



Assessment of vehicle-to-grid potential in airport vehicle fleet

Version number:	1.0
Dissemination level	PU (public)
Work package:	WP4 and WP5
Date:	17-10-2025
Lead beneficiary:	DTI (Danish Technological Institute HG (Hybrid Greentech)
Author(s):	Freja Faber Boxill (DTI) Lea Kornbeck Askholm (DTI) Nikita Padmadas (HG)
Contact person	Lea Kornbeck Askholm, lkoa@dti.dk



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957824

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3 Executive summary

This report presents a preliminary methodology for analysing the Vehicle-to-Grid (V2G) potential of Ground Support Equipment (GSE) in airports, along with a case study application at Copenhagen Airport (CPH). The study aims to provide a framework for determining the total battery capacity in a conceptual fleet of battery-electric GSE and assessing V2G availability during charging periods.

Key aspects of the methodology include:

- A two-phase approach for analysing V2G potential in airport GSE fleets.
- Guidelines for categorising and sorting GSE units.
- A framework for estimating battery capacity and V2G availability.
- Considerations for various operational scenarios and limiting factors.

The case study at CPH demonstrates the application of this methodology, revealing:

- A total battery capacity of 56.5 MWh in the conceptual CPH-owned fleet of battery-electric GSE, of which 43.1 MWh is allocated in the trucks, snow ploughs and cars.
- Significant variations in V2G availability based on factors such as weather conditions, day of the week, and air traffic levels.
- The importance of optimising charging/discharging power based on battery capacities, as the analysis demonstrated that mismatched charging powers can significantly limit V2G potential - particularly for large vehicles where low charging powers (50 kW) resulted in only partial utilisation of their substantial battery capacities (300-540 kWh), effectively creating a bottleneck in the system's energy transfer capabilities.
- The involvement of personnel working with GSE operation is crucial to bridge the gap between theoretical analysis and real-world applicability, leading to more robust and actionable findings.

This study provides valuable insights for airports considering V2G implementation and highlights areas for further investigation in the field.

Analyses to enlighten the potential value from V2G are performed looking at ancillary service markets and CO₂-optimisation using V2G and included in this report.

4 Introduction

The integration of Vehicle-to-Grid (V2G) technology represents a transformative approach in the utilisation of electric vehicles (EVs) within the energy system. V2G technology enables EVs not only to draw electricity from the grid but also to deliver electricity back to it, offering a dual functionality that can significantly enhance energy management. This capability presents several potential benefits that are crucial for advancing sustainable energy solutions [1].

Firstly, V2G technology's bidirectional power flow capabilities optimise the use of renewable energy and enhance grid flexibility. By charging vehicles during periods of high renewable generation and low CO₂ intensity and subsequently feeding this stored energy back to the grid during periods of high demand, V2G creates a dynamic energy storage solution. This system also enables economic benefits through price arbitrage, charging when electricity costs are low and supplying power during high-price periods. The technology is particularly effective for vehicles with scheduled operational patterns, such as GSE units, where predictable idle periods allow for maximised utilisation of battery capacity for both operational requirements and grid services. [1]

Secondly, V2G technology offers substantial cost-saving opportunities. By utilising periods of lower electricity prices for charging and enabling the sale of stored electricity back to the grid during peak price periods, EV owners can achieve significant reductions in their electricity expenses. This economic incentive is essential for promoting the widespread adoption of V2G systems [1].

Furthermore, V2G enhances grid flexibility by allowing EVs to act as distributed energy resources capable of providing ancillary services. By participating in these services, EVs contribute to a more resilient and reliable energy system. [1]

This report serves as a description of the methodology used to assess the V2G potential in airports as well as a review of a V2G case study at CPH.

5 Scope

5.1 Definition of V2G

Vehicle-to-Grid (V2G) technology allows for bidirectional communication and transfer of energy between electric vehicles and the power grid. This means that vehicles equipped with V2G capability can not only draw power from the grid to charge their batteries but also deliver power back to the grid when needed. This functionality can help balance grid load, reduce CO₂ emissions, and create economic value by providing flexibility and balancing services to grid operators.

In the Alight project, the focus is on exploring the potential of V2G technology in airports, particularly at Copenhagen Airport (CPH):

1. **Technological Context:** V2G technology is still under development, with only a few cars on the market supporting this function, primarily with CHAdeMO charging ports. There is limited availability of charging stations with V2G capability in Europe, which restricts opportunities for large-scale demonstrations.
2. **Analyses and Tools:** The project aims to map the use of ground support equipment at the airport, analyse the potential for V2G in the airport's fleet of Ground Support Equipment, and develop a value assessment tool for V2G for selected vehicles/fleets.
3. **Economic and Environmental Benefits:** V2G can offer many benefits, including load balancing and peak shaving during high-demand periods, increased self-consumption from local renewable energy production, revenue generation from grid services, and cost savings on electricity during expensive peak demand periods.

Overall, V2G technology provides a potential method to optimize energy consumption and production in conjunction with renewable energy and grid stability, also in specialized environments like airports.

5.2 Baseline/scenario

This analysis of the V2G potential in airports focuses on the airside equipment and vehicles, which henceforth will be referred to as Ground Support Equipment or GSE. The airside of an airport encompasses the aircraft operations area, the surrounding terrain where both aircraft and GSE function, as well as secured sections of terminal buildings or their components. Access to the airside is restricted and regulated, necessitating passage through security checkpoints in compliance with aviation regulations [2]. This excludes any equipment that operates on the other side of the security checkpoints as well as passenger vehicles.

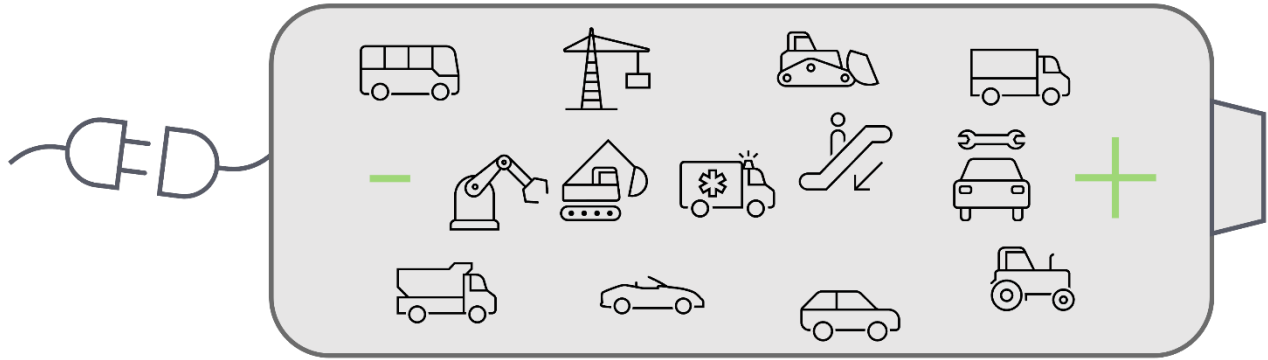


Figure 1 – Conceptual sketch of V2G in airside equipment in airports.

The fleet of GSE will be viewed as a whole, meaning that this project aims to analyse the V2G potential in the entire fleet of GSE. This concept is illustrated in the conceptual sketch in Figure 1.

5.2.1 Definition of Ground Support Equipment

Ground Support Equipment, commonly referred to as GSE, is utilised to service aircraft during the intervals between flights. These services encompass a variety of essential tasks, including refuelling aircraft, towing aircraft or luggage, loading luggage, transporting passengers, providing potable water, removing sewage, loading food, de-icing aircraft, and fire-fighting [3].

GSE can be owned by the respective airport or third-party providers such as catering companies or contracting companies.

5.3 Preconditions and assumptions

The baseline for the analysis is a fully electrified fleet of GSE. The preconditions and assumptions are as follows:

- **Technology:** Vehicles and equipment are analytically electrified based on commercialised technologies. All units of equipment must be battery electric.
- **Usage pattern:** The conceptual fleet of electrified GSE is of the same magnitude and usage pattern as presented in the data from the respective airport.
- **Chargers:** It is assumed that V2G chargers are available.

6 Methodology

The analysis of the V2G potential can be divided into two main phases. Firstly, an estimation of the potential energy and power capacity available for V2G in the electrified fleet of GSE. Secondly, an analysis of driving patterns and availability for V2G during plug-in-times.

This can further be divided into the following steps.

6.1 Phase 1

An illustration of phase 1 has been made in the shape of a flowchart as shown in Figure 2. A description of each step can be found in the following sections.

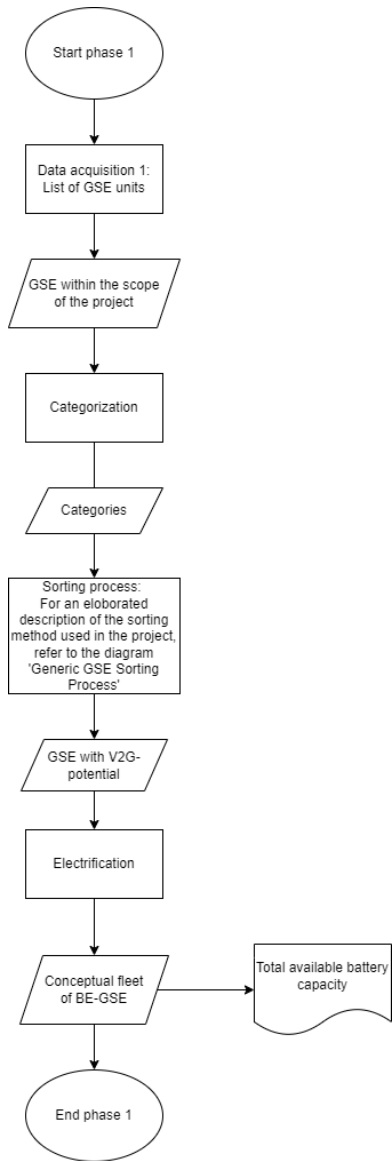


Figure 2 – Flowchart illustrating phase 1 in the analysis.

6.1.1 List of GSE in the airport

The very first step in this analysis is to gather the necessary information about the GSE within the scope of the project. The outcome of this data acquisition should be a list of the GSE units containing the following information:

- Type/function: The type or function of the GSE unit, e.g., a truck or passenger stairs.
- Energy source: This specifies the energy source for the GSE unit. This is later used to differentiate between the GSE units that are already battery electric and the categories where a battery electric equivalent must be found.
- Ownership: This specifies the ownership of the GSE unit. This can be relevant if the scope of the project only involves a specific owner, e.g., the airport or if the owners need to share data or be involved in decision making processes at a later stage.

6.1.2 Sorting the GSE

Not every GSE unit has the possibility to contribute to the energy and power capacity in the conceptual fleet of battery electric GSE. These are GSE units for which there does not exist an already commercialised battery electric equivalent, GSE units that are required to be always fully charged due to their critical role in operations, and GSE units that are out of service. The outcome of the sorting process is the fleet of GSE that have V2G potential.

This sorting process is illustrated in Figure 3.

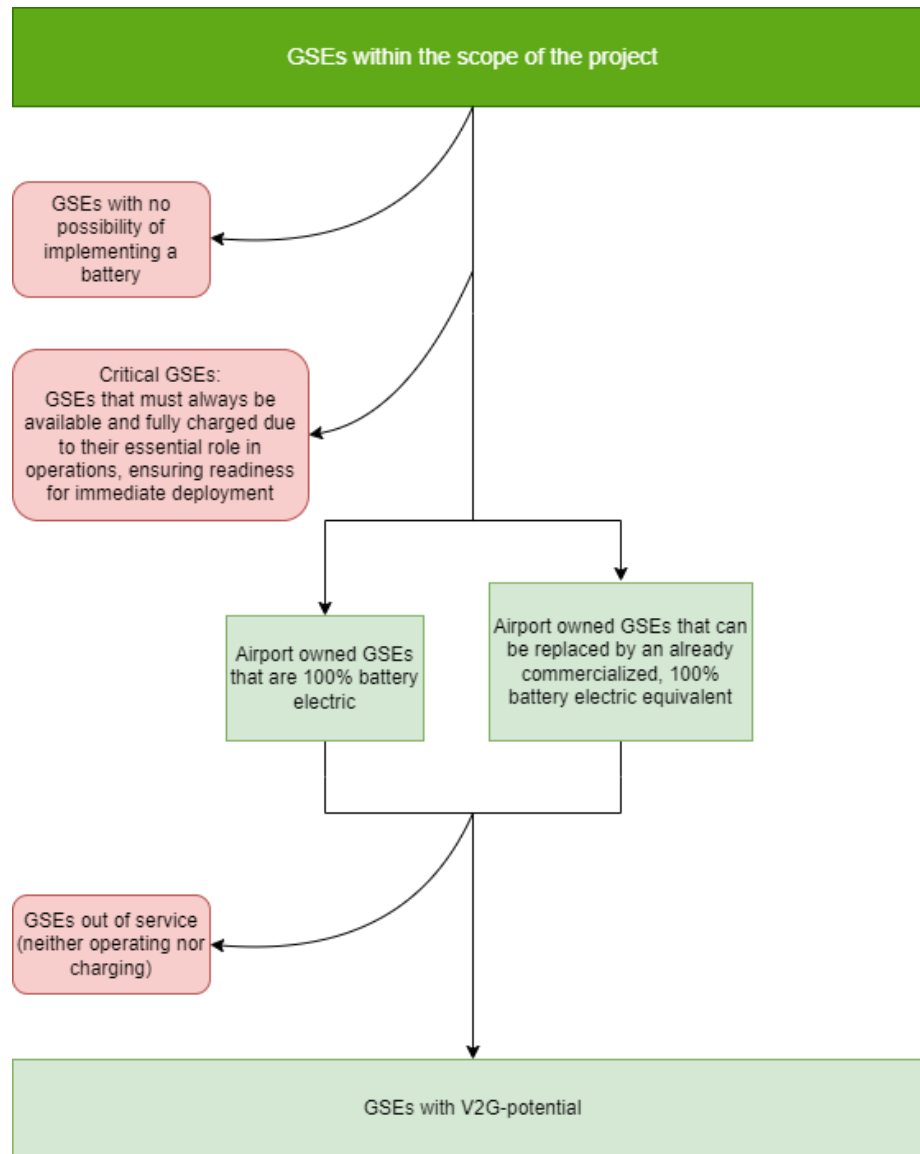


Figure 3 – Diagram showing the process of filtering out GSEs without V2G potential.

6.1.3 Categorisation

The fleet of GSEs with V2G potential identified in the above step is divided into categories based on type, size and/or functionality. This is done to minimise the amount of further data processing. The outcome of this categorisation is a list of categories, each specified by a representative GSE unit. The GSE unit chosen to represent its category must be listed with the following:

- Name of category (e.g. "passenger stairs").
- Number of GSE units in this category.

- Model/type of GSE chosen as representative (e.g. TIPS FREEWAY1842Pe Passenger Stairs).
- Motor type/energy source.
 - o This is only used to differentiate between the categories represented by an already battery electric GSE and the categories where a battery electric equivalent must be found.

