Accelerating Zero Emission Distribution

Author(s)
Heath, Edward ; Warmerdam, Jos

Publication date
2025

Document Version
Final published version

License
Unspecified

Link to publication

Citation for published version (APA):
Heath, E., & Warmerdam, J. (2025). *Accelerating Zero Emission Distribution*. Hogeschool van Amsterdam.

Accelerating Zero Emission Distribution (AZED)

Authors

Edward Heath

Jos Warmerdam

Contents

Chapter 1 Introduction

With a low-/no-emission zone coming into effect in Amsterdam city centre, Albert Heijn must switch to electric delivery vans to if it is to continue its grocery delivery service to customers' doors. Albert Heijn intends to scale up to 750 delivery vans in the 4 large cities in the coming years [1], meaning the Amsterdam depot can expect up to 200 vans.

When considering the congested grid that grips the Netherlands and the increased demand for new and larger grid connections, charging this fleet of electric vehicles is no easy or cheap task. The Accelerating Zero Emission Delivery (AZED) project aims to better inform Albert Heijn on how to charge their delivery vans in a grid congested environment through the use of a stationary battery energy storage system (BESS).

The Albert Heijn distribution centre in Amsterdam is connected to the grid via a substation with a capacity of 6000 kVA. The substation feeds three transformers with a nominal capacity of 2000 kVA each. The current pilot project installed at the Amsterdam Albert Heijn distribution centre consists of 36 charging stations; 33 x dual 22 kWAC, thus 66 connections of 11 kWAC, and 3 x 50 kWDC chargers. The charging stations are connected behind one of these three transformers. With all the charging stations used simultaneously at their nominal power, the power requested from the transformer is 876 kVA (assuming a power factor of 1).

More charging stations will be connected as the delivery truck fleet is increasingly electrified. A BESS will also be installed to reduce the peak load on the grid connection. The capacity and power of the BESS are still to be defined and is investigated in this study.

In the pilot project Albert Heijn used a combination of Orten e-HDV, SAIC Maxus, Streetscooters Work L, and VW e-Crafters. However, the data provided included only the Orten and SAIC delivery vans. Table 1 presents the delivery van specifications as provided by the manufacturer specification sheets.

Table 1: Delivery van specifications

	Orten ET 35 M	SAIC eDeliver9
Capacity	58 kWh / 87 kWh	77 kWh / 88 kWh
Range	100 km / 150 km	240 km / 275 km
Charging Power	22 kWAC	22 kWAC or 90 kWDC
Gross Total Weight	5250 kg	4250 kg
Max speed	80 km/h	100 km/h

Chapter 2 Data Analysis

2 datasets were available: week 49 2021 and week 18 2022. These were merged and filtered to contain only deliveries from the Amsterdam distribution centre, in total 3696 deliveries.

The raw data contained the following parameters:

- Delivery Number: Identification number per delivery
- Departure Time: Time when then van left the depot
- Arrival Time: Time when the van returned
- Depot ID number: Identification number used for the specific depot (Amsterdam 8968)
- Start KM: Odometer reading before departure
- End KM: Odometer reading upon return
- Total KM: Total kilometres driven
- Service: PO/PA, morning (ochtend) or evening (avond) delivery

To build a model only the data of departure time, arrival time, distance driven, and duration was kept from this raw data. Assuming the energy usage per km was 0.4 kWh/km [2] an estimated energy usage per delivery trip was deduced. Table 2 shows the mean and standard deviation for these five variables.

Table 2: Measured data distributions separated into morning and evening delivery service

		Mean	Median	Std_dev
PO	Departure [hh:mm]	07:29	07:26	0:38
	Arrival [hh:mm]	13:05	13:08	0:47
	Energy [kWh]	22.11	20.00	8.82
	Distance [km]	55.27	50.00	22.05
	Duration [h:mm]	5:35	5:43	0:58
PA	Departure [hh:mm]	15:48	15:46	0:33
	Arrival [hh:mm]	21:29	21:33	0:41
	Energy [kWh]	22.60	20.80	8.44
	Distance [km]	56.49	52.00	21.09
	Duration [h:mm]	5:40	5:46	0:52

The data was then filtered to include only deliveries with a distance between 30 km and 120 km, filtering out 472 deliveries of which 66 % were less than 30 km. Only deliveries between 3 hours and 7.5 hours were considered, filtering out a further 100 deliveries. Morning departure times before 06:00

or after 10:00 were filtered out, as were evening departures before 14:00 and after 18:00. This reduced the number of usable deliveries to 3003, of which 1589 were morning deliveries and 1414 were evening deliveries.

Given that there are few neighbourhoods in Amsterdam less than a 20 km return drive from the distribution centre, a 30 km minimum delivery route was deemed appropriate. A maximum of 120 km is also logical when considering the maximum range of the vans and the need to keep reserve capacity. If one disregards the minimum 30 km delivery length, all other filtering steps would individually include 95 % of the original data set.

Between the morning and evening services is a break in which the vans can be charged, the driver changed, and new groceries loaded. This break is, on average, 2.69 hours (2:41). However, since there was no delivery van identification number it was not possible to plot the distribution of time between PO and PA services per van. The mean lunch break was calculated from the mean PO arrival time and the mean PA departure time.

Chapter 3 Model

The filtered delivery data was used to develop a system model. This section describes the process and the decisions made.

Truncated normal distributions were formed from the filtered delivery data, the characteristics of each are presented in Table 3. Truncated normal distributions were chosen since a maximum and minimum value is necessary for all parameters when randomly sampling the distribution. Each measured delivery was first rounded to the closest 5 minutes.

Table 3: Inputs for truncated normal distributions used in the model to simulate delivery parameters.

Distribution	Minimum	Maximum	Mean	Standard Deviation
PO departure	06:30	10:00	06:45	0.91 hours
PA departure	14:30	18:00	15:35	0.95 hours
PO delivery	3 hrs	7.5 hrs	Departure dependent	Departure dependent
PA delivery	3 hrs	7.5 hrs	Departure dependent	Departure dependent
PO delivery	30 km	120 km	Departure dependent	Departure dependent
PA delivery	30 km	120 km	Departure dependent	Departure dependent
Energy usage	0.25 kWh/km	0.55 kWh/km	0.4 kWh/km	0.05 kWh/km

The mean and standard deviation of the simulated departure time were the mode and standard deviation of the measured data. It was observed that delivery duration and delivery distance were dependent on the time of departure. Therefore, the measured data was sliced to ±15 minutes from the sampled departure time. The mean and standard deviation of the simulated delivery duration was then the mean and standard deviation of the sliced measured data. The mean and standard deviation of the simulated delivery distance was the mode and standard deviation of the sliced measured data.

It is important to note that the mean and standard deviation supplied to form the truncated normal distribution are not the same as the mean and standard deviation of the truncated distribution. This is a result of the truncation itself. The values shown in Table 3 describe the normal distribution before truncation.

PO arrival time and PA arrival time were calculated using the respective sampled values of departure time and delivery duration. If PO arrival time was later than 14:00, the delivery duration was resampled until it was earlier than 14:00 to ensure alignment with the measured data.

If there was less than 2 hours between PO arrival time and PA departure time, PA departure time was resampled until it was more than 2 hours later than PO arrival time. It was assumed that 30 minutes were required to load the groceries onto the delivery vans.

The mean energy usage per delivery trip was calculated using a value sampled from a truncated normal distribution describing energy usage per kilometre. The distribution had a mean of 0.4 kWh/km and a standard deviation of 0.05 kWh/km, and bounds 0.25 kWh/km and 0.55 kWh/km. This sampled value was then multiplied by the delivery distance to calculate the energy usage per delivery trip.

The measured and simulated distributions are shown below. On the left are the filtered measured distributions, on the right the simulated distributions. Table 4 presents the distributions numerically and compared against the measured filtered data.

