Validating Freight Electric Vehicles in Urban Europe

Publishable Executive Summary of

D3.1 Technical Suitability of EVs for Logistics

Work package: WP3 Analysis

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Contents

List of figures and tables

1. Introduction

As part of the FREVUE project, eight of Europe's largest cities, including six capitals, demonstrate that electric vehicles operating "last mile" freight movements in urban centres can offer significant and achievable decarbonisation of the European transport system.

By exposing over 80 electric vehicles to the day to day rigours of the urban logistics environment, the project aims to prove that the current generation of electric vans and trucks can offer a viable alternative to diesel vehicles - particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed local policy.

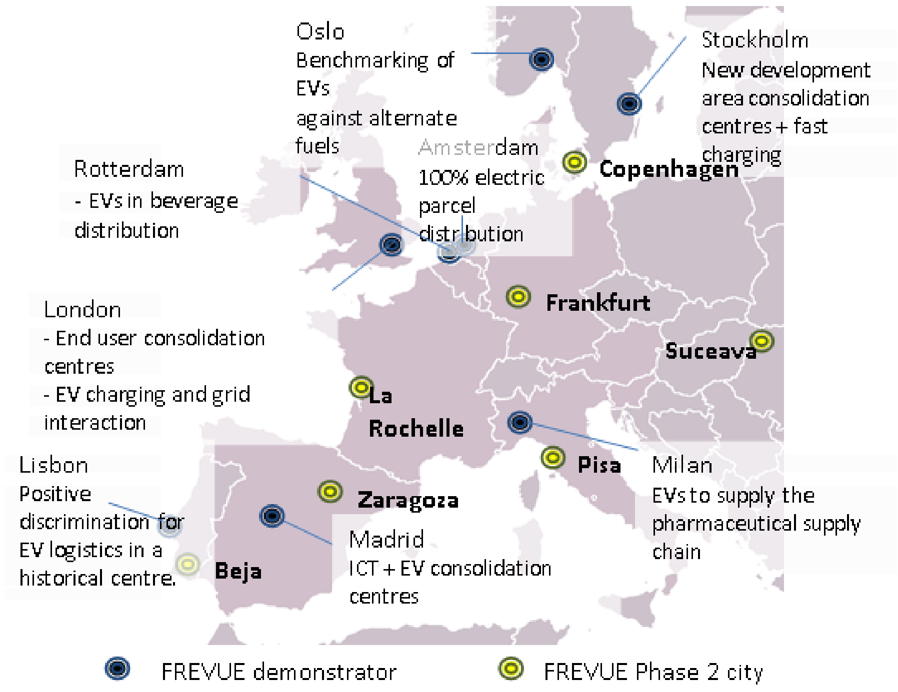

Figure 1: FREVUE demonstrator activities

The 4.5-year project that started in March 2013 demonstrates solutions to the barriers currently inhibiting uptake of EVs in the sector. Novel leasing and procurement models are explored to help mitigate the high capital cost penalty for EV purchase. The impact of a wide range of local policies on the overall ownership case for EVs in logistics applications is also tested.

The project includes leading European research institutions with expertise in transport policy, logistics and electric vehicle technologies. These institutions have designed and implemented a data capture protocol and subsequent assessment framework for the project. This ensures that the project creates a valuable European evidence base on the role of EVs in urban logistics. Partners will produce clear guidelines and recommendations targeted towards the key focus groups of this project: Freight operators and fleet managers, public authorities at the local and regional level, energy network operators, ICT and service providers, and vehicle manufacturers.

2. Technical performance of vehicles

2.1 Introduction

The technical suitability of EVs for logistics operations is being evaluated based on a monitoring programme recording static and dynamic vehicle data, as well as interviews with logistics operators, drivers and city managers. Based on data from the FREVUE demonstrators, the following points will be evaluated in this report:

- Vehicle daily performance
- Battery performance in real traffic conditions, including the possible influence of variations in weather conditions during the year
- Maintenance intervals and overall vehicle availability
- Practical issues

Static data describes EFV model, type, ID, size battery capacity, charging option, operator, payload, etc. For the purpose of collecting this type of information, a special *FREVUE EFV Static Data Template* (Excel sheet) was provided to all operators. Completed data sheets have been received from most operators. For the others, only information on vehicle ID, weight and battery capacity has been obtained.

Dynamic vehicle data provides information from the actual operation of the vehicles. Data requirements were described in FREVUE Deliverable 1.1 Central Assessment Framework. For a long time it proved more difficult and laborious than anticipated to obtain sufficient data of the required quality. The problems which were encountered are described in Chapter 5 of this report. However, the situation improved during the latter half of 2016, so that for this report sufficient data was available for meaningful analyses.

The first section of this chapter describes all dynamic vehicle data that were received. The analyses of vehicle performance were performed on a subset of vehicles having state of charge parameters and other valid trip data. This is the second section in this chapter. Ten operators are included in this section, and the aggregation level of the data is a single day. To be able to compare daily performance on equal terms, data for the operators that reported on a per trip basis were aggregated to single days.

2.2 All vehicles

Fifteen operators delivered dynamic data to the database management system at SINTEF. Table 1 shows the identity of these operators and the number of vehicles, total distance driven, aggregation level and the frequency of data recording. The level of aggregation of the data was either per trip or per day, and the frequency was either per second, per twenty seconds or per day. Ten of the fifteen operators recorded state of charge (SoC) of the battery (in percentage of battery capacity) at the start and end of each trip, and had otherwise valid trip data. These ten operators are highlighted in the table.

