MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY

ACRONYM: MERGE

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WP 2
TASK 2.1
DELIVERABLE D2.1

MODELLING ELECTRIC STORAGE DEVICES FOR EV

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REVISION HISTORY

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EXECUTIVE SUMMARY

This report is part of the deliverable for the MERGE project Work Package 2: "Developing Evaluation Capability". The goal of this work package is to implement an evaluation suite composed of several simulation tools that will incorporate specific models capable to deal with the integration of electric vehicles (EV) either in "charging-only" mode or under the V2G concept.

This report covers the deliverables for Task 2.1 which looks at "Modelling electric storage devices for EV". It comprises five main Sections that represent the five main sub-tasks from the MERGE project Description of Work (DoW), shown in Table 1:

DoW SUB-TASK	DESCRIPTION	SECTION
2.1.1	"Perform a review of the state of the art of present car battery technology"	1
2.1.2	"Development of software-based models of available and predicted energy storage systems/devices appropriate for use in EV"	2
2.1.3	"Characterisation of the energy storage devices and identification of how this data might influence the design of possible charging interface systems"	3
2.1.4	"Research of available and future battery management systems"	4
2.1.5	"Analysis of said energy storage models to simulate EV penetration of the transport sector and the potential impact on European energy grid. Incorporation into this model of the through life characterisation and end-of-life conditions, plus usage implications for use with the modelling of the energy grid when using EV as distributed stored energy"	2 and 5
2.1.6	"Integration of these energy storage models into the overall evaluation suite for EV to be produced by the MERGE project"	This task has no written content in this report as it is a liaison task between work packages

Table 1: WP2 Task 2.1 sub-tasks

This report is based on publicly available data on EV and components and no testing has been conducted as part of this work. The published battery cell data available from manufacturers' own sources was analysed and Ricardo's interpretation of this data and a prediction of trends have been given. A generalisation of different battery cell behaviours was necessary.

In order to contextualise the data analysed, the time spans considered by the report are from 2010 until 2020 for battery technology, and for the uptake of EV it has been taken to be from 2010 to 2030. Beyond 2020, battery technology assumptions may change excessively as the technology develops, whereas vehicle technology is more stable as it is more mature.

The electric vehicles surveyed covered those intended for sale in Europe during this period and included concept cars and manufacturers' demonstrator vehicles. In addition to battery electric vehicles (BEV) the survey included extended-range electric vehicles (EREV) and plug-in hybrid electric vehicles (PHEV). The vehicle classes covered ranged from small 4-wheeled quadricycles up to 12 tonne trucks in four categories (L7e, M1, N1 and N2).

Layout of Report

A summary of the contents of each of the five sections is given below.

Section 1 explains the information within a new database of EV specifically constructed for the MERGE project. It contains information obtained about all EV intended for the European market. It also provides an introduction to the cost of battery technology which is used in EV. The vehicles investigated include production vehicles, concept cars and manufacturers' demonstrator vehicles. The database provides the current specification of BEV, EREV and PHEV as defined in Table 2.

	DEFINITION	DESCRIPTION
BEV	Battery electric vehicle	BEV use no other power source than the battery
PHEV	Plug-in hybrid electric vehicle	PHEV use a battery as main energy source for daily trips, but run in common hybrid mode, with use of the combustion engine running on hydrocarbons, after batteries are depleted
EREV	Extended-range electric vehicle	EREV use a battery as main energy source for daily trips, but use a combustion engine driven range-extender running on hydrocarbons to sustain the battery and to overcome range limitations

Table 2: EV definitions [1]

Section 2 introduces the data which will allow the MERGE partners to model the charging and discharging of EV batteries while connected to the energy grid. The form of the battery model was discussed and agreed with Task 2.1 partners at meetings in early 2010. It was agreed that Ricardo would provide data in 7 main areas, namely:

1) Battery cell specifications.
2) Electric vehicle specifications.
3) Electric vehicle market data.
4) Electric vehicle usage data.
5) Battery ageing effects.
6) Ambient temperature effects.
7) Estimates of electric vehicle state-of-charge (SOC) at the time of connection to a charging point.

With this data, MERGE project partners will be able to use a mathematical battery model of their choice (several model formats have been proposed and are described briefly) to represent the effects of populations of electric vehicles being connected to the grid, particularly grid loading effects resulting from EV battery charging and the potential for vehicle-to-grid (V2G) energy transfer.

Section 3 introduces the influence of energy storage devices on the design of charging points. Most notably, it describes the maximum charge and discharge rates that may be expected and achievable from different battery chemistries. Implications of battery ageing and ambient temperature, introduced in Section 2 are also brought into perspective with respect to charging and discharging rates.

Section 4 introduces the influence on battery management system (BMS) design that energy storage devices may have. The basic required functions of the BMS are described, followed by a definition of additional BMS features that would be required to support controlled charging and V2G functionality.

Section 5 concerns the anticipated uptake of EV in Europe and refers to two separate reports, Work Package 3 (Task 3.2) and Work Package 5 (Task 5.1). With the information reported in this Section, the MERGE project partners will be able to model the impact of mass EV uptake on the electricity grid.

Key Conclusions

The information in this report should provide enough information for MERGE partners to be able to model the impact of mass uptake of EV on the grid. Battery capacities, charging rates, number of EV of different types are all outputs of this report. The key conclusions from this report are:

- Section 1
  - Commercial data on available and prototype EV has been presented and classified according to vehicle type.
  - Information has been collected on battery chemistry, battery capacity, drivetrain power, charging rates and likely EV driving range.
  - A review of the cost of battery packs has been reported as well as a forecast of battery cost reduction methods.
- Section 2
  - The data collected in the EV database is analysed and presented.
  - Battery charge and discharge cycles, charge rate limits, internal resistance and future size development will be demonstrated in cell specifications.
  - EV market data is used to define vehicle age by class.
  - A study of vehicle trips and suitability of EV usage is demonstrated for three EV ranges: 160km, 80km and 50km.
  - The ageing effects of batteries are explained and methods for estimating these are given.
  - Low ambient temperatures during winter will affect EV charging.
  - It is likely that EV arriving at a Charge Point (CP) would already have a high State of Charge (SOC) if being charged daily.
  - A battery lifetime model is presented.
- Section 3
  - The maximum charge and discharge rates for EV are given. Charging/discharging at higher rates is less efficient and loses energy as heat.
  - Typical charging and discharging profiles for Li-ion and lead-acid cell chemistries are explained.
  - The battery and CP will ‘see’ different calculated battery energy levels due to the losses in charging and discharging processes.
  - Vehicle to CP communication requirements are explained.
  - The vehicle owner needs to be able to communicate with the grid if the vehicle is used in controlled charging mode and V2G mode.
- Section 4
  - The link between battery manufacturers and OEM is presented.
  - The BMS functions and requirements are given.
  - Additional BMS functions to enable EV use in V2G have been identified.
  - The BMS will be able to estimate the ‘damage’ caused to the battery from V2G use.

  - The BMS and CP need to communicate to charge/discharge safely and reliably at high rates.
  - Two 'drive-away' calculation scenarios have been explained:
    - Controlled charging when charging is deferred by the controller.
    - V2G.
- Section 5
  - Vehicle sales forecasts have been estimated up to 2030 and an aggressive prediction of EV penetration was applied (Scenario 2 from MERGE Task 3.2 report) to produce EV car parc figures for Germany, UK, Spain, Portugal and Greece over this period.
  - EV car parc figures were split by vehicle category (L7e, M1, N1, and N2), vehicle type (BEV, PHEV and EREV) and charge location (urban, sub-urban and rural split).
  - The data presented in Section 5 and in Section 2.9 can be used to form the basis of the input parameters for models to be run by MERGE partners. This data should enable the effects of the mass integration of EV on European electricity grids to be considered.

Glossary

TERM	DEFINITION
BMS	Battery Management System
CC-CV	Constant current-Constant voltage
CP	Charging Point
CPM	Charging Point Manager
DOD	Depth of Discharge
DOW	Description of Work
ECU	Electronic Control Unit
EU	European Union
EV	Battery electric vehicle (BEV) , Plug-in hybrid electric vehicle (PHEV) or Extended-range electric vehicle (EREV)
ICE	Internal Combustion Engine
Li-ion	Lithium ion battery
NiMH	Nickel metal hydride battery
PbA	Lead-acid battery
PbA-AGM	Advanced Glass Mat lead-acid battery
OEM	Original Equipment Manufacturer
SOC	State of Charge
SOH	State of Health
V2G	Vehicle-to-Grid
VRLA	Valve-regulated Lead-acid battery
ZEBRA	Sodium nickel chloride battery

Table 3: Glossary of terms

All units used in this report are part of the International System of Units (SI) and, as such, are not defined herein.

TABLE OF CONTENTS

1 REVIEW OF STATE OF THE ART PRESENT EV BATTERY TECHNOLOGY

1.1 Introduction

As stated in the foreword, this section provides the current specification of BEV, EREV and PHEV intended for the European market and an introduction to the cost of battery technology. The vehicles surveyed include production vehicles, concept cars and manufacturers' demonstrator vehicles. The database is based on publicly-available manufacturers' data.

The database (a Microsoft Excel © spreadsheet) covers*:*

- Battery chemistry
- Battery capacity
- Battery power (assumed to be the same as drivetrain power)
- Battery voltage
- Charging power (regular and fast charging options if available)
- Vehicle driving range (claimed*)

* **Caution must be taken with all values in the database, especially vehicle driving range which depends heavily on the duty cycle of the vehicle (which is often not stated with the claimed range).**

1.2 EV Database

Please refer to the electronic file available to MERGE partners:

'MERGE_Task_2.1_EV_database_01Oct2010.xls'

Technology	Vehicle Type	Status	Manufacturer	Model	Battery Technology	Battery Capacity (kWh)
EV	M1	concept	Audi	R4 e-tron	Li-ion	45
EV	M1	concept	Audi	R8 e-tron (Fra	Li-ion	53
EV	M1	concept	Audi	R8 e-tron (Det	Li-ion	45
EV	M1	concept	batScap	Bolloré Bluecar	Li-ion	28
EV	M1	demo	BMW	Mini-E	Li-ion	35
EV	M1	demo	BYD	e6	Li-ion	48
EV	M1	demo	BYD	e6	Li-ion	72
EV	M1	prod	Citroen	C-Zero (iMiEV de	Li-ion	16
EV	M1	prod	Citroen/Electric (	C1 ev'eie	Li-ion	20
EV	M1	prod	Commuter Cars	Tango	PbA	15.9
EV	M1	concept	Dodge	Circuit EV		-

Drivetrain power (kW)	Charge Rate (kW)	Fast Charge Rate (kW)	Battery Voltage (V)	Plug-in Type	Claimed EV Range (km)	Claimed Consumption (Wh/km)
						180.0
						212.0
						180.0
						112.0
						209.6
						184.6
						180.0
						123.1
						178.6
						198.8
						-

Figure 1: Snapshot of part of the EV specifications database for the EU (Source: Ricardo analysis)

The database shown in Figure 1 includes information available in March 2010 and was taken from publicly-available sources (often the EV manufacturers themselves) and has not been independently verified. Similarly, EV development is currently fast-paced and data is subject to change (both for the vehicles themselves and their battery parameters). The database was organised into legislated vehicle classes.

Please note that due to the source of the information collected, not all variables studied were available for some vehicles. This means that the plots shown in Section 2, where analysis of this data is performed, may not have all the data points that are expected for each vehicle class.

1.3 Battery Cost Trends

This section introduces the cost of the battery technology used in EV. It is known that battery cost is one of the main cost components of EV. Public data for Axeon battery technology [2] illustrates the breakdown of the battery pack for an EV. The majority of the pack cost stems from the cells as can be seen in Figure 2; however, the BMS also makes up some of the cost.