6.1.4 Electrification

Every GSE category identified in the above step is replaced with its battery electric equivalent (if not already battery electric). These battery electric GSE units (BE-GSE units) are listed with the following parameters:

- Name of category.
- Model/type of GSE chosen as representative.
- Number of GSEs in this category.
- Model/type of BE-GSE equivalent.
- Battery capacity [kWh].

6.1.5 Total battery capacity

From the data listed in step 6.1.4, it is possible to calculate the total battery capacity of the conceptual fleet of BE-GSE as the accumulated battery capacity of the categories.

$$Total\ battery\ capacity = \sum_{i=1}^n N_i \times C_i,$$

Where n is the number of categories, and each category i has N_i GSE units each with a battery capacity of C_i .

This is the first of two intermediate results of this analysis.

6.2 Phase 2

6.2.1 Acquisition of usage logs for GSEs

The usage logs for the GSE units within the scope of the project are acquired from the airport and/or third-party providers. There can be different approaches regarding how much and which information is needed. The simplest approach is to assume that all GSE units have a “workday”, which is immediately followed by a standstill period in which charging and V2G is possible. This workday is assumed to be of the same length and time of day for all GSE units within a category. If this simple approach is chosen, the following information is needed for each category of GSE. This is, of course, in addition to the information already acquired in phase 1:

- For normal operation: Normal operation refers to the standard, routine functioning and utilisation of ground support equipment in accordance with established

procedures and protocols, considering average air traffic levels typical environmental conditions.

- Start time of operation/start of workday.
- End time of operation/end of workday.
- For peak operation: Peak operation refers to the extended use of ground support equipment during periods of increased demand, which may be driven by high air traffic volumes or other factors such as adverse weather conditions
 - Start time of operation/start of workday.
 - End time of operation/end of workday.

The mapping of the GSEs can be made more detailed in several ways. The following are some suggestions:

1. As with the first method, it assumed that all BE-GSE units within a category have the same usage pattern. The usage pattern is created by specifying the use of a GSE category per hour.
2. For the second approach, different usage patterns are assumed for the BE-GSEs within a category. The usage pattern is created by specifying the number of BE-GSEs in use in each category per hour.

The above-described methods give rough estimates of the usage patterns, and other methods can be used depending on available data and specific needs.

6.2.2 Usage pattern

The data acquired in step 6.2.1 is mapped as a function of time. To map the usage patterns, only the usage logs acquired in step 6.2.1 is needed.

Moreover, it is crucial to choose a pattern for the charging and discharging of the BE-GSE. This involves committing to several assumptions and preconditions regarding the usage of the BE-GSE in the fleet. At a minimum, the following must be decided upon:

- Charging pattern of the batteries:
 - Is it assumed to be linear for simplicity, or does it mimic the charging curve of, e.g., a lithium-ion battery?
 - Is it the same for all batteries?
 - Does the charging begin immediately as a standstill period is entered, or is there a time margin?
- Discharging pattern of the batteries:
 - Is it assumed to be linear for simplicity, or does it mimic the discharging curve of, e.g., a lithium-ion battery?
 - Does it depend on the driven distances, or the number of tasks done in the working hours?
 - Is it the same for all batteries?

- V2G preconditions
 - Is the battery available for V2G the entire time it is connected to the V2G charger?
 - Is the battery only available for V2G after the battery has been fully charged and is still connected to a charger?
 - Is the battery available for V2G in a period of the stand still time where the minimum charging time has been subtracted?

For a more specific description of one possible approach to map the usage patterns of the BE-GSE refer to step 7.2.2 in the following case study.

6.2.3 **Battery capacity available for V2G**

The battery capacity available for V2G is meant to be understood as both the energy and power capacity available for V2G as a function of time.

This capacity is estimated based on the usage patterns mapped in step 6.2.2 and the BE-GSE specifications as found in step 6.1.4.

To accurately estimate the battery capacity available for V2G, it is essential to decide on the assumptions that will be used as a starting point:

- What is the charging/discharging power in the V2G chargers?
 - Is the starting point a commercial V2G charger, or is it conceptual?
 - Is the charging and discharging power assumed to be the same?
 - Are efficiencies considered, or is it assumed that the power electronics needed for V2G have efficiencies high enough, to not take them into account in the analysis?

The outcome of this step is the second intermediate result: the battery capacity available for V2G over time.

7 Case study CPH

A case study has been conducted to determine the V2G potential at Copenhagen Airport (CPH). The scope for this case study is the CPH-owned fleet of GSE. The case study aims to determine the following two intermediate results:

1. The total battery capacity in the CPH-owned fleet of battery-electric ground support equipment.
2. V2G availability during charging.

These intermediate results are achieved by following the methodology described in section 6. This section, however, describes in detail the specific methods, approaches, and assumptions used to obtain the results, and thereby serves as a concise step-by-step guide on how V2G potential in airports can be estimated.

The results will finally be discussed with a focus on technical, economic, logistical, practical, and regulatory barriers.

It should be emphasised that the following section describes a relatively simple approach to estimating the V2G potential at CPH. This is specifically reflected in the case-specific assumptions, which can be seen in section 7.2.3.1. The assumptions are rough, leading to a coarse estimate of the potential. This choice is made for two primary reasons. The first is that it makes the analysis more generic and manageable. The second is that the nature of the analysis is considered to be more conceptual and qualitative than quantitative.

7.1 CPH case study – phase 1

7.1.1 Data acquisition 1 – List of GSEs

A list of ground support equipment (GSE) was obtained from the relevant fleet management system. For the purposes of this analysis, key information to be collected on each GSE unit includes:

- **Model identification or specification** (optional/if available)
- **Equipment type or functional category** (e.g., vehicle, loader, tow tractor, power unit, stairs, etc.)
- **Primary energy source** (e.g., diesel, petrol, electricity, gaseous fuels, hybrid)

These basic data points form the foundation for subsequent categorisation, electrification mapping, and analysis of V2G potential across the GSE fleet.

7.1.2 Categorisation

In the list, there is a total of 536 GSE units. For the categorisation, the following 13 categories, in Table 1, are chosen. This categorisation is chosen based on similarities in function and size among the GSE units in each category. In addition to the existing information, insights were gathered from airport planners, enhancing the categorisation of GSE. Their expertise provided crucial details about vehicle functions. For instance, they clarified that

sweeper attachments are exclusively used for snow removal and are mounted on trucks. Consequently, a number of trucks equal to the number of sweeper attachments were categorised as snow removal equipment.

The first column, “Category name”, contains the names chosen for each category. “Types included” contains the names of the different GSE types, as written in the “equipment type”-column, belonging to each category. “Number of units” contains the accumulated number of units in each category.

Category name	Types included	Number of units
Cars	Small car	
	Pick-up	
	Small electric car	
	Small hybrid car	
	Car	
	Hybrid car	
Large vehicles	Tractor	
	Backhoe loader	
	Heavy-duty truck	
GPUs	GPU	
	Electric GPU	
PCAs	PCA	
Passenger stairs	Electric passenger stairs	
Tow trucks	Electric tow truck	
Small motorised equipment	Small motorised equipment	
	Front loader	
	Forklift	
	Electric forklift	
	Electric small motorised equipment	
	Electric painting equipment	
	Painting equipment	
Lifting equipment	Lifting equipment	
	Electric lifting equipment	
Golf cars	Electric golf car	
Fire trucks	Fire truck	
Buses	Bus	
Snowplough trucks	Snowplough truck	
	Snow sweeper truck	
	Sweeper attachment*	
No fuel	No fuel	
Total		536

Table 1 – CPH case study: Categorization of CPH-owned GSEs

*The sweeper attachments will not be electrified.

7.1.3 **Sorting process**

As illustrated in the sorting process in Figure 3, certain types of ground support equipment (GSE) are excluded from the V2G assessment. This includes units that are considered operationally critical and must remain fully charged at all times, as well as those that operate continuously or serve essential safety functions. Further fleet analysis and stakeholder input revealed additional complexity in operational patterns, resulting in the exclusion of other units based on continuous operation, specific usage requirements, or marginal relevance to V2G. Some equipment types were also removed from consideration if their usage patterns, battery size, or operational roles contributed only minimally to the overall V2G potential. Categories with no commercially available battery-electric equivalent were also excluded.

Finally, it is not relevant to search for an electric equivalent to the “No fuel” category, which means that what is left are 11 categories as shown in Table 2.

The specific details underlying these exclusions are considered confidential and are therefore not included in this report.

Category name	Types included	Number of GSE units
Cars	Small car	CONFIDENTIAL
	Pick-up	
	Small electric car	
	Small hybrid car	
	Car	
	Hybrid car	
Large vehicles	Tractor	CONFIDENTIAL
	Backhoe loader	
	Heavy-duty truck	
PCAs	PCAs	CONFIDENTIAL
GPUs	GPU	CONFIDENTIAL
	Electric GPU	
Passenger stairs	Passenger stairs	CONFIDENTIAL
Tow trucks	Tow truck	CONFIDENTIAL
Small motorized equipment	Front loader	CONFIDENTIAL
	Forklift	
	Electric forklift	
Lifts	Lifting equipment	CONFIDENTIAL
	Electric lifting equipment	
Golf cars	Electric golf car	CONFIDENTIAL
Buses	Bus	CONFIDENTIAL
Snow removal	Snowplough truck	CONFIDENTIAL
	Snow sweeper truck	
	Sweeper attachment	
Total		383

Table 2 – Remaining categories after sorting process.

The second step in the sorting process is to identify GSEs with no possibility of replacing them with an already commercially available 100% battery-electric equivalent. This is done by systematically researching for battery-electric equivalents for all the remaining categories.

7.1.3.1 List of electric equivalents to GSE-categories

For each of the remaining 11 categories, an already commercialised 100% battery-electric equivalent is sought. It should be noted that while these battery-electric equivalents have been identified for the purpose of this analysis, their actual V2G compatibility has not been verified. For the purposes of this study, it is assumed that all battery-electric equivalents are V2G compatible, though this may not reflect real-world conditions. This assumption simplifies the analysis but should be considered when interpreting the results. Table 3

shows the result of this research. For as many of the categories as possible, the equivalent GSE is chosen to be an already existing battery-electric GSE in the CPH-fleet.

Reading guide for Table 3:

- **Category name:** The names chosen for each category.
- **Battery electric equivalent:** The name of the vehicle/piece of equipment chosen as the battery-electric equivalent to the category.
- **Battery capacity [kWh]:** The battery capacity in the battery-electric equivalent written in kWh. The battery capacity is found from the data sheet for each BE-GSE. It is assumed that the listed battery capacity in the data sheet is the actual battery capacity.
 - o For some of the BE-GSE units, the battery capacity wasn't directly listed in kWh but as a working voltage, V, and Ah. In these cases, the battery capacity has been estimated as

$$\text{Battery capacity} = V \cdot Ah$$
- **Manufacturer:** The manufacturer behind the battery-electric equivalent.
- **Country:** Country code for the country in which the HQ of the manufacturer resides.
- **Pointer to documentation:** a pointer to where the documentation for the battery-electric equivalents can be found.

Category name	Battery-electric equivalent	Battery capacity [kWh]	Manufacturer	Country
Cars	Volkswagen ID4 style	77	VW	DE
Large vehicles	Volvo FMX11 4x4 Rigid - Rear Air Suspension - N3G FMX 44R 1A	360	Volvo	SE
GPUs	ITW GSE 7400 eGPU	160/248/310	ITW GSE	USA/DK
PCAs	None found			
Passenger stairs	TIPS Freeway 1842Pe Passenger Stairs	24V, 720Ah	TIPS	SI
Tow trucks	TRANS-LIFT electric tractor, model TL200	24V/105Ah, 24V/160Ah	TRANS-LIFT	DK

Small motorized equipment	STILL RX 60-30 Electric Forklift Truck	80V, 560-620Ah	STILL	DE
Lifting equipment	LGMG Greentech Telescopic Boom Lift	80V, 542Ah	LGMG Europe	NL
Golf cars	Melex 391.1 Cargo	48V, 120/150/180/205/240 Ah	Melex	PL
Buses	MAN Lion's city 12E	445kWh	MAN	DE
Snow removal	Volvo FMX11 4x4 Rigid - Rear Air Suspension - N3G FMX 44R 1A	540	Volvo	SE

Table 3 – CHP case study: Electric equivalents for each category.

As it can be seen in the table, it has not been possible to find a battery-electric equivalent to the “Pre Conditioned Air”-units (PCAs). It is therefore concluded that the PCAs will not contribute to the battery capacity in the conceptual fleet of battery-electric GSE.

The same Volvo trucks were chosen as the electric equivalent to the large vehicles category and the snow removal category. However, a bigger battery capacity was chosen for the snow removal trucks, as these will require larger batteries than standard electric trucks to power energy-intensive equipment, maintain extended operational hours during winter storms, and compensate for reduced battery efficiency in cold temperatures.

7.1.4 Electrification and estimation of total battery capacity in the conceptual CPH-owned fleet of BE-GSEs

The term electrification in this context covers the process of replacing each of the GSE categories with its battery-electric equivalent from Table 3. From this step, we gain the following result presented in Table 4.

Reading guide for Table 4:

- Key ID: Key identifier.
- Category name: The names chosen for each category.
- Battery electric equivalent name: The name of the vehicle/piece of equipment chosen as the battery-electric equivalent to the category.
- Battery capacity per unit [kWh]: The battery capacity in the battery-electric equivalent, written in kWh.

- For some of the BE-GSE units, the battery capacity wasn't directly listed in kWh but as a working voltage and Ah. In these cases, the battery capacity has been estimated as

$$\text{Battery capacity} = V \cdot Ah$$

- Number of units: The accumulated number of units in each category.
- Accumulated battery capacity [kWh]: the total battery capacity in kWh for each category, found as

$$\text{Accumulated battery capacity} = \text{battery capacity per unit} \cdot \text{number of units}$$

Key ID	Category name	Battery electric equivalent	Battery capacity per unit [kWh]	Number of units [count]	Accumulated battery capacity [MWh]
1	Cars	VW ID.4	77		
2	Large vehicles	Volvo FMX11 4x4 Rigid - Rear Air Suspension - N3G FMX 44R 1A	360		
3	GPUs	ITW GSE 7400 eGPU	248		
4	Passenger stairs	TIPS Freeway 1842Pe Passenger Stairs	17.28		
5	Tow trucks	TRANS-LIFT electric tractor, model TL200	3.84		
6	Small motorized equipment	STILL RX 60-30 Electric Forklift Truck	49.6		
7	Lifting equipment	LGMG Greentech Telescopic Boom Lift	43.36		
8	Golf cars	Melex 391.1 Cargo	11.52		
9	Buses	MAN Lion's city 12E	445		
10	Snow removal	Volvo FMX11 4x4 Rigid - Rear Air Suspension - N3G FMX 44R 1A	540		
Total battery capacity [MWh]				383	56.5

Table 4 – CPH case study: Electrification and estimation of battery accumulated battery capacity.

Table 4 presents the first intermediate result of the case study at CPH. The conceptual CPH-owned fleet of BE-GSE has a total battery capacity of 56.5 MWh.

