry-standard set of flexibility products, which are offered both in Piclo and Epex Spot UK markets. These are summarized in Figure A.3. In practice, what can be seen on both Piclo and EPEX is that only a subset of these products is traded in a given market, and each DSO selects which products to offer within its region. The Scheduled Utilisation product entails that the FSPs commit to provide flexibility at pre-agreed times, and are compensated for activation. The product timeframe can be adjusted, and within UK Power Networks' area using EPEX Local Flex, the product is divided into Long-Term Scheduled Utilisation and Day-Ahead Scheduled Utilisation. In that case, a Long-term Scheduled Utilisation means that there is a

Table 4.2: Products offered on the LFM platforms NODES, Switch, Piclo and Epex Localflex, categorized into the product types free bidding, mandatory bidding and capacity limitation contract.



Market/platform	NODES	Switch	Piclo & Epex Localflex
Free bidding	ShortFlex	Direct Orders	Operational Utilisation
Mandatory bidding	LongFlex	Availability Orders, Seasonal Availabilty	Scheduled Availability + Operational Utilisation, Variable Availability + Operational Utilisation
Capacity limitation contract	MaxUsage		Peak Reduction, Scheduled Utilisation

long-term delivery schedule (no regular activation instruction) similarly to NODES' MaxUsage. The Day-Ahead Scheduled Utilisation, instead, means that FSPs enter an auction to deliver flexibility at a day's notice, more similar to ShortFlex and Direct Orders. Operational Utilisation is similarly to ShortFlex a request for flexibility closer to real-time. Scheduled Availability + Operational Utilisation, similarly to LongFlex and Availability orders, means that the FSP commits to being available to reduce demand during set contracted windows, but actual activation is confirmed the day before. The difference between Scheduled Availability + Operational Utilisation and Variable Availability + Operational Utilisation is that for the former, availability is defined at the point of procurement and cannot be modified, and in the latter it can be refined closer to real-time. The Peak Reduction products seeks a reduction in peak power utilized over time, and can for example be provided by energy efficiency measures.

The products are summarised in Table 4.2 and categorised based on their functionalities into three different product categories: free bidding, mandatory bidding, and capacity limitation contract. All markets offer free bidding options, allowing the participant to be flexible and submit bids on short notice. This time is however varying across markets. For Effekthandel Väst on Nodes, the free bidding must be submitted at least 12 hours ahead, while Switch offers an intraday option, allowing bids until three hours ahead of delivery. For Epex LocalFlex in UKPN grids, the equivalent to ShortFlex and Direct orders are Day ahead Scheduled Utilisation, where FSP or aggregator can submit their bids until 12 a.m. the day before delivery [43]. These products all requires active FSPs or aggregator, and depends on how large the demand for flexibility is, in other words, how many activations that take place, as the compensation is based only on activation. Also longer term availability contracts are offered at all markets in the form of LongFlex, Availability orders, Seasonal Availability, Scheduled Availability + Operational Utilisation and Variable Availability + Operational Utilisation. MaxUsage, Scheduled Utilisation, and Peak Reduction are capacity limiting contracts, which have no equivalent on Switch.

4.3.2 Requirements

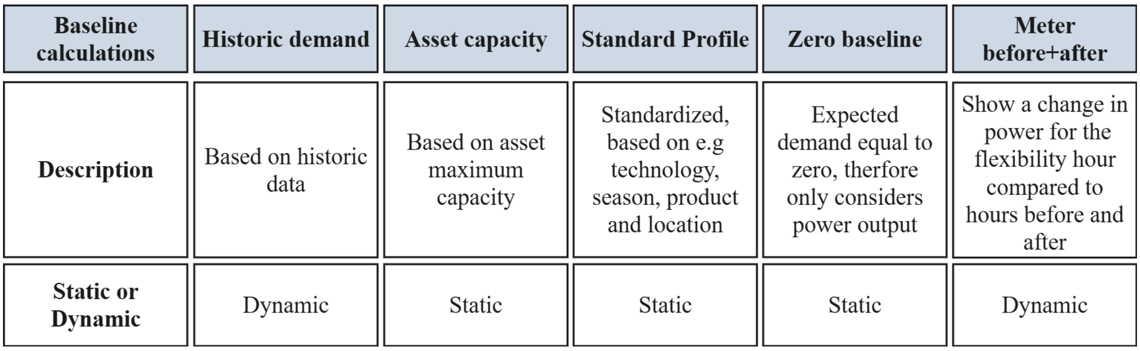
The platforms all enforce some technical and geographic criteria for participation. Assets must be located within the designated competition boundary and connected at a compatible voltage level. It must also be able to provide the required capacity, meaning be capable of regulating its power output in response to market signals and accepted bids. Each market also has some minimum capacity and duration requirement FSPs to qualify for participation. The limit for Epex Localflex is at least 10 kW for 30 minutes, while NODES requires 50 kW for one to two hours, and Switch at least 100 kW for one hour. For Piclo markets, the minimum capacity limit varies between DSOs [44, 43, 45, 41].
The flexibility asset must also have metering installed for the purposes of performance management and payment. UK Power Networks operating on Epex Local Flex state that the metering must be located at a suitable location and must be at least half-hourly. Meter data needs to be submitted monthly, for baseline verification and settlement calculations. In addition, UK Power Networks reserves the right to request disaggregated meter data for audit purposes [43]. No further technical requirement regarding, for example, battery ramp-up time has been found for any of the markets. Through the capacity limitation contract products MaxUsage Peak, Reduction and Scheduled Utilisation, also FSPs that are unable to respond to activation instructions can participate, given that the flexibility is delivered at the pre-agreed times.

None of the markets apply financial penalties for insuffiecient delivery, except for a reduced payment. On Switch, at least 75% of the committed flexibility must be delivered to receive compensation, which is scaled proportionally to the actual delivery [41]. UK Power Networks uses a performance factor to penalize SAOU providers who under-deliver, and availability payments are adjusted based on this factor. On NODES, full compensation is received if the FSP delivers 80% or more. For a delivery of less than 80% of the agreed flexibility, the payment is reduced by 2.5% for each 1% that is missing. At 40% delivery or lower, no compensation is received [45].

4.3.3 Baseline Methodologies

On NODES for the ShortFlex and LongFlex products, the baseline is calculated as the mean value of measurement data for the delivery hour over the past five weekdays. This is a kind of baseline calculation that is specific to each FSP based on historical demand. This can be compared to a case where the baseline is not individually adjusted to the regular consumption of the speciis here defined as dynamic. For MaxUsage, the baseline is defined as a constant value corresponding to the maximum power usage. This is a static kind of baseline, not reliant on historical user patterns, and can be called an asset capacity kind of baseline. For residual energy storage, a zero baseline is used, which assumes an output of 0 MW under normal, unutilized conditions. This means that the asset is only compensated for the energy output and not the decreased demand. The choice of baseline method on NODES is determined by agreement between the grid company and the FSP,

Table 4.3: Summary of baseline calculations used in reviewed markets.



Baseline calculations	**Historic demand**	**Asset capacity**	**Standard Profile**	**Zero baseline**	**Meter before+after**
Description	Based on historic data	Based on asset maximum capacity	Standardized, based on e.g technology, season, product and location	Expected demand equal to zero, therfore only considers power output	Show a change in power for the flexibility hour compared to hours before and after
Static or Dynamic	Dynamic	Static	Static	Static	Dynamic

and an alternative baseline may be provided by the flexibility supplier along with a documented calculation method, once agreed upon with the DSO. The flexibility supplier must submit the calculated baseline to NODES for all hours during the trading period and must also document the calculation and the data used [45].

In Piclo, the baseline calculations vary between DSOs and markets. National Grid Electricity Distribution states that they have moved away from dynamic, historical demand-based baselines in favour of more static approaches that reflect the characteristics of the participating technology. They use four different types of baseline methodologies: Zero Baseline, Asset Capacity Baseline, Self-Nominated Baseline based on historic demand, and Planning Profile Baseline. The Asset Capacity Baseline, sets the baseline equal to the declared capacity of the asset as registered during onboarding. Self-Nominated Baseline is calculated from historical demand data. This baseline is submitted monthly, calculated as a single average value based on the provider's usage during weekdays from 15:00 to 20:00 over the preceding four weeks. Planning Profile Baselines offer a standardized, fixed baseline that varies according to season (summer or winter), technology type, product category, and geographic location [46].