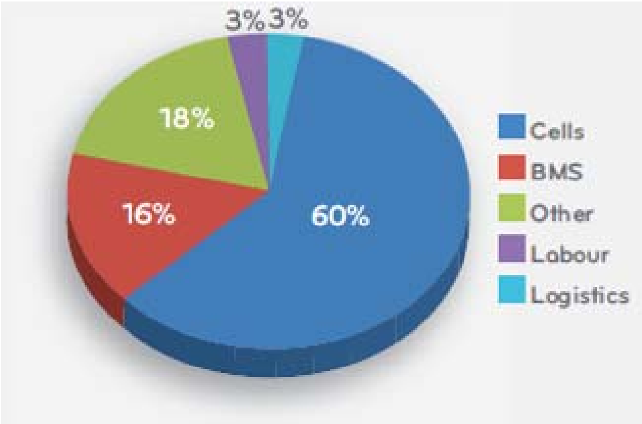


Figure 2: Battery pack cost breakdown for a 25kWh EV [2]

If the cell is considered in more depth (Figure 3), the majority of the cost comes from the cathode material. This is mainly due to the use of lithium for its increased capacities over other materials. The separator material also fronts a big part of the cost as these are usually carbon/graphite based materials.

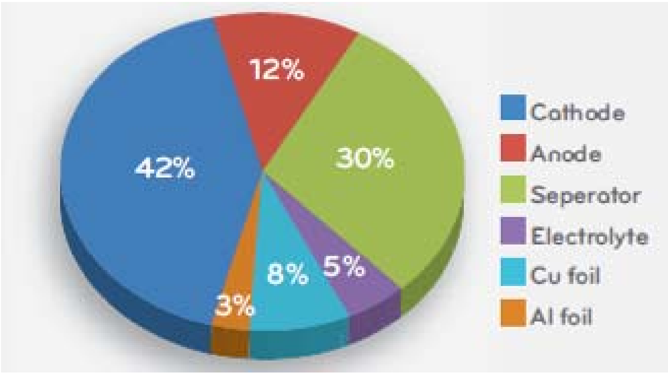


Figure 3: Cell cost breakdown [2]

Effort is being put into reducing the cost of the cell materials by using common materials and simplifying the manufacturing of the cells. Cost reduction plans are also being used on BMS modules and other electrical components to help reduce the overall cost.

Figure 4 illustrates the potential for reducing the overall cost of the cells in the near future. There could be cost reductions of up to 50% in 10 years if there is a significant increase in the uptake of Li-ion batteries.

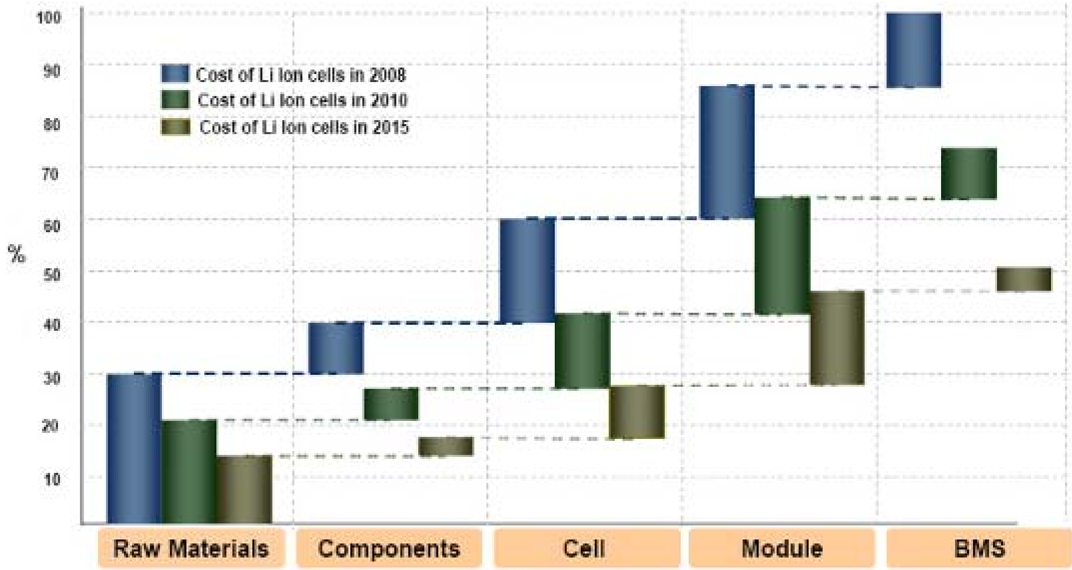


Figure 4: Potential cost breakdown for Li-ion cells (Source: Ricardo presentation [3])

A large driver to the reduction of the battery pack cost is the economies of scale which comes from the increase in market penetration. But also new business models will arise which could make batteries more economical such as selling electricity to the grid through V2G or second-hand battery trading.

There are many forecasts for battery costs. In one review, compiled by HSBC [4], it has been forecasted that the cost of Li-ion batteries will be cut from the present $1000 per kWh to $350 per kWh in 2020. This reduction will mainly be achievable by improvements in design and manufacturing, economies of scale and the new business models proposed above.

1.4 Section Conclusions

- An EV database has been developed that accumulates data from the public realm on existing and future EV as well as some prototypes. Information has been collected on battery chemistry, battery capacity, drivetrain power, charge rate and claimed ranges.
- Battery costs are critical to the success of EV. A review of the future projections and how cost savings may occur has been carried out.
- Analysis of the parameters in the EV database is performed in Section 2.

2 ANALYSIS OF EV BATTERY PARAMETERS FOR USE IN ELECTRICITY GRID SYSTEM MODELLING

2.1 Introduction

The purpose of this section is to provide the data to support EV battery modelling by the MERGE project partners.

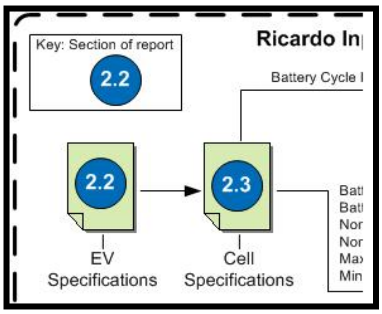
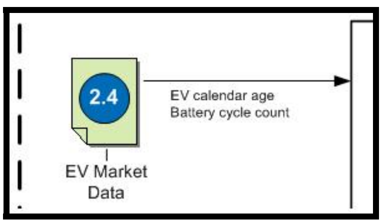
Discussions with MERGE partners during February to April 2010 had established:

- Partners had a variety of preferred formats and intended uses for the battery model.
- A probabilistic approach to modelling populations of EV seemed attractive, in order to consider aggregated populations of vehicles.

With this in mind, the approach taken was to provide the data that would support any of the chosen model types (equivalent circuit model, Simulink model, or parametric model) and to allow the MERGE partners to use their model in a series of 'Monte-Carlo' analyses to represent their chosen scenarios.

This approach is summarised in Figure 5, which shows the Ricardo input (left-hand side block) feeding data to the battery model (central block) according to the needs of the model users (right-hand side block).

The remainder of this section addresses the topics shown in Figure 5, and considers:

TOPIC	SECTION	
Electric vehicle specifications	Section 2.2	
Battery cell specifications	Section 2.3	
Electric vehicle market data	Section 2.4	

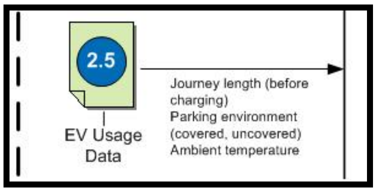
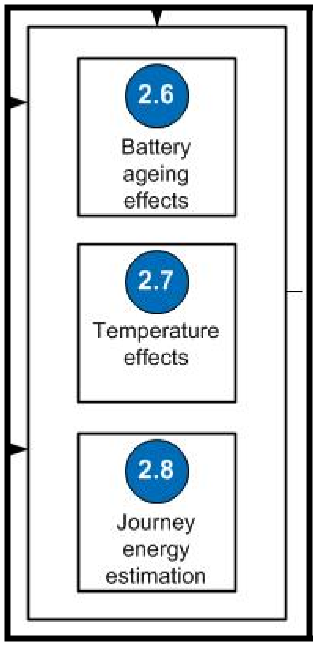
Electric vehicle usage data	Section 2.5	
Battery ageing effects	Section 2.6	
Ambient temperature effects	Section 2.7	
Estimates of electric vehicle states-of-charge at their time of connection to a charging point	Section 2.8	

Table 4: Section 2 breakdown

The EV battery analysis concludes with a summary of the key information required to model EV batteries – namely battery capacity and charging rates for different vehicle classes. This data can be used in conjunction with EV sales predictions for the different vehicle classes (given in Section 5) to assess the impact of EV on electricity grids.

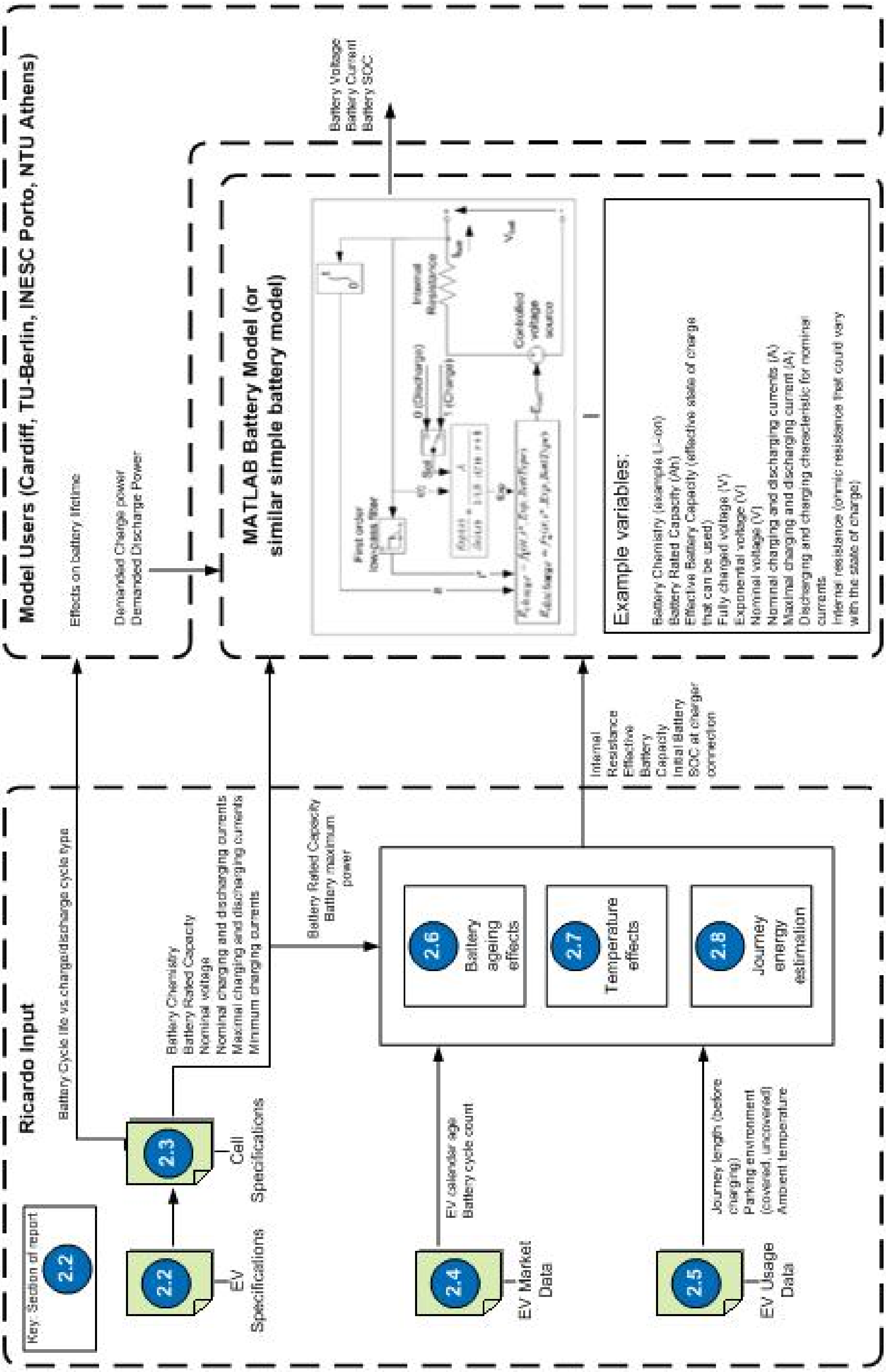


Figure 5: Battery Model Structure (Source: Ricardo analysis)

2.2 EV Specifications

As described in Section 1.2, a database of European EV has been built up for this project, containing the published specifications of 119 current (up to 2010) and proposed BEV, EREV and PHEV vehicles.