Operator	Number of vehicles	Total distance driven	Aggregation	Frequency
Italy, Milano, AMAT	1	5 651 km	Day	Day
Netherlands, Amsterdam & Rotterdam, TNT	7	123 078 km	Trip	Second
Netherlands, Amsterdam, Heineken	6	22 534 km	Trip	Second
Netherlands, Rotterdam, EMOSS	2	33 167 km	Day	Second
Netherlands, Rotterdam, Heineken	5	72 786 km	Day	Second
Netherlands, Rotterdam, Operator 1	8	20 640 km	Day	Second
Netherlands, Rotterdam, Operator 2	1	0 km	Day	Second
Netherlands, Rotterdam, Operator 3	1	13 902 km	Day	Second
Netherlands, Rotterdam, UPS	4	71 095 km	Day	Day
Norway, Oslo, Bring	5	150 241 km	Trip	Second
Portugal, Lisbon, CTT	15	4 184 km	Trip/Day	Second/Day
Portugal, Lisbon, EMEL	1	6 172 km	Trip	Second
Spain, Madrid, Calidad Pascual & SEUR & TNT	4	43 688 km	Trip	Twenty seconds
United Kingdom, London, Clipper	1	2 094 km	Trip	Second
United Kingdom, London, UPS	43	187 846 km	Day	Day
Total	**104**	**757 073 km**	-	-

Table 1: Operator overview

Towards the end of the data collection period, data was received from some operators located in the Netherlands that were not FREVUE partners. For anonymity reasons, these were denoted Operator 1, 2 and 3. The true identity of the Dutch vehicles were discovered only after the data was organized into the groups denoted as operator. This was because static vehicle information sheets were not received in time. It became clear that operator names were in some instances misleading. For instance, *Rotterdam EMOSS* was really operating in Amsterdam, *Rotterdam Heineken* vehicles also contained vehicles operating in Arnhem and Amsterdam and *Rotterdam Operator 1* contained 7 vehicles operating in Amsterdam and 1 vehicle in Rotterdam. Further, after the submission of D3.1 it was discovered that the submission of vehicle data from the operator labelled *Netherlands, Amsterdam, Heineken,* which ended month 6/2016, continued as part of the submission of data from the operator labelled *Netherlands, Rotterdam, Operator 1* for the period month 8 to month 11 of 2016. The IDs however had changed from GINAF 001, 002, etc. to proper vehicle registration numbers. Hence, the number of vehicles should be reduced from 8 to 2 for this operator.

2.3 Vehicles with state of charge (SoC) parameters

2.31 Time periods and vehicle groups

Data analysed in this report was collected from early June 2014 to mid-November 2016. Figure 2 shows how the number of vehicle days for the ten operators with SoC information was distributed by month and year.

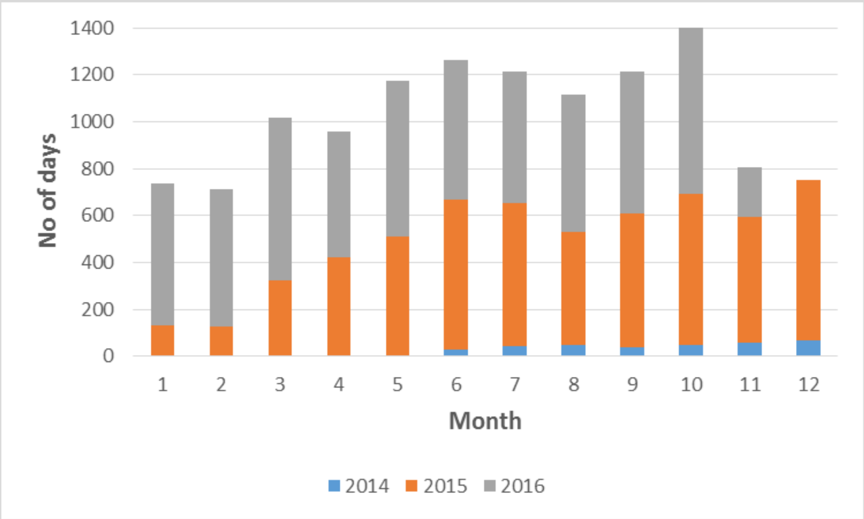

Figure 2: Total number of days with trips by month and year

Since the original grouping of vehicles into operator names for some of the Dutch vehicles were arbitrary, and for preserving the anonymity of the non-FREVUE partners, the results in this report will be classified by weight group only.

Table 2 gives a breakdown of the number of vehicles by weight group and operator. No vehicles in the range of 7.5 to 12 tonnes were represented in the data. There is a natural and strong correlation between battery size (kWh) and gross vehicle weight. Average battery size for the small vehicles were < 25 kWh, for medium vehicles 51-62 kWh and for large vehicles 120-200 kWh.

Operator	Weight group		
	Small (< 3.5 t)	Medium (3.5t - 7.5 t)	Large (> 12 t)
Amsterdam & Rotterdam, TNT		7	
The Netherlands, various operators			16
Rotterdam, UPS		4	
Oslo, Bring	4		
Madrid, TNT & SEUR & Pascual	3		
London, UPS		43	
Total	**7**	**54**	**16**

Table 2: Size of vehicles by operator

The small vehicles were deployed in Oslo and Madrid, the medium vehicles by TNT in Amsterdam and Rotterdam and by UPS in Rotterdam and London and all large vehicles by various operators in The Netherlands.

Figure 3 shows how the number of vehicle days for these weight groups was distributed by month of the year.