On EPEX Local Flex in the UK Power Networks grid, baseline methods vary by asset type. Similarly to National Grid Electricity Distribution, they state that they have moved towards a technology based, static baseline. For storage assets, such as stationary batteries, a zero baseline is used. For domestic electric vehicles and heat pumps, the baseline is based on average load profiles and flexibility is measured as deviations from the standard profile. The baseline curve for EVs is shown in 4.1 [43]. The different types of identified baseline calculations on the markets are summarized in Table 4.3.

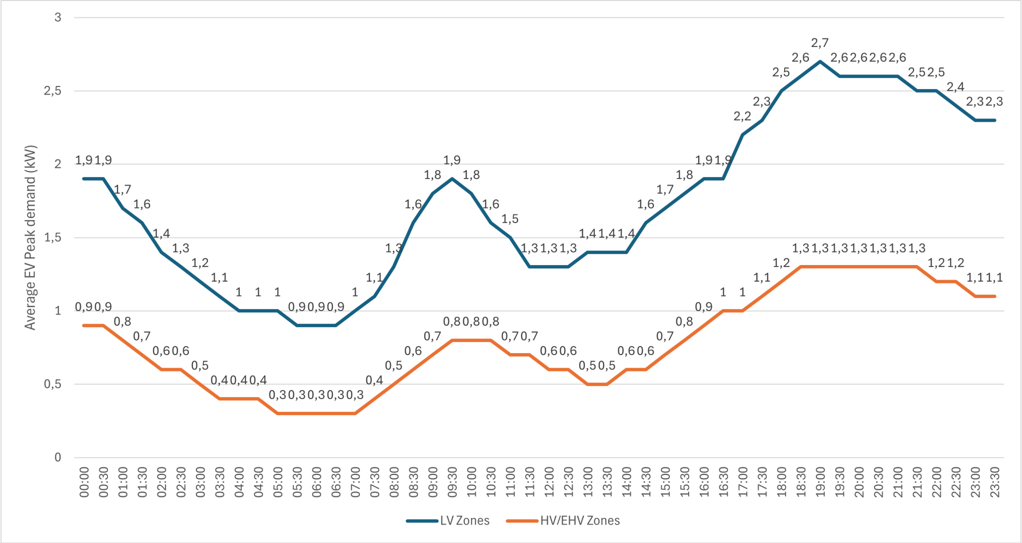


Figure 4.1: Technology specific baseline for EVs on EPEX Localflex in the UK. The baseline is based on a standard profile, meaning it is not individually adjusted to the FSP, and the voltage level for congestion zone; low voltage (LV Zones) and high to extra high voltage (HV/EHV Zones)

5

Results from the Case Study Simulations

The following chapter presents the results of the case study of an aggregator participating in LFM Effekthandel Väst in January 2025.

5.1 Smart Charge

In Figure 5.4, the reduction in total cost is shown for participation through smart charging for all products and activation scenarios. MaxUsage offers the highest cost reduction of 28%. The second highest is LongFlex with a high activation scenario at 3%, and the rest of the LongFlex or ShortFlex options offer a cost reduction of 1-2%.

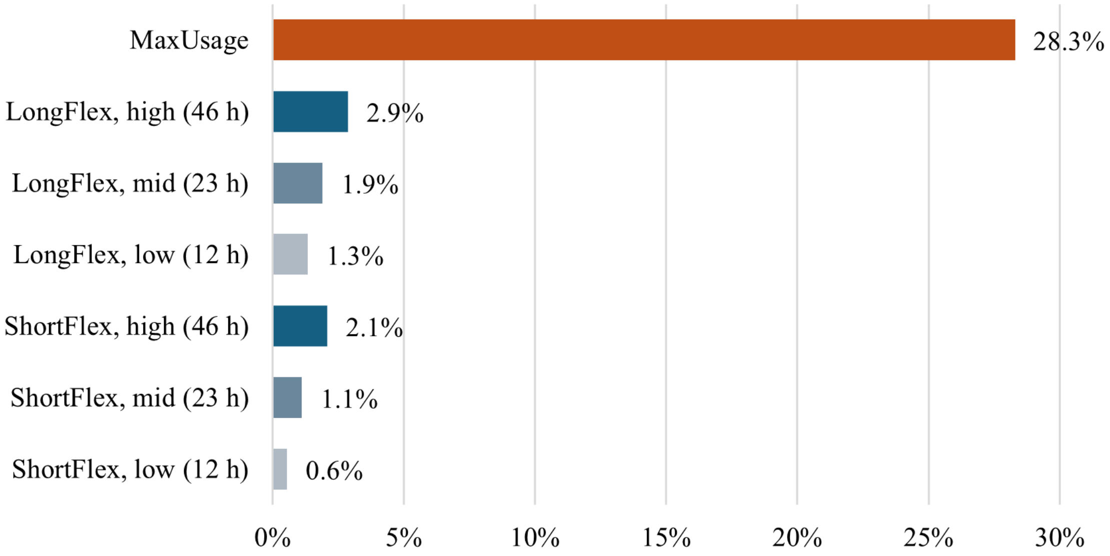


Figure 5.1: Cost Reduction from participating in Effekthandel Väst in January 2025 with its products through three activation scenarios for Smart Charging

When breaking down the cost reduction, it is clear that the costs of importing electricity are equal to 246,094 SEK for all products and cases, as seen in Figures 5.2 and 5.3. This indicates that the charging pattern is identical or has been shifted to hours with a similar spot price. This means that the charging schedule has not been largely impacted by the LFM participation compared to the reference case.

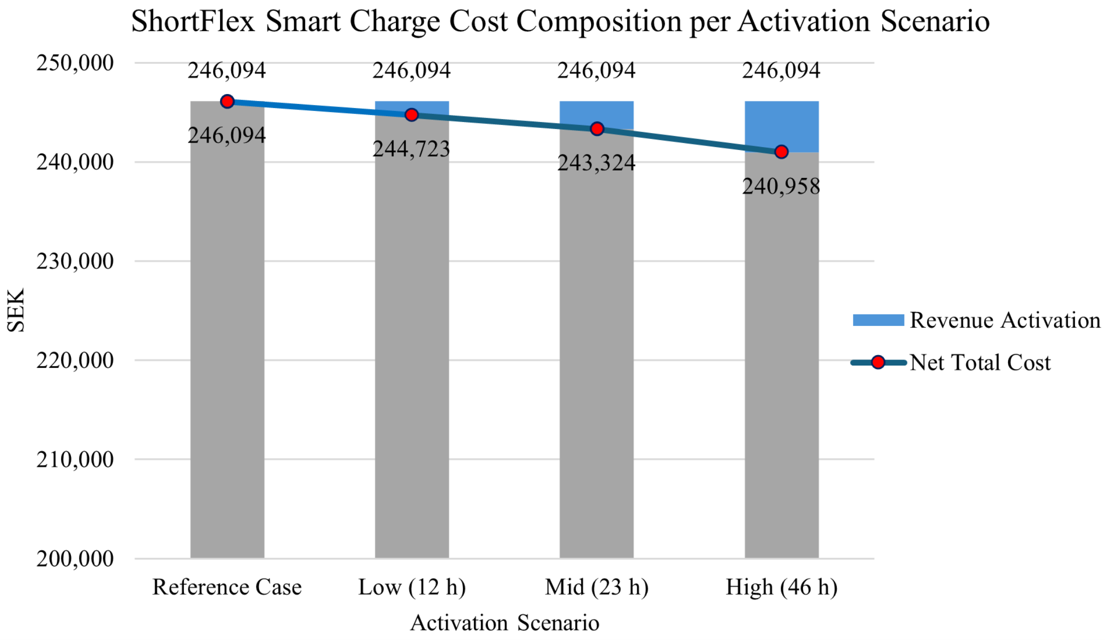


Figure 5.2: Cost composition for ShortFlex with three activation scenarios through Smart Charge participation. The height of the bars show the total cost of import of electricity, from which a revenue from LFM participation is subtracted to receive the net total cost of charging.