The data that has been collected has been used to categorise the commercially available EV in the EU.

2.2.1 Vehicle Classes

Vehicles considered in this report fall into four categories as shown in Table 5.

VEHICLE CLASS	DESCRIPTION	
L7e	Quadricycle - Four wheels, with a maximum unladen mass of 400kg or 550kg for a goods carrying vehicle (not including the mass of the batteries in an electrically powered vehicle) and a maximum net power, whatever the type of engine or motor, of 15kW	
M1	Passenger vehicle, four wheels and up to 8 seats in addition to the driver's seat.	
N1	Goods-carrying vehicle, four wheels, with a maximum laden mass of 3500kg.	
N2	Goods-carrying vehicle, four wheels, with a maximum laden mass between 3,500kg and 12,000kg.	

Table 5: Vehicle classes [5]

The composition of the vehicles on the road network is varied; however, the majority of the vehicles that are sold in Europe are passenger vehicles, or M1 vehicles. This can be seen in Figure 6 with 87.1% of the total vehicle fleet in 2008 being non-commercial cars [6]. For this reason the majority of the model outputs focus on passenger vehicles as this makes up the majority of the European vehicle fleet.

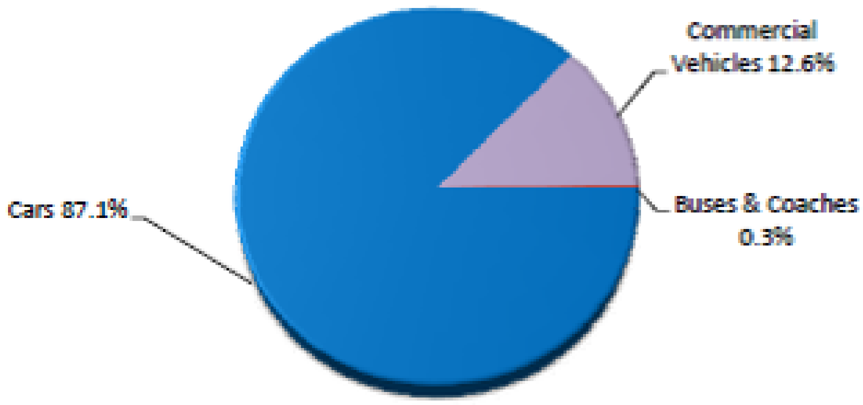


Figure 6: EU fleet by vehicle type, 2008 [6]

These categories will be explored in more detail in the following Sections.

2.2.2 L7e Vehicles

As stated above, the first category to be explored is the L7e or quadricycle. These vehicles are small city purpose vehicles (see Figures 7, 8 and 9).

Figure 7: Kewet 'Buddy' [7]

Figure 8: Reva 'G-Wiz' [8]

Figure 9: MEGA 'e-City' [9]

Figure 10 shows that there is some correlation between the vehicle drivetrain power (maximum of 15 kWh in an L7e vehicle by definition) and battery capacity.

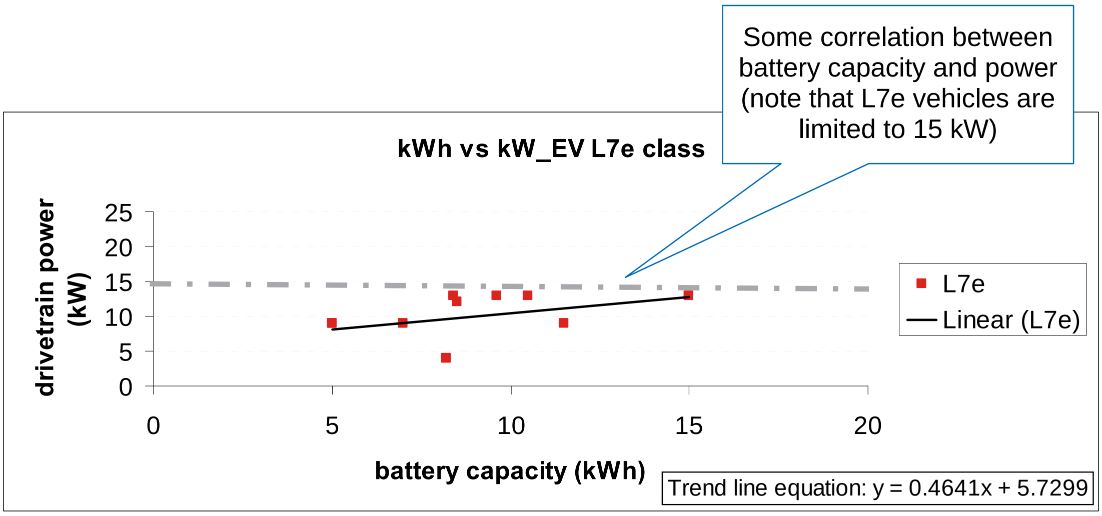


Figure 10: Summary graph of drivetrain power versus battery capacity for L7e vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class – L7e (19 examples found)

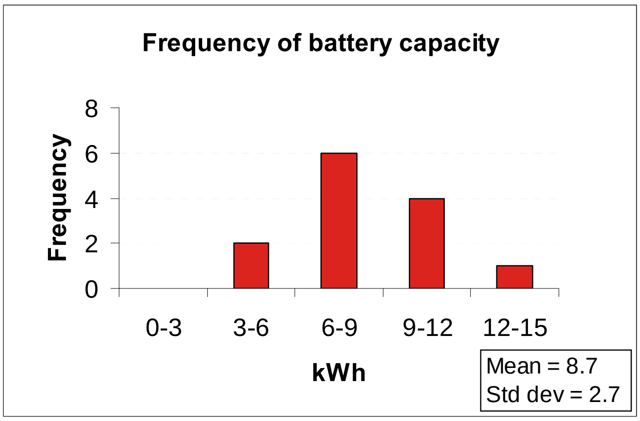


Figure 11:Frequency of battery capacity - L7e (Source: Ricardo analysis)

In Figure 11 it is possible to see the small range of battery capacity available for L7e class EV. This is mainly due to the limitations of cost and weight of these vehicles.

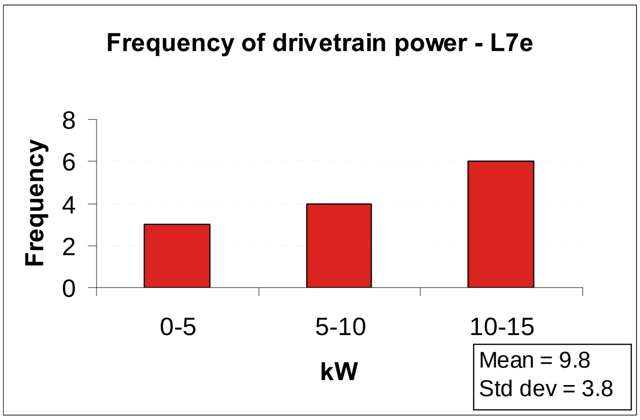


Figure 12: Frequency of drivetrain power - L7e (Source: Ricardo analysis)

Similarly, Figure 12 shows the available power for this class of vehicle. In this case, the power is limited to 15 kW by legislations.

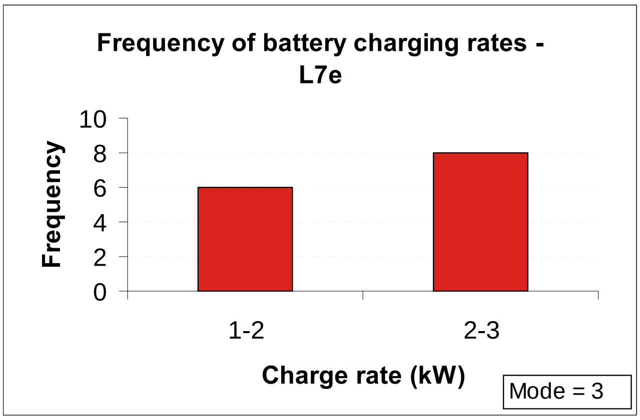


Figure 13: Frequency of charging rates - L7e (Source: Ricardo analysis)

The predominant charge rate for L7e EV is via a 3kW charger (Figure 13), although a high proportion of lower charge rates are recommended by the battery manufacturers as well.

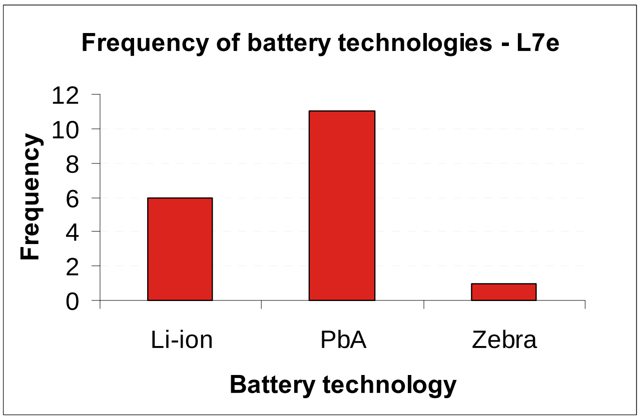


Figure 14: Frequency of battery technologies – L7e (Source: Ricardo analysis)

It can be seen from Figure 14 that PbA is the most common battery technology for L7e vehicles. This is due to the overall low cost of these batteries. However, it is expected that these will be replaced in the future by Li-ion batteries for their lifetime benefits.

For MERGE partners wishing to simulate quadricycle batteries, it is recommended to model a single typical battery of 8.7 kWh capacity.

Chargers supplied with these vehicles have a maximum charge rate of 3kW (i.e. they are intended for domestic single-phase mains outlets). It is unlikely that fast-charging is required, due to the small capacity of the batteries.

Lead-acid is the most common battery chemistry for this class, chosen for its low cost of purchase, but will have a poor cycle life compared to Li-ion alternatives.

Table 6 and Table 7 give a summary of the battery capacities and charging rates respectively for L7e vehicles.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
L7e	BEV	8.7	3	15	BEV only for L7e – no PHEV/EREV Data from 2010 – may change in time but not significantly

Table 6: Summary of L7e battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max	Range	
L7e	BEV	3	1	3	3-7.5	3kW is expected to be standard charging rate

Table 7: Summary of L7e charging rates

2.2.3 M1 Vehicles

The next category is the M1 vehicle, which generally comprises 4-seater passenger vehicles.

Figure 15: GEM 'Peapod Electric Car' [10]

Figure 16: Citroen 'C-ZERO' [11]

Figure 17: Nissan 'LEAF' [12]

Figure 18 shows that there is some correlation between battery capacity and drivetrain power. Outliers on this plot are high performance vehicles such as the Lightning GT EV sports car.

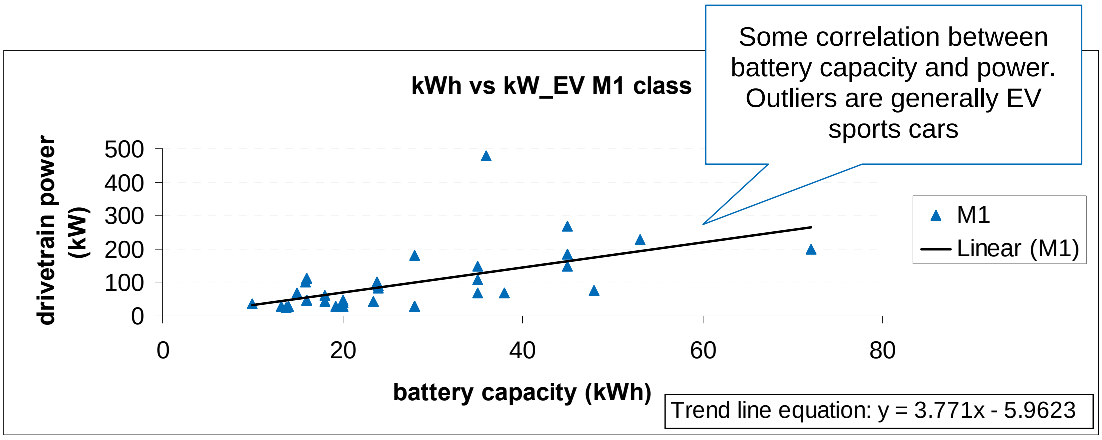


Figure 18: Summary graph of drivetrain power versus battery capacity for M1 vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class M1 (67 examples found)

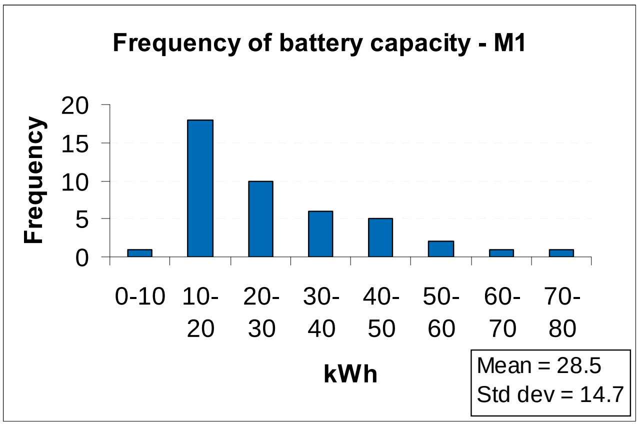


Figure 19: Frequency of battery capacity - M1 (Source: Ricardo analysis)

Figure 19 shows that there is a wide range of battery capacities for M1 class EV. This is as a result of the popularity and diverse nature of this class of vehicle.