Figure 4 illustrates the distribution of battery capacity across the different BE-GSE categories. These visualizations reveal a significant disparity in the contribution of different GSE categories to the overall V2G potential. Specifically, five categories - cars, large vehicles, GPUs, buses, and snow removal trucks - emerge as the primary contributors to the total battery capacity. While these five categories contribute an overwhelming 96% of the total battery capacity, they represent a significantly smaller proportion of the total GSE units. This disproportionate contribution underscores their importance in the V2G context and justifies focusing the subsequent analysis on these key categories. Consequently, the decision was made to exclude the remaining five categories from further V2G potential assessment, as their impact on the overall V2G capacity is of small significance.

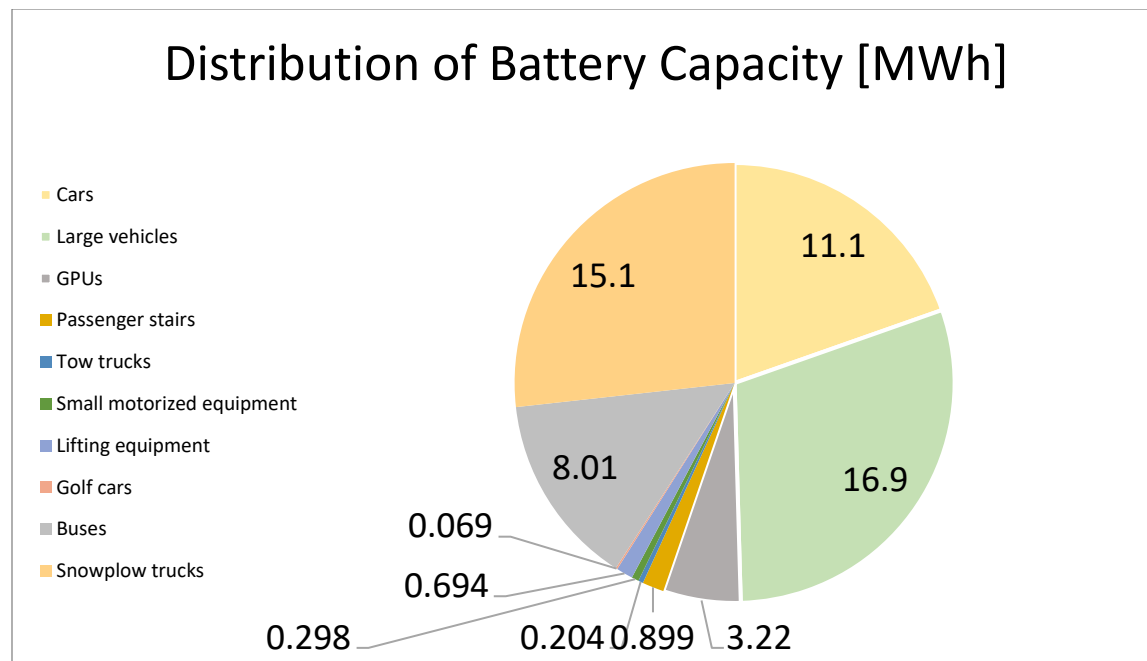


Figure 4 – CPH case study: Distribution of battery capacity.

7.2 CPH case study - phase 2

7.2.1 Acquisition of usage logs from CPH

To gather the necessary data for creating representative patterns of the use of GSEs, as well as charging and discharging patterns, a series of interviews with relevant personnel at CPH were conducted. Before conducting the interviews, a thorough “interview guide” was formulated to serve as a script for the interviewer to ensure consistent data. This interview guide was sent out to the interviewees in advance to allow enough preparation time. The generic interview guide can be found at the end of this document. The interview was recorded and transcribed to ensure credibility and reliability of the information.

7.2.2 Constructing a usage pattern

The usage patterns of CPH's ground support equipment were quantified based on operational data and expert input specific to the airport. However, due to the confidential nature of CPH-specific operations, detailed information regarding these usage patterns is not disclosed in this report.

7.2.2.1 Quantifying the information

To proceed with the analysis, it is essential to quantify the information provided by the asset management team. In this context, quantification refers to determining the precise number of GSE units in use per category at any given time. To capture the full range of operational scenarios, usage patterns were constructed for both peak and low utilization periods for each category, spanning a 24-hour period with hourly resolution. To accurately reflect the nuanced operational patterns described by the CPH planners, some categories were further divided into subcategories. This approach allows for a more granular and representative model of GSE usage throughout the day, accounting for variations in demand and operational requirements.

The specific quantification of these patterns for CPH is considered confidential and is therefore not included in the published report.

7.2.3 Estimating the V2G-availability

Before estimating the V2G-availability it is necessary to make a number of assumptions. For this specific case study, the assumptions are as described in the following section.

7.2.3.1 Case specific assumptions

- Instantaneous charging/discharging: It is assumed that charging and discharging processes occur instantaneously, without buffer periods between stand still and operation periods.
- Operational State of Charge (SoC) Range: Vehicles operate within a 10% to 80% state of charge range. Linear charging and discharging are assumed in this range.
- Charging, Discharging, and V2G Availability Pattern:
 - Initial Connection: Upon completing its operational period, the vehicle is immediately connected to a V2G-capable charger.
 - Starting Condition: Each charging cycle begins with the vehicle at 10% SoC.
 - First Charging Phase: For the initial half of the available charging time, the vehicle charges linearly from 10% to 45% SoC.
 - V2G Availability Phase: Upon reaching 45% SoC, the vehicle enters a V2G-ready state, capable of both power import and export. The 45% level is chosen as the midpoint between 10% and 80%, maximizing flexibility for bidirectional power flow.

- Final Charging Phase: When half of the total available charging time remains, the vehicle resumes linear charging from 45% to 80% SoC.
- End State: The vehicle is returned to service with an 80% SoC, ensuring operational readiness.

These assumptions are all illustrated in Figure 5. This model will be the baseline for all following calculations.

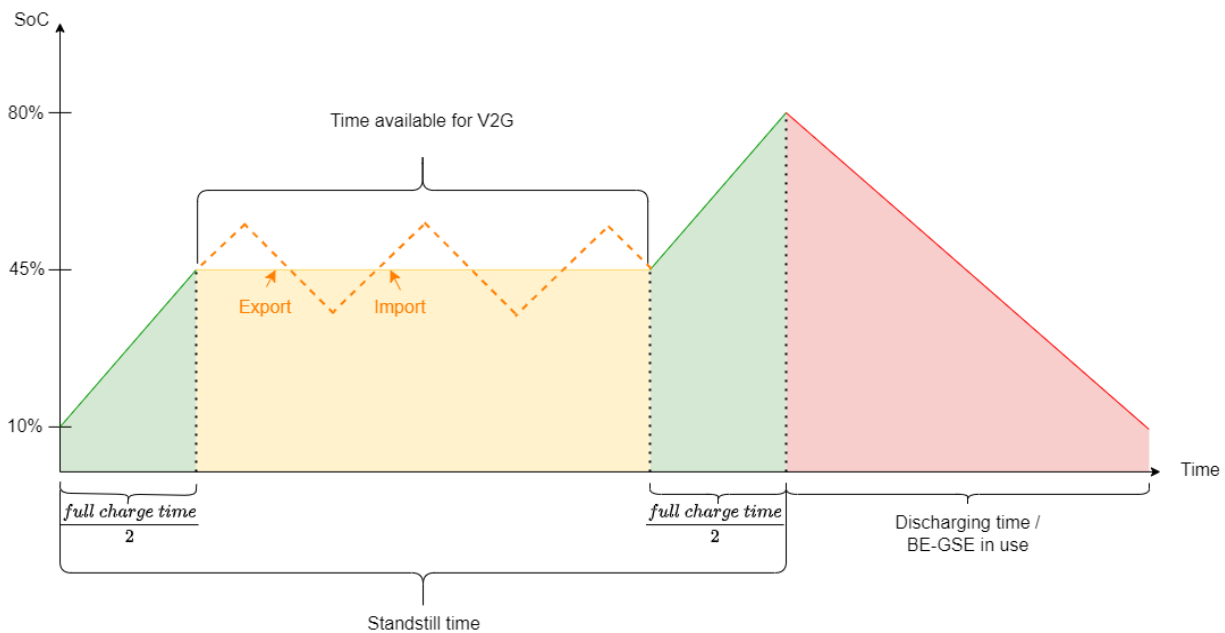


Figure 5 – CPH case study: Charging, discharging and V2G availability pattern.

7.2.4 V2G availability per category

The entire analysis was conducted using Microsoft Excel to ensure transparency and reproducibility of the calculations.

For each of the five key categories identified – "Cars", "Large vehicles", "GPUs", "Buses", and "Snow removal" – a set of calculations was performed to model both peak and low usage scenarios. This dual-scenario approach allows for a comprehensive understanding of the V2G potential across varying operational conditions. The following sections detail the specific calculations and methodologies applied to each category under both usage scenarios.

1. State of Charge (SoC) Calculation: The State of Charge was calculated for each subcategory within the five key GSE categories. Table 5 provides an illustrative example, showcasing the peak use pattern for the "Large vehicles" category. In this example, the subcategories are denoted as 2.1.1, 2.1.2, and 2.1.3. To enhance clarity and visual interpretation, a colour-coding scheme was implemented in the table. This scheme corresponds to the different operational stages - charging, discharging, and V2G availability – as defined in Figure 5.

This visual representation allows for an intuitive understanding of the SoC fluctuations and V2G potential throughout the 24-hour cycle for each subcategory. This approach not only provides a detailed breakdown of SoC variations but also facilitates a comprehensive view of how different subcategories within a GSE category may have distinct usage patterns and, consequently, varying V2G potentials.

Time	2.1.1 [%]	2.1.2 [%]	2.1.3 [%]
01:00	45	39	45
02:00	45	33	45
03:00	45	28	45
04:00	57	22	57
05:00	68	16	68
06:00	80	10	80
07:00	74	22	73
08:00	68	33	66
09:00	63	45	59
10:00	57	45	52
11:00	51	45	45
12:00	45	45	38
13:00	39	45	31
14:00	33	45	24
15:00	28	45	17
16:00	22	57	10
17:00	16	68	22
18:00	10	80	33
19:00	22	74	45
20:00	33	68	45
21:00	45	63	45
22:00	45	57	45
23:00	45	51	45
00:00	45	45	45

Table 5 – CPH case study: SoC per subcategory for the "Large vehicles" category.

2. Available Energy Calculation: The available energy in the batteries was calculated for each subcategory and accumulated on an hourly basis. The calculation of available energy was performed using the following formula:

$$\text{Available energy} = \text{SoC [\%]} \cdot \text{battery capacity} \cdot \text{number of units in subcategory}.$$

This calculation allows for an assessment of the total energy available in the batteries at any given hour, accounting for variations in SoC across different units within a subcategory.

Using these calculations, it was possible to generate plots illustrating both the SoC and available energy for each category over a 24-hour period. Figure 6 presents this data for the "Large vehicles" category during peak usage, serving as a representative example of the analysis conducted for all categories.

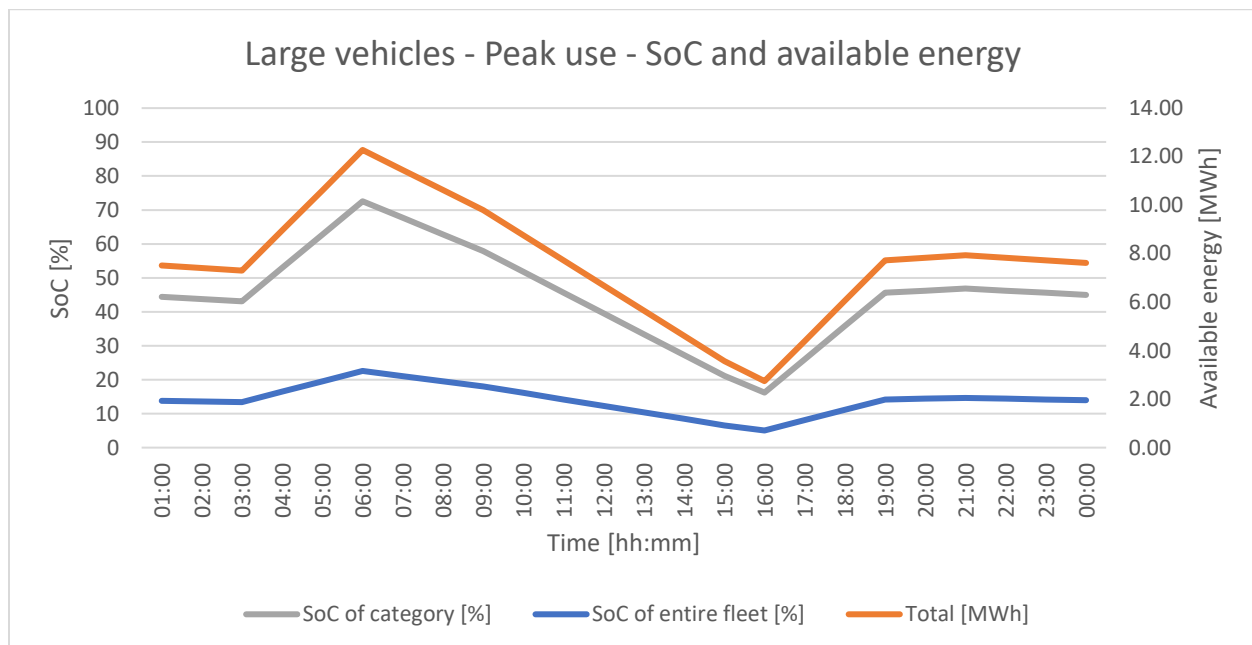


Figure 6 – CPH case study: "Large vehicles" - Peak use - SoC and available energy.

3. V2G Availability Calculation: The final step in the analysis involves calculating the number of units available for V2G participation, both at the subcategory and category levels. As outlined in section 7.2.3.1, a GSE unit is considered available for V2G during standstill periods that exceed the time required for a full charge cycle, excluding the period used for linear charging from 10% to 80% SoC. In the accompanying tables, these periods of V2G availability are highlighted in yellow for easy identification.

It is important to note that this calculation assumes the availability of V2G-compatible chargers for all GSE units, which may not reflect real-world conditions but serves as a best-case scenario for the analysis.

Using the number of GSE units available for V2G and the assumed charging/discharging power, both the power capacity and energy capacity available for V2G were calculated on an hourly basis. Figure 7 illustrates this calculation for the "Large vehicles" category during peak usage, assuming a charging/discharging power of 50 kW per unit.