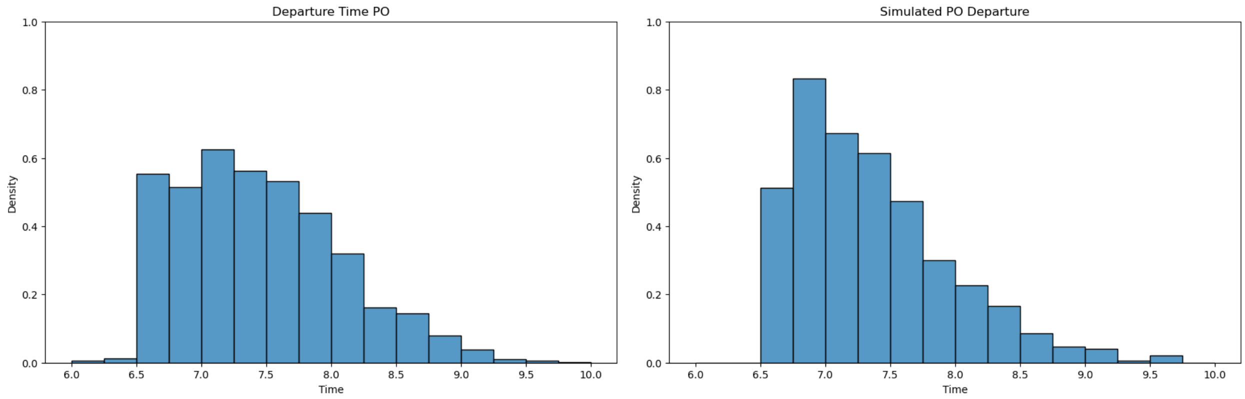

Figure 1: Comparison of morning departure time distributions

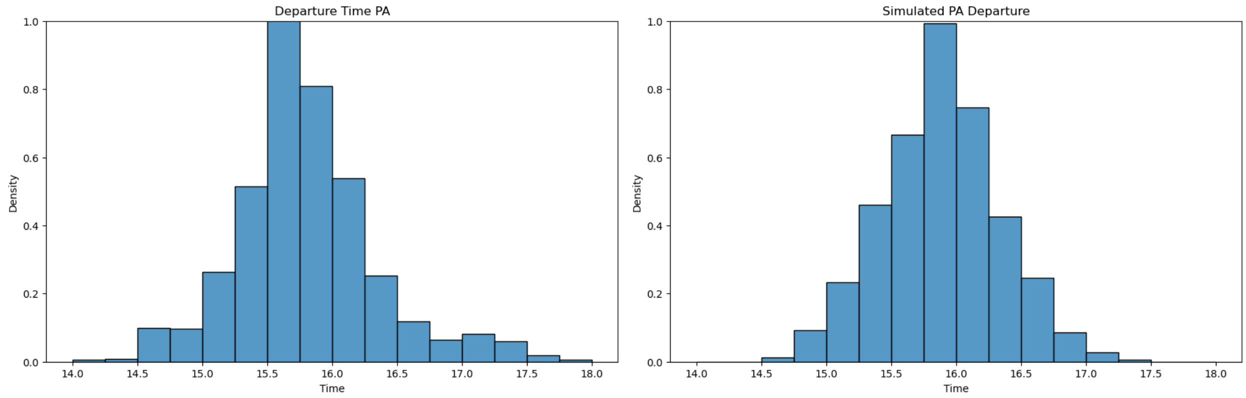

Figure 2: Comparison of evening departure time distributions

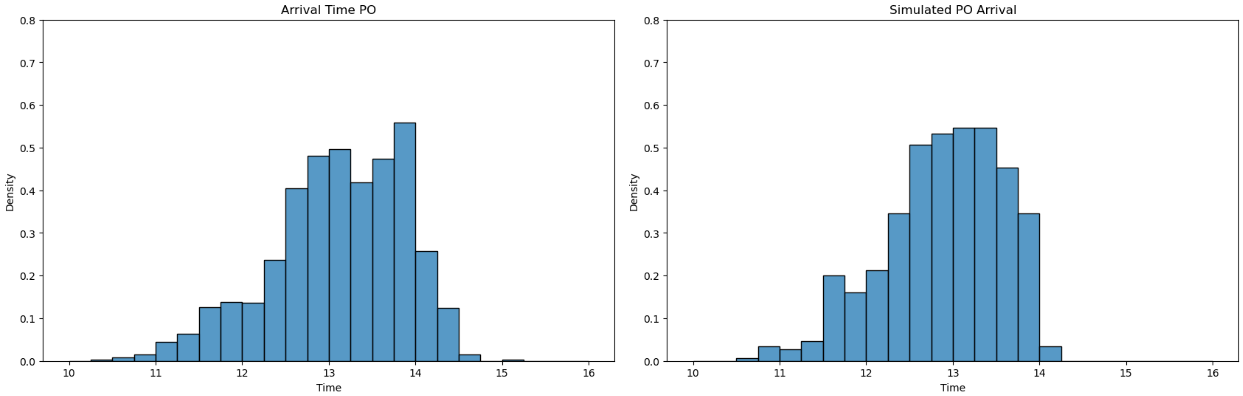

Figure 3: Comparison of morning arrival time distributions

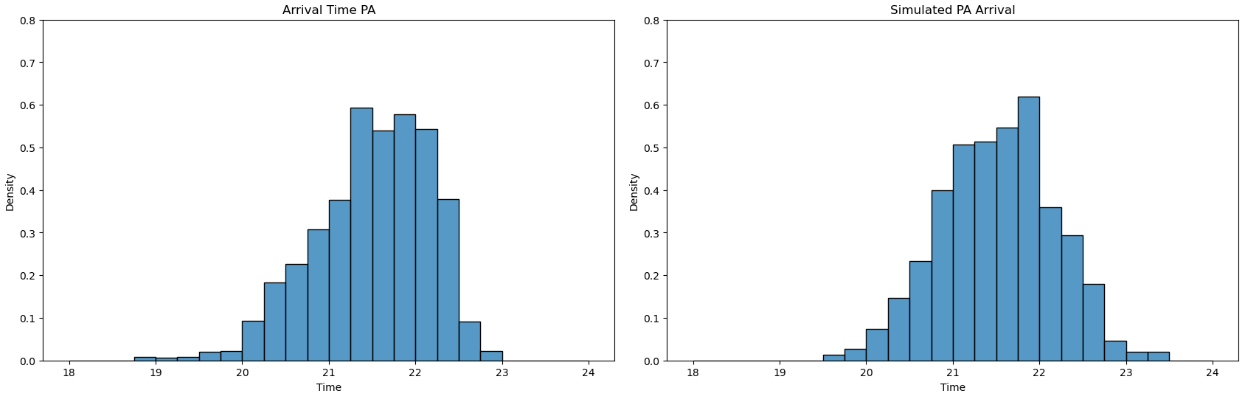

Figure 4: Comparison of evening arrival time distributions

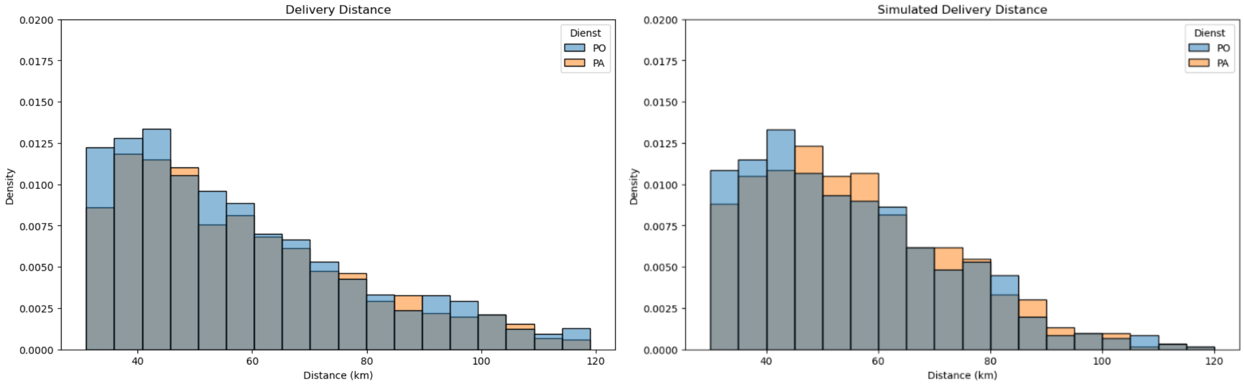

Figure 5: Comparison of delivery distance distributions, highlighting morning and evening services