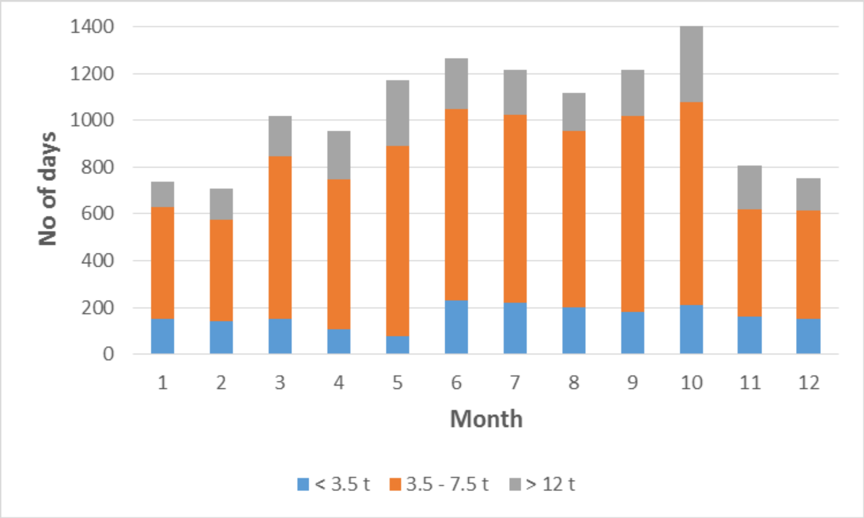

Figure 3: Total number of trips by month and weight group

2.32 Vehicle performance on a daily basis

As noted in Table 1, for some operators the aggregation level is one day and for others one trip during the day. In fact, four operators have delivered dynamic data in which each trip during a day can be distinguished. Two examples are shown below. In Figure 4 a fully charged vehicle starts out from the depot in the morning and makes its first trip followed by a rather long stop. The second trip is followed by a slightly longer stop where the battery is recharged. Then a third trip is followed by a short stop and a fourth trip to the depot for recharging during the evening and night.

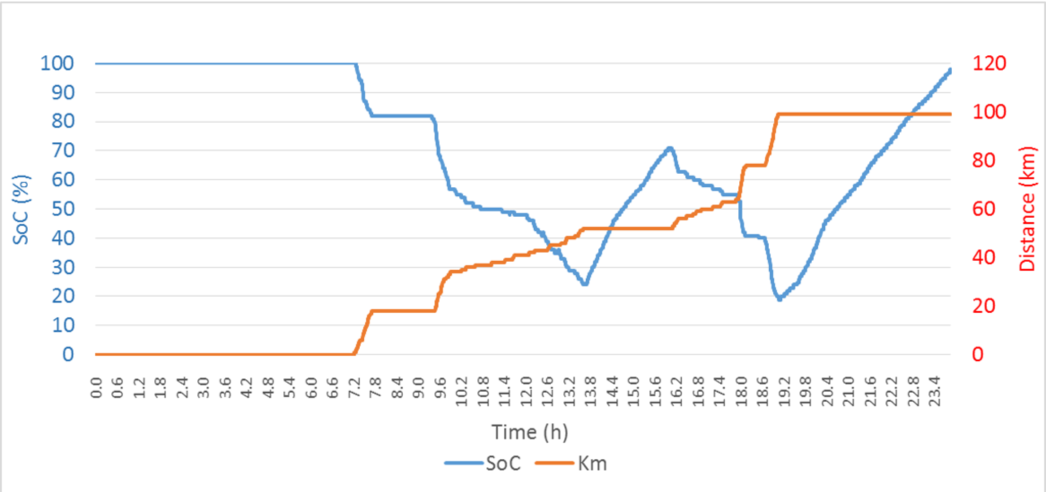

Figure 4: Example of SoC and distance driven for a 24-hour period

Figure 5 shows a succession of many short trips and stops for loading and unloading. In the middle of the day the vehicle stops for fast charging the battery from about 50% to 70%.

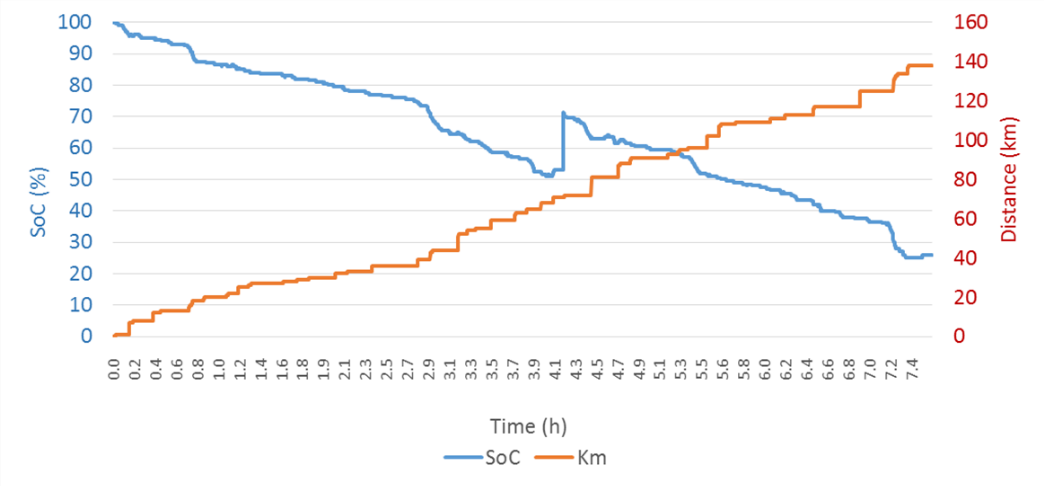

Figure 5: Example of SoC and distance driven for a working day

However, please note that this is based on data provided by the operators: one trip for the Oslo vehicles starts when they begin running until they stop. Whereas for the Madrid and Netherlands vehicles, one trip is the time they run either before or after charging. The Madrid vehicles had on average 1.3 trips/day, compared to 11.2 trips/day for the Oslo vehicles. Additionally, the Amsterdam and Rotterdam TNT vehicles made 2.7 trips/day and the Amsterdam Heineken vehicles 1.1 trips/day.