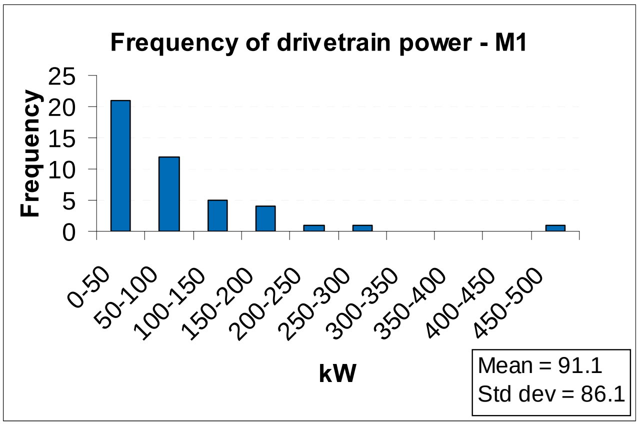


Figure 20: Frequency of drivetrain power - M1 (Source: Ricardo analysis)

In Figure 20 it is possible to see that there is also an extensive range of drivetrain power available. As with Figure 19 above, this is due to the large number of M1 vehicles.

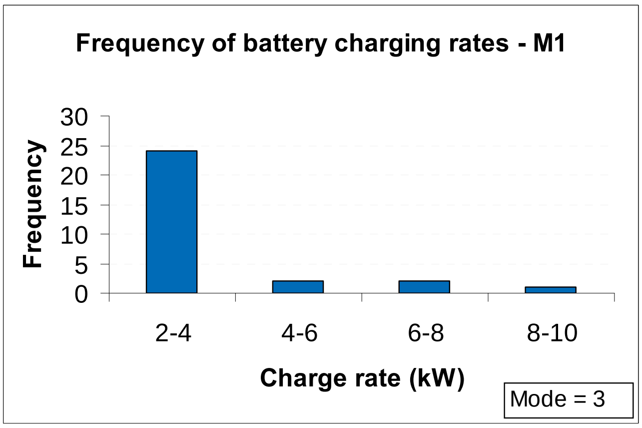


Figure 21: Frequency of charging rates - M1 (Source: Ricardo analysis)

The dominant charging rate is 3kW as can be seen in Figure 21. In 2010, higher charge rates are not very common.

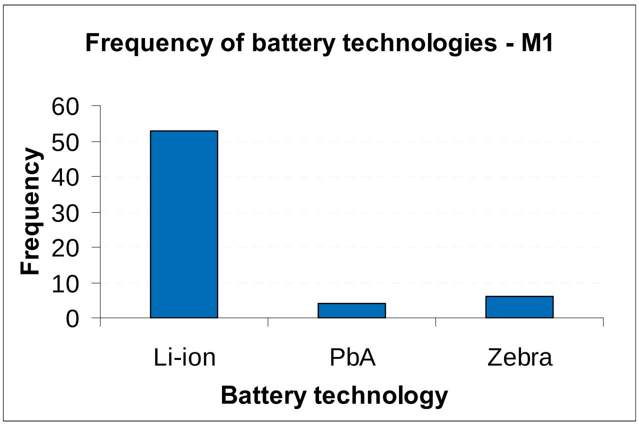


Figure 22: Frequency of battery technologies - M1 (Source: Ricardo analysis)

It is apparent from Figure 22 that the battery technology of choice for M1 vehicles is Li-ion due to their benefits for EV usage – energy density and cycle life in particular.

There is a good correlation between the battery capacity and power, therefore when simulating a 'high-end' M1 vehicle, it would be sensible to select matching values for power and capacity (for example, 50kWh/182kW, or 20kWh/68kW). The trend line equation (y = 3771x – 5.9623) shown in Figure 18 allows these matching values to be calculated. The distribution of the capacity/power distributions is skewed towards the smaller end, so simulated populations of M1 vehicles should reflect this.

Summary tables of battery capacity and charge rates are given in Table 8 and Table 9 for M1 vehicles.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
M1	BEV	29	10	72	Large variation witnessed with the majority being below 30kW

Table 8: Summary of M1 battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max	Range	
M1	BEV	3	2	8.8	3-240	The higher 'fast charge' rate of BEV M1's is due to a small minority of high-performance vehicles

Table 9: Summary of M1 charging rates

2.2.4 N1 Vehicles

The next vehicle class looks at four-wheeled EV for the carriage of goods and with a maximum laden mass of less than 3,500 kg.

Figure 23: Ford 'Transit Connect EV' [13]

Figure 24: Stevens 'ZeVan' [14]

Figure 25: Mitsubishi 'iMiEV Cargo' [15]

Figure 26 shows a good correlation between the battery capacity and the drivetrain power.

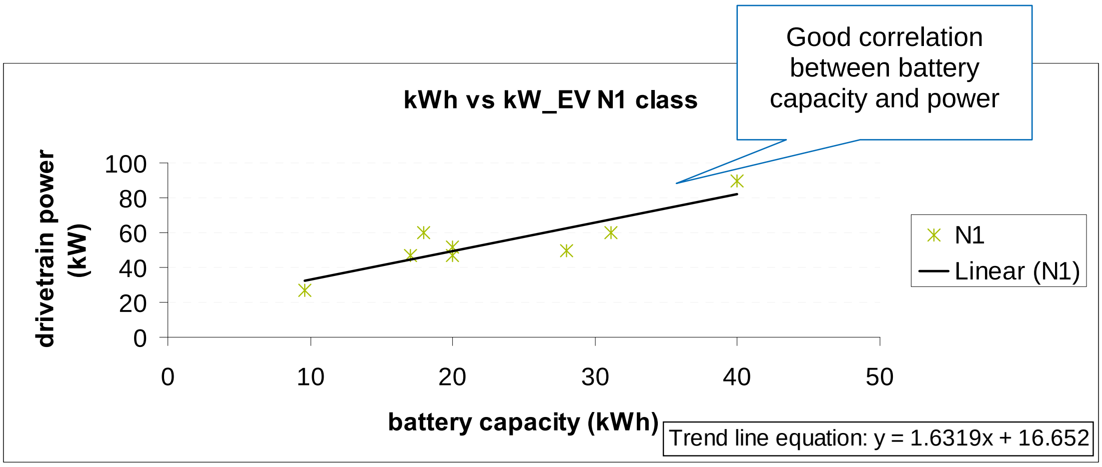


Figure 26: Summary graph of drivetrain power versus battery capacity for N1 vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class N1 (12 examples found)

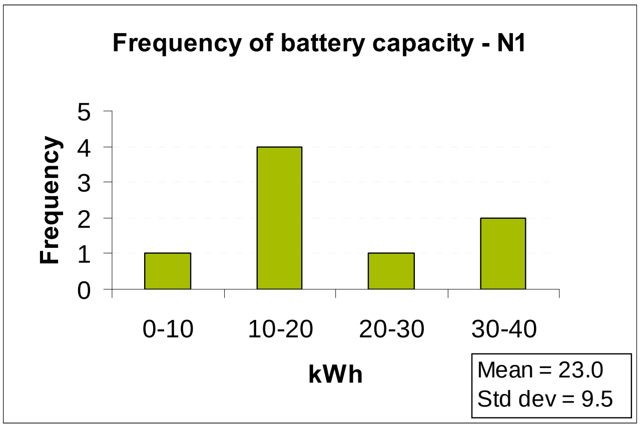


Figure 27: Frequency of battery capacity - N1 (Source: Ricardo analysis)

Figure 27 shows that the mean battery capacity for N1 vehicles is 23 kWh, with a maximum of 40 kWh.

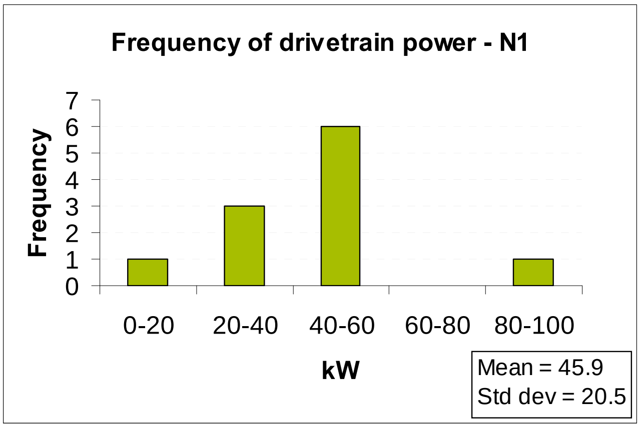


Figure 28: Frequency of drivetrain power -N1 (Source: Ricardo analysis)

Figure 28 shows that the most common drivetrain power for N1 vehicles is in the range of 40-60kW. However there are some outliers which correspond to smaller or larger vehicles.

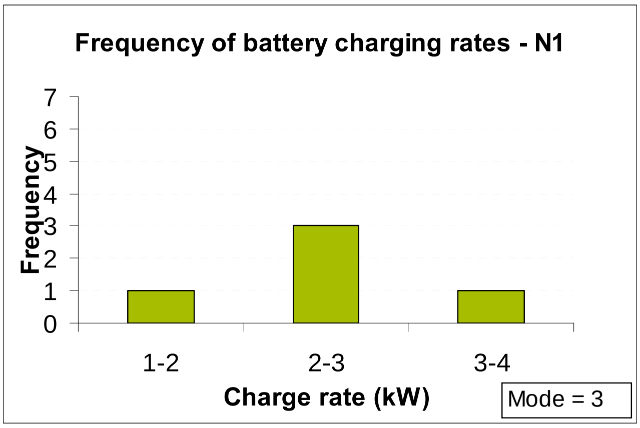


Figure 29: Frequency of charging rates - N1 (Source: Ricardo analysis)

As with the previous classes, the most common charge rate is 3kW (Figure 29).

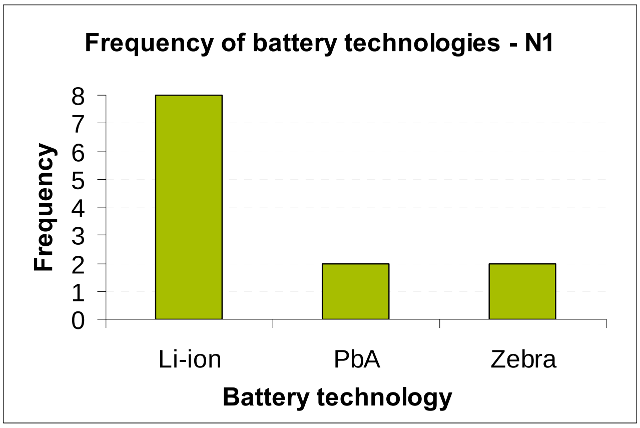


Figure 30: Frequency of battery technologies - N1 (Source: Ricardo analysis)

In Figure 30, Li-ion is shown to be the prevalent chemistry, with lead-acid in use for smaller vehicles and 2 examples with a ZEBRA battery.

Data surveyed for the small van class (N1) showed only 12 examples, but this is a class that is likely to become more popular, due to the fleet operation of many vans (organised charging facilities and a 'return to base' daily operating regime) within a local area where range will be less of an issue.