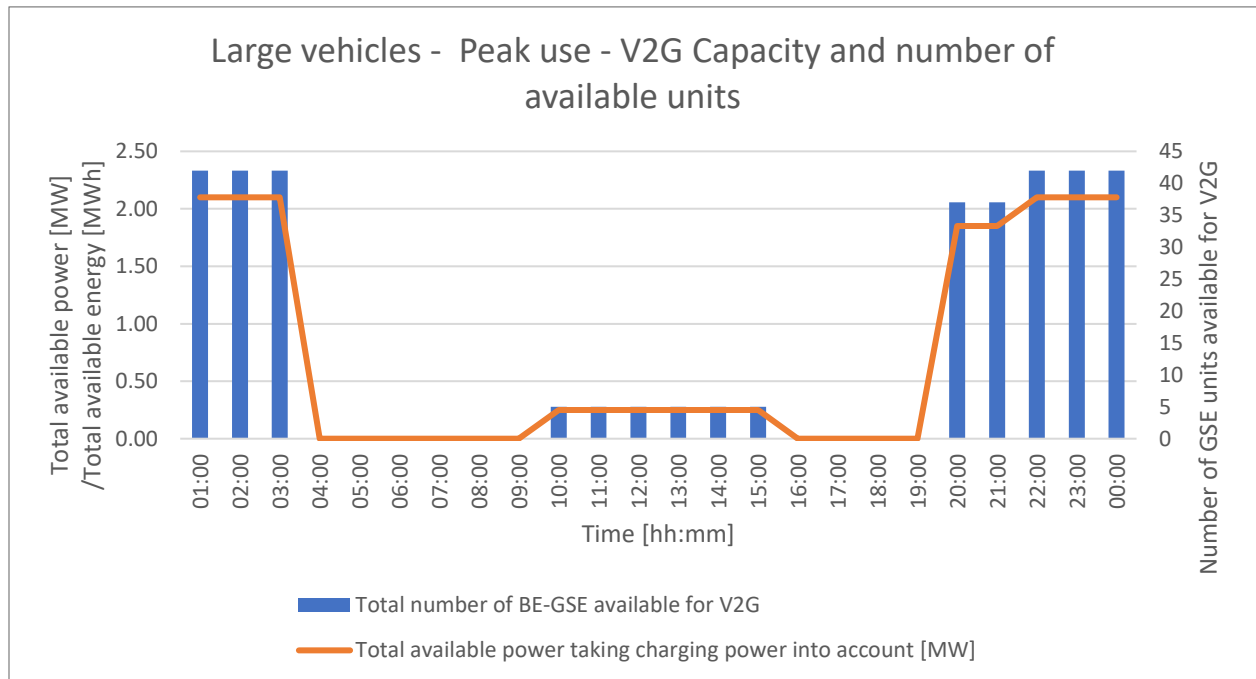


Figure 7 – CPH case study: "Large vehicles" - Peak use – Capacity and number of available units

It should be noted that in Figure 7, power and energy are plotted on the same y-axis. This representation is valid due to the 1-hour time resolution of the analysis, which results in power (kW) and energy (kWh) values of the same numerical magnitude for each time step.

The energy capacity available for import or export through V2G was calculated based on the number of units available and their battery capacities. It is important to emphasize that this calculation does not account for the limitations imposed by the assumed charging/discharging power of the V2G chargers.

Two scenarios warrant consideration:

1. If the calculated energy capacity exceeds the energy limit set by the V2G charger, it indicates suboptimal utilization of the battery energy. In such cases, increasing the charging power could lead to improved energy utilisation.
2. Conversely, if the calculated energy capacity is lower than the energy limit of the V2G charger, it suggests that the assumed charging power is excessive relative to

the battery capacities. In this scenario, a reduction in charging power would be appropriate.

It is crucial to note that in cases where the V2G charger limits the energy transfer, the energy values should be adjusted downwards to reflect the actual available energy in the batteries. This adjustment ensures that the analysis accurately represents the practical limitations of the V2G system.

7.2.5 **Combined V2G availability**

The combined V2G potential for the entire fleet is determined through a series of fictional scenarios that explore the extremes in the usage patterns of the categories. To illustrate the differences between these extremes, they are compared in various combinations, some of which are highlighted below. It was assumed that all stationary units have access to V2G-compatible chargers with charging/discharging rates of 22 kW for cars and 50 kW for the remaining categories.

7.2.5.1 *Snow and frost*

The usage of large vehicles and snow removal equipment, which collectively hold 32 MWh of battery capacity, is largely determined by weather conditions, with snow ploughs potentially available round-the-clock during non-winter periods.

A comparison of the V2G availability on a weekday with high air traffic, both with and without snow and the need for road salting, yields the results shown in Figure 8. This plot clearly demonstrates that the snow ploughs and trucks used during snowfall and for road salting possess a crucial battery capacity. Particularly during daytime hours, these vehicles could increase the available potential from 0 W to 1.7 MW.

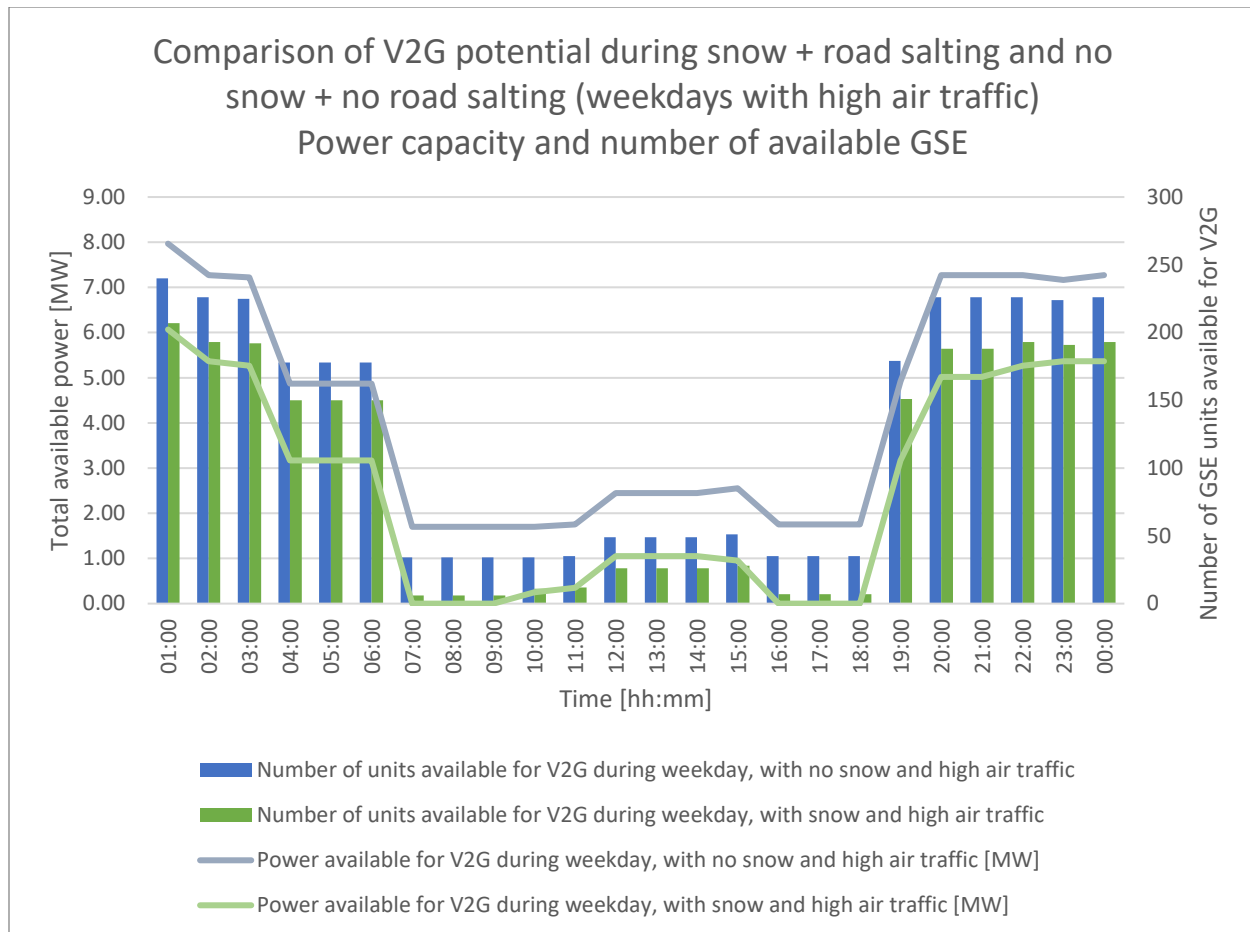


Figure 8 – CPH case study: The effect of the usage of snow removal equipment and road salting machines on the overall V2G potential of the fleet.

7.2.5.2 Weekends vs weekdays

The entire fleet of cars, which holds 11.1 MWh of battery capacity, is purely dependent on whether it is a weekday or a weekend day. A comparison is made between a weekday and a weekend day, both during high air traffic, with no snow and no need for road salting. The result of this comparison can be seen in Figure 9. This plot clearly shows that the fleet of cars makes a significant difference in V2G availability during daytime hours, substantially increasing the number of available units and, consequently, the power.

At first glance, it may seem counterintuitive that the cars, which hold only 11.1 MWh of battery capacity, have a greater V2G potential than the large vehicles and snow removal vehicles. However, this can be explained by the fact that the charging power is limited to 22 kW and 50 kW for the cars and larger vehicles, respectively. These plots demonstrate that, under the chosen assumptions, the number of vehicles is more important than the battery capacities, as the power and energy available for V2G are limited by the charging/discharging powers.

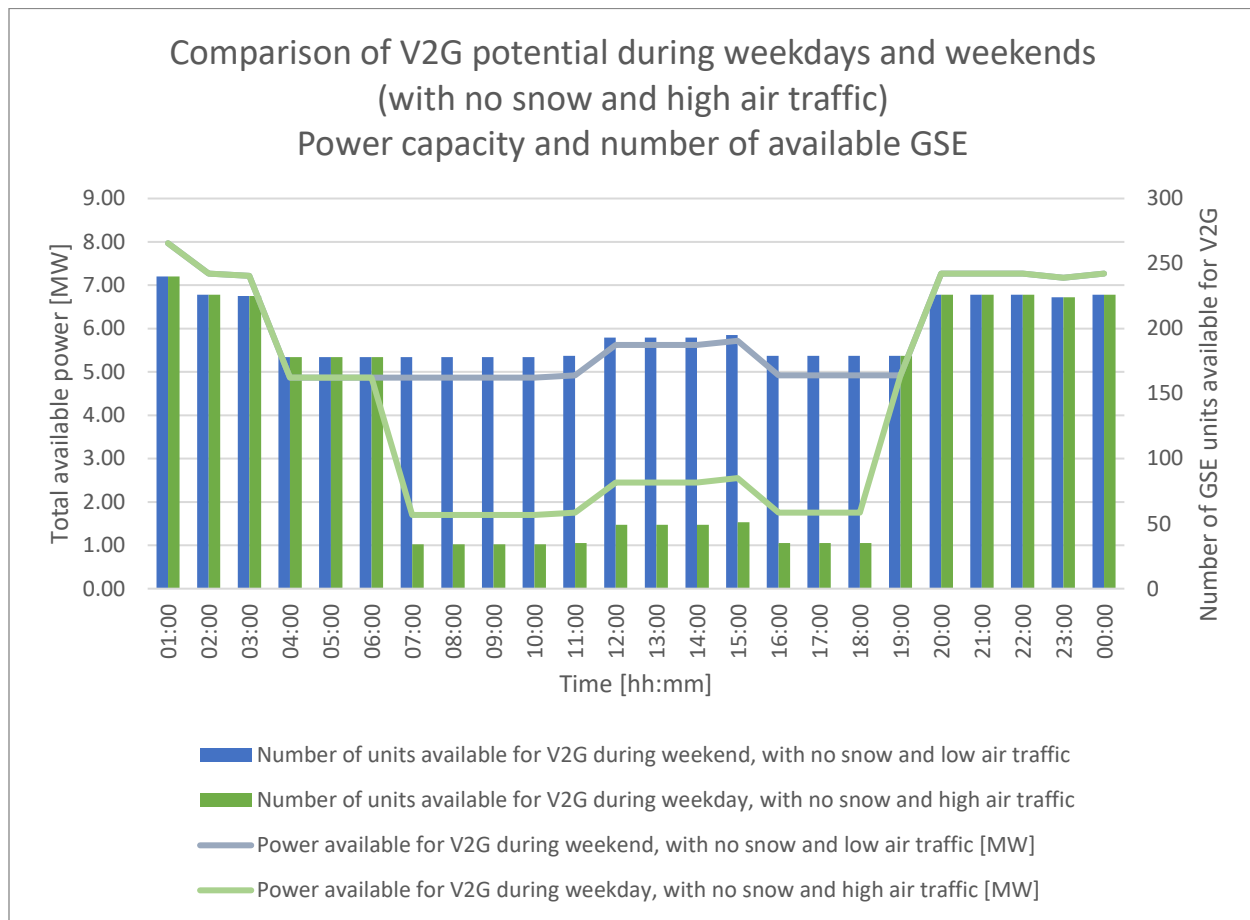


Figure 9 – CPH case study: The effect of the day of the week (weekend or weekday) on the overall V2G potential of the fleet.

7.2.5.3 High vs low air traffic

The usage of buses and GPUs depends on air traffic levels, meaning that increased air traffic leads to increased usage of the GSE units in these categories. To assess the effect of air traffic on the V2G potential of the fleet, a weekday with high air traffic is compared to a weekday with low air traffic. Both days are without snow or need for road salting. The resulting plot is depicted in Figure 10.

This plot demonstrates that air traffic has a minor effect on the overall V2G potential of the fleet. However, it can be observed that some units are available for slightly longer periods during lower air traffic at midday compared to high air traffic conditions.

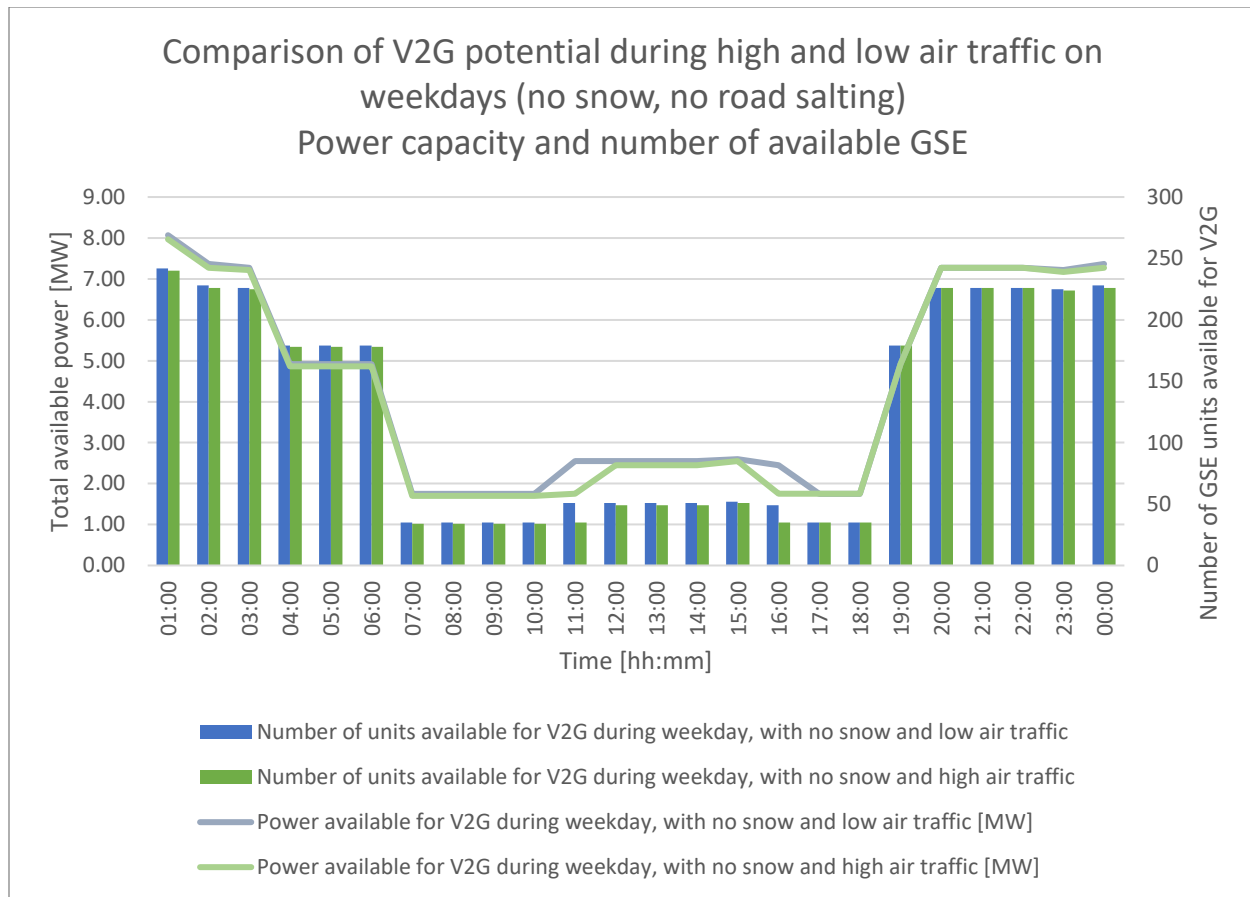


Figure 10 – CPH case study: The effect of high air traffic on the overall V2G potential of the fleet.