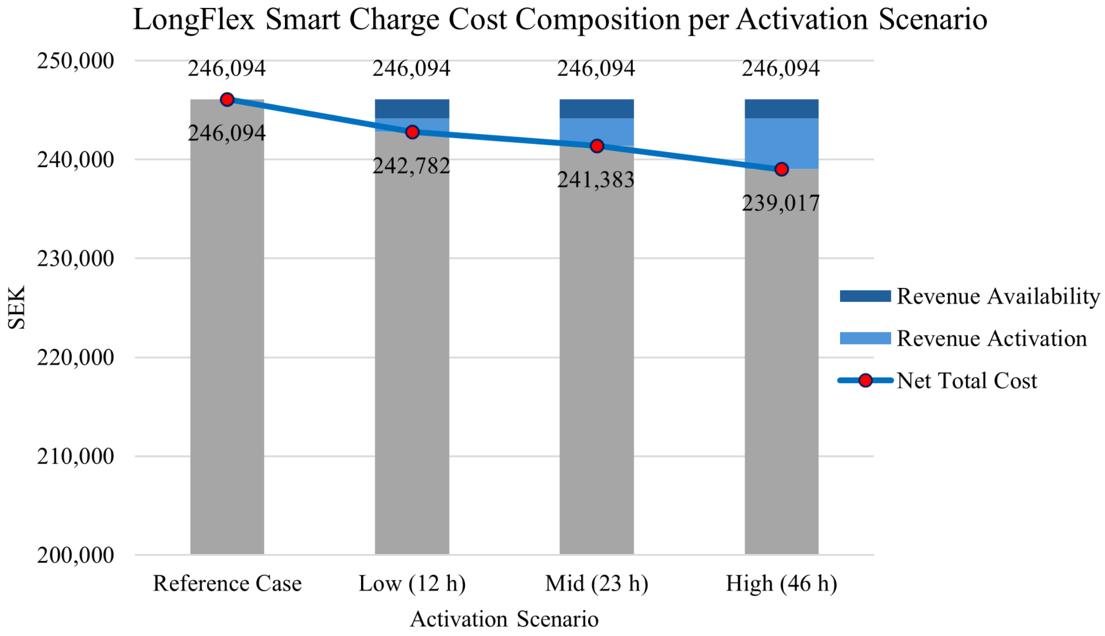


Figure 5.3: Cost composition for ShortFlex with three activation scenarios through Smart Charge participation.

5.2 V2G

For V2G participation in the LFM, cost reductions of up to 56% are achieved. The greatest cost reduction is rewarded by LongFlex participation, given that there is a high flexibility demand from the DSO, in this case 46 activation hours. For a lower and middle activation scenario, MaxUsage yields the largest cost reduction of 38%. ShortFlex provides a cost reduction of 12%, 22% and 43% for the low, mid and high scenarios.

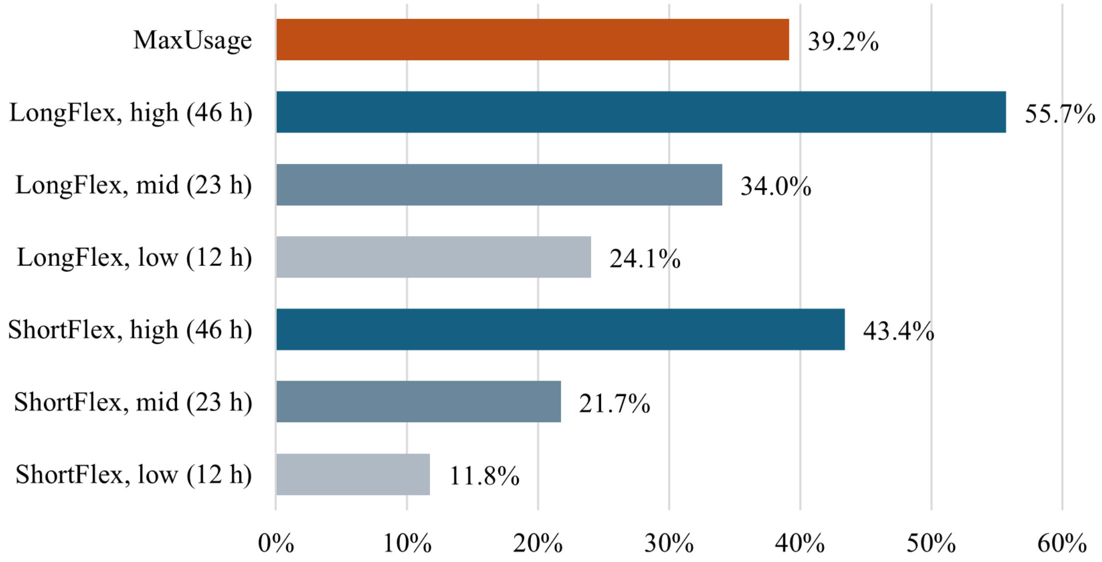


Figure 5.4: Cost Reduction from participating in Effekthandel Väst in January 2025 with its products through three activation scenarios for V2G

When breaking down the costs for V2G participation, the reference case contains a total import cost of 296,765 SEK for the 588 vehicles. A revenue of 171,870 SEK that is earned from the spot market is subtracted from this value, giving a net total cost of 177,733 SEK, shown in Figure 5.5. For the three activation scenarios, the cost of power import increases with more activation hours. Consequently, more power is exported, giving a higher revenue from spot-market export. In addition, the revenue from activation is increased with a higher flex demand scenario. The net total cost is reduced from 1̃77,000 in the reference case to 1̃00,000 SEK in the high activation scenario.

For LongFlex, an additional revenue is subtracted from the cost, shown in Figure 5.6. This results in all cases having the same LFM revenue as the ShortFlex case, but with a constant added reduction from the ShortFlex revenue, no matter the activation scenario.

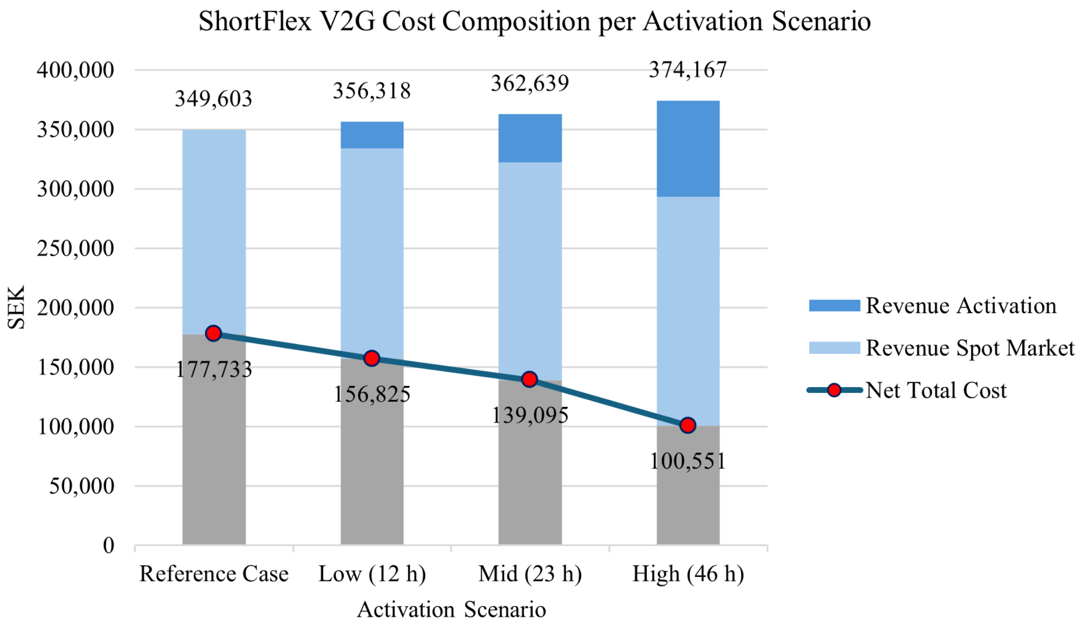


Figure 5.5: Cost composition for ShortFlex with three activation scenarios through V2G participation.