Battery capacities and powers were strongly correlated, with none of the 'high performance' outlier points that were seen with the M1 class (Figure 26).

Summary tables of battery capacity and charge rates are given in Table 10 and Table 11 for N1 vehicles.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
N1	BEV	23	9.6	40	Mean battery capacity is 23kWh, with a maximum of 40kWh

Table 10: Summary of N1 battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max	Range	
N1	BEV	3	1.3	3.3	10-45	3kW charge rate expected to be the most common

Table 11: Summary of N1 charging rates

2.2.5 N2 Vehicles

The fourth vehicle class considered in this report is the N2 vehicle which has a maximum laden mass of 3,500 kg to 12,000 kg and is for commercial purposes.

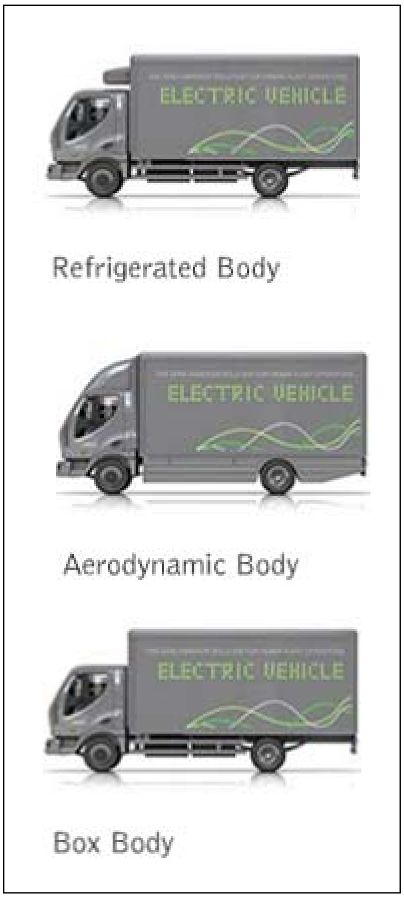


Figure 31: Smith Electric Vehicle 'Newton' [16]

Figure 32: Modec Vehicles 'Chassis Cab' [17]

Figure 33 shows that there is a strong correlation between battery capacity and drivetrain power, although there are only four examples in the sample.

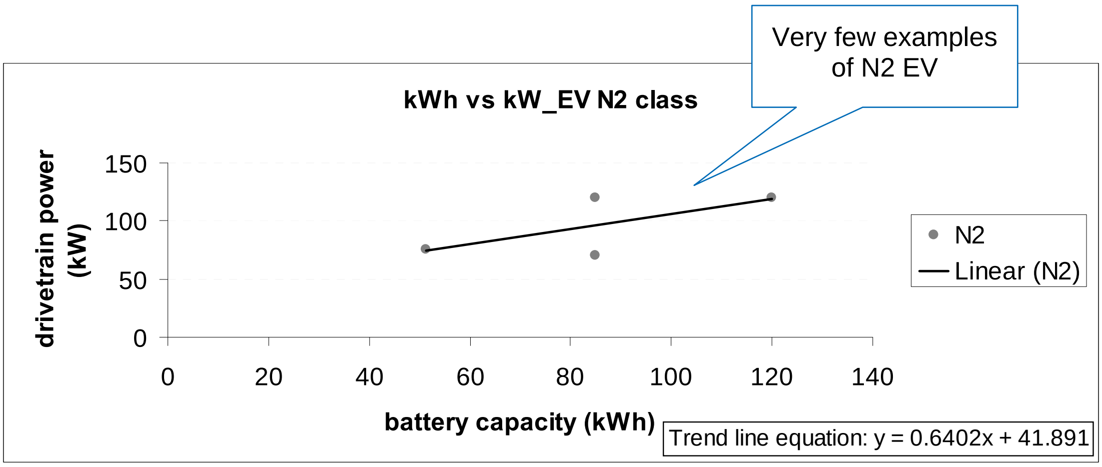


Figure 33: Summary graph of drivetrain power versus battery capacity for N2 vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class N2 (4 examples found)

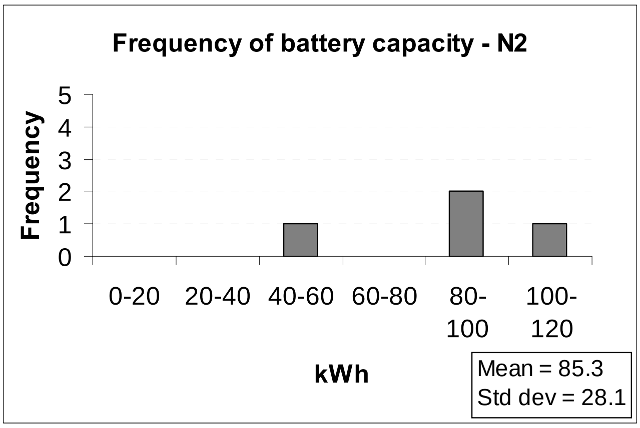


Figure 34: Frequency of battery capacity - N2 (Source: Ricardo analysis)

As can be seen in Figure 34, N2 vehicles have higher capacities in order to cope with the higher payloads of these vehicles.

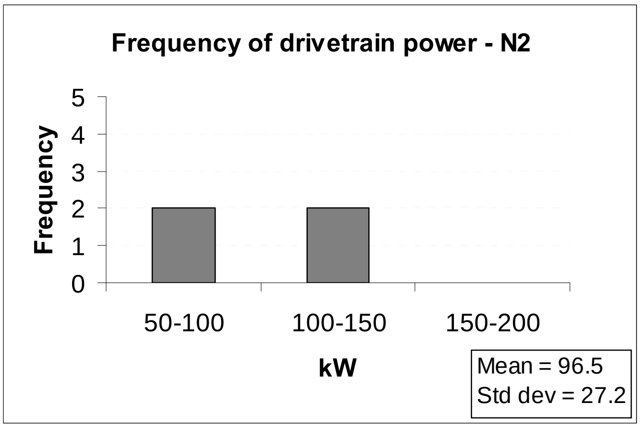


Figure 35: Frequency of drivetrain power - N2 (Source: Ricardo analysis)

Drivetrain powers of 70 kW, 76 kW and 120 kW were observed in the N2 class (Figure 35).

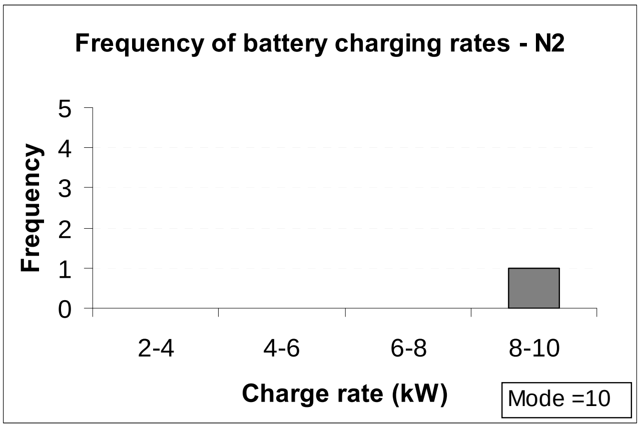


Figure 36: Frequency of charging rates - N2 (Source: Ricardo analysis)

As opposed to the other types of EV, N2 vehicles require fast charging capacities to charge the larger battery capacities (Figure 36). The mode charging rate is 10 kW for N2 vehicles.

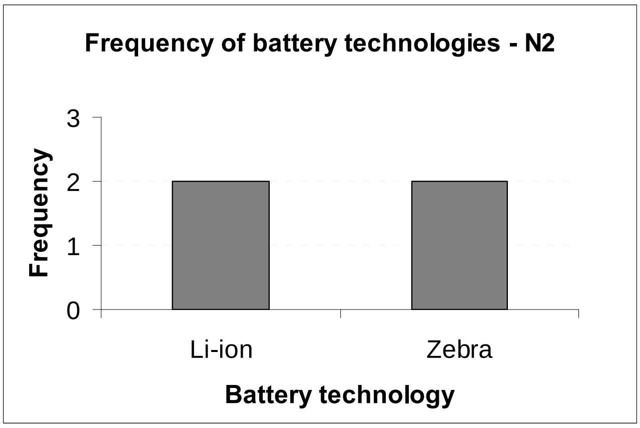


Figure 37: Frequency of battery technologies - N2 (Source: Ricardo analysis)

As can be seen in Figure 37, the available battery technologies are Li-ion and Zebra. However, the Zebra batteries are being replaced by Li-ion due to their increased capacities.

EV examples of vehicles in the N2 class were limited to those from two manufacturers. The vehicles are of similar power, and are each available in optional battery sizes. Both manufacturers are now concentrating on Li-ion battery versions of their vehicles, although ZEBRA batteries were offered initially.

The large size of these batteries means that a fast charge facility is very important since a standard 3kW domestic mains charger would take over 24 hours to fully charge.

Summary tables of battery capacity and charge rates are given in Table 12 and Table 13.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
N2	BEV	85	51	120	Higher capacities in order to cope with higher payload

Table 12: Summary of N2 battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max	Range	
N2	BEV	10	-	-	35-60	Higher charge rate to cope with higher battery capacity. Only one sample available

Table 13: Summary of N2 charging rates

2.2.6 PHEV Vehicles

This section considers the battery technology for plug-in hybrid electric vehicles (PHEV) as defined in Table 2. This type of vehicle has the same properties as M1 class vehicles and will be assumed to be appropriate for N1 class vehicles as well.

Figure 38: Volvo 'C70 Plug-in hybrid' [18]

Figure 39: Toyota 'Prius Plug-in prototype' [19]

Figure 40 shows that the battery capacity of PHEV is smaller than that of equivalent BEV; however the drivetrain power remains the same. There is a good correlation between battery capacity and drivetrain power.

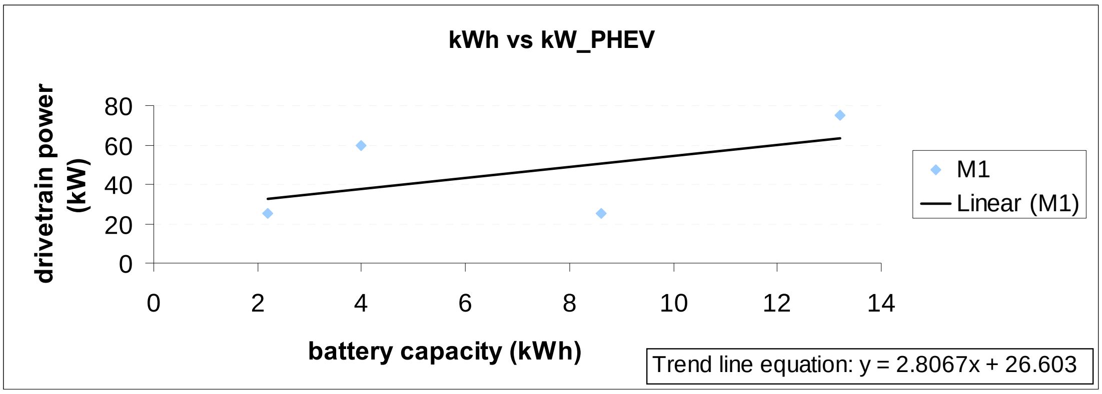


Figure 40: Summary graph of drivetrain power versus battery capacity for PHEV vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class PHEV (7 examples found)

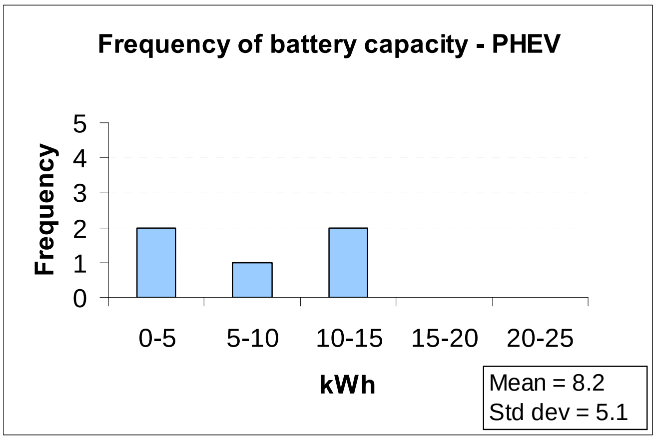


Figure 41: Frequency of battery capacity - PHEV (Source: Ricardo analysis)

Figure 41 shows the battery capacity of this class of vehicle. Since they do not use the battery as their sole source of power, the battery capacity is generally lower than that of an M1 class vehicle (8.2 kWh vs 29 kWh).