7.2.6 Further analysis

For the results highlighted in this report, it is assumed that there is a V2G-compatible charger available per stationary vehicle. If the number of available V2G-compatible chargers per GSE unit is changed, the overall available power, energy, and number of units participating in V2G will vary accordingly. Similarly, adjusting the charging and discharging power for each category would affect the outcomes.

The V2G chargers for large vehicles and snow removal trucks are assumed to import and export energy with a power of 50 kW. Examining Figure 11, it is evident that the energy in these vehicles is not used optimally. For this comparison, two scenarios are considered:

1. The first scenario assumes 22 kW charging/discharging power for cars and 50 kW for the remaining categories.
2. The second scenario assumes 22 kW for cars, 50 kW for GPUs, and 100 kW for large vehicles, buses, and snow removal equipment.

This comparison demonstrates that an increase in charging/discharging power for the GSE units with larger battery capacities leads to more effective utilisation of the battery capacities.

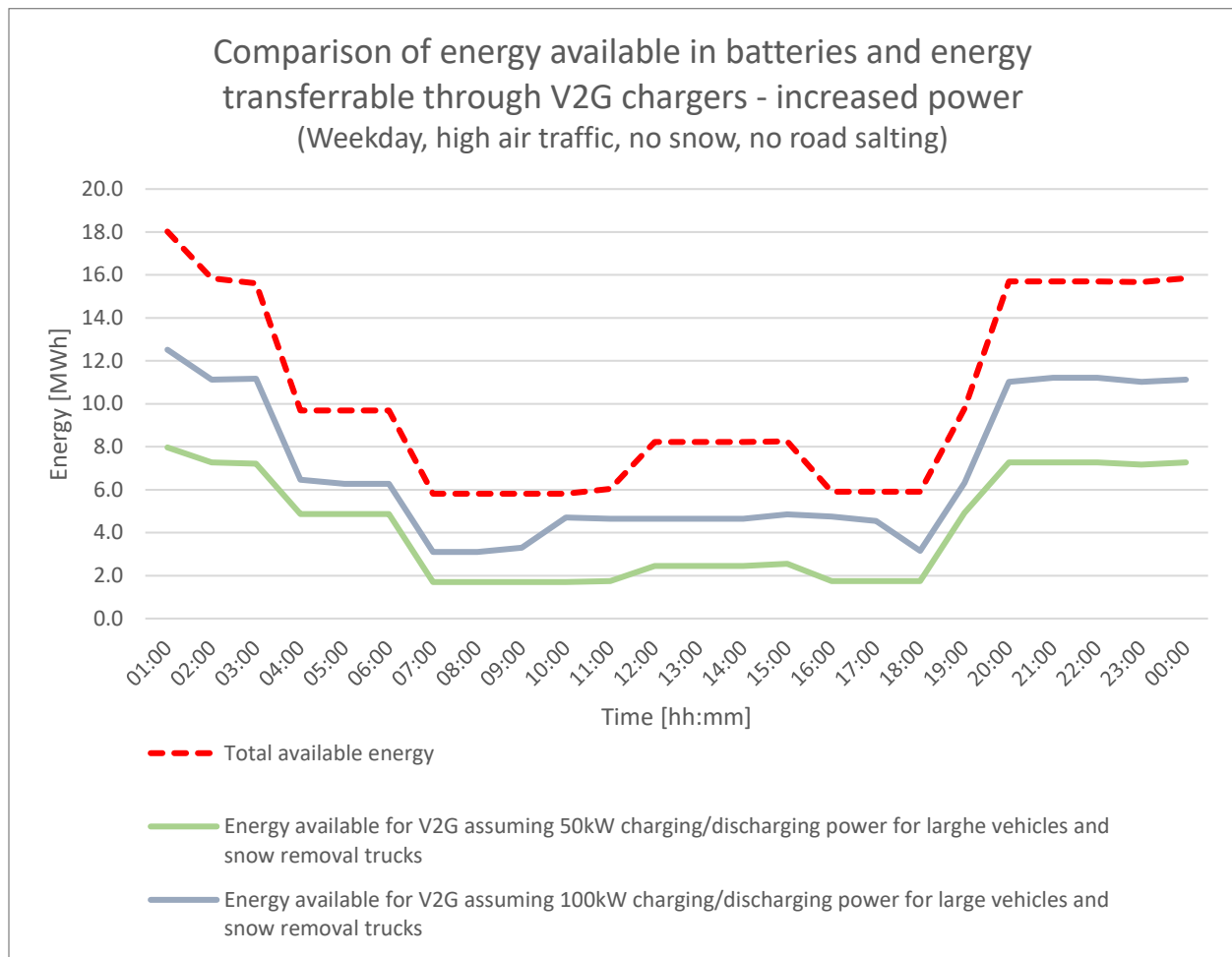


Figure 11 – CPH case study: Comparison of energy available for V2G when increasing charging/discharging power for large vehicles and snow removal trucks.

7.3 Conclusions on CPH case study

In this case study, the Vehicle-to-Grid (V2G) potential of Ground Support Equipment (GSE) at Copenhagen Airport was examined, revealing significant insights and areas for further investigation.

A substantial potential in the conceptual fleet of electric GSEs, with a total battery capacity of 56.5 MWh, was demonstrated. Referring to **Error! Reference source not found.** and Figure 4, five categories – cars, large vehicles, GPUs, buses, and snow removal trucks – contribute to 96% of the total battery capacity while accounting for a significantly smaller percentage of the total GSE units, highlighting their importance for V2G applications.

Through interviews with CPH asset management team and subsequent quantification of usage patterns, V2G availability was estimated. It was assumed that all stationary units have access to V2G-compatible chargers and charging/discharging rates of 22 kW for cars and 50 kW for other vehicles were considered, leading to a projection of total V2G potential.

Figure 12 contains a comparison of the two most extreme of the fictional scenarios of V2G availability.

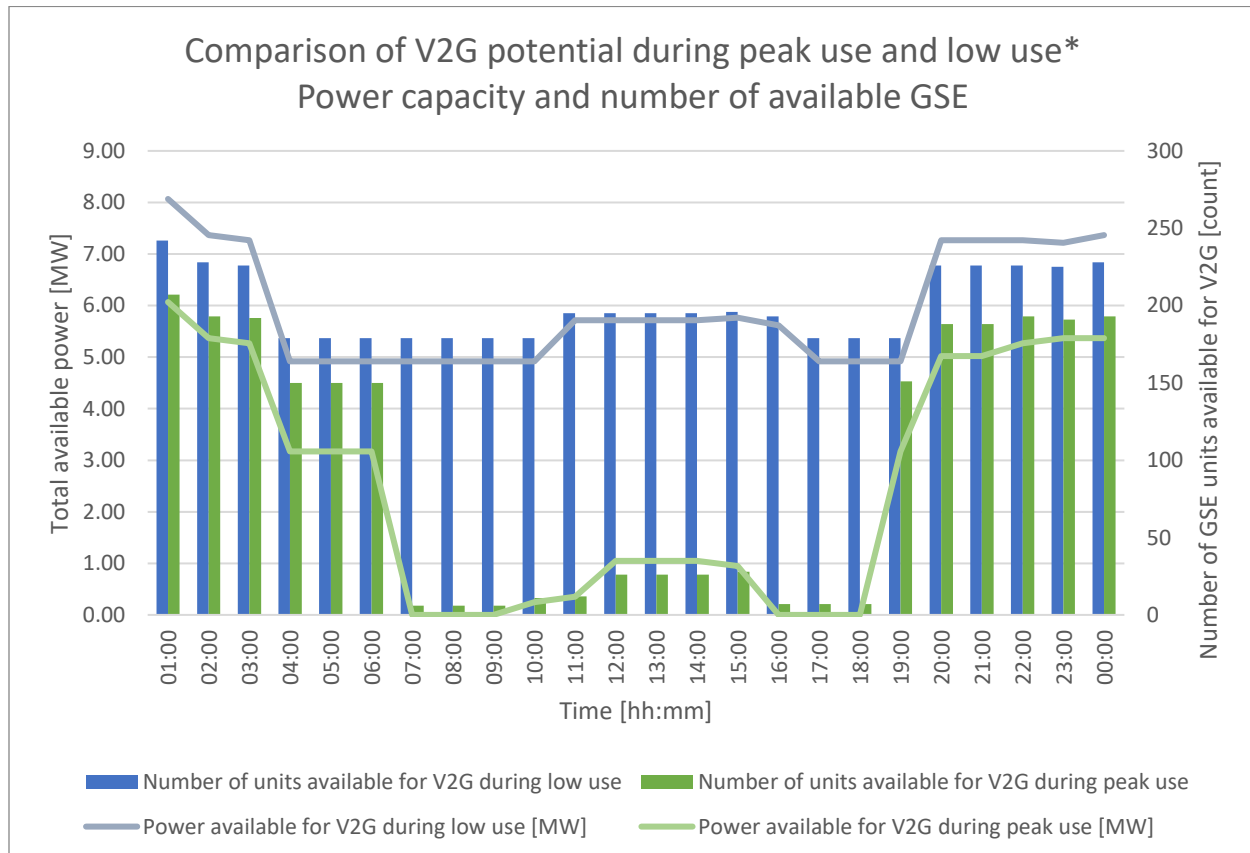


Figure 12 – CPH case study: Comparison of V2G potential during peak use and low use of GSE. *Peak use = Weekday, high air traffic, snow and need for road salting. Low use = weekend, low air traffic, no snow and no need for road salting.

The key differentiator between these scenarios is the availability of large vehicles and snow removal equipment, which collectively hold 32 MWh of battery capacity. Their usage is largely determined by weather conditions, with snow ploughs potentially available round-the-clock during non-winter periods. Another key difference is the availability of the fleet of cars, with a total battery capacity of 11.1 MWh. The cars are widely idle on weekends and therefore possess significant V2G potential during this time.

Increased air traffic only marginally affects the available battery capacity; however, a noticeable difference can be observed between 10:00 and 17:00, primarily due to variations in the use of buses and GPUs.

It is furthermore evident that the chosen charging/discharging powers for the available V2G chargers are crucial. Selecting the power based on the battery capacities in the different categories of GSE will lead to more effective use of the battery capacities, thereby increasing the V2G potential in the fleet.

It is crucial to note that this analysis is based on broad assumptions and does not account for temperature effects, precise daily usage patterns, or battery degradation. As such, it serves as an initial exploration of the concept.

A significant limitation of this study is its reliance on 'static' snapshots. Future research should incorporate the flexibility of V2G availability periods and conduct a comprehensive value assessment of this concept.

In conclusion, while promising V2G potential in Copenhagen Airport's GSE fleet has been revealed, the need for more detailed, dynamic analyses to fully understand and quantify the practical implementation and economic viability of such a system is also underscored.

8 Discussion

The findings of this analysis provide a comprehensive overview of the battery capacities within the fleet of battery-electric ground support equipment (BE-GSE). However, it is important to recognize that these estimates should be considered generous due to the exclusion of several limiting factors that could influence the outcomes.

8.1 Battery lifespan

One significant consideration is the potential impact of frequent charging cycles on the battery lifespan of GSE when utilised for Vehicle-to-Grid (V2G) applications. The increased availability of V2G introduces more charging and discharging cycles, which may affect the overall longevity of the batteries. Further investigation into the long-term effects of V2G on battery health is necessary to ensure sustainability and cost-effectiveness.

8.2 The impact of weather and climate

Additionally, weather and climate conditions play a crucial role in determining battery performance. Variations in temperature can significantly affect battery capacity, potentially leading to reduced efficiency during extreme weather conditions. This aspect warrants further analysis to optimise operations in diverse climatic environments.

8.3 Security

Security remains a paramount concern when implementing V2G systems. A thorough risk analysis must be conducted to address potential vulnerabilities associated with the use of V2G chargers. Ensuring robust security measures will be essential to protect both the infrastructure and the data involved in these transactions.

8.4 Load shifting

While this analysis focuses primarily on V2G, it does not delve into the possibilities of load shifting, a key component of smart charging systems. Load shifting can optimise energy usage and reduce costs, and its integration into V2G strategies should be explored further to enhance the efficiency of energy management.

8.5 Load sharing

Moreover, the current analysis assumes no load sharing among chargers. In practical scenarios, load sharing is likely to occur when multiple BE-GSE units connect to a charger with multiple charging points. Understanding the implications of load sharing on overall system performance is crucial for accurate capacity planning.

8.6 The need for additional GSE units

The transition to an electrified fleet of GSE also raises the question of whether additional vehicles are necessary. Determining if electrification results in a need for more GSE units is vital for strategic planning and resource allocation.

9 Summary of V2G potential and assessment methodology

This study presents a comprehensive methodology for assessing V2G potential in airport GSE fleets and demonstrates its application through a case study at Copenhagen Airport. The analysis reveals promising V2G potential in airport GSE fleets while highlighting the complexities involved in implementation.