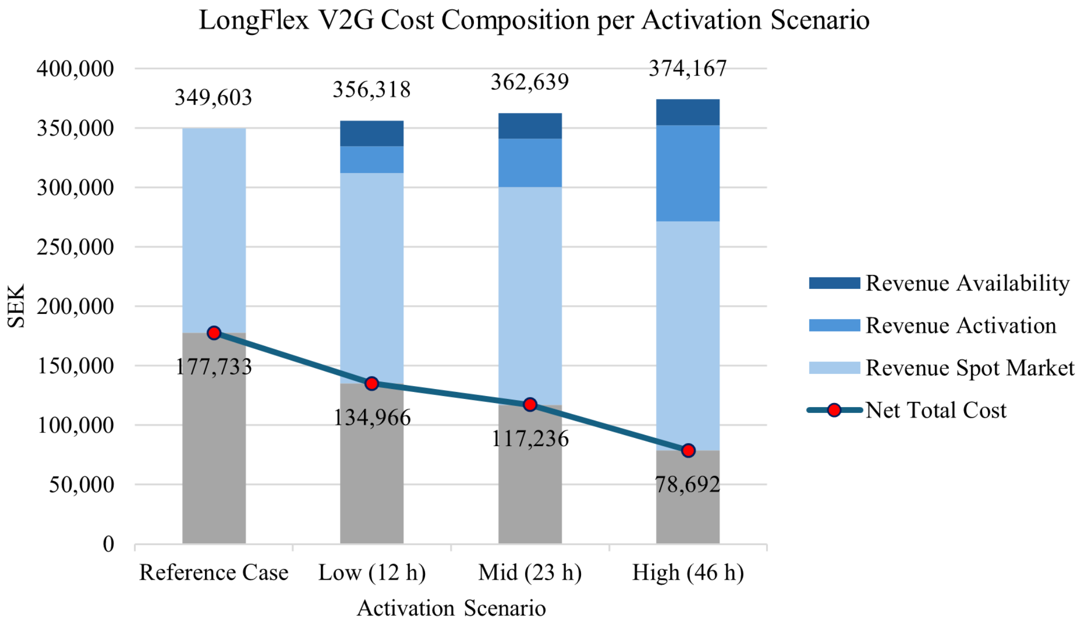


Figure 5.6: Cost composition for LongFlex with three activation scenarios through V2G participation.

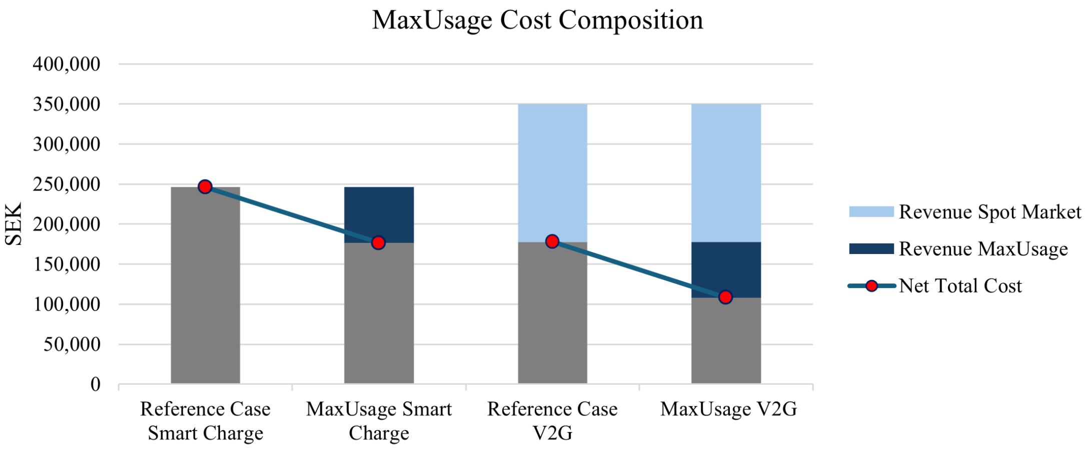


Figure 5.7: Cost composition for MaxUsage with smart charge and V2G participation.

5.3 Summary

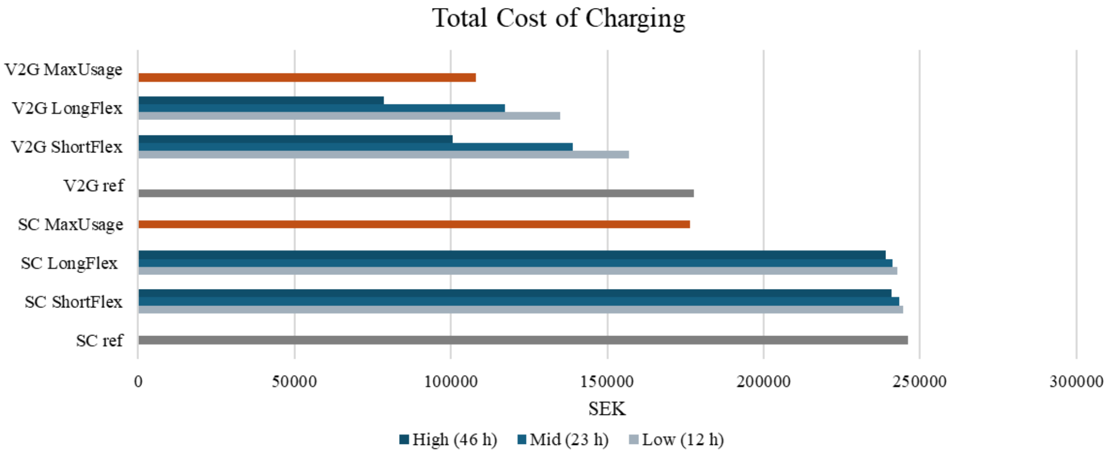


Figure 5.8: Total cost of charging the entire EV fleet for every scenario (high, mid and low), and participation case.

The total cost of charge for all 588 EVs is shown in Figure 5.8, illustrating the differences between products and activation scenarios for both smart charge and V2G. The corresponding numbers can be found in Table 5.1. The figure shows that the total cost for V2G is lower than smart charge for all products and activation scenarios, except for smart charging MaxUsage participation, which results in a total cost of approximately 176,000 SEK, which is lower than the V2G reference case at 178,000 SEK. As shown in Table 5.1, with only smart charge, the lowest total cost is achieved in the MaxUsage case. Respectively, with V2G the lowest total cost is found using LongFlex with a high activation scenario. In the figure, it can be seen that the differences for LongFlex and Shortflex compared to the reference case are small in comparison to the respective differences with V2G.

The revenue from participation in MaxUsage is equal for smart charge and V2G, shown in Figure 5.4. A comparison of the cost composition in Figure 5.7 shows that the revenue from the participation of the spot market reduces the total cost in the V2G case, with the LFM revenue being equal between V2G and SC; therefore, the difference in the revenue between the two comes only from the V2G having the ability to output power towards the spot market.

Table 5.1: Total Cost by Scenario in SEK

Scenario	**Low (12 h)**	**Mid (23 h)**	**High (46 h)**
SC ref	246,094		
SC ShortFlex	244,723	243,324	240,958
SC LongFlex	242,782	241,383	239,017
SC MaxUsage	176,458		
V2G ref	177,733		
V2G ShortFlex	156,825	139,095	100,551
V2G LongFlex	134,966	117,236	78,692
V2G MaxUsage	108,098		

6

Discussion

Due to the minimum capacity requirements, it is not possible for a single EV to participate in most markets. This makes aggregators important enablers for EVs' LFM participation. Furthermore, aggregation can help overcome issues regarding the practicalities of participating for the individual EV owner. If participation in LFM comes with the implication that the EV owner cannot use their EV for an hour or more, many owners may opt out of participation. Aggregation helps address this by pooling many vehicles, increasing the chance that another EV can step in if one disconnects.

Although the market map in 4.1 does not give a full picture of all markets in Europe, it suggests that far from all geographic areas are included in an LFM. It is therefore far from all EVs that will have the opportunity to participate. In section 4.3, it is shown that the markets share some principles like the general basis for compensation and types of products, but are still relatively diverse and have different time frames for bidding, product specifications, and baseline methodologies. For example, when an aggregator decides to participate in LFMs across Sweden, it has to take into account that the two platforms, NODES and Switch, differ in some aspects regarding products, market hours, activations, etc. In the UK, there is a standardisation of flexibility products, but the methodologies for determining baselines are not aligned.