To be able to compare daily performance across all ten operators on equal terms, the trips for these four operators were aggregated to single days. Table 3 shows the key statistics for number of vehicle days (rather than number of trips), distance per vehicle per day and duration of operation per vehicle per day. Average values for speed, gross vehicle weight and battery size are also shown. Duration and speed were not recorded for the UPS vehicles.

Weight group	Number of vehicle days	Distance (km) per vehicle per day	Duration (hours) per vehicle per day	Average speed (km/h)	Gross vehicle weight (t)	Battery size (kWh)
< 3.5 t	1982	77.4	5.8	17.2	2.2	22.3
3.5 - 7.5 t	8059	43.0	7.5	13.9	6.4	59.6
> 12 t	2325	63.6	8.0	9.3	13.8	154.7
Total/Average	**12366**	**52.4**	**7.2**	**13.2**	**7.2**	**71.5**

Table 3: Basic characteristics of the operations by weight group[1]

2.33 Performance characteristics of vehicles

Based on the state of charge at the beginning and end of each trip (recorded in percentage in the data files), the battery capacity of each vehicle and kilometres driven, a number of key performance indicators can be computed (Table 4).

[1] In this report cases with distance < 0.5 km or duration > 16 hours are excluded. This implies that 97.6% of the number of cases in D3.1 are retained.

Weight group	Energy spent per day (kWh)	Energy spent per km	Energy spent per tonkm	Km per kWh	Average range (km)
< 3.5 t	16.2	0.23	0.12	4.8	106
3.5 - 7.5 t	23.0	0.65	0.11	1.9	115
> 12 t	60.6	1.01	0.07	1.1	170
Average	**29.0**	**0.65**	**0.10**	**2.2**	**124**

Table 4: Key performance indicators by weight group

Energy spent per day or per km is as expected strongly related to gross vehicle weight of the vehicles. The indicator Km per kWh shows that the smallest vehicles can do more than four times as many kilometres on one kWh of energy compared to the largest vehicles; which is not surprising given their low weight. Average range (km) is computed as the product of the previous indicator and Battery size (kWh) of each vehicle. This shows that the large vehicle group has the largest average range.

We have no information about the load carried by the vehicles, but energy spent per gross vehicle weight and km driven can be computed. This proxy indicator shows that the large vehicle group is potentially as efficient, or even more so, as the other vehicle groups.

2.34 Climate data

All weather parameters are retrieved from Yr.no, an online weather service from the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation. Yr.no offers weather forecasts for large parts of the world, and keeps weather archives for the Norwegian locations. Unfortunately, there is no archived data for places outside Norway.

Since it was not possible to simply download archived data for the relevant time period, SINTEF built a system that continuously (twice an hour) downloads the current weather from all FREVUE cities. Due to the technical constraint mentioned above, the "current" weather data is actually the forecast for up to two hours into the future (depending on the location), but this is assumed to be sufficiently accurate. This system has been downloading and storing weather data since December 2014, and is still running at the time of writing.

In most large cities, Yr.no's weather forecasts are updated once every hour. This makes the data granular enough that multiple measurements can be combined for a single trip in the data base. To calculate the weather attributes for any given trip, all measurements are averaged over the period of the trip (for example 08:00 to 15:30).

Figure 6 on the next page shows average values for the four climate parameters considered most relevant; Temperature (°C), Humidity (%), Precipitation (mm/hour) and Wind (m/s). Data for four cities are shown, Oslo representing Northern Europe, Rotterdam and London representing Middle Europe and Madrid representing Southern Europe.

The most striking difference is of course the warmer and less humid weather in Madrid compared to the other cities. Otherwise, Madrid had more extreme variations in precipitation with heavy downpours in March and November, and London was in general windier than the other cities.

In this report only the effect of temperature on vehicle performance will be studied.