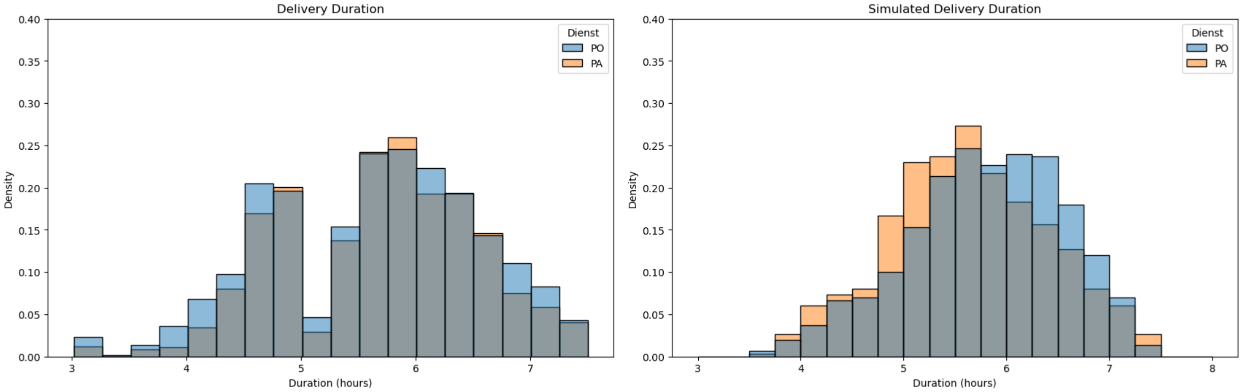

Figure 6: Comparison of delivery duration distributions, highlighting morning and evening services

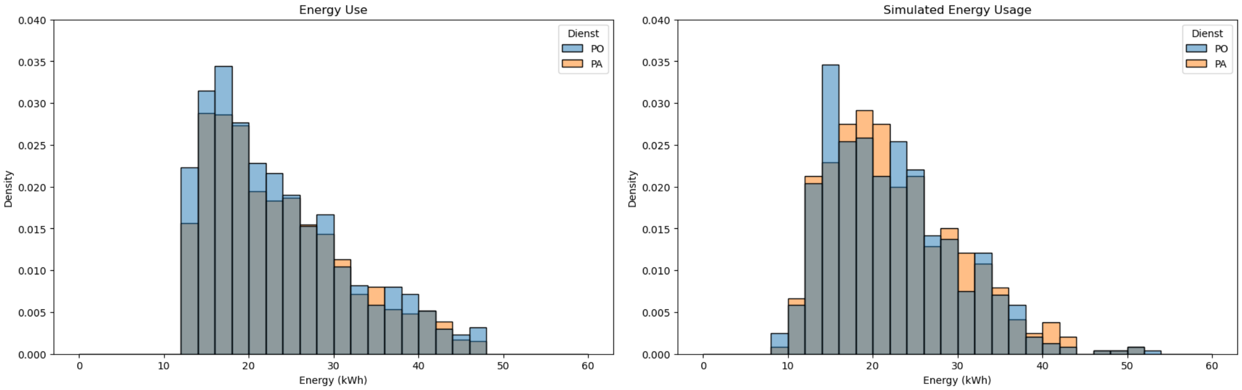

Figure 7: Comparison of delivery energy use distributions, highlighting morning and evening services

Table 4: Comparison of measured and simulated distribution metrics.

Observed		Mean	Median	Std_dev	Simulated	Mean	Median	Std_dev
PO	Departure [hh:mm]	07:29	07:26	0:38		07:04	07:00	0:25
	Arrival [hh:mm]	13:05	13:08	0:47		12:48	12:50	0:41
	Energy [kWh]	22.11	20.00	8.82		21.83	20.16	7.44
	Distance [km]	55.27	50.00	22.05		54.47	51.49	17.02
	Duration [h:mm]	5:35	5:43	0:58		5:43	5:47	0:46
PA	Departure [hh:mm]	15:48	15:46	0:33		15:47	15:45	0:28
	Arrival [hh:mm]	21:29	21:33	0:41		21:28	21:30	0:40
	Energy [kWh]	22.60	20.80	8.44		22.32	20.93	7.86
	Distance [km]	56.49	52.00	21.09		55.85	52.58	18.21
	Duration [h:mm]	5:40	5:46	0:52		5:40	5:41	0:47

With a minimum lunch break of 2 hours, the mean simulated lunch break was 2.95 hours (2:57) compared to the observed 2.69 (2:41).

The vans were charged such that above a SOC of 80 % the charging power gradually reduced until a minimum value of 4.1 kWAC or 10 kWDC, using the following formulas:

$$a = P_{nom}/(80 - 100)$$

$$b = -P_{nom} * 100/(80 - 100)$$

$$P_{Ch} = min(P_{Ch}, a * SOC + b) * rm$$

where *rm*, a coefficient used to randomly generate some noise, was sampled from a normal distribution with parameters mean = 1 and standard deviation = 0.01.

4.1 kWAC was chosen since it represents the minimum current of 6 A per phase, as per the IEC 61851-1 standard, assuming all vehicles were charged via a 3-phase connection.

If the total charging load exceeded the available capacity then the available capacity was split proportionally across the vans. Once this calculation was performed, it could be that a van would receive less than the accepted minimum charging power of 4.1 kWAC, or 10 kWDC. In this case, the charge session was paused until there was adequate capacity to charge the van.

The simulations performed consisted of 5 minute time intervals and span one week. Days Monday – Saturday had both morning and evening delivery services, whilst Sundays included evening services only.

Assumptions:

- All vans are fully charged at the beginning of the week
- The BESS is fully charged at the beginning of the week
- The BESS discharges at a rate of 0.051 % per hour
    - This includes self-discharge and auxiliaries
- Upon return, the van is charged immediately. The last 30 minutes of the lunch break is for loading groceries
- The vans can use the full 100 % SOC
- The BESS uses the range 10 % - 95 % SOC
- Efficiencies:
    - DC charger 90%
    - AC charger 85%

There were two charging scenarios considered; the regular uncontrolled charging that would take place with an unlimited grid connection and no smart control, and the shaving of peak loads using a stationary BESS. The next sections introduce these two control scenarios.

Uncontrolled Charging

This scenario portrays the unsupervised charging that would occur given a limitless grid connection capacity and no other constraints to consider, such as electricity price, local electricity generation etc.

In this scenario, all vans were charged at 11 kW immediately upon arrival. If the van SOC was lower than 40 % after the morning delivery service it was charged via the 50 kW DC charger. Once the van SOC reached 80 % the charging power was gradually reduced to a minimum of 4.1 kWAC or 10 kWDC.

In the example below 100 vans were charged with no failed deliveries, defined as having a SOC fall below 0 % during the delivery. One van was not fully charged as a result of arriving late in the evening with a low SOC. This shows that even with unlimited charging power it was not possible to fully charge some vans overnight using AC chargers alone.