In addition to the fact that LFMs are not available everywhere, the limited traded volumes could also pose a barrier to EV integration. In the case study, it is assumed that all flexibility offered by the fleet is accepted during activation hours. However, in smaller markets, activations may occur irregularly, and even when they do, the procured volumes can be limited. This means that the actual demand for flexibility from the DSO may differ significantly from the theoretical supply explored in this study. As a simplification, the analysis assumes that any flexibility the EV fleet offers will be accepted. Exploring the desired amount of flexibility procurement that the DSO requires represents a promising topic for future research. The same goes for exploring the potential benefits for the grid that might come from a higher degree of flexibility market utilisation, compared to alternative costs for investing in new grid infrastructure.

The geographic requirements are relevant also within flexibility zones. In the optimisation study, it is assumed that EVs can join the market from anywhere, something that is not true under current regulations in Effekthandel Väst. In practice, according to the regulations, flexibility is delivered through the registered EV charger, and not the car. This means that in reality, an aggregator can treat the EV as a flexible asset only when it is connected to a registered charger. It is not unreasonable that this could change in the future, but under current regulations, some of the charging sessions would need to be removed from the dataset used in the simulation to give a better estimation of revenue since they were conducted in charging points that are not registered. The charging location was not included in the data used for this study, and therefore this was not considered in the optimisation.

The baseline calculation has a great impact on the case study results, suggesting that it is a key characteristic for the aggregator to consider when assessing the potential of EV participation in an LFM. The market review showed that there are several different baseline methods used in the markets and that some markets have moved away from dynamic baselines based on historical data in favour of static ones. In the case study for ShortFlex and LongFlex, the baseline is produced by running a simulation without LFM participation, but still cost minimizing. This leads to the charging of electric vehicles to be conducted predominantly in the times of low electricity price, which seldom coincides with LFM activation in Effekthandel Väst. Given the higher electricity price in the morning and the afternoon, i.e., the times when Effekthandel Väst is most often activated, there is often little to no charging to reduce in comparison with the baseline at these times, resulting in low revenue for the smart charging case.

In comparison, the MaxUsage method always allows some flexibility to reduce consumption and generate revenue, as it is based on the charger's maximum capacity rather than historical usage, leading to greater cost reductions. However, because MaxUsage treats the fleet's maximum charging capacity as the baseline, the DSO effectively pays the EV aggregator to avoid charging at full power during periods of high spot market prices. This raises questions about the true value and cost-efficiency of the product, as the DSO requires flexibility, but may be unwilling to pay for what is essentially standard smart charging that could have occurred also without incentive from the LFM.

As shown in Table 5.1, the total cost when participating in LFMs is lower when participating through V2G than participation with the same product through smart charging. This can be explained both through the modelling approach as well as conceptually. As explained above, the fleets in the smart charging case have very little flexibility to alter their power consumption during the market hours, since the reference case most often hasn't charged at all during these hours because of a high electricity price. This problem is completely avoided when enabling V2G since the cars can output power in the case that the baseline power is 0kW, as vehicles are generally not expected to discharge. This is true given that the same baseline calculation applies to bi-directional and uni-directional cars. If the cost for battery degradation was included in the optimization, it is possible that the higher utilization of the battery with V2G would bring down the potential revenue. However, it is clear that bi-directional charging brings a higher degree of flexibility and thereby greater potential to participate in LFMs.

7

Conclusions

In this study, a review of current LFMs in Europe has been conducted, identifying operating markets and describing some of their products, baseline methodologies, and requirements. The review shows that products on the markets have similar design principles regarding remuneration mechanisms that are primarily based either on availability or activation, but have different time frames for bidding, product specifications, and baseline methodologies. The requirements for market participation are for minimum bid sizes of 10-100 kW for a duration ranging from 30 minutes to two hours depending on the market. The flexible asset must also be geographically located within the area and connected to the grid. These requirements preclude the involvement of individual EV owners and require the aggregation of EVs for participation.

To estimate the potential value of EV participation in LFMs, a case study of an aggregator participating in LFM Effekthandel Väst in January 2025 was conducted through a MILP optimization. Three different activation scenarios were used to represent different demands for flexibility from the DSO. The results of this optimization suggest that the participation through V2G technology could have provided significant cost reductions for all activation scenarios and products, spanning from around 12% to 56% for highest activation scenario. For participation through smart charging, the capacity limitation contract MaxUsage offers the largest savings of 28%, while the bidding products ShortFlex and LongFlex result in cost saving of around 1-3%, regardless of activation scenario.

This is because when the baseline is set based on smart charging behavior, unidirectional EVs offer very limited flexibility in LFM activation periods. This is changed with the V2G functionality, since it opens up more flexibility to participate. As discussed in chapter 6, this highlights that the baseline methodology is essential to the potential earnings of EV aggregators participating in LFM.

Bibliography

[1] International Energy Agency. *Unlocking the Potential of Distributed Energy Resources*. Licence: CC BY 4.0. Paris, 2022. URL: `https://www.iea.org/reports/unlocking-the-potential-of-distributed-energy-resources`.

[2] Hannah Ritchie. "Tracking global data on electric vehicles". In: *Our World in Data* (2024). https://ourworldindata.org/electric-car-sales.

[3] International Energy Agency. *Clean Energy Market Monitor – March 2024*. Licence: CC BY 4.0. Paris, 2024. URL: `https://www.iea.org/reports/clean-energy-market-monitor-march-2024`.

[4] *ACER Report on Electricity Transmission and Distribution Tariff Methodologies in Europe*. Agency for the Cooperation of Energy Regulators (ACER), 2023. URL: `https://acer.europa.eu/sites/default/files/documents/Publications/ACER_electricity_network_tariff_report.pdf`.

[5] European Union. *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast)*. Official Journal of the European Union, L 158, 14.6.2019, p. 125–199. 2019. URL: `https://eur-lex.europa.eu/eli/dir/2019/944/oj/eng`.

[6] Katarina Knezović et al. "Distribution grid services and flexibility provision by electric vehicles: A review of options". In: *2015 50th International Universities Power Engineering Conference (UPEC)*. 2015, pp. 1–6. DOI: `10.1109/UPEC.2015.7339931`.

[7] Sergio Potenciano Menci and Orlando Valarezo. "Decoding design characteristics of local flexibility markets for congestion management with a multi-layered taxonomy". In: *Applied Energy* 357 (2024), p. 122203. ISSN: 0306-2619. DOI: `https://doi.org/10.1016/j.apenergy.2023.122203`. URL: `https://www.sciencedirect.com/science/article/pii/S0306261923015672`.

[8] International Energy Agency. *The Who and How of Power System Flexibility*. `https://www.iea.org/commentaries/the-who-and-how-of-power-system-flexibility`. IEA, Paris. 2019.

[9] Å.L. Sørensen et al. "Energy profiles and electricity flexibility potential in apartment buildings with electric vehicles – A Norwegian case study". In: *Energy and Buildings* 305 (2024), p. 113878. ISSN: 0378-7788. DOI: `https://doi.org/10.1016/j.enbuild.2023.113878`. URL: `https://www.sciencedirect.com/science/article/pii/S0378778823011088`.

[10] Jaitesh Upadhyay, Piyush Sharma, and Harshit Panchal. "Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a micro grid". In: *Juni Khyat* 11.1 (2021), pp. 1031–1036. ISSN: 2278-4632.

[11] Hasan Mehrjerdi and Elyas Rakhshani. “Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power”. In: *Journal of Cleaner Production* 229 (2019), pp. 463–469. ISSN: 0959-6526. DOI: `https://doi.org/10.1016/j.jclepro.2019.05.023`. URL: `https://www.sciencedirect.com/science/article/pii/S0959652619315392`.

[12] Jean-Michel Clairand. “Participation of Electric Vehicle Aggregators in Ancillary Services Considering Users’ Preferences”. In: *Sustainability* 12.1 (2020). ISSN: 2071-1050. DOI: `10.3390/su12010008`. URL: `https://www.mdpi.com/2071-1050/12/1/8`.