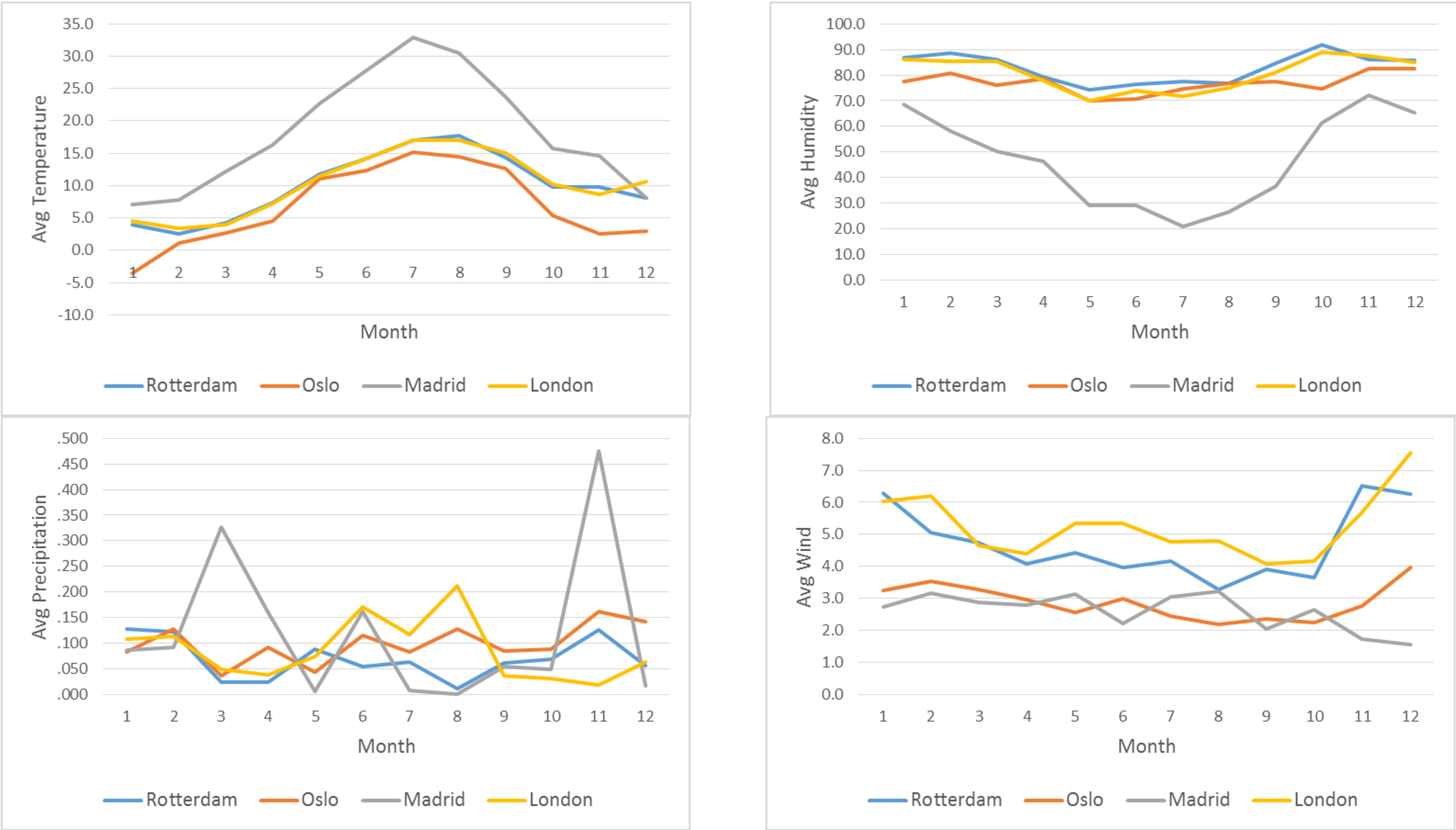

Figure 6: Climate parameters for Rotterdam, Oslo, Madrid and London

2.35 The influence of temperature on vehicle performance

It is well known from the literature that the range of electric cars is affected negatively both by extreme cold and by extreme hot weather. But does the same apply to EFVs? The FREVUE data allows us to examine this question empirically. Figure 7 shows the performance measured as km per kWh as a function of temperature range for the three weight groups. The pattern is very clear for the group of small vehicles. The efficiency increases gradually from when the temperature is below zero to a maximum when the temperature is 10°-15°. Then it decreases gradually to its minimum at temperatures above 25°. In practical terms, the efficiency is 39% higher at 10°-15° compared to when the temperature is 25°+.

The result is different for the medium and large sized trucks. Medium sized trucks seem to benefit from increasing temperature, as do the large sized trucks, although the effect is smaller.

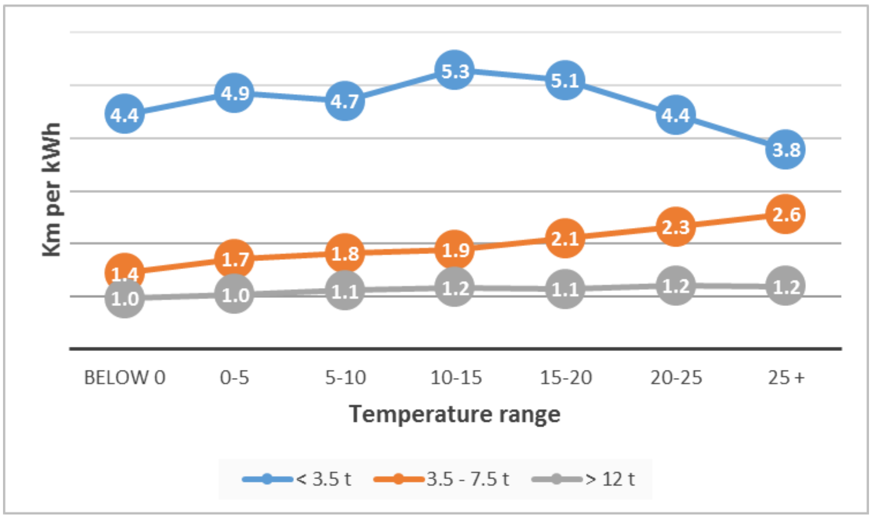

Figure 7: Km per kWh depending on temperature range and weight groups

2.36 The effect of time of year on vehicle operation

Figure 8 shows Km per kWh as a function of time of year for the three weight groups. Winter is defined as December-February, spring March-May, summer June-August and autumn September-November.