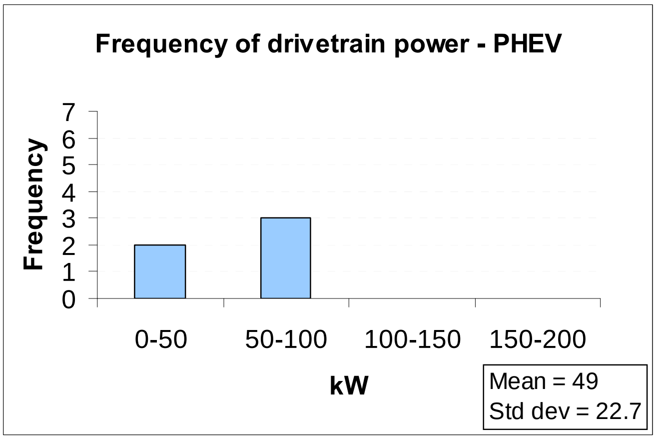


Figure 42: Frequency of drivetrain power - PHEV (Source: Ricardo analysis)

The drivetrain power of these vehicles is smaller than M1 EV (91 kW for BEV vs 49 kW for PHEV) due to the hybrid drivetrain (Figure 42).

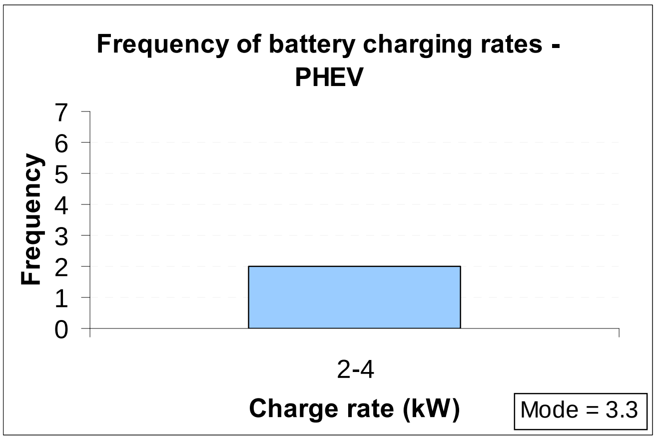


Figure 43: Frequency of charging rates - PHEV (Source: Ricardo analysis)

As with M1 and L7e vehicles, the charge rate required is typically circa 3 kW as shown in Figure 43 due to the relatively small battery capacity.

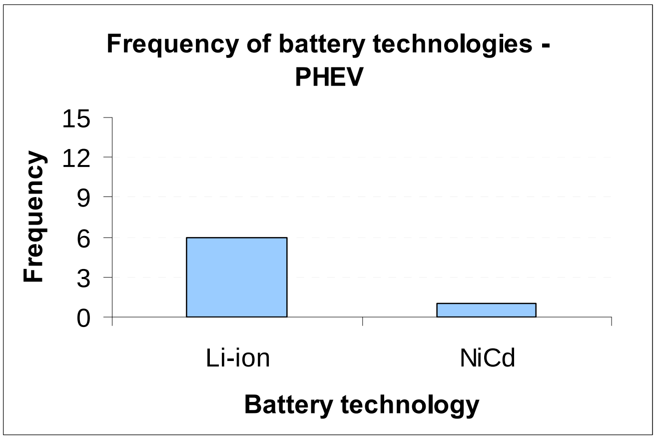


Figure 44: Frequency of battery technologies - PHEV (Source: Ricardo analysis)

As these vehicles have a high number of charge and discharge cycles, the prevalent battery technology is Li-ion (Figure 44).

PHEV vehicles have been designed to benefit the low-mileage user of a hybrid vehicle who wishes to benefit from the low cost of mains-supplied energy to top-up their vehicle battery, but still have the option to go on a longer journey.

Table 14 and Table 15 give the summary battery capacity and charging rates for PHEV.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
M1	PHEV	8.2	2.2	13.6	Since PHEV vehicles do not use the battery as sole source of power, battery capacity is lower than equivalent M1 BEV
N1	PHEV	8.2	2.2	13.6	Assumed the same as M1 for PHEV

Table 14: summary of PHEV battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max		
M1	PHEV	3	3	3	11*	Charging rate is typically 3kW *Only one example of fast charge found
N1	PHEV	3	3	3	11	Assumed the same as M1 for PHEV

Table 15: Summary of PHEV charging rates

From the EV Database it is possible to see that the fast charge capability of a PHEV is less common than with BEV. This is due to the inclusion of a small ICE which removes the range issues of batteries, therefore these vehicles are less dependent on being able to recharge quickly if the battery power is depleted.

2.2.7 EREV Vehicles

This section considers the battery technology for extended-range electric vehicles (EREV) as defined in Table 2. This type of vehicle has the same properties as M1 class vehicles and will be assumed to be appropriate for N1 class vehicles as well.

Figure 45: Lotus 'Evora 414E Hybrid' [20]

Figure 46: Chevrolet 'Volt' [21]

Figure 47 shows that the battery capacity of EREV is smaller than similar class BEV; however the drivetrain power remains similar. In this case there is good correlation between battery capacity and drivetrain power.

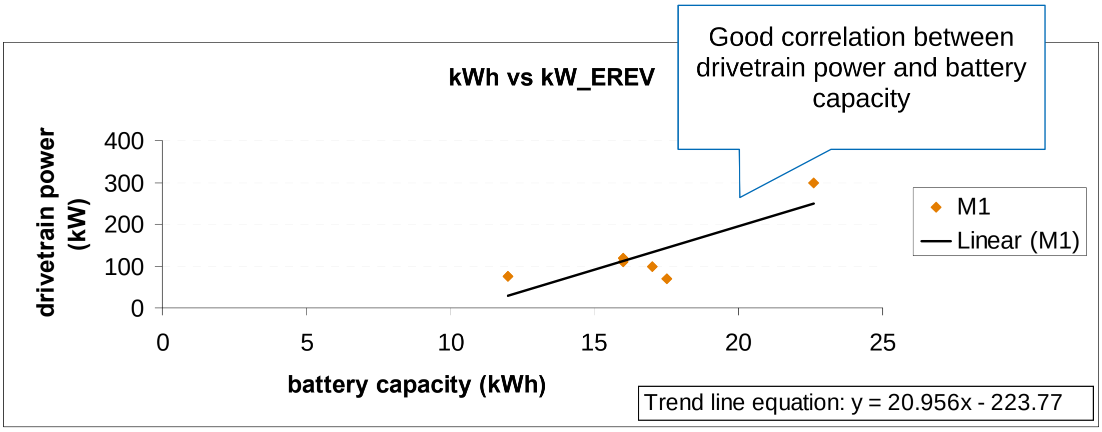


Figure 47: Summary graph of drivetrain power versus battery capacity for EREV vehicles (Source: Ricardo analysis)

Statistical distributions of battery parameters by vehicle class EREV (7 examples found)

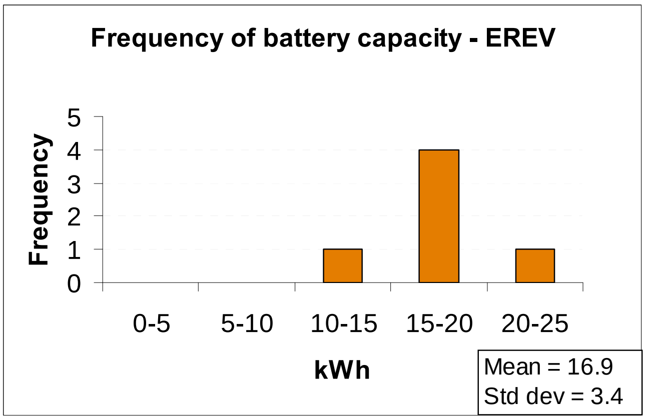


Figure 48: Frequency of battery capacity - EREV (Source: Ricardo analysis)

Figure 48, shows the battery capacity of this class of vehicle. Since they do not use the battery as their sole source of power, the battery capacity is generally lower than that of an M1 class vehicle (16.9 kWh vs 28.5 kWh).

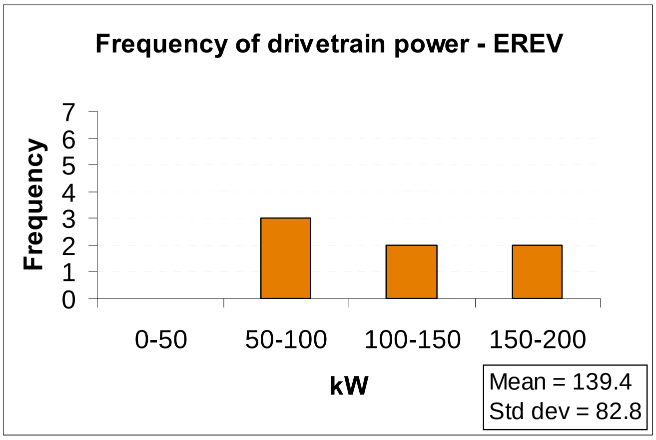


Figure 49: Frequency of drivetrain power - EREV (Source: Ricardo analysis)

The drivetrain power of these vehicles remains similar to M1 EV (91 kW for BEV vs 139 kW for PHEV) (Figure 49).

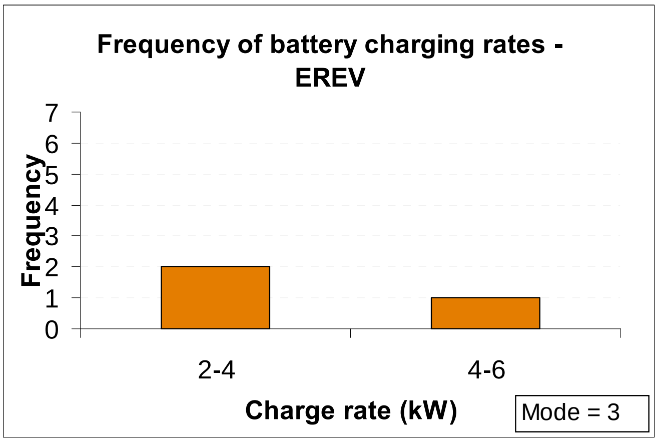


Figure 50: Frequency of charging rates - EREV (Source: Ricardo analysis)

As with M1 and L7e vehicles, the charge rate required is typically 3kW as shown in Figure 50 due to the relatively small battery capacity.

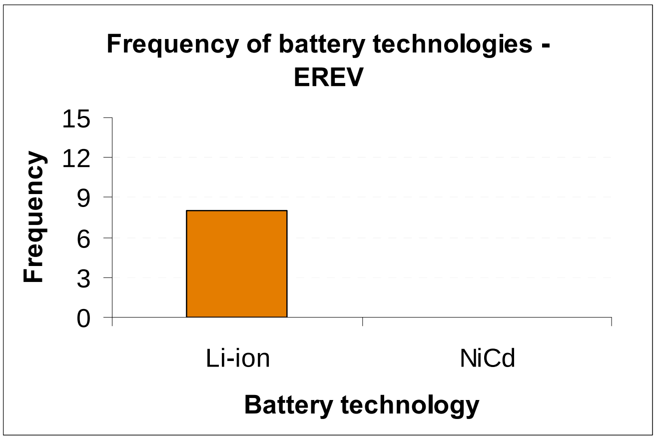


Figure 51: Frequency of battery technologies - EREV (Source: Ricardo analysis)

As these vehicles have a high number of charge and discharge cycles, the prevalent battery technology is Li-ion (Figure 51).

The EREV class of vehicles has arisen largely to address the concerns with range that BEV have. This is addressed with the inclusion of a small engine/generator, which in turn allows a reduction of the battery capacity required. This means that the overall cost of the vehicle is reduced as there is no need to supply the vehicle with large/expensive batteries.

Table 16 and Table 17 give the summary battery capacity and charging rates for EREV.