Key conclusions include:

- The proposed methodology offers a structured approach to estimate V2G potential, adaptable to various airport contexts. The analytical methodology developed for the CPH case study has been translated into the tool: *"V2G assessment tool for airport GSE"*. This Excel-based tool retains all calculation frameworks and analytical tools whilst excluding case-specific values, enabling other airports to conduct similar V2G potential assessments of their GSE fleets. The workbook provides a structured approach to data input, analysis, and visualisation, making it a practical tool for airports exploring V2G implementation opportunities.
- V2G availability in airport GSE fleets is highly dependent on operational factors such as weather conditions and day of the week, and less dependent on air traffic levels.
- Optimising charging/discharging power based on battery capacities can significantly enhance V2G potential.
- The case study underscores the need for more detailed, dynamic analyses to fully understand and quantify the practical implementation and economic viability of V2G systems in airport operations.
- Involving relevant operational personnel in the process of sorting, categorising, and mapping GSE is crucial for an accurate and comprehensive analysis. Their insights can significantly enhance the accuracy of categorisation, ensure proper consideration of operational constraints, and provide critical context for usage patterns that may not be apparent from raw data alone. In this study, input from asset management team led to more precise categorisation of vehicles with multiple functions and clarified the operational patterns of seemingly similar equipment. This collaborative approach not only improves the quality of the analysis but also ensures that the resulting V2G potential assessment aligns closely with the practical realities of airport operations. Ultimately, the involvement of operational personnel bridge the gap between theoretical analysis and real-world applicability, leading to more robust and actionable findings.

- Further research is needed to address limitations such as the impact of temperature effects, precise daily usage patterns, and battery degradation.

While this analysis provides valuable insights into the V2G potential of airport GSE fleets, it also highlights the complexity of implementing such systems. The findings of this study can serve as a foundation for future investigations and pilot projects aimed at realising the full potential of V2G technology in airport operations worldwide.

9.1 Recommendations

Based on the findings of this study, several key recommendations can be made for airports considering the implementation of V2G technology with their GSE fleets.

Firstly, airports should focus on high-capacity GSE categories when initiating V2G implementation. The analysis revealed that certain categories of GSE contribute disproportionately to the total battery capacity of the fleet. In the case of Copenhagen Airport, cars, large vehicles, GPUs, buses, and snow removal trucks accounted for 96% of the total battery capacity while comprising a smaller portion of the total GSE units. Other airports should conduct similar analyses to identify their equivalent high-potential categories. By prioritizing these categories, airports can maximise the potential benefits of V2G implementation with minimal initial investment.

Secondly, optimising the charging infrastructure is crucial for effective V2G implementation. The study demonstrated that the choice of charging/discharging power significantly impacts the utilisation of available battery capacity. Airports should invest in V2G-compatible chargers with power ratings tailored to the battery capacities of different GSE categories. This optimisation ensures more effective use of the available battery capacity and enhances the overall V2G potential of the fleet.

Lastly, airports should consider developing seasonal strategies for V2G implementation, particularly for equipment with high capacity but seasonal usage patterns. The case study at Copenhagen Airport highlighted the significant impact of seasonal factors, such as snow and frost, on V2G availability. For instance, snow removal equipment, which holds substantial battery capacity, remains largely idle during non-winter periods. Airports could develop strategies to maximise the V2G potential of such equipment during their off-seasons, while ensuring their readiness for seasonal operations. This approach could significantly enhance the year-round V2G capacity of the airport's GSE fleet.

By focusing on these key areas - prioritising high-capacity GSE categories, optimising charging infrastructure, and developing seasonal strategies - airports can take practical steps towards realising the potential of V2G technology in their GSE fleets. This approach allows for a targeted and efficient implementation of V2G technology, potentially leading to significant environmental and economic benefits while maintaining operational readiness.

9.2 The Active Role of GSE Operators in V2G Implementation

The successful implementation of V2G technology in airport GSE fleets will require active participation from GSE operators, introducing a new level of complexity to their roles. Operators will need to adopt new habits and responsibilities, such as consistently connecting GSE units to V2G-compatible chargers when not in use. They will also play a key role in providing accurate information about anticipated usage times, allowing for more efficient scheduling of charging and V2G operations. Additionally, operators may need to input data about the state of charge required for their next task, ensuring that vehicles are adequately charged for operational needs whilst maximising V2G availability.

Moreover, the introduction of V2G technology will necessitate a significantly higher degree of planning and coordination. Logistics and scheduling will take on a new dimension, incorporating considerations of energy consumption patterns and real-time electricity prices. This shift requires a completely new mindset, where operators and planners must balance traditional operational requirements with energy management strategies. This balance can be achieved through either enhanced manual planning and coordination processes, or through the implementation of an energy management system (EMS). An EMS would automate the complex decision-making process, optimising the interplay between operational requirements, energy consumption patterns, and grid service opportunities while maintaining operational readiness.

To effectively manage this increased complexity, airports will likely need to invest in advanced software systems and computational power. These systems will help optimise the interplay between operational needs, energy consumption, and V2G opportunities, potentially using artificial intelligence and machine learning algorithms to predict usage patterns and energy prices. This new approach to GSE management represents a paradigm shift, requiring extensive training and adaptation from operators and planners alike. The integration of energy considerations into daily operations will not only contribute to the success of V2G implementation but also to the overall sustainability and efficiency of airport operations.

10 Ancillary Market analysis for V2G

10.1 Introduction

Denmark's transition to renewable energy and electric mobility presents both significant challenges and opportunities for power grid stability. The country aims to achieve 100% renewable energy by 2035 while simultaneously accommodating a projected EV fleet growth from 150,000 to potentially 1-1.5 million vehicles by the same year. Unmanaged EV charging could destabilize electricity grids through simultaneous charging demand, while the current grid infrastructure cannot accommodate this expansion in time. [4]. Vehicle-to-

Grid (V2G) technology offers a solution by transforming electric vehicles from grid challenges into valuable assets. Rather than simply consuming electricity, V2G-enabled vehicles can provide grid services, store renewable energy, and participate in energy markets. This analysis examines V2G performance specifically at airport facilities, focusing on energy market revenue potential and CO2 optimization opportunities.

Airports provide ideal environments for V2G implementation through electric ground support equipment (GSE) fleets. Airport GSE—including baggage tugs, pushback tractors, and ground power units—operate in predictable patterns with extended idle periods between flights, creating optimal conditions for grid service participation.

Electric GSE fleets offer distinct advantages. Vehicles remain on-site with consistent grid connection, aggregated battery capacity from large fleets provides substantial flexibility resources, and centralized management enables coordinated strategies that balance operational needs with grid services. Flight schedule predictability allows advance planning to ensure vehicles maintain sufficient charge for operations while maximizing grid participation during idle periods.

Operational constraints like weather conditions affect availability—snow operations may temporarily redirect equipment to runway clearing—but these patterns can be forecasted and integrated into optimization models. Airport V2G systems can participate in energy markets, generating revenue that offset electrification costs while supporting grid stability. This study demonstrates how EV fleets in the airport can deliver scalable V2G benefits.

10.2 Comparative Scenarios

The study evaluates three operational scenarios that reflect varying weather conditions and air traffic levels, both of which directly impact GSE availability. The analysis provides insights into potential revenue from energy markets and opportunities for carbon footprint reduction through intelligent charging and discharging strategies. GSE availability data is obtained from Copenhagen Airport (CPH), and the scenarios are described below.

Scenario 1 (S1): No Snow, Low Traffic

Optimal conditions with clear weather and reduced airport activity. Most GSE remains available for V2G participation.

Scenario 2 (S2): No Snow, High Traffic

Clear weather with high airport traffic. GSE availability remains almost uncompromised despite increased operations.

Scenario 3 (S3): Snow, High Traffic

Snow conditions with high air traffic. The snow removal equipment becomes unavailable for V2G participation.

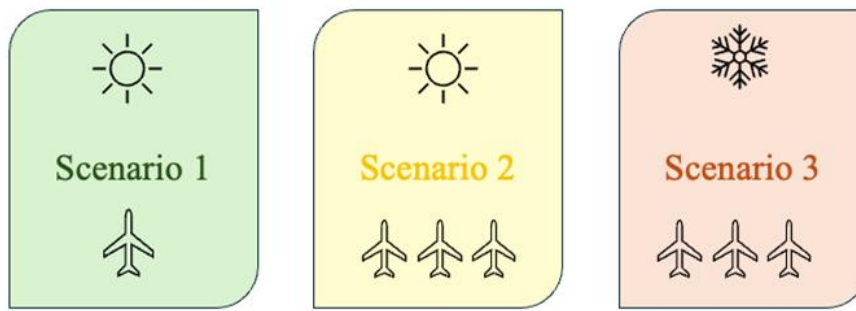


Figure 13: Study Scenarios

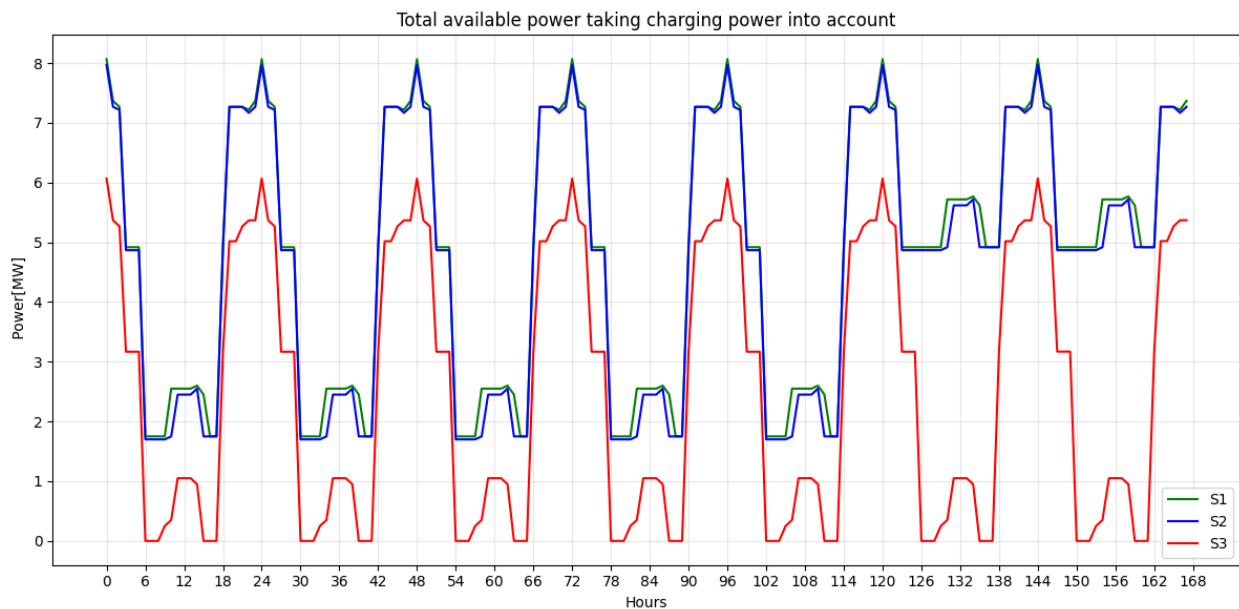


Figure 14 : Power available across scenarios

Figure 2 illustrates the total power availability for three distinct scenarios (S1, S2, and S3) over a week-long period. S1 and S2 consistently outperform S3 in terms of total power availability throughout the week. S3 exhibits markedly lower power availability, with notably reduced peak and average power levels. The reduced power availability is attributed to snow conditions and high traffic scenarios.

Clear distinctions are observable between weekday and weekend power availability patterns in S1 and S2. It must be kept in mind that the weekend pattern wasn't available for S3, and the weekday data is used to replicate the weekend data here.

There are only minimal differences in power availability between S1 and S2. Power availability also shows a clear daily cycle. At night, power levels shoot up high, while during the day, power drops very low.

10.3 Market and Period Selection

V2G technology enables electric vehicles to participate in Denmark's frequency containment reserve markets, generating revenue by providing flexibility services. EV owners can monetize their vehicle's availability to support grid stability by offering their battery as a reserve resource. FCR-D UP market is a good fit among other ancillary servicemarkets like FCR, FCR-N, FCR-D down and aFRR for public EV chargers considering the market prices and the minimal effect of charging duration of the vehicles.

FCR-D is an abbreviation of Frequency Containment Reserve– Disturbance. FCR-D is designed to stabilize the frequency in the power grid in DK2 and the rest of the Nordic synchronous area in the event of frequency drops or deviations. The rationale behind the FCR-D UP market being the most suitable for V2G services is explained in the previous section of the report. [5]

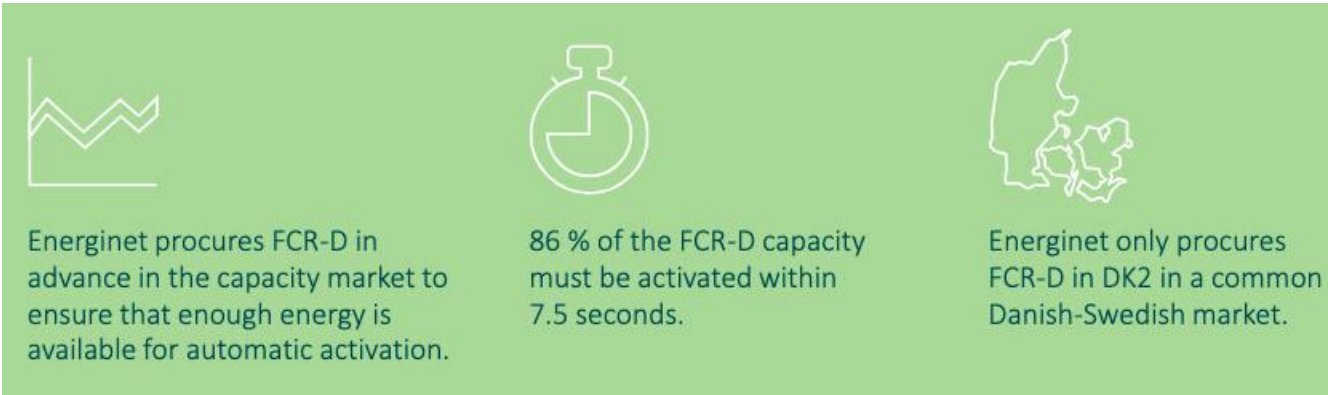


Figure 15 : FCR-D market details from Energinet

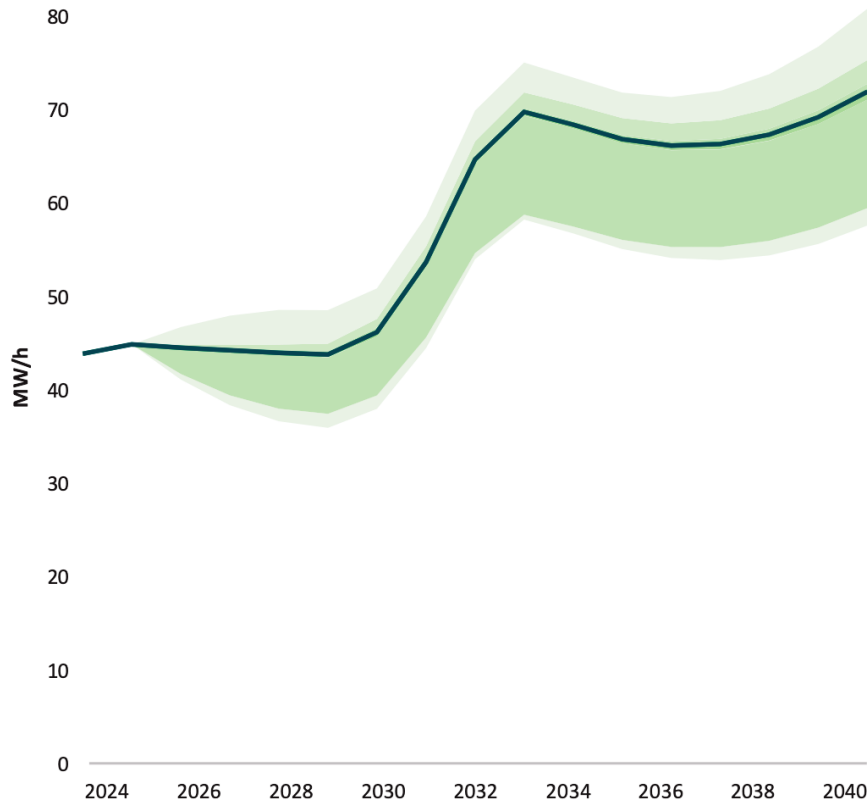


Figure 31 Median of projected need with 90 %,75 % and 10 % confidence intervals.