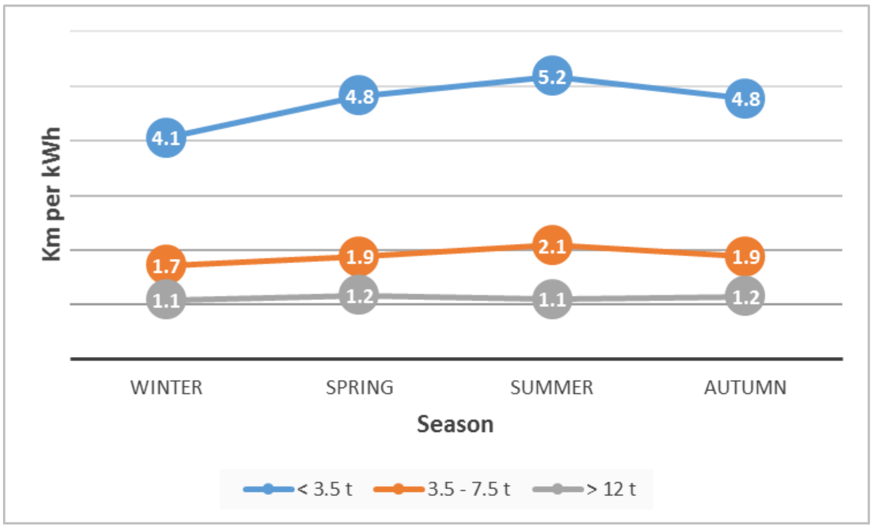

Figure 8: Km per kWh depending on season year and weight groups

The general trend is the same as above. For small vehicles the average efficiency is 27% higher during summer compared to winter. For medium-sized vehicles there are small improvements in efficiency as the season changes from winter, through spring to summer. For large vehicles, the average efficiency is about the same throughout the year.

Another question is whether the effective range of vehicles is affected by seasonal variations in temperature. Figure 9 shows how the average range of the vehicle groups vary by season.

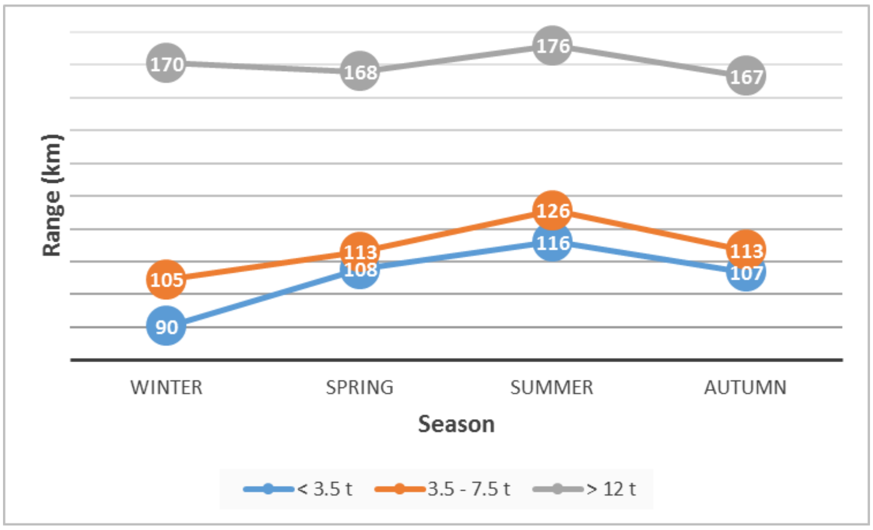

Figure 9: Average range (km) depending on season and weight groups

The smaller vehicles have distinct and logical variations in range depending upon season of the year. The ranges during spring and autumn are almost identical, and the ranges during summer compared to winter are 29% longer for small vehicles and 20 % longer for medium vehicles.

One of the ways that operators can adapt to the fact that vehicles may have a lower range when the weather is cold, is to take more energy out of the battery so that the state of charge is closer to zero at the end of the day.

Figure 10 shows that all vehicle groups have their lowest average SoC at the end of the day during winter and their highest SoC at the end of the day during summer. This pattern is most distinct for the small vehicles and less distinct for the large vehicles.

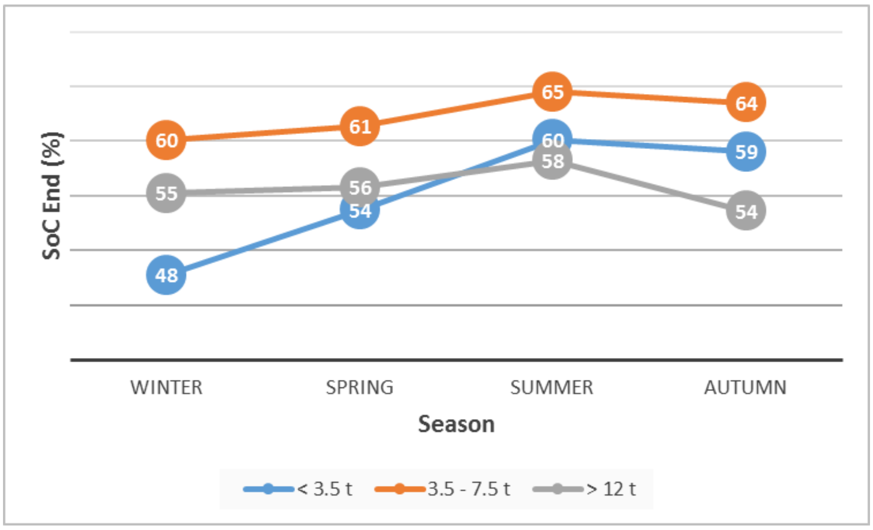

Figure 10: Average state of charge of the battery at the end of the day depending on season and weight groups

2.37 The effect of speed

It is well known that for inner city cycles at low speeds the idle consumption of ICE vehicles is significant, and the total consumption per km is high. With increasing speed the total consumption per km for ICE vehicles is decreasing until it levels out at a certain speed (typically at around 60 km/h).