Type		Battery Capacity (kWh)			Comments
		Mean	Min	Max	
M1	EREV	17	12	22.6	Since EREV vehicles do not use the battery as sole source of power, battery capacity is lower than equivalent M1 BEV
N1	EREV	17	12	22.6	Assumed the same as M1 for EREV

Table 16: summary of EREV battery capacity

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate (kW)	Comments
		Mode	Min	Max	Range	
M1	EREV	3	3	5.3	-	Charging rate is typically 3kW No examples of fast charge rate found for EREV
N1	EREV	3	3	5.3	-	Assumed the same as M1 for EREV

Table 17: Summary of EREV charging rates

As with PHEV, EREV have an ICE which removes the range anxiety of BEV therefore, it is quite likely that fast charge capacity is not included in this type of vehicle.

2.2.8 Claimed EV Ranges for L7e, M1, N1, N2, PHEV and EREV

This section looks at the claimed electric (only) vehicle range of the different vehicle classes stated in the previous sections.

It is important to note that claimed EV ranges are often based on manufacturers' claims and will depend heavily on the drive-cycle used, and to a lesser extent on the ambient temperature affecting both battery efficiency and ancillary heating to warm the passenger cabin. Please treat claimed range values with caution.

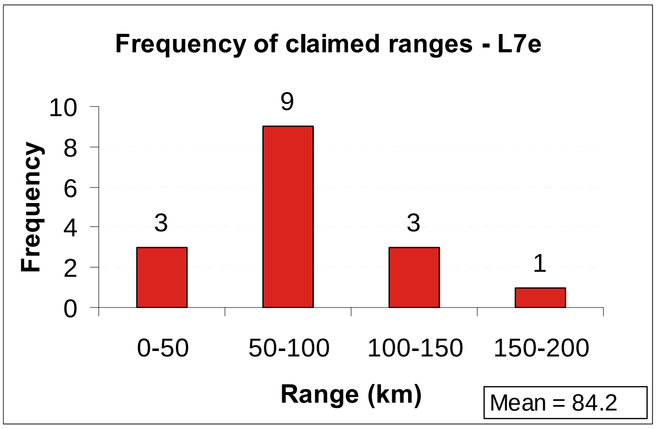


Figure 52: Frequency of claimed ranges - L7e (Source: Ricardo analysis)

Typical claimed vehicle range for L7e is circa 85 km on average as seen in Figure 52.

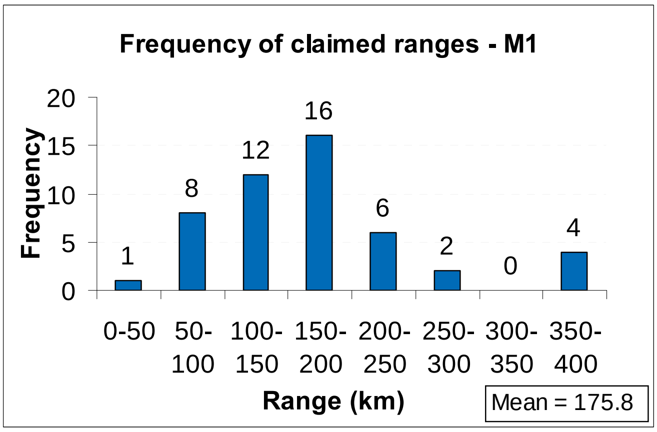


Figure 53: Frequency of claimed ranges - M1 (Source: Ricardo analysis)

Figure 53 shows that M1 vehicles have an average range of 175 km, with some high performance vehicles claiming up to 350 km range.

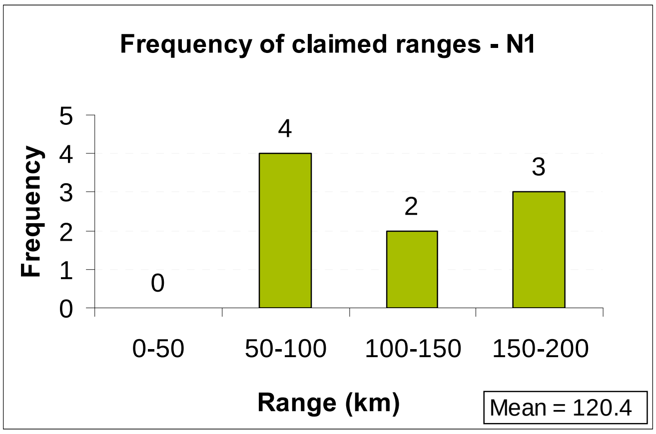


Figure 54: Frequency of claimed ranges - N1 (Source: Ricardo analysis)

N1 class vehicles have a higher range of circa 120 km on average (Figure 54). This makes these vehicles a good match for fleet vehicles which operate within a small area.

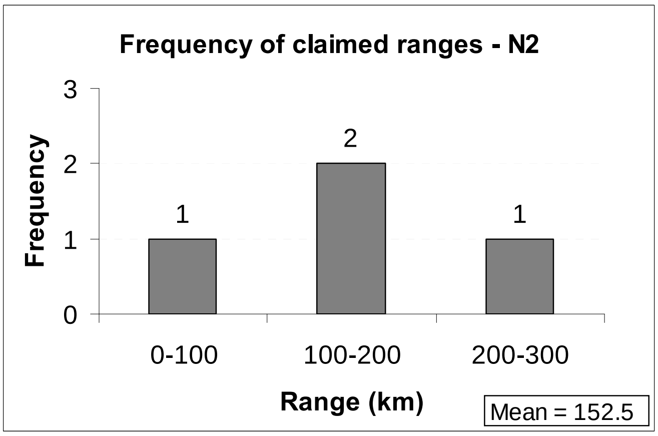


Figure 55: Frequency of claimed ranges - N2 (Source: Ricardo analysis)

N2 vehicles have an average range of circa 150 km. This is principally due to the larger battery capacity that these vehicles possess (Figure 55).

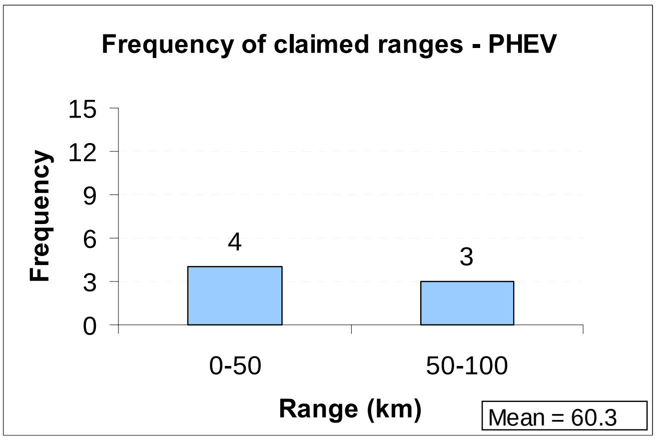


Figure 56: Frequency of claimed ranges - PHEV (Source: Ricardo analysis)

Typical average EV range for a PHEV is 60 km as can be seen in Figure 56.

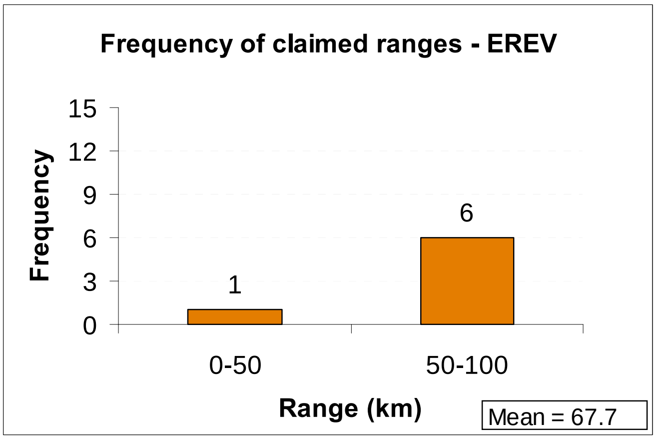


Figure 57: Frequency of claimed ranges - EREV (Source: Ricardo analysis)

The average EV range for an EREV is circa 68 km (Figure 57).

2.2.9 Claimed Vehicle Energy Consumption for L7e, M1, N1, N2, PHEV and EREV

This section looks at the claimed vehicle energy consumption of the different vehicle classes stated in the previous sections.

It is important to note that these values have been calculated using values from manufacturers' claims and will depend heavily on the drive-cycle used – treat these consumption values with caution.

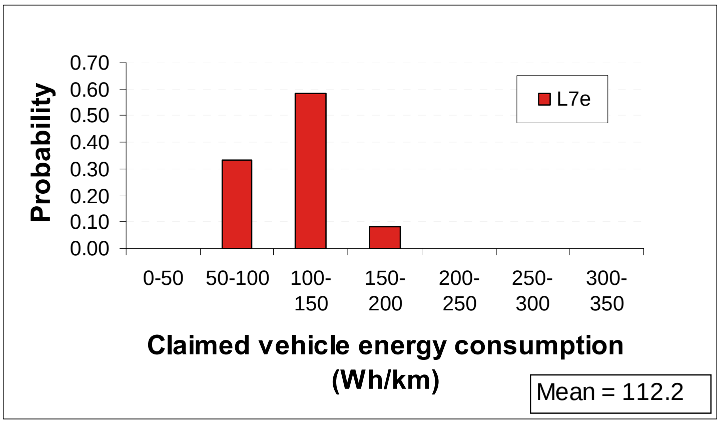
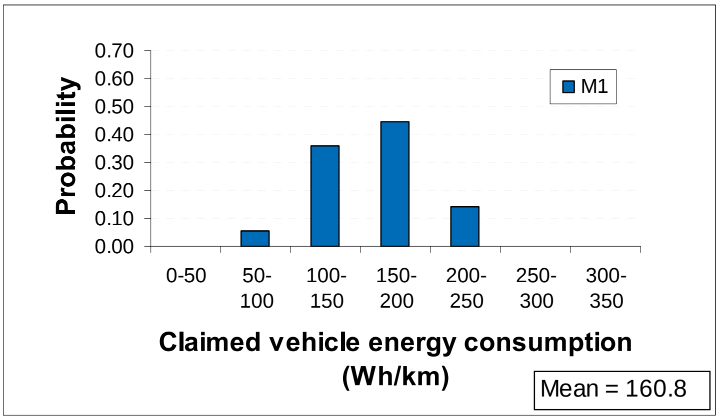


Figure 58 shows that L7e vehicles have relatively low mean consumption, circa 112 Wh per km.

Figure 58: Claimed vehicle energy consumption - L7e



M1 vehicles have a slightly higher mean consumption of circa 160 Wh per km (Figure 59).

Figure 59: Claimed vehicle energy consumption – M1

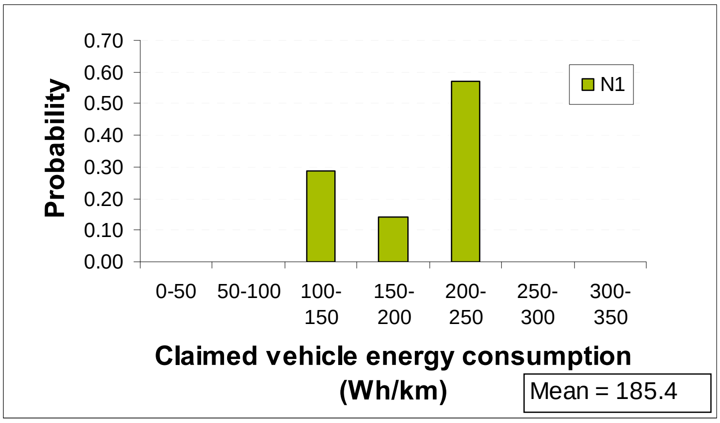


Figure 60: Claimed vehicle energy consumption – N1

N1 vehicles have higher mean energy consumption than M1 vehicles since they are larger, 185 Wh/km vs 160 Wh/km (Figure 60).