Figure 16 :The projected need for FCR-D in DK2 from Energinet.

Energinet's projected need for FCR-D in DK2 towards 2040 is shown in the figure above [6] . Since the need for FCR-D for up-regulation and down- regulation will be very similar, the projections are shown together. FCR-D is procured on a common Danish-Swedish market.

2025-2030 Period: Danish requirements for FCR-D capacity show consistent growth through this period. Forecasts suggest Danish procurement will reach 38-51 MW by 2030. Meanwhile, reduced Swedish demand leads to declining total capacity needs across the combined Danish-Swedish market.

2030-2035 Period: Danish FCR-D requirements experience substantial growth, particularly after 2033 when the Bornholm Energy Island begins operations. Projections indicate Danish capacity needs between 55-72 MW by 2035. Despite this domestic increase, the joint Danish-Swedish market continues its gradual downward trajectory.

2035-2040 Period: Danish FCR-D capacity requirements maintain upward momentum, with forecasts ranging from 58-81 MW by 2040. The combined Danish-Swedish market reverses its decline during this phase, with total procurement volumes returning to levels observed in 2030. The overall trend shows the promising revenues from this market.

The study is done to evaluate the effect of the snow conditions. Hence the market period selected in December and January months and Figure 5 shows the market prices.

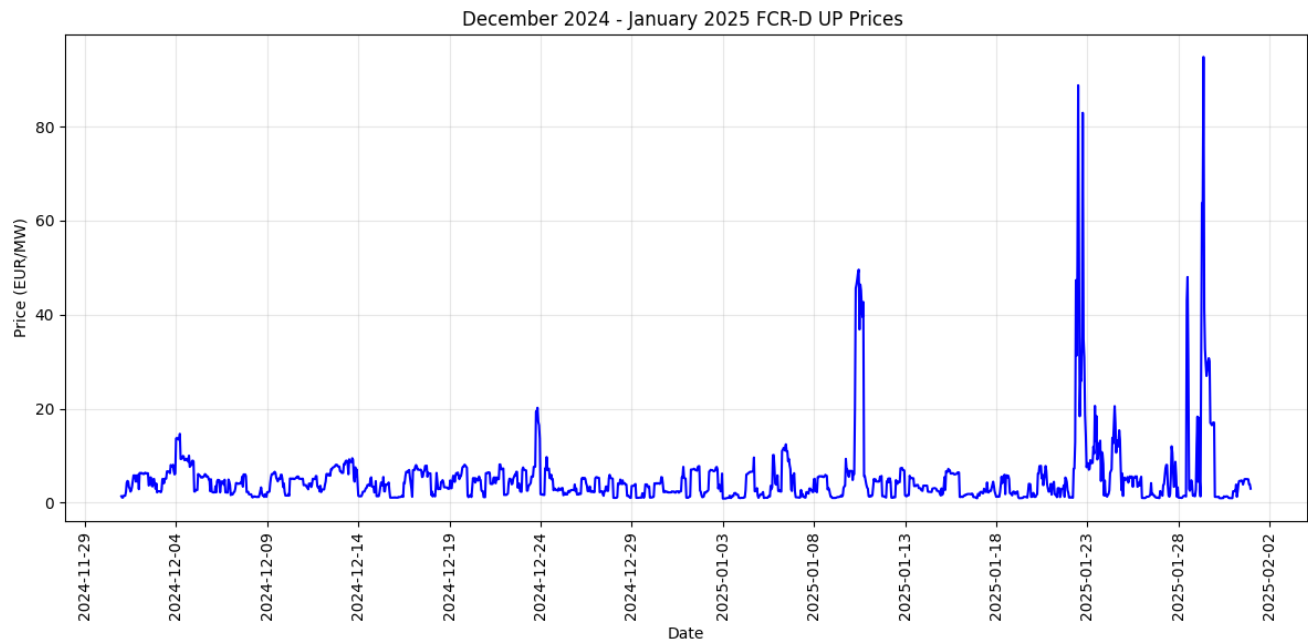


Figure 17 : FCR-D UP Price for December and January

Month	Period	Mean	Median	Std
December 2024	Weekday	4.81	4.87	2.75
	Weekend	3.20	3.25	1.76
January 2025	Weekday	7.00	3.09	11.43
	Weekend	3.20	2.34	2.16

Table 6: Price comparison: Weekday vs Weekend

The analysis reveals a consistent pattern where weekdays command higher FCR-D UP prices than weekends in both months, but the premium increased dramatically from December to January (Table 1). In December 2024, weekdays averaged 4.81 EUR/MW compared to 3.20 EUR /MW on weekends, representing a moderate 50% premium with relatively stable pricing patterns. However, January 2025 showed an escalation, with weekday prices surging to 7.00 EUR while weekend prices remained unchanged at 3.20 EUR, creating a substantial 119% weekend premium. The key driver of this change was extreme weekday

volatility in January (standard deviation of 11.43), indicating frequent price spikes, while weekends maintained consistent, predictable pricing across both months.

For the analysis, two distinct weeks were selected based on FCR-D market price trends to evaluate the impact of market conditions on V2G revenue generation. Week 50 in 2024 was chosen for its flat pricing trend with minimal spikes, providing a baseline for stable market conditions. In contrast, Week 4 in 2025 was selected due to its characteristic price volatility, featuring the typical spikes observed during winter demand periods.

10.4 Revenue Analysis:

Calculations

A simple analysis is done to calculate the revenue from the energy market. It is calculated based on the minimum of either the vehicle's available V2G power capacity or the required FCR-D up volume in the market, multiplied by the prevailing FCR-D up price.

$$\text{Revenue} = \text{Min} [\text{Available V2G Power}, \text{FCR D up Vol.}] * \text{FCR D up Price}$$

The FCR D price and Volume are obtained from Energinet's public database. [7]

It is important also to be aware of extra costs related to V2G-chargers, agreements with Balancing Responsible Parties and other costs associated with establishing and operating a V2G-fleet.

10.5 Results

Scenario 1

The revenue comparison between the two market periods reveals significant differences attributable to market conditions. Week 50 in December 2024 achieved €3281.33 in revenue. Clear weather and low traffic conditions resulted in the highest GSE availability for V2G participation, as fewer vehicles were needed for airport operations. Week 4 in January 2025 reached €5320.90 in revenue. The favorable operational conditions continued, allowing maximum fleet participation while improved market prices drove higher earnings. Revenue increased by €2039.57. The flat market trend during December provided consistent but moderate earning opportunities.

Low traffic periods maximize V2G revenue potential by freeing up the largest portion of the GSE fleet. The €3281-5321 revenue range demonstrates strong performance when GSE availability is highest.

Scenario 2

Week 50 in December 2024 produced €3193.15 in revenue. Despite high air traffic volumes, clear weather conditions meant GSE availability remained largely unaffected, with most vehicles still accessible for V2G services. Week 4 in January 2025 generated €5148.75 in revenue. High traffic operations continued while improved market conditions enhanced overall performance. Revenue increased by €1955.60.

High traffic does not significantly constrain V2G participation under normal weather conditions. The €3193-5149 revenue range shows that GSE availability remains sufficient even during peak airport activity.

Scenario 3

During Week 50 in December 2024, the system generates €1607 in revenue. Week 4 in January 2025 demonstrated markedly different results, with total revenue reaching €2593. This period was characterized by notable price spikes, with hourly prices exceeding €250/MWh during peak demand periods. The revenue differential of €986 represents a 61% increase compared to the December baseline.

The analysis demonstrates a direct correlation between market price volatility and V2G earning potential. The substantial revenue increase during the January market period was primarily driven by the ability to capitalize on price spikes exceeding €250/MWh during peak hours. This €986 difference highlights the significant impact that market conditions have on the system's profitability. Revenue from ancillary markets exhibits substantial week-to-week variation, directly tied to market price dynamics and demand patterns. The analysis suggests that V2G systems positioned to offer power delivery during peak pricing hours can achieve significantly enhanced returns. The results indicate that revenue optimization depends on the system's ability to respond to and benefit from high-price market events.

10.6 Revenue Analysis Comparison: S1, S2, S3

This comparative approach enables a clear assessment of how market price dynamics influence revenue generation across different operational scenarios. The study design evaluates both weather-related constraints and traffic variations as key variables affecting V2G system performance. The market period for analysis remains the same.

Scenarios	S1	S2	S3
Week 50 Revenue (EUR)	3281.33	3193.15	1607.89
Week 4 Revenue (EUR)	5320.90	5148.75	2593.74

Table 7: Results

December Performance Analysis

The December market period (Week 50) demonstrated clear performance differentiation across the three airport operational scenarios. Scenario 3 generated €1607.89, representing the lowest revenue due to ground support equipment being unavailable during snow conditions. The weather-related operational constraints significantly limited the airport's V2G fleet participation in ancillary markets. Scenarios 1 and 2 substantially outperformed Scenario 3, achieving €3281.33 and €3193.15 respectively. Despite different traffic levels, the revenue performance between no-snow scenarios showed remarkable similarity, with only a €88.18 difference. This suggests that GSE availability has a more significant impact on V2G revenue than air traffic volume variations. The revenue differential between the snow-constrained scenario and the operational scenarios was approximately €1,500-1,600, representing more than a doubling of revenue potential when GSE remains available for V2G participation.

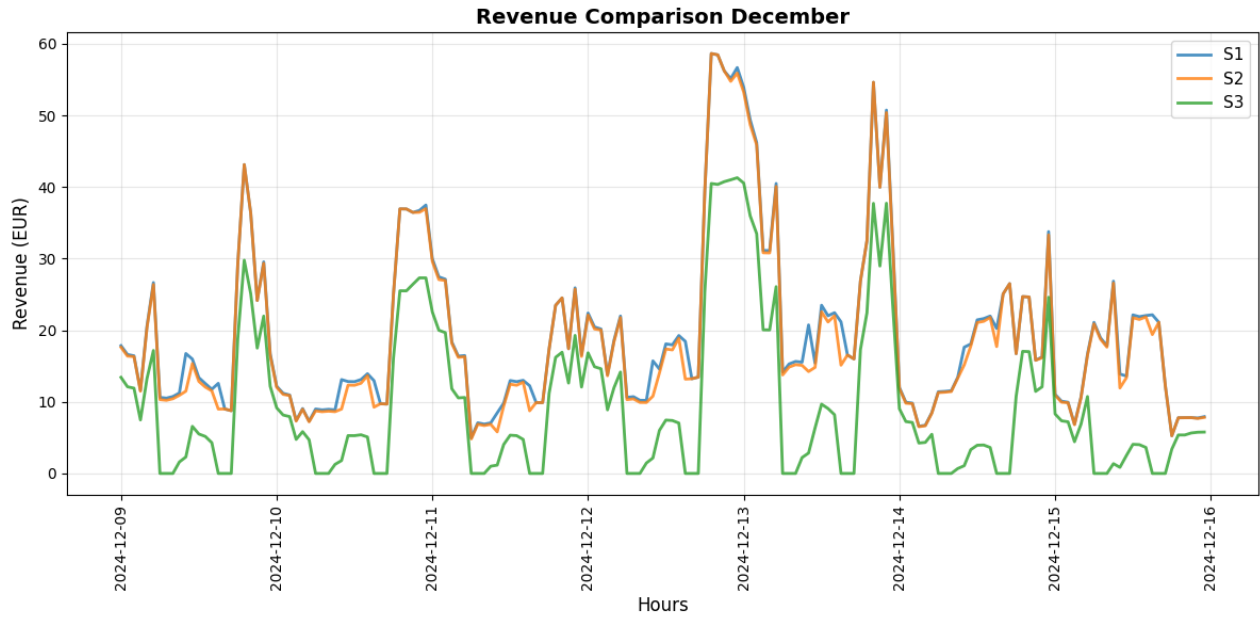


Figure 18 : Revenue for December case

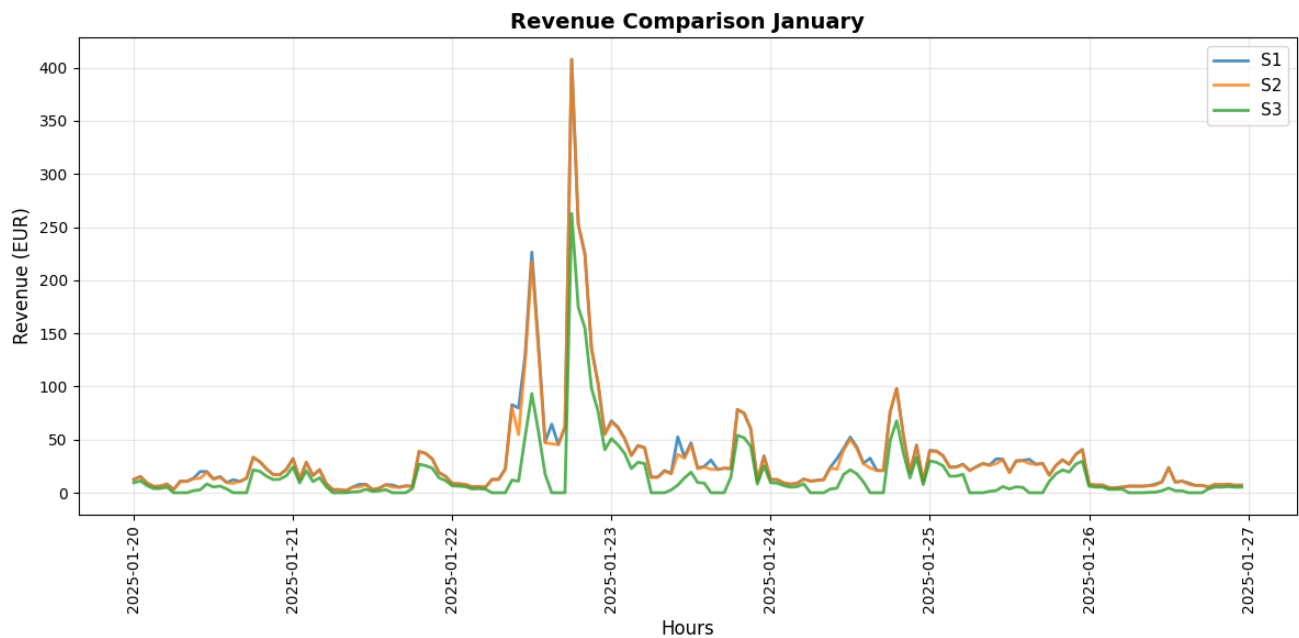


Figure 19 : Revenue for January case

January Performance Analysis

January's higher market volatility period (Week 4) maintained similar comparative patterns while demonstrating increased overall revenue across all scenarios. Scenario 3 achieved €2593.74, representing a 61% increase from December but maintaining its position as the

lowest-performing scenario due to GSE unavailability. Scenarios 1 and 2 continued to demonstrate superior performance, generating €5320.90 and €5148.75 respectively. The performance gap between the no-snow scenarios remained minimal at €172.15, reinforcing that traffic variations have limited impact compared to GSE availability. Both operational scenarios (S1 and S2) achieved approximately double the revenue of the snow scenario, maintaining the same proportional relationship observed in December.