[13] Rahmat Khezri, David Steen, and Le Anh Tuan. “A Review on Implementation of Vehicle to Everything (V2X): Benefits, Barriers and Measures”. In: *2022 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*. 2022, pp. 1–6. DOI: `10.1109/ISGT-Europe54678.2022.9960673`.

[14] Rahmat Khezri, David Steen, and Le Anh Tuan. “Willingness to Participate in Vehicle-to-Everything (V2X) in Sweden, 2022—Using an Electric Vehicle’s Battery for More Than Transport”. In: *Sustainability* 16.5 (2024). ISSN: 2071-1050. DOI: `10.3390/su16051792`. URL: `https://www.mdpi.com/2071-1050/16/5/1792`.

[15] SCALE Project. *D1.4 - Multi-actor Smart Charging & V2X System Architecture*. Tech. rep. Accessed: 2025-02-13. SCALE Horizon, 2023. URL: `https://scale-horizon.eu/publications/`.

[16] CEER Distribution Systems Working Group et al. “CEER Paper on Alternative Connection Agreements”. In: *Council of European Energy Regulators (CEER), Brussels, Report C23-DS-83–06* (2023), p. 20.

[17] National Energy System Operator. *The Local Constraint Market*. Accessed: 2025-03-14. 2025. URL: `https://www.piclo.energy/profiles/neso`.

[18] Marieke Ziedses des Plantes. *Grid congestion gets companies negotiating with grid operators*. Press release, 15 January 2025. 2025. URL: `https://www.abnamro.com/en/news/grid-congestion-gets-companies-negotiating-with-grid-operators.html`.

[19] Nima Mirzaei Alavijeh et al. “Capacity limitation based local flexibility market for congestion management in distribution networks: Design and challenges”. In: *International Journal of Electrical Power & Energy Systems* 156 (2024), p. 109742. ISSN: 0142-0615. DOI: `https://doi.org/10.1016/j.ijepes.2023.109742`. URL: `https://www.sciencedirect.com/science/article/pii/S0142061523007998`.

[20] Power Circle. *Hur kan lokal flexibilitet få rum att utvecklas - Insikter från projektet Uppflex*. Tech. rep. Accessed 2025-04-17. Power Circle, June 2024. URL: `https://powercircle.org/lokalflex.pdf`.

[21] Power Circle. *Local Flexibility Markets*. Accessed 2025-04-17. Apr. 2022.

[22] Rahmat Khezri et al. “Optimal V2G Scheduling of an EV With Calendar and Cycle Aging of Battery: An MILP Approach”. In: *IEEE Transactions on Transportation Electrification* 10.4 (2024), pp. 10497–10507. DOI: `10.1109/TTE.2024.3384293`.

[23] NODESmarket. *Effekthandel Väst*. Accessed: 2025-03-05. 2025. URL: `https://nodesmarket.com/effekthandel-vast/`.

[24] NODES. *NODES Platform*. Accessed: 2025-05-09. URL: https://portal.nodesmarket.com/onboarding/dashboard_gl=1*13o0gh8*_ga*NjMyOTk2MjkuMTczNzQ4NTQz
.*_ga_WD0MWXFJ6V*czE3NDczMDAwMDgkbzgwJGcwJHQxNzQ3MzAwMDA4JGowJGwwJGgw#market-data.

[25] Goteborg Energi. *Elnatsavgiften*. Accessed: 2025-05-09. URL: https://www.goteborgenergi.se/privat/elnat/elnatsavgiften#overforing.

[26] Chondrogiannis S et al. "Local electricity flexibility markets in Europe". In: KJ-NA-31-194-EN-N (online) (2022). ISSN: 1831-9424 (online). DOI: 10.2760/9977(online). URL: https://publications.jrc.ec.europa.eu/repository/handle/JRC130070.

[27] Energimarknadsinspektionen. *Kartläggning av flexibilitetsmarknader*. Tech. rep. 2022:1. Sweden: Energimarknadsinspektionen, Mar. 2022. URL: https://ei.se/download/18.368ff5bc17f44a78fbe299e5/1649254603113/Kartl%C3%A4ggning-av-flexibilitetsmarknader.pdf.

[28] Stylianos Zikos et al. "Local Energy and Flexibility Markets: State of the art and technological gap analysis". In: *2023 8th International Conference on Smart and Sustainable Technologies (SpliTech)*. 2023, pp. 1–6. DOI: 10.23919/SpliTech58164.2023.10192975.

[29] NODESmarket. *Successful start for Euroflex*. https://nodesmarket.com/successful-start-for-euroflex/. Accessed: 2025-03-17.

[30] Epex Spot. Accessed: 2025-05-09. URL: https://www.epexspot.com/en/news/epex-spots-localflex-dutch-market-connection-gopacs-completed-successfully.

[31] National Grid. *IntraFlex*. https://www.nationalgrid.co.uk/projects/intraflex. Accessed: 2025-03-17.

[32] Ellevio AB. Accessed: 2025-05-09. URL: https://www.ellevio.se/nyheter/nyheter/sthlmflex-lardomar-och-resultat-fran-ett-banbrytande-flexibilitetsprojekt/.

[33] Vattenfall Eldistribution. Accessed: 2025-05-09. URL: https://www.vattenfalleldistributi
se/var-verksamhet/vart-arbete/innovation/coordinet/.

[34] E.ON Sverige. *Vi utökar flexibilitetsmarknaderna inför kommande vinter*. Accessed: 2025-03-05. 2025. URL: https://www.eon.se/nyheter/vi-utoekar-flexibilitetsmarknaderna.

[35] Smart Senja. *Nyheter - Smart Senja*. Accessed: 2025-05-09. 2025. URL: https://smartsenja.no/nyheter/.

[36] NODESmarket. *Euroflex - Norway*. Accessed: 2025-03-05. 2025. URL: https://nodesmarket.com/euroflex/.

[37] NODESmarket. *Markets in Finland*. Accessed: 2025-06-06. 2025. URL: https://nodesmarket.com/markets-in-finland/.

[38] NODESmarket. *Markets in Belgium*. Accessed: 2025-06-06. 2025. URL: https://nodesmarket.com/markets-in-belgium/.

[39] UK Power Network. Accessed: 2025-05-09. URL: https://ukpowernetworks.opendatasoft.com/explore/embed/dataset/ukpn-flexibility-dispatches/insights/?dataChart=eyJxdWVyaWVzIjpbeyJjaGFydHMiOlt7InR5cGUiOiJjb2x1bW4iLCJmdW
3D.

[40] GOPACS. *How Does Participation Work?* Accessed: 2025-03-13. 2025. URL: `https://www.gopacs.eu/en/participate/how-does-participation-work/`.

[41] E.ON Sverige. *Flexibilitet i elnätet.* Accessed: 2025-03-05. 2025. URL: `https://www.eon.se/foeretag/elnaet/flexibilitet-i-elnaetet`.

[42] SWITCH. *SWITCH - Frigör potentialen i flexibla lösningar.* `https://info.switchmarket.se/`. Accessed: 2025-03-12. 2025.

[43] UK Power Networks (Operations) Limited. *Participation Guidance - Flexibilty Services.* Version 1.1. Oct. 2024. URL: `https://d1lf1oz5vvdb9r.cloudfront.net/app/uploads/2024/10/Participation-Guidance-Oct-2024-v1.1.pdf`.

[44] Piclo Flex. *Asset Qualification.* `https://support.picloflex.com/article/153-asset-qualification`. Accessed: 2025-03-17.