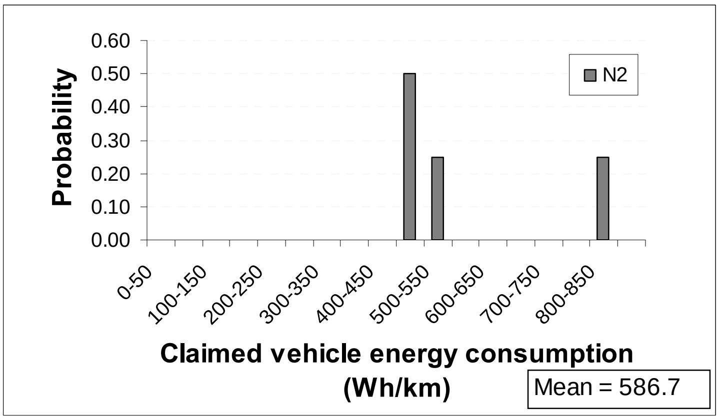


Figure 61: Claimed vehicle energy consumption – N2

The largest vehicle category, N2 has the highest mean consumption as can be seen in Figure 61 (circa 590 Wh/km).

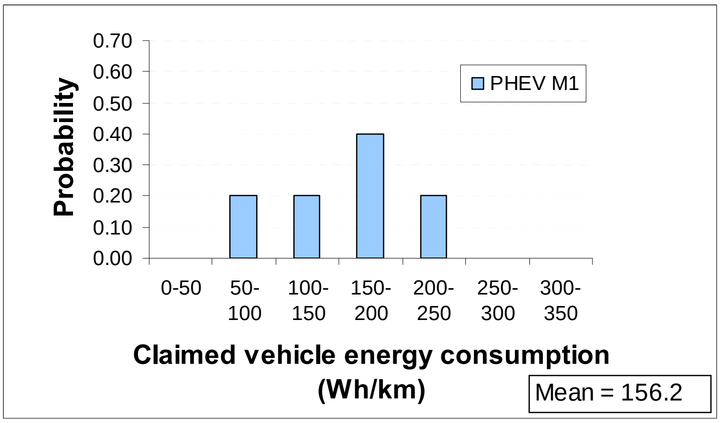


Figure 62: Claimed vehicle energy consumption – PHEV M1

Mean consumption for M1 PHEV is similar to M1 BEV at circa 156 Wh/km (Figure 62).

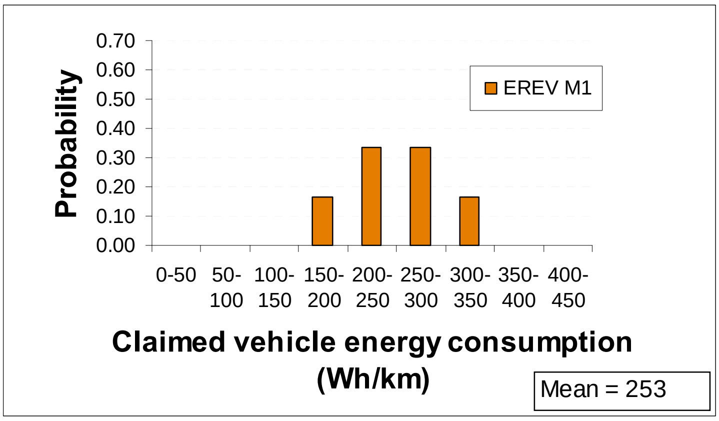


Figure 63: Claimed vehicle energy consumption – EREV M1

Mean energy consumption for EREV is slightly higher at 253 Wh/km (Figure 63).

2.3 Cell Specifications

This section gives a review of the cell specifications for EV batteries. For a more complete overview of battery technology, please refer to Axeon's "Our Guide to Batteries" [2] and AGM's "Li-ion Product Datasheet" [24].

2.3.1 Effects of discharge cycles on battery lifetime

Exercising batteries or cells with repeated charge/discharge cycles is known to reduce their life. Different equations describing the wear-out process exist in literature and two alternative sources of generic cell ageing curves for different EV battery chemistries were considered:

1) Markel et al suggested a set of equations that can be seen in Figure 64 [22].

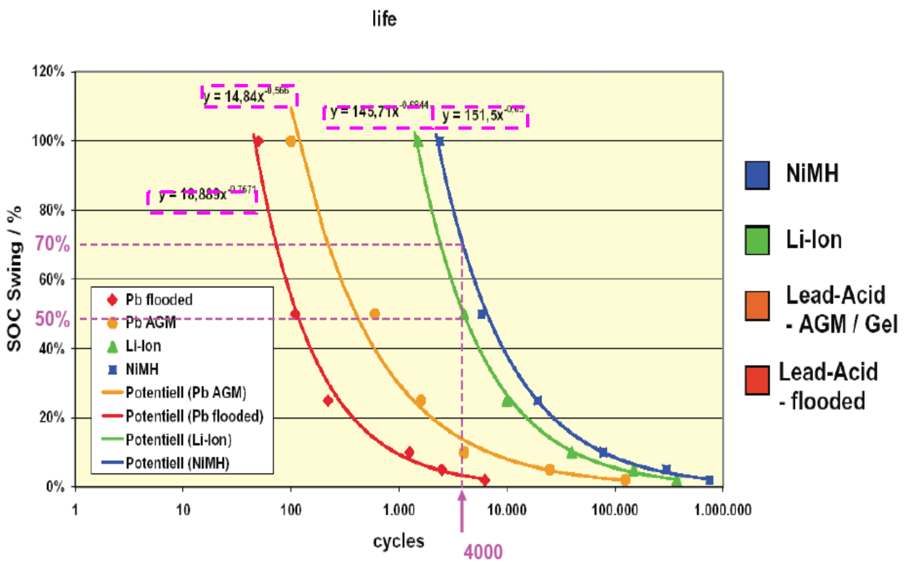


Figure 64: Reduction of battery capacity as a function of cycle number [22]

2) A set of generic curves was obtained from Firefly Energy shown in Figure 65.

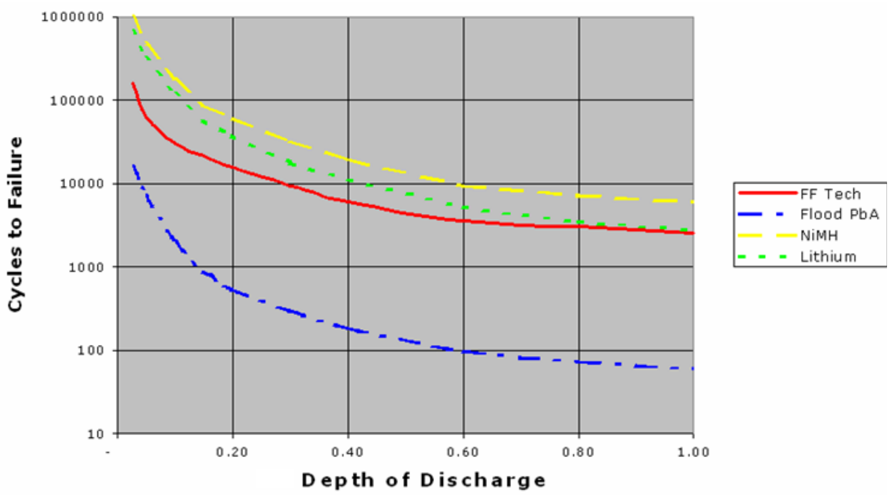


Figure 65: Battery DOD as a function of cycle life [23]

2.3.2 Proposed cell ageing data

For this work, it is proposed to use the Markel et al cell ageing data for the following reasons:

1) It is a generic representation (hence no single curve will be 'correct' for all batteries' conditions).
2) It provides curve equations which are easier to represent in a model.
3) When plotted on the same axes, it matches the corresponding Firefly Energy data well for DOD>30% (Li-ion) and for all DOD (flooded PbA, AGM PbA).

The comparison graphs that were plotted are shown below:

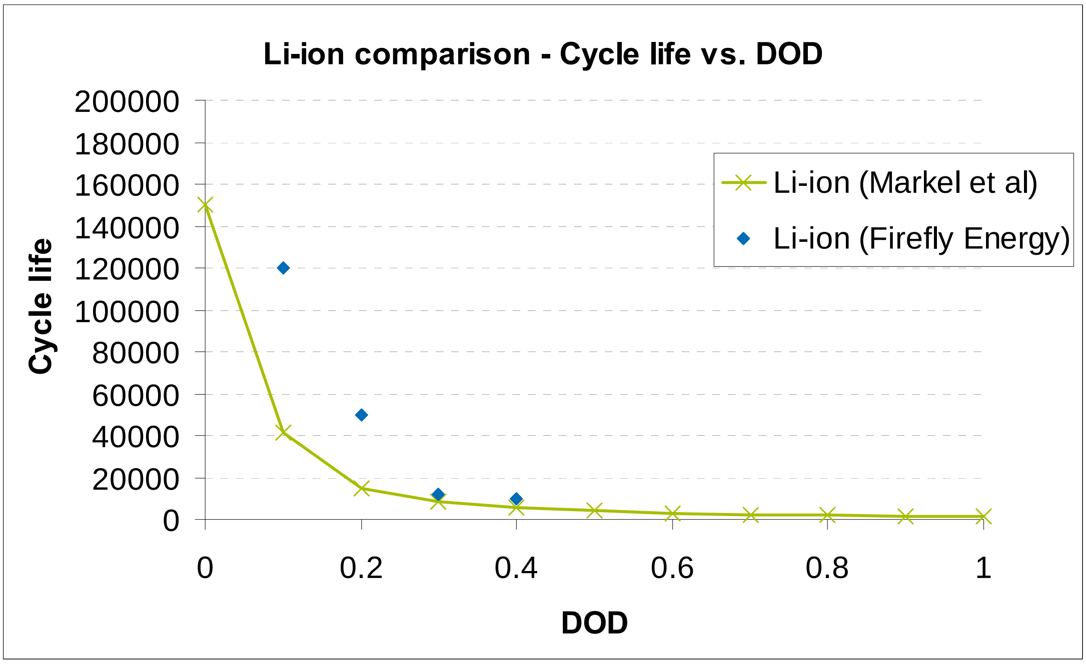


Figure 66: Cycle life versus DOD for Li-ion batteries (Source: [22], [23], Ricardo analysis)

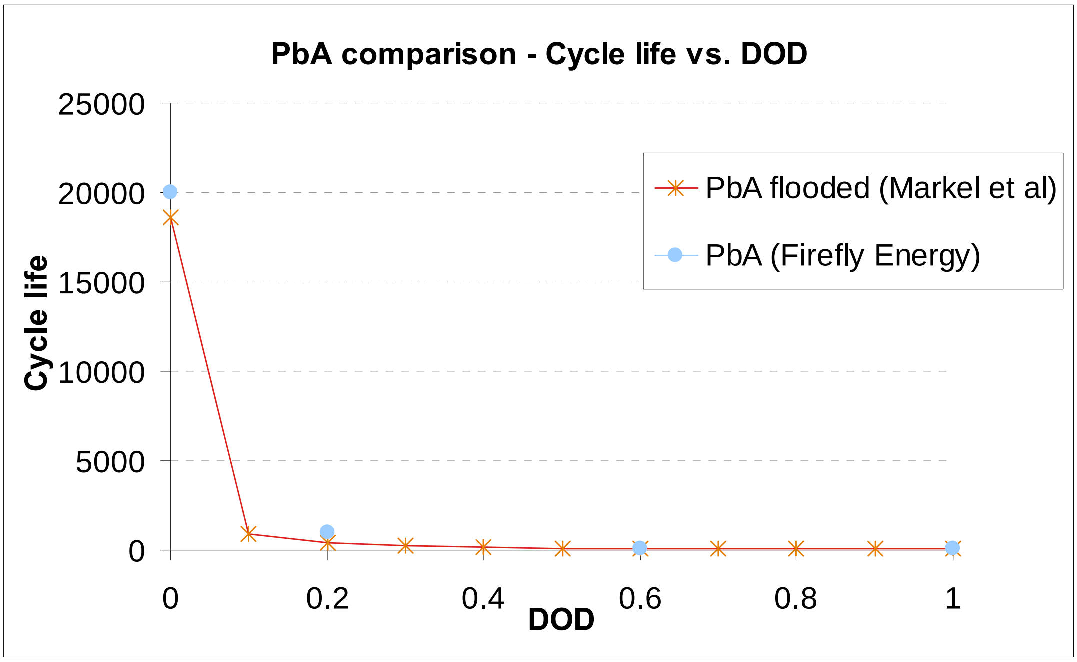


Figure 67: Cycle life versus DOD for PbA batteries (Source [22], [23], Ricardo analysis)

The equations from both sources showed similar trends for Li-ion and PbA (Figure 66