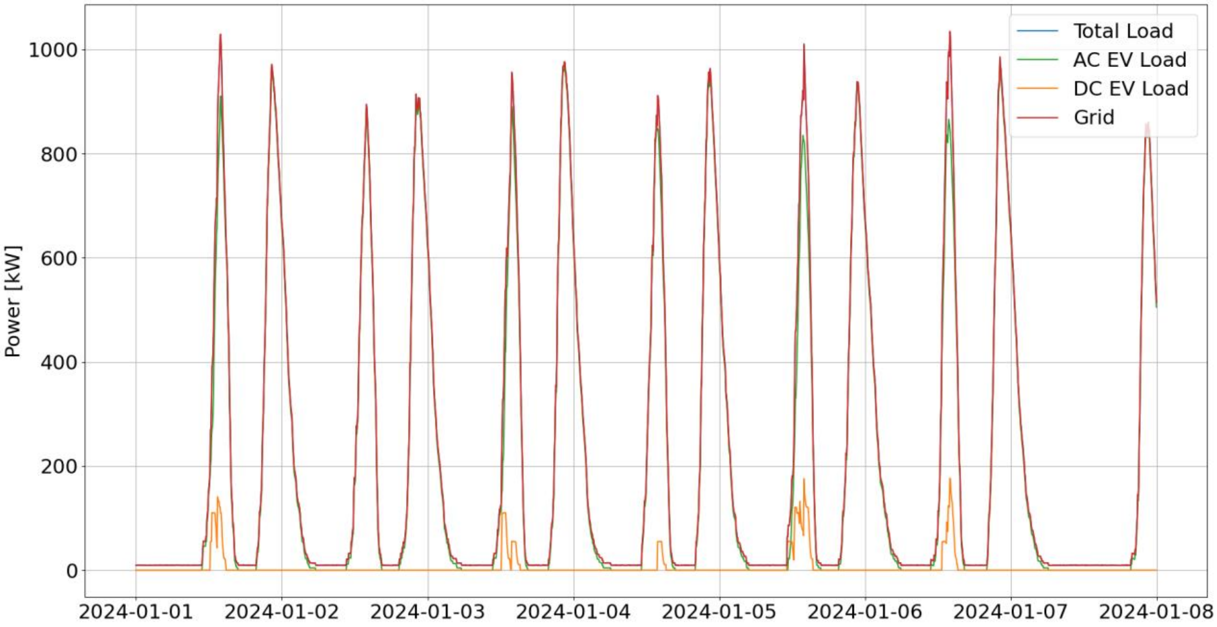

Figure 8: Power profile for one week of service in the uncontrolled case

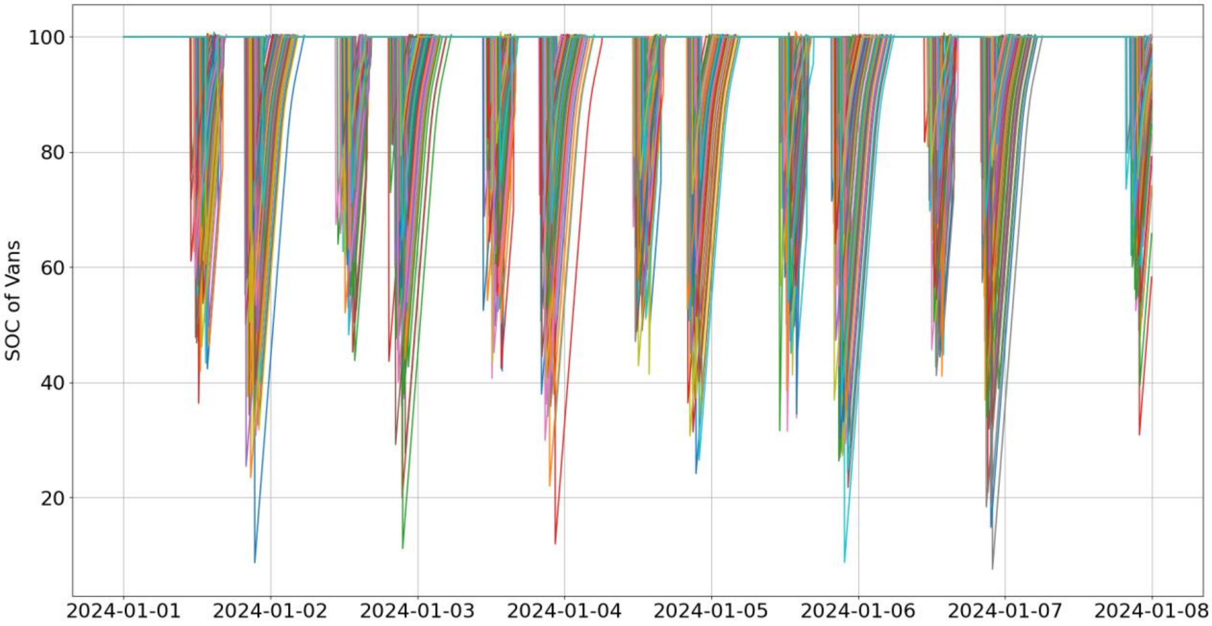

Figure 9: SOC of vans for one week of service in the uncontrolled case

Peak Shaving

In this scenario, a stationary BESS was added to the system. If the total van charging load exceeded the grid connection capacity, the BESS delivered power up to its maximum power until the energy storage was depleted.

The vans were preferably charged via the AC charging stations and fed via the grid connection with a nominal charging power of 11 kW. The actual charging power was dependent on the total instantaneous charging load and the specific van SOC. If the total instantaneous charging load exceeded the grid connection capacity, accounting for the base power demand and losses in EV supply equipment (EVSE), then the BESS supplied the excess demand. If the total power demand was greater than the combined grid and BESS power capacity or the BESS was depleted, the available capacity was split proportionally amongst the vans (load sharing).

In this scenario vans used the DC chargers if the predicted energy usage in the evening delivery service exceeded the estimated capacity after using AC chargers over the lunch break. This assumes a pre-determined schedule and route for each van, and relies on approximate energy usage per km driven and charging power values.

In this model it was not possible to extend the lunch break for a specific van to increase charging duration. It was assumed that each van had a fixed lunch break with a minimum of 2 hours including the 30 minutes required to load the groceries. This means a minimum of 1.5 hours charging time.

The BESS inverter capacity is scaled in response to the maximum BESS power output. The data for this was gathered from the BESS and inverter combination in another project, where the AC and DC power, either side of the inverter, was recorded and a curve fitted to the data.

In this example 100 vans were charged with a grid connection capacity of 750 kW and a BESS sized at 500 kW, 1000 kWh. This proved adequate for the 100 vans in this scenario. There were no failed charge sessions and all vans were fully charged overnight. The current convention defines a negative BESS current as discharging and a positive current as charging.