For EVs the actual idle consumption is relatively low, but by the laws of physics, the energy needed for propulsion, particularly air resistance, implies that the higher the speed, the higher the consumption.

Figure 11 shows the empirical results for Km per kWh for the weight groups of vehicles as a function of average speed range. Note that the UPS vehicles are not included because they provided no speed data, and recorded vehicle speeds below 5 km/h are excluded.

It is interesting to note that the performance of medium and large size trucks seems to be relatively unaffected by speed. Small vehicles, on the other hand, seem to be most efficient at 25-45 km/h.

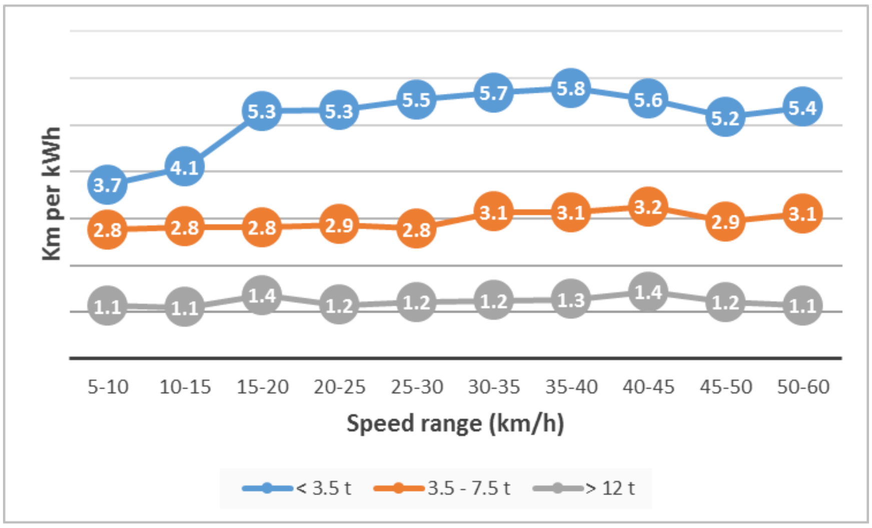

Figure 11: Km per kWh depending on average speed for weight groups

3. Technical performance of the charging infrastructure

3.1 Introduction

There is an increasing need to facilitate the uptake of electric vehicles for the transportation of goods in urban areas by building new cost-effective charging infrastructure. The electricity distribution networks should be able to support the new demand from EVs and be prepared for the next generation of large trucks with high battery capacity. Therefore, the development of new smart charging strategies is necessary to effectively plan the distribution of electricity and to provide reliable charging facilities. In order to evaluate the needs in terms of charging, it is important to assess the current use of charging systems from EFVs in operation.

The current study presents use cases based on the charge needs of different types of freight electric vehicles.

The key objective of the analysis was to collect data from the eight FREVUE demonstrations to perform a technical assessment of the charging infrastructure. This includes identifying charging patterns to evaluate the efficacy of the different systems deployed in the project. However the low quantity of charging data collected has limited the analysis that could be performed; especially when it comes to the estimation of the future electricity demand from freight vehicles. Information about the consequences of the additional load on the networks is not known as well as the planning to accommodate this load. The focus of this report, therefore, is not the impact of charging on the electricity distribution networks.

The study is based on charging use cases divided in three different groups of EV battery capacity. The results provide charging usage patterns and show the efficacy and suitability of the charging infrastructure for the different groups of EVs.

Based on data availability, the report aims to provide answers to the following research questions:

- What are the different charging profiles of the three EV battery capacity groups?
- What is the impact of charge start times, post occupancy times, energy charged, and state of charge before and after charging on the charging profiles?
- What are the repair issues reported by the operators?

The analysis is based on the following parameters: the duration and frequency of the charging events, the length of time of post occupancy, the energy consumption and efficiency, and the reported malfunctions (when provided). These parameters are reported for different vehicle battery capacities and charging system types.

3.2 Summary results

The analysis of group 1, large trucks with high battery capacity of 160 – 200 kWh, shows a charging profile based on one charge a day between 16:00 and 18:00. The truck is charged all night and requires an average daily energy charged of 163 kWh. The truck has around 25% left before charging and is fully charged when leaving the terminal in the morning. The truck is driven approximately 163 km per weekday and charged after the last trip.

The small vans from group 2 with medium battery capacity of 50 – 60 kWh have the same type of charging profiles with charging during the night after working hours between 16:00 and 18:00. These vans require less energy with 30 kWh per day and are driven around 89 km each weekday. They are also charged during the night and each vehicle has an available post at disposal when they arrive from their last trip.

Group 3 consists of light vehicles with low battery capacity of 22 kWh. These vehicles have varying charging profiles depending on the operator. Their profiles are more similar to those of private cars with a spread of charge start time distribution over several hours. Some vehicles require charging twice a day; a short charge at lunchtime and a longer one during the night.

Despite the low number of charge events, the results show a contrast to the charging patterns of private and commercial light electric cars where the diversity in charging is really high (Green eMotion project). The charging profiles of freight vehicles are less heterogeneous since most of them require to be charged at the same time every weekday. They have a very low energy demand during the working hours followed by a sudden high peak after 6 pm. They do not generally require any charging during the weekends.

The demonstrations have confirmed that the additional demand from freight results in high peaks during the evening and night hours. Their charging also coincides with a peak in household electricity demand after 6 pm when the batteries start charging until they stop drawing power. The demand in the morning hours is less important since the batteries are mostly charged by then.