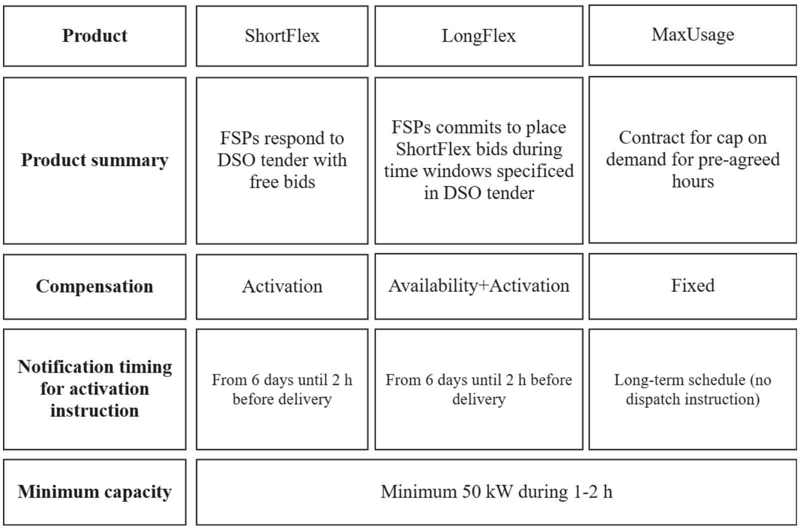
[45] *Regelboken i korthet.* Accessed: 2025-02-21. 2024. URL: `https://ds7yx6kld6i0w.cloudfront.net/wp-content/uploads/2024/09/04153325/2024.08.30-Regelboken-i-korthet-1.pdf`.

[46] Piclo. *Guidance for Electricity Distribution Flexibility Service Providers.* Accessed: 2025-05-09. 2024. URL: `https://www.flexiblepower.co.uk/locations/national-grid-electricity-distribution/tools-and-documents`.

A

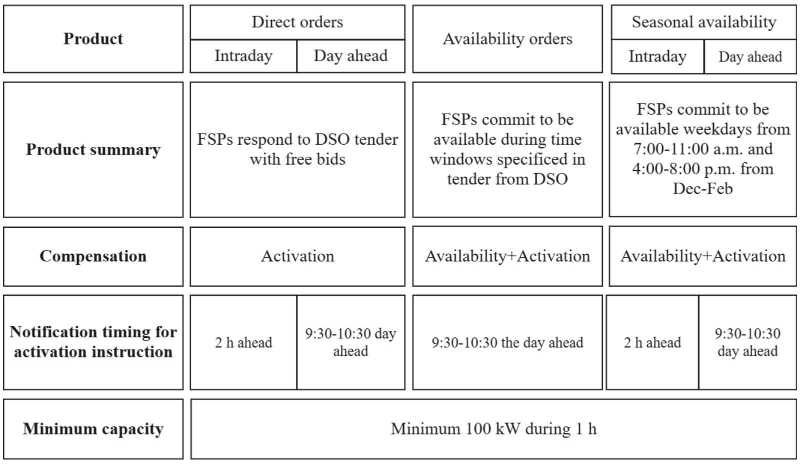
Appendix 1

Table A.1: Overview of products on NODES



Product	ShortFlex	LongFlex	MaxUsage
Product summary	FSPs respond to DSO tender with free bids	FSPs commits to place ShortFlex bids during time windows specificed in DSO tender	Contract for cap on demand for pre-agreed hours
Compensation	Activation	Availability+Activation	Fixed
Notification timing for activation instruction	From 6 days until 2 h before delivery	From 6 days until 2 h before delivery	Long-term schedule (no dispatch instruction)
Minimum capacity	Minimum 50 kW during 1-2 h		

Table A.2: Overview of flexibility products on Switch.

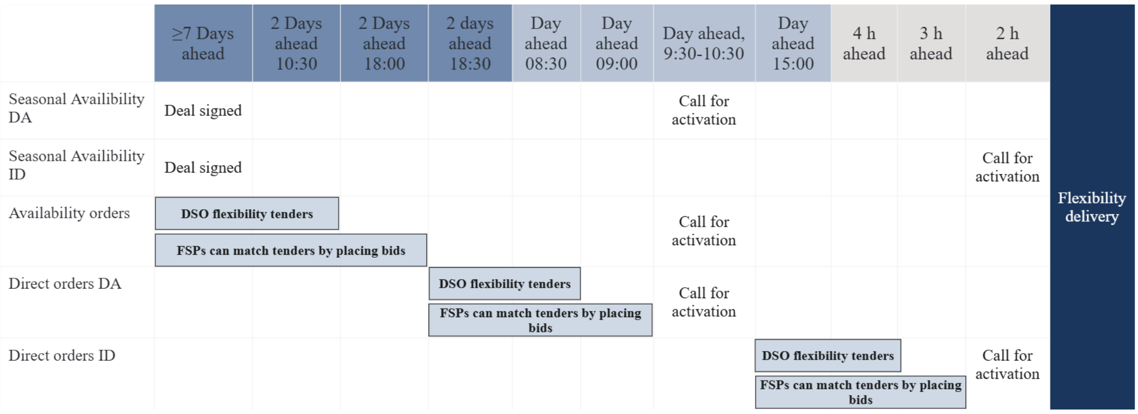


Product	Direct orders		Availability orders	Seasonal availability	
	Intraday	Day ahead		Intraday	Day ahead
Product summary	FSPs respond to DSO tender with free bids		FSPs commit to be available during time windows specificed in tender from DSO	FSPs commit to be available weekdays from 7:00-11:00 a.m. and 4:00-8:00 p.m. from Dec-Feb	
Compensation	Activation		Availability+Activation	Availability+Activation	
Notification timing for activation instruction	2 h ahead	9:30-10:30 day ahead	9:30-10:30 the day ahead	2 h ahead	9:30-10:30 day ahead
Minimum capacity	Minimum 100 kW during 1 h				

Table A.3: Industry standard products in the UK.

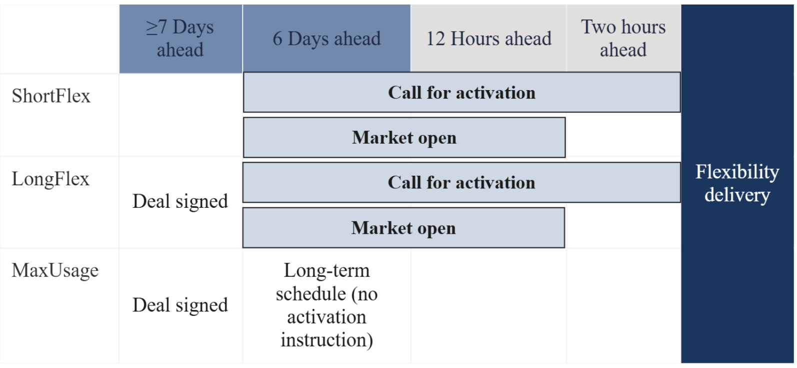
Product	Peak Reduction	Sheduled Utilisation	Operational Utilisation	Scheduled Availability+ Operational Utilisation	Variable Availability+ Operational Utilisation
Product summary	Contract for reduction in peak power utilised over time	FSPs commit to provide flexibility at pre-agreed times	Request for flexibility closer to real-time	FSPs commit to be available during time windows specificed in tender from DSO	Pre-agreed availability where the DSO can refine the requirements closer to real-time
Compensation	Activation	Activation	Activation	Activation+Availability	Activation+Availability
Notification timing for activation instruction	Long-term schedule (no dispatch instruction)	Long-term schedule (no dispatch instruction)	Real Time Response time: 2 min Response time: 15 min Week ahead	Real Time Response time: 2 min Day ahead	Real Time Response time: 2 min Response time: 15 min Week ahead Day ahead

Table A.4: Timeline and processes for flexibility product participation for Switch

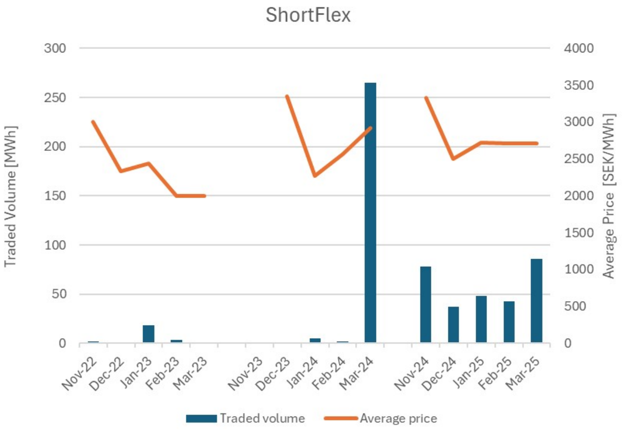


	≥7 Days ahead	2 Days ahead 10:30	2 Days ahead 18:00	2 days ahead 18:30	Day ahead 08:30	Day ahead 09:00	Day ahead, 9:30-10:30	Day ahead 15:00	4 h ahead	3 h ahead	2 h ahead	
Seasonal Availibility DA	Deal signed						Call for activation					Flexibility delivery
Seasonal Availibility ID	Deal signed										Call for activation	
Availability orders	**DSO flexibility tenders** **FSPs can match tenders by placing bids**						Call for activation					
Direct orders DA				**DSO flexibility tenders** **FSPs can match tenders by placing bids**			Call for activation					
Direct orders ID								**DSO flexibility tenders** **FSPs can match tenders by placing bids**			Call for activation	