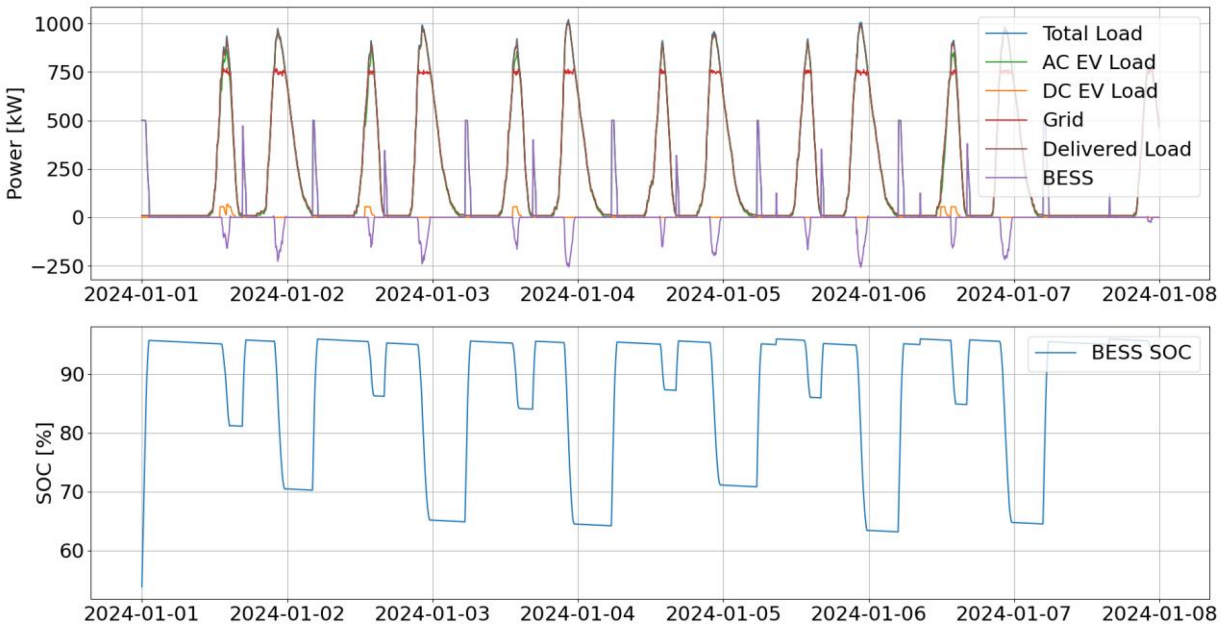

Figure 10: Power profile and BESS SOC for one week of service in the peak shaving case

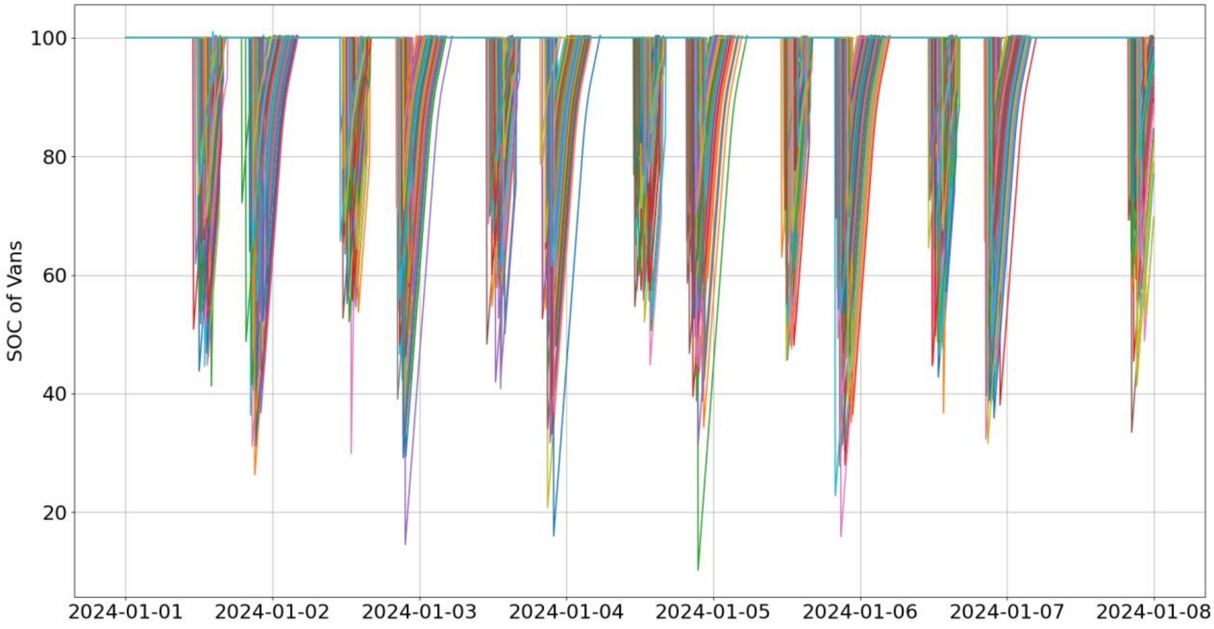

Figure 11: SOC of vans for one week of service in the peak shaving case

Chapter 4 Optimisation

An optimisation problem was then formed to deduce the minimum BESS storage capacity and minimum number of DC charging stations that were required to adequately supply a pre-generated load profile considering a fixed grid connection capacity. Considering the ambitions of AH to electrify their delivery van fleet, the chosen number of vans for the Amsterdam depot were 100, 150, and 200 vans. A charging profile for each scenario was simulated. The chosen grid connection capacities were 500 kW, 750 kW, and 1000 kW. Thus, nine optimisation problems were solved as shown in Table 5.

Table 5: Optimisation problems to solve

		Grid connection capacity		
		500 kW	750 kW	1000 kW
Vans	100	500x100	750x100	1000x100
	150	500x150	750x150	1000x150
	200	500x200	750x200	1000x200

The PyMOO python library was chosen since the authors developed the NSGA-II (Non-dominated Sorting Genetic Algorithm) and the library was well documented. To solve the optimisation problem a mixed variable optimisation algorithm was used. The decision variables and objective function are given below:

$$P_B = \{20k \mid k \in [P_{B,min} .. P_{B,max}]\}$$

$$N_{DC} = [0 \dots 12]$$

Where P_B is the battery charge/discharge power and N_{DC} is the number of DC charging stations. P_B is a series from $P_{B,min}$ to $P_{B,max}$ in 20 kW steps. $P_{B,min}$ and $P_{B,max}$ were set at appropriate values depending on the number of vans which aided in approaching an optimal solution. N_{DC} was an integer series up to a maximum of 12.

$$f = \min(C_{BESS} + C_{BESS,OM} + C_{DC} + C_{DC,OM})$$

Where, C_{BESS} is the purchase and installation cost of the BESS and C_{DC} is the purchase and installation cost of the DC charging stations. The subscript *OM* denotes operation and maintenance costs.

$$C_{DC} = 40000 * n_{DC} / lifetime$$

$$C_{DC,OM} = 1500 * n_{DC}$$

$$C_{BESS} = 500 * E_B / lifetime$$

$$C_{BESS,OM} = 25 * P_B / lifetime$$

$$lifetime = 15$$

All installation and O&M costs were provided from expert interview and supported by documents and papers found [3-5].

There were two constraints in the optimisation itself. These required that no van was to run out of energy on its delivery trip and that all vans were to end the overnight charge session with a full SOC. A van was deemed fully charged if its SOC was greater than 95 %. This was chosen since in many simulations vans would be left with a SOC of between 95 % - 100 %, effectively fully charged. These solutions would then not count as a successful solution and make the optimisation process difficult to solve. It is worth noting that in reducing the minimum SOC required to be deemed fully charged, the number of failed deliveries did not increase.

$$failed\_deliveries = 0$$

$$not\_fully\_charged = 0$$

All other constraints were internal to the system model and were handled during simulation runtime. These included the power balancing, the battery state-of-charge (SOC) limits, and the battery charge/discharge power limits.

$$P_{Base}(t) + P_{EV,D}(t) + P_B(t) = P_G(t) \qquad \forall t \in T$$

$$0.10 \cdot E_{B,max} < E_B(t) < 0.95 \cdot E_{B,max}$$

$$0 \leq P_{B,ch,t} \leq P_{B,ch,max}$$

$$0 \leq P_{B,dch,t} \leq P_{B,dch,max}$$

$P_{Base}(t)$ is the base power demand at time *t*, $P_{EV,D}(t)$ is the total EV van demand at time *t*, $P_B(t)$ is the battery power demand/supply at time *t* (current convention defines a negative current for discharging), and $P_G(t)$ is the power supplied by the grid at time *t*. $E_B(t)$ is the battery energy capacity at time *t*, with subscripts *min* and *max* denoting minimum and maximum battery energy storage capacities.