10.7 Summary

- Snow conditions create a fundamental constraint that persists regardless of market conditions
- Market pricing conditions equally impact value creation in ancillary services
- Weather-related GSE unavailability is the critical determinant of airport V2G revenue optimization
- Traffic variations (S1 vs S2) have minimal impact
- Both weather contingency and market timing strategies must be considered together
- Revenue varies substantially week-to-week based on market price dynamics
- Strategic power delivery during peak pricing hours can increase revenue returns
- Key value driver for airport V2G operations during demand spikes and price volatility

11 CO2 Optimization using V2G Systems

V2G technology offers significant opportunities for carbon emission reduction through intelligent charging and discharging strategies. By aligning EV charging patterns with grid conditions and renewable energy availability, V2G systems can contribute substantially to CO2 optimization while providing economic benefits.

11.1 Smart Charging Strategy

Smart charging implementation enables direct contribution to carbon emission reduction and cost optimization by shifting EV charging to periods with the lowest electricity prices and CO2 intensity. This approach leverages the strong correlation between electricity pricing, grid congestion, and carbon intensity to achieve multiple optimization objectives simultaneously.

The fundamental principle involves adjusting charging power during different pricing periods to maximize renewable energy utilization. When electricity prices are low or even negative, the system can charge at maximum capacity, providing both financial benefits and CO2 optimization. These low-price periods typically indicate abundant renewable energy generation, creating an optimal window for carbon-efficient charging. But the correlation

will be dependent on various factors including the share of renewable energy production in the specific country/area.

Conversely, high electricity prices generally correspond to periods of high demand relative to supply, when the grid relies more heavily on non-renewable energy sources. By reducing charging during these periods, V2G systems minimize carbon footprint while avoiding peak pricing. This general trend remains the same in most countries, but it varies according to the electricity mix.

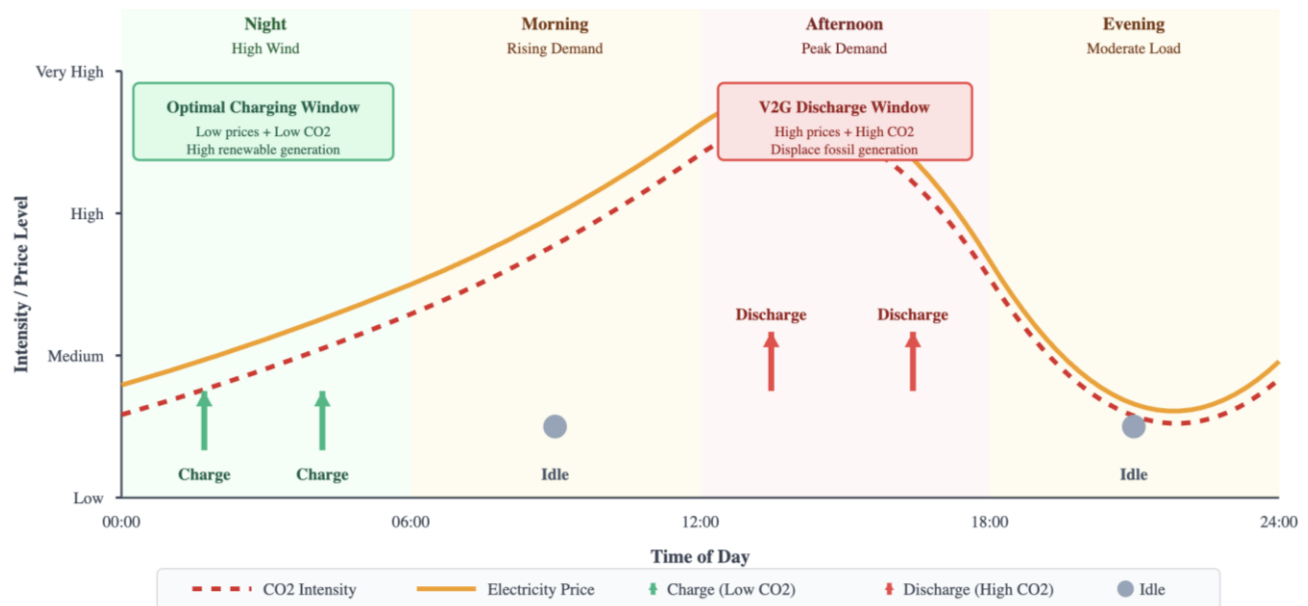


Figure 20 : Smart Charging Strategy

This figure demonstrates potential charging and discharging opportunities for electric vehicles. It's important to understand that the image doesn't show actual price or CO2 intensity trends. Instead, it provides a conceptual view of when a vehicle might optimally charge or discharge power to the grid.

The model for CO2 optimization could incorporate multiple forecasting inputs including weather patterns, renewable energy generation forecasts, spot price forecast, EV demand predictions, and spot price forecasting to improve financial gains and reduce carbon footprint. By predicting vehicle availability and energy requirements alongside market conditions, the system can optimize charging and discharging decisions in real-time on an hourly basis or finer time granularities, adapting to changing grid conditions while ensuring maximum renewable energy utilization and meeting operational demands. The optimization strategy could center on maximizing renewable energy utilization during low-price periods while meeting primary constraints including vehicle availability windows, minimum

operational charge requirements, grid connection capacity limits, and battery degradation considerations.

11.2 Benefits of CO2 optimization

Environmental Impact

- Direct reduction in carbon emissions through renewable energy alignment
- Decreased reliance on fossil fuel-based peak generation
- Support for grid stability during high renewable energy production periods

Economic Advantages

- Cost reduction through low-price period charging
- Revenue generation during high-price discharge periods
- Grid congestion mitigation reducing system-wide costs

Operational Efficiency

- Automated charging optimization based on real-time market conditions
- Improved fleet utilization through intelligent energy management
- Enhanced grid integration supporting renewable energy transition

11.3 Summary

V2G systems provide an effective way to cut carbon emissions and reduce costs by smartly coordinating when electric vehicles charge and discharge with clean energy production patterns. The effectiveness of this approach depends heavily on how much the low electricity prices correspond to lower carbon emissions, which differ significantly across regions based on their renewable energy adoption and fossil fuel dependency. Through good prediction models that integrate weather forecasts, energy output, and electricity market data, V2G technology can achieve substantial environmental improvements while maintaining operational reliability and financial viability. This positions V2G as a key technology for advancing carbon emission reduction and supporting grid resilience during the energy transition.

12 References

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13 Interview Guide

Purpose:

This interview is conducted in connection with the ALIGHT project. The ALIGHT project is an EU-funded project that, based at Copenhagen Airport, focuses on integrating electrification and renewable energy sources into airport operations to create a sustainable, CO₂-neutral airport. The project includes the development of smart energy management and energy storage to supply buildings, vehicles, and aircraft with 100% renewable energy.

Part of this project aims to analyse the potential of Vehicle to Grid (V2G) in Copenhagen Airport's fleet of Ground Support Equipment (GSE). V2G is a technology where electric vehicles not only receive electricity from the grid but can also deliver electricity back to the grid. This makes it possible to use electric vehicle batteries as a dynamic energy reserve that can help stabilise the power grid by supplying power when demand is high.

In this context, we, the Danish Technological Institute, need your help to map driving patterns and usage patterns for GSE in CPH. It's about gaining insight into how the equipment is used, so we can assess during which time periods they could potentially act as an energy reserve for the power grid.

Expected duration: max 60 min

Practical information: The interview is conducted in person at Copenhagen Airport (if possible). The Danish Technological Institute takes notes during the interview. If all parties consent, the entire interview will be recorded and transcribed. The questions are divided into "Need to know" and "Nice to know". "Need to know" is information that is crucial for our further work in the ALIGHT project. "Nice to know" is information that could contribute to our understanding of electric GSE but is not critical for the project's progress.

Questions to be asked during the interview:

Need to know:

- What is the function of your vehicles/equipment?
- Which vehicles does it include?
- Are these vehicles used simultaneously? If not, is there a specific pattern in which they are used?
- Which vehicles contribute most to the total energy consumption in this category? Which vehicles are refueled most often? This question is asked to determine which vehicle might best represent the category.
- Peak load and normal operation:

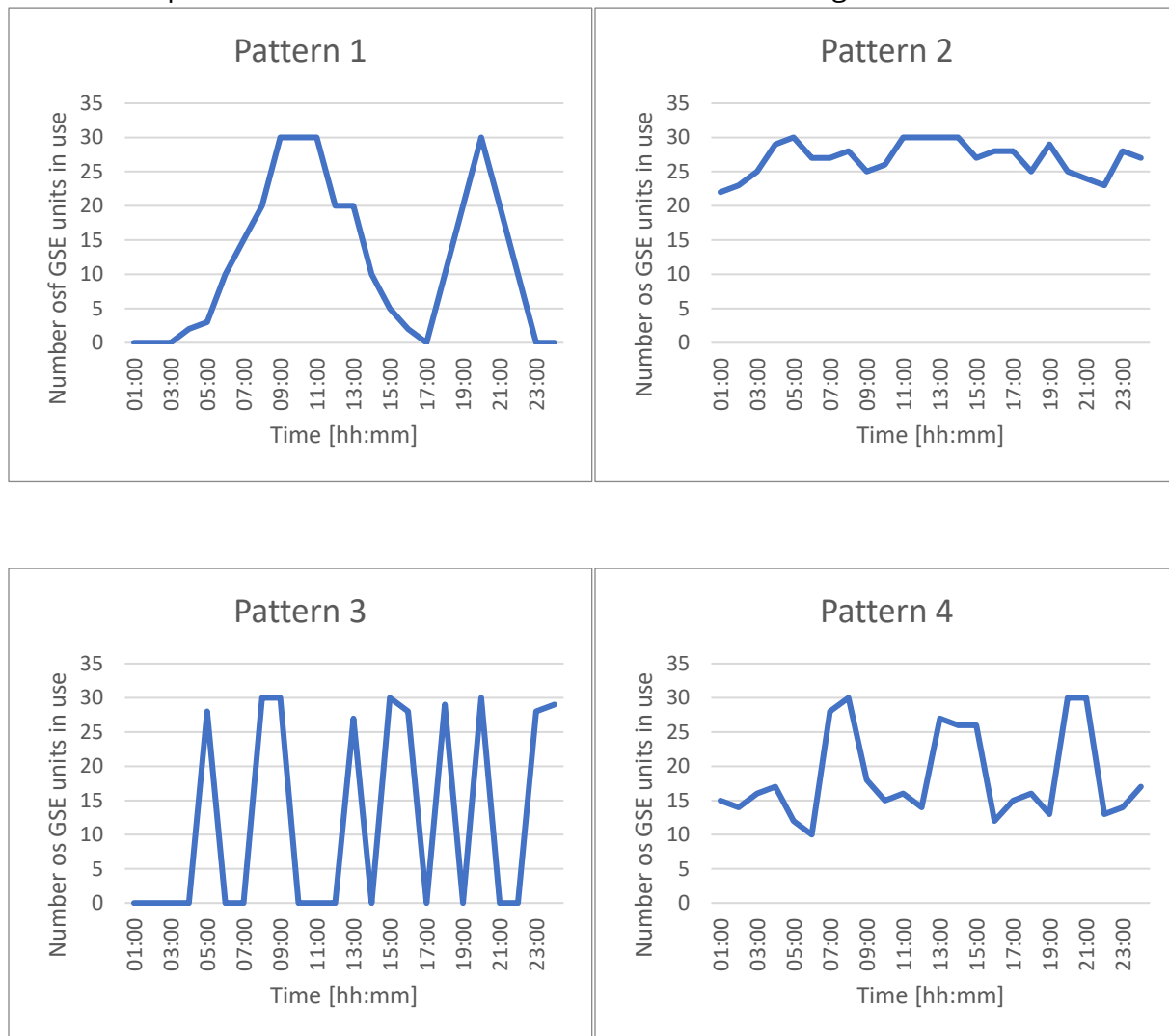
- Peak load: The periods of maximum activity, such as aircraft arrivals and departures. It can also refer to periods where, for example, weather contributes to increased activity of GSEs.
- Normal operation: When GSEs are used within expected and planned parameters without errors or deviations.
- When is the typical period for peak load and normal operation respectively?
 - Is it seasonal, for example?
 - Duration of peak load and normal operation respectively
- What does the operation look like?
 - Is there one "combined" working day, and if so, how long is it?
 - What proportion of the day is the vehicle actually in use?
 - Alternatively: Which "daily pattern" most closely resembles your operation?
 - Four examples have been made of what a daily pattern might look like. These can be found at the bottom of the document under "Examples of usage patterns". Does the daily pattern in peak load and normal operation resemble one of these patterns?
 - Completion of form (if possible) possibly based on one of the graphs. The forms can be found at the bottom of the document under "Form - daily pattern".

Nice to know:

- On average, how far do your vehicles travel on a working day?
- What are your experiences with electric GSEs?
 - Have you experienced increased downtime? That is, periods where the GSEs have not been functional.
 - Do battery specifications (capacity, range, etc.) match actual experiences?
 - Are more electric vehicles needed than conventional vehicles? Is it necessary to use 1.5 times more electric GSEs to achieve the same work output as with conventional GSEs?
 - What is the general attitude towards the electric vehicles in your fleet of GSEs?
 - Is it generally positive or negative?
- Is there anything else that might be relevant for us to consider?
 - Unforeseen challenges?
 - Positive changes?

Examples of Usage Patterns

These examples are based on a fictional fleet of GSEs consisting of 30 units.



13.1 Form - Daily Pattern

Fill in one of these two forms. The first form is chosen if it is possible to divide the category into subcategories depending on, for example, function or engine size. The second form is chosen if it is not possible to further divide the category. A form is filled out for both peak load and normal operation; that is, a total of two forms. For both forms, the number of GSEs in use is indicated for each time slot. The first time slot, 01:00, indicates the period from 00:00-01:00, and so on.

13.1.1 Form 1

Time	Number of GSE units in use
01:00	
02:00	
03:00	

04:00	
05:00	
06:00	
07:00	
08:00	
09:00	
10:00	
11:00	
12:00	
13:00	
14:00	
15:00	
16:00	
17:00	
18:00	
19:00	
20:00	
21:00	
22:00	
23:00	
00:00	

13.1.2 Form 2

Time	Subcategory 1	Subcategory 2	Subcategory 3	...
01:00				
02:00				
03:00				
04:00				
05:00				
06:00				
07:00				
08:00				
09:00				
10:00				
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