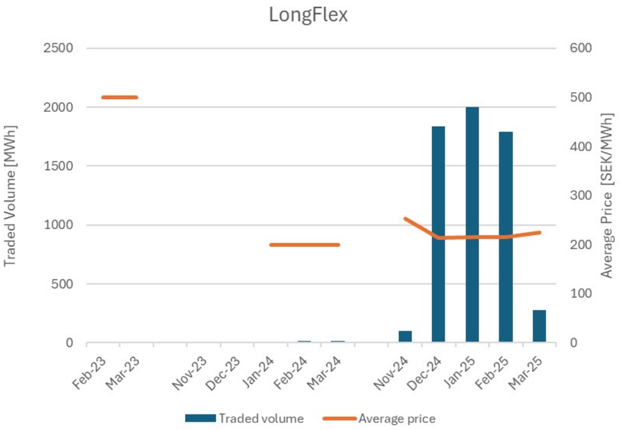
Table A.5: Timeline and processes for flexibility product participation for NODES



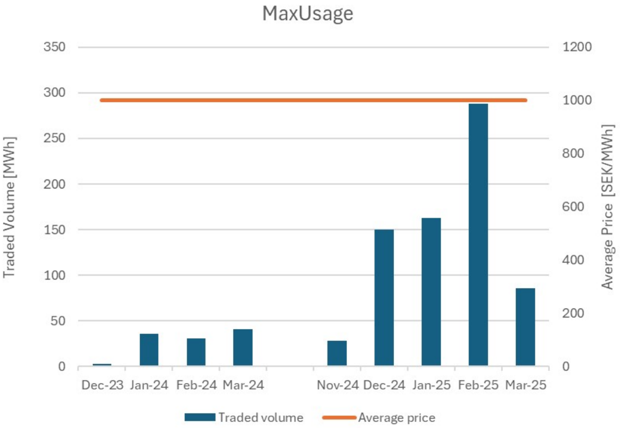
	≥7 Days ahead	6 Days ahead	12 Hours ahead	Two hours ahead	
ShortFlex		**Call for activation** **Market open**			Flexibility delivery
LongFlex	Deal signed	**Call for activation** **Market open**			
MaxUsage	Deal signed	Long-term schedule (no activation instruction)			



(a) ShortFlex



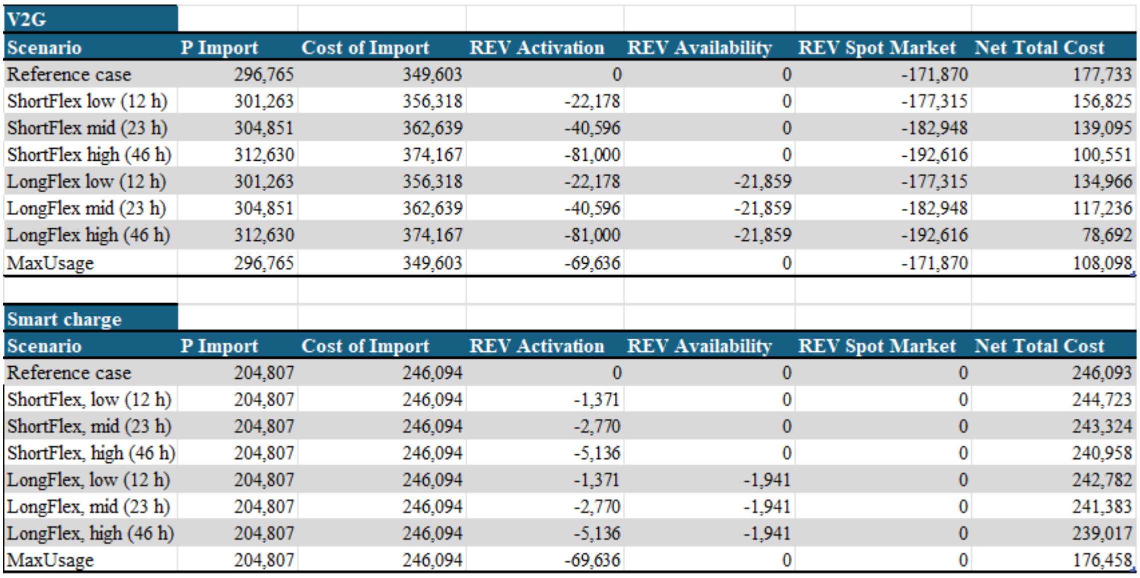
(b) LongFlex



(c) MaxUsage

Figure A.1: Traded volume and average price for different products on Effekthandel Väst

Table A.6: Summary of simulation results for all products and activation scenarios on Effekthandel Väst in January 2025 for 588 EVs.



V2G

Scenario	P Import	Cost of Import	REV Activation	REV Availability	REV Spot Market	Net Total Cost
Reference case	296,765	349,603	0	0	-171,870	177,733
ShortFlex low (12 h)	301,263	356,318	-22,178	0	-177,315	156,825
ShortFlex mid (23 h)	304,851	362,639	-40,596	0	-182,948	139,095
ShortFlex high (46 h)	312,630	374,167	-81,000	0	-192,616	100,551
LongFlex low (12 h)	301,263	356,318	-22,178	-21,859	-177,315	134,966
LongFlex mid (23 h)	304,851	362,639	-40,596	-21,859	-182,948	117,236
LongFlex high (46 h)	312,630	374,167	-81,000	-21,859	-192,616	78,692
MaxUsage	296,765	349,603	-69,636	0	-171,870	108,098

Smart charge

Scenario	P Import	Cost of Import	REV Activation	REV Availability	REV Spot Market	Net Total Cost
Reference case	204,807	246,094	0	0	0	246,093
ShortFlex, low (12 h)	204,807	246,094	-1,371	0	0	244,723
ShortFlex, mid (23 h)	204,807	246,094	-2,770	0	0	243,324
ShortFlex, high (46 h)	204,807	246,094	-5,136	0	0	240,958
LongFlex, low (12 h)	204,807	246,094	-1,371	-1,941	0	242,782
LongFlex, mid (23 h)	204,807	246,094	-2,770	-1,941	0	241,383
LongFlex, high (46 h)	204,807	246,094	-5,136	-1,941	0	239,017
MaxUsage	204,807	246,094	-69,636	0	0	176,458

Table A.7: Case study Participation Scenarios

Simulation case	**Description**
Smart charging reference case (cost minimization, no market participation)	EVs are charged optimally based on spot prices without participating in LFM. Charging schedules minimize electricity costs while ensuring user energy needs are fully met.
Smart charging + ShortFlex	Charging is optimized based on spot prices, and the aggregator participates in the ShortFlex market by offering load reductions during active bidding periods. Revenue is earned only upon activation.
Smart charging + LongFlex	The aggregator has entered into contractual agreements to provide flexibility during specific time windows. Availability payments are added to the activation revenues.
Smart charging + MaxUsage	Charging is planned to ensure the total load remains below a pre-agreed threshold during specified peak hours. The aggregator receives passive income for staying within the contracted limit.
V2G reference case (cost minimization, no market participation)	EVs are charged based on spot prices and also allowed to discharge power back to the grid.
V2G + ShortFlex	EVs are charged based on spot prices and also allowed to discharge power back to the grid. The aggregator participates in the ShortFlex market by offering load reductions during active bidding periods. Revenue is earned only upon activation.
V2G + LongFlex	The aggregator offers both charging and discharging flexibility within contracted windows under LongFlex.
V2G + MaxUsage	The aggregator uses V2G to manage charging and discharging within a contracted power limit under MaxUsage.

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