A single load profile was used per optimisation problem to ensure the target was consistent during the repetitive optimisation process. For each optimisation problem a population of 20 potential solutions were evaluated in each of the 5 generations, meaning 100 potential solutions were analysed. A binary tournament selection was employed to speed up convergence, meaning 2 potential solutions were compared and the solution with the highest fitness value progressed to the next generation then repeated for all solutions in the population. Mutation and crossover parameters were left as default.

Finally, the grid cost incurred were calculated using Liander tariffs [6], considering the peak monthly power, assumed to be the peak in the simulated week, and the total annual energy demand, assumed to be 52 times the energy demand in the week simulated. Also included was the one time connection cost but no additional cost per metre of cabling was considered.

This optimisation problem was solved first using a 2 hour minimum lunch break. This parameter was then varied to 1.5 hours and 2.5 hours to observe the sensitivity and to see if cost reductions can be increased whilst not disturbing charging, and therefore delivery, efficacy.

Chapter 5 Results

This section presents the results of the optimisation problems comparatively, with the results for the three durations of minimum lunch break beside one another. This section finishes with the lunch break duration distributions per minimum lunch break.

BESS Energy Storage Capacity

Figure 12 displays the optimal BESS sizing for the three minimum lunch break durations when using the BESS for peak shaving. In each of the minimum lunch break durations, the charging period was 30 minutes less, since the last 30 minutes were reserved for loading of groceries and miscellaneous activities.

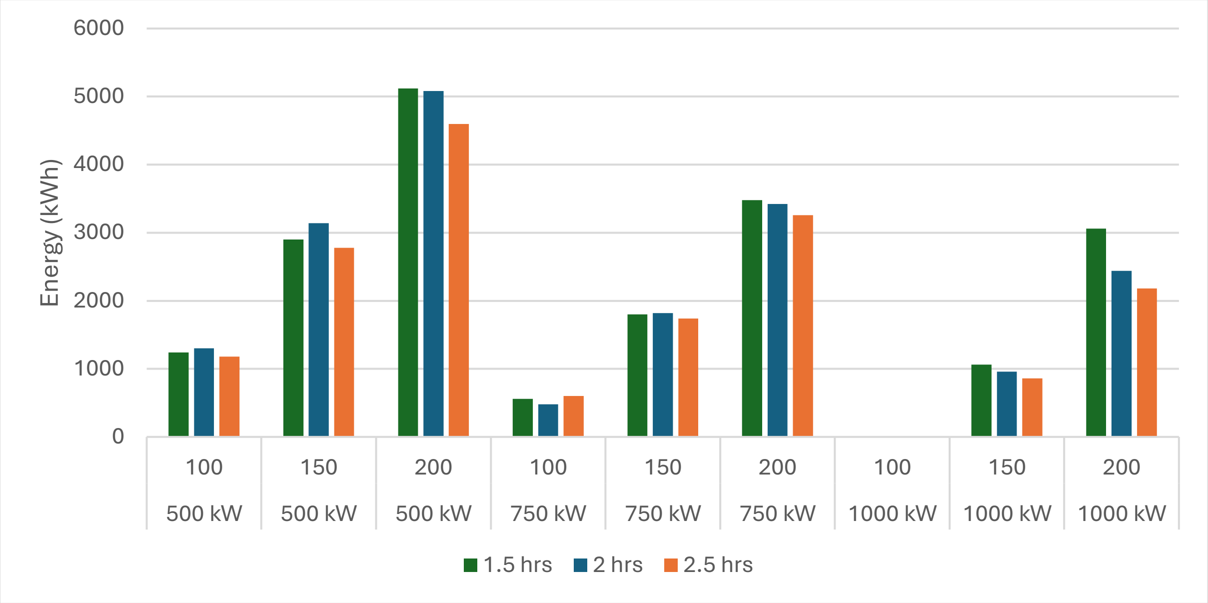

Figure 12: Comparative plot of BESS energy storage capacity for various fleet sizes, grid connection capacities, and minimum lunch break durations.

As expected, with increasing grid connection capacity the required BESS capacity falls. This pattern is consistent for all scenarios.

The BESS tended to be smaller with a 2.5 hour minimum lunch break than with a 2 hour minimum lunch break. Only one of the nine scenarios had a larger BESS size and one had the same at 0 kWh. All others saw 5 % - 11 % reduction in energy storage capacity.

The BESS tended to be larger with a 1.5 hour minimum lunch break than with a 2 hour minimum lunch break. Three of the nine scenarios had a larger BESS and one had the same at 0 kWh. Two scenarios saw 1 % - 2 % reduction in energy storage capacity, whilst the remaining three scenarios saw a 10 % - 20 % reduction in energy storage capacity.

DC Fast Chargers

Figure 13 presents the number of DC charging stations required for the three minimum lunch break durations. The results here are less consistent.

With a 2 hour minimum lunch break, the number of DC fast chargers required for a given fleet size stayed the same with increasing grid connection capacity until 1000 kW. 150 vans & 1000 kW saw a reduction of one, whilst 200 vans & 1000 kW saw an increase of one. This shows that the number required during the lunch break is independent of overnight charging and available grid capacity.

Given that these are approximate optimal solutions due to the manner in which GAs solve optimisation problems, one can assume that for 150 vans & 1000 kW the optimal number of required DC fast chargers would be three instead of five. This is because only three were required in the other two grid connection capacity scenarios.

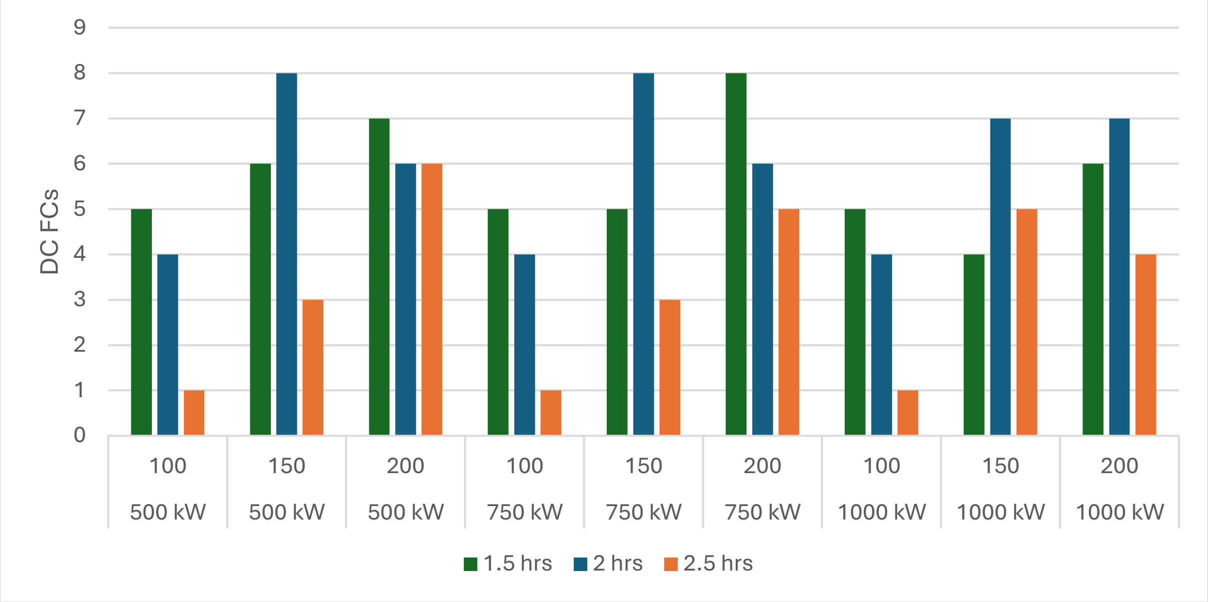

Figure 13: Comparative plot of number of DC fast chargers for various fleet sizes, grid connection capacities, and minimum lunch break durations.