The charging profiles for the three groups of vehicles presented in this report indicate that the vehicles are all connected to the infrastructure all night and if necessary, quickly charged during the day. The charge events observed take place at the terminals. The vehicles are charged during night hours at dedicated spaces to be prepared for loading and dispatched in the morning.

The new large electric trucks require around 160 kWh to daily recharge during the weekdays, which is much higher than the light vehicles and vans that are predominantly used now. All the freight vehicles require more power than private vehicles. It is expected that the electricity network will be under stress during weekdays if the number of large electric trucks or fleets of vans drastically increase locally. However, there is little variability in charging and driving, which should facilitate the planning of appropriate infrastructure and anticipation of future demand. It is important to follow the concentration in freight electric vehicles at a national and local level to plan changes in the electricity network both in terms of time and location.

Since the vehicles can be stationary during the night, use of slow or normal charging is not an issue and fast charging not considered necessary (if the range is adapted). The data analysis shows that most of the vehicles are at a State of Charge of at least 25% after operation and before charging. This indicates that most operators use the electric vehicles on well-suited routes.

There is a need for new smart technologies to support the integration of EFV charging into the electricity network and to efficiently manage the whole distribution network. By coordinating the electricity distribution between consumers and producers, the objective to only exploit green power could then be achieved. Smart charging will facilitate charging of EVs by avoiding peak loads on the power grid, waiting times for charging and drivers' anxiety. It should also be enabled into the fleet management systems, integration of booking charging times at designated posts of all the vehicles and continuous recording of the real-time vehicle SoC status to optimise the use of the fleet. Then, in case of a deviation, the vehicle data monitoring allows to adjust the trip and to use more battery capacity than the operators or drivers would take the risk to use today.

4. Lessons learnt from the data collection and conclusion

FREVUE Deliverable 1.1 Central Assessment Framework described the data collection protocols and central assessment framework for the demonstrators. The protocols included data formats for data collection, processing and reporting. Special attention was given to the quality and comparability of the data. However, since data were provided from different sources, no common data analysis was possible until after several steps of data processing were performed. The most important and common problems in the data collection were caused by:

- Some data were sent by e-mail, but most of them were directly uploaded to the SINTEF server. Most of the data were collected from existing data sources (e.g. fleet management systems, data service providers) and were delivered in their original data formats. Only vehicles using the same logging system provided common file and data formats.
- SINTEF received data as Excel documents, .txt files, .xml files, .csv files, binary files, and even scanned pictures of handwritten notes. All of these have their own unique way of being opened and processed, and pictures of handwritten notes are impossible to automate. Data quality control was continuously performed to ensure that the requirements were met. Data were parsed and checked for format and content errors.
- The contents of the files were unlike: different parameters using different units, and even when the parameters were the same, their names were usually different, so SINTEF had to handle them individually.
- Data were aggregated either by trip, by day, every 20 seconds, or every second.
- Updating was performed by some data providers with a new data row for every time slot, while others updated just single values, one at a time.
- New data were provided either as one file per day, one file per trip, or even multiple files for each trip.
- Most of the data providers sent files with no documentation making it difficult to be quickly handled.

- In many cases, there was no logical connection between the data files and the vehicles, making it impossible to easily identify which of the trips were driven by which of the vehicles.
- Some vehicle ID numbers were changed during the project period, creating additional work for identifying which of the new vehicle ID numbers corresponded to the previous ones.
- Formats were changed by data providers during the project period (without adding or removing any contents), creating unnecessary additional work for SINTEF.
- Another common problem was the timestamps. Date and time were provided in different formats. Some of the timestamps were not automatically updated in summertime/wintertime.
- In addition to the time format issues, collected data were provided with different data formats within a single file.
- Some vehicles are owned by their drivers and used for private trips as well.
- Some vehicles left at terminals are used for other purposes than deliveries.

This myriad of configurations created additional work for data to be identified, parsed, cleaned and converted to a common format before being finally analysed. Because of missing documentation and changes in formats, SINTEF repeatedly needed clarifications and supplementary information before processing data, which consumed a lot of time.

For each different format, SINTEF created a distinct parsing algorithm. Multiple parsing algorithms were needed when formats were changed, or multiple formats were provided from the onset. Each parsing algorithm read the data files each operator had delivered, parsed them, extracted parameters, and stored them in a MongoDatabase. The MongoDatabase is a schema-free database, which made it perfect for data provided with different formats. In the database, each trip was stored with common parameters when available (such as GPS position, time, state of charge, etc), and additional parameters were stored as "Extra_" parameters. This solution was adapted for extracting trips having common parameters, and also allowed the use of unique parameters for some vehicles.

Based on the lessons learnt, the recommendations for future data collection would be that the data providers deliver data in one common format. The conversion of the data into a specific format requires a certain technical expertise and it might not be realistic to assume that the logistics partners or the data service providers could provide this additional work. Then, the only way to ensure that all the data providers deliver data in the same (and consistent) data format is to supply a common data source. Using the same technological device in vehicles is a solution providing the same data formats and avoiding missing trips. This solution should be envisaged in future data collection, especially to follow the degradation of the vehicle battery over time, which is a common concern of operators and drivers. For the coding of parameters, guidelines provided by Green eMotion or FREVUE are suitable for future projects on electromobility.

The overall conclusion of this report is that the electric vehicles demonstrated in FREVUE are technically suitable for the logistics operations they all perform. The small and medium electric vehicles have a limited range and need frequent charging. However, the building of inner city fast charging infrastructure and new battery packs with higher capacity will further remove these barriers. Therefore, it is expected that the new generation of electric freight vehicles will be even more suitable for logistics operations and the types of operations the EVs will be able to be deployed for will greatly expand in the coming years.