The number of DC fast chargers required with a 2.5 hour minimum lunch break was lower for eight of the nine scenarios when compared to the 2 hour minimum, and one had the same number of DC fast chargers. This means more vans received adequate energy from AC charging stations during the lunch break by increasing the minimum duration to 2.5 hours.

Four out of the nine scenarios saw a marginally increased number of DC fast chargers with 1.5 hour minimum lunch break when compared to the 2 hour minimum. This is logical since the vans with a shorter lunch break had less time to charge, thus the likelihood of requiring a DC fast charger was higher. However, the distributions of lunch break duration is similar for the two scenarios, as shown in Figure 15.

Total Annual System Cost

With increasing number of vans, the cost reduction from increasing the grid connection capacity increased, as shown in Figure 13. With 100 vans the change in total annual cost when increasing the grid connection capacity from 500 kW to 1000 kW was -€14,000. However, with 200 vans the annual cost fell by -€44,000, from €256,000 at 500 kW to €212,000 at 1000 kW, due to the drastically smaller BESS required.

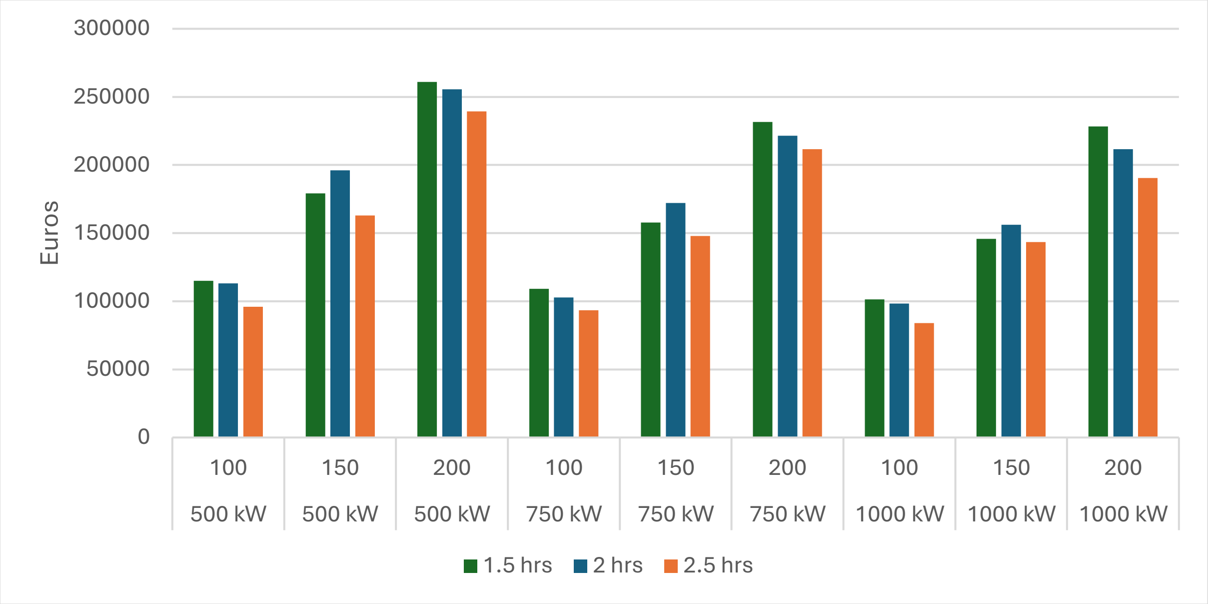

Figure 14: Comparative plot of total annual cost for various fleet sizes, grid connection capacities, and minimum lunch break durations.

For all combinations of van and grid connection capacity the total annual cost was reduced when using a 2.5 hour minimum lunch break when compared to the 2 hour minimum lunch break. The range of annual cost reduction was 5 % to 27 %, the lowest cost reduction being for 200 vans & 750 kW, the greatest cost reduction for 150 vans & 500 kW.

However, when using a 1.5 hour minimum lunch break the total annual cost increased in six of the nine scenarios when compared to a 2 hour minimum lunch break. The range of annual cost increase was 2 % to 7 %, the lowest cost increase being for 100 vans & 500 kW, the greatest cost increase for 200 vans & 1000 kW.

Lunch Break Duration Distribution

1.5 Hour Minimum Lunch Break

As shown in Figure 15, the number of vans in the 30 minute window between 1.5 hours and 2 hours is relatively small – approximately 10%. By decreasing the minimum lunch break from 2 hours to 1.5 hours, the mean lunch break duration fell from 2.97 (3:00) to 2.9 hours (2:55). The median lunch break remained at 2.83 (2:50).

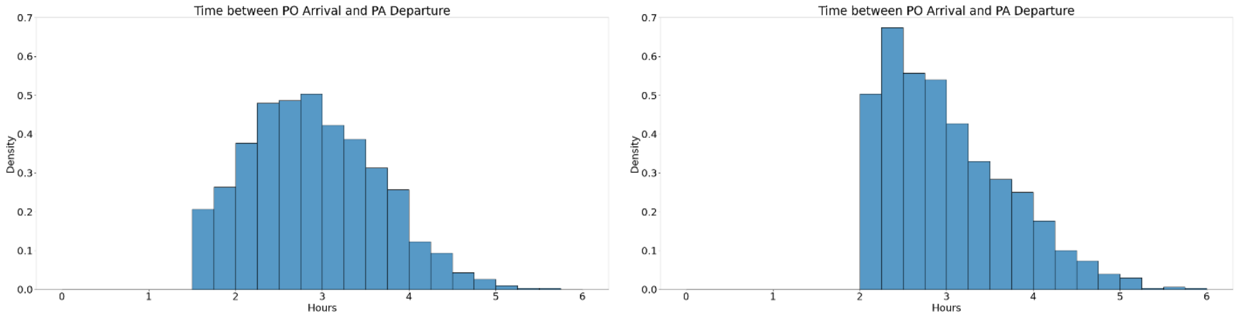

Figure 15: Lunch break distribution with a minimum of 1.5 hours (left) and 2 hours (right)

2.5 Hour Minimum Lunch Break

By increasing the minimum lunch break to 2.5 hours far more vans were effected – approximately 25%. The mean lunch break duration rose to 3.15 hours (3:10), whilst the median rose to 3.0 hours (3:00). The distribution is shown in Figure 16.

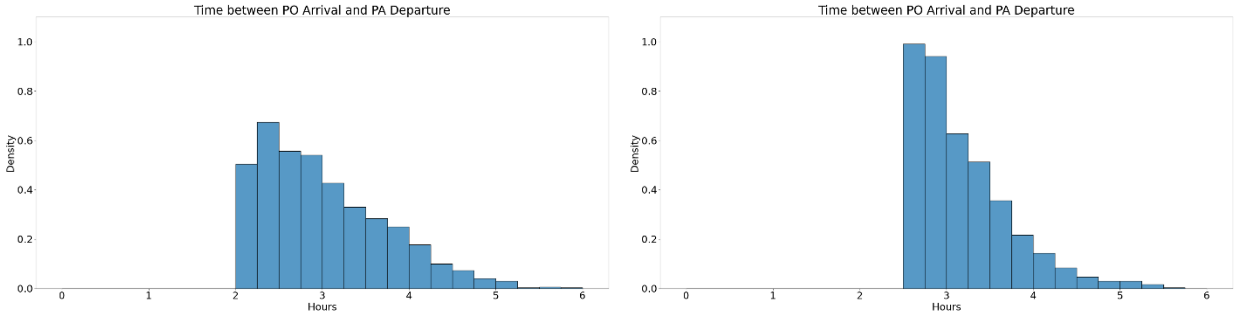

Figure 16: Lunch break distribution with a minimum of 2 hours (left) and 2.5 hours (right)

Chapter 6 Discussion

The strategy to determine which vans used the DC fast chargers employed in the BESS-included simulations relied on the ability to estimate the energy usage in the evening delivery service. This resulted in a much more efficient use of the DC fast chargers when compared to the regular uncontrolled charging case which used a van SOC of 40 % after the morning service as the DC fast charger indicator. However, this assumed the smart scheduling of vans' delivery routes in advance.

However, improving the delegation of DC fast chargers is not the only method to improve lunch time charging efficacy. Vans using AC chargers are susceptible to inadequate energy transfer due to a short charging duration. With perfect knowledge of the van schedule, the lunch break could be extended for vans that would otherwise receive too little energy, so long as the predicted evening arrival time is not past midnight (or another arbitrary limit). This could again reduce the required number of DC fast chargers and annual system cost.

Smart fleet charging methods can be employed in which the vans with lowest SOC upon connection receive prioritised charging, and thus a higher charging power. The prioritisation control could go one step further and include the urgency in their charging, with regards to the expected departure time. Currently, the available capacity is split proportionally amongst the vans depending on the charging power demanded (if a van has SOC > 80 % it demands a lower power than a van with < 80 %). An example might be that vans with SOC < 50 % receive a higher charging power than those with a SOC > 50 %. This would be especially beneficial during the lunch break charge session since the vast majority of failed deliveries occur in the evening delivery service after not receiving enough energy during the lunch break. Table 6 presents an example of how the charging limits could look.

Table 6: Smart charging current limits

Van SOC	Current per Phase	Charging Power
SOC < 50 %	16 A	11 kW
50 % < SOC < 75 %	12 A	8.3 kW
SOC > 75 %	8 A	5.5 kW

To ensure some vans that would otherwise not be fully charged overnight are indeed fully charged, the DC chargers can be used as necessary in the morning before the vans are loaded with groceries. It is likely that the SOC is already over 80 %, probably even 90 %, so the time spent at the DC charger would be very short, less than 10 minutes (approximately 7 kWh required at 90 % SOC, DC charging power has 10 kW minimum).

All optimisation calculations presented in this study are approximate optimal solutions, due to the method in which a genetic algorithm solves the problem. A genetic algorithm was chosen for its ease of implementation with simulation based optimisations. The given BESS sizing and number of DC fast chargers should be used as representational. Increasing the number of DC fast chargers or BESS capacity above the optimal calculated here may be an expensive option but could provide a safety margin for future developments, such as increased number of electric delivery vans, degraded delivery van battery, or longer van delivery journeys.

Finally, the accuracy of this model would be improved if complete measured data were used, namely, the inclusion of delivery van battery SOC before and after each delivery service. This would require unique identification numbers per delivery van.

Chapter 7 Conclusions

Due to governmental and municipal targets and requirements, many forms of logistics vehicles must electrify in the coming years if they are to access central areas of Dutch cities. This presents the challenge of charging the growing fleet of vehicles since the power grid in the Netherlands has reached capacity in many areas. This means smart charging solutions and battery energy storage systems (BESS) are required. This study investigated the use of a BESS to support the charging of an increasingly electrified fleet of delivery vans for Albert Heijn in a grid congested environment.

Data was supplied by Albert Heijn spanning two separate weeks in different months of the year, from which a computer model was formed.

The delivery services provided by the delivery vans consisted of a morning and evening delivery on days Monday – Saturday, and evening services on Sundays. There was an average 2:40 hour lunch break between these services, in which 30 minutes were required for loading groceries.

An optimal BESS size was calculated for each combination of grid connection capacity (500 kW, 750 kW, 1000 kW) and delivery van fleet size (100, 150, 200). The results were then compared to the respective optimal solutions after varying the minimum duration of lunch break from the default 2 hours, to 1.5 and 2.5 hours.

It was observed that the required BESS capacity and the number of DC fast chargers both tended to slightly decrease with increasing minimum lunch break duration. This effect was best observed when increasing the minimum lunch break duration from 2 hours to 2.5 hours. This resulted in a lower annual cost without negatively impacting charging efficacy, and therefore delivery services.

However, it was acknowledged that this model had its limitations. Namely, the lack of smart charging integration, the unexplored possibility of extending van lunch breaks, and the use of DC fast chargers before the morning service to ensure all vans have a fully charged battery. The last two of these are very pragmatic and realistic actions in such a system, and the smart charging approach will soon be the norm amongst fleet charging. Thus, future study is recommended.

Chapter 8 References

1. Project Accelerating Zero Emission Distribution (AZED) DKTI submission docment
2. https://evdb.nz/v/mercedes-benz-esprinter#mercedes-benz-esprinter, retrieved 12/10/24
3. Ramasamy, V.; Zuboy, J.; O'Shaughnessy, E.; Feldman, D.; Desai, J.; Woodhouse, M.; Basore, P.; Margolis, R. US Solar Photovoltaic System and Energy Storage Cost Benchmarks, with Minimum Sustainable Price Analysis: Q1 2022; National Renewable Energy Lab (NREL): Golden, CO, USA, 2022.
4. European Automobile Manufacturers' Association, *European EV Charging Infrastructure Masterplan*, March 2022
5. Idaho National Laboratory, *Breakdown of Electric Vehicle Supply Equipment Installation Costs,* August 2022
6. Liander. Available online: https://www.liander.nl/grootzakelijk/aansluiting/nieuw (accessed on 13 March 2023).

Chapter 9 Appendix

A. Tables of optimisation results

Table 7: Optimisation results with a 1.5 hour minimum lunch break

Grid (kW)	Vans	BESS Power (kW)	BESS Energy (kWh)	DC FCs	Cost (€/yr)	Grid Cost (€/yr)	Total (€/yr)
500	100	620	1240	5	63200	51743	114943
500	150	1450	2900	6	124083	55205	179288
500	200	2560	5120	7	204100	56867	260967
750	100	280	560	5	39967	69203	109170
750	150	900	1800	5	82333	75491	157824
750	200	1740	3480	8	152233	79353	231586
1000	100	0	0	5	20833	80548	101381
1000	150	530	1060	4	52833	92978	145811
1000	200	1530	3060	6	129550	98750	228300

Table 8: Optimisation results with a 2 hour minimum lunch break

Grid (kW)	Vans	BESS Power (kW)	BESS Energy (kWh)	DC FCs	Cost (€/yr)	Grid Cost (€/yr)	Total (€/yr)
500	100	650	1300	4	50283	52128	113211
500	150	1570	3140	8	115333	55541	196157
500	200	2540	5080	6	198567	57108	255674
750	100	240	480	4	32517	69708	102775
750	150	910	1820	8	72217	76620	172137
750	200	1710	3420	6	130367	79765	221615
1000	100	0	0	4	16667	81548	98215
1000	150	480	960	7	35317	94095	156062
1000	200	1220	2440	7	77000	99180	211714

Table 9: Optimisation results with a 2.5 hour minimum lunch break

Grid (kW)	Vans	BESS Power (kW)	BESS Energy (kWh)	DC FCs	Cost (€/yr)	Grid Cost (€/yr)	Total (€/yr)
500	100	590	1180	1	44483	51488	95971
500	150	1390	2780	3	107583	55320	162903
500	200	2300	4600	6	182167	57266	239433
750	100	300	600	1	24667	68812	93479
750	150	870	1740	3	71950	75879	147829
750	200	1630	3260	5	132217	79454	211671
1000	100	0	0	1	4167	79835	84002
1000	150	430	860	5	50217	93339	143556
1000	200	1090	2180	4	91150	99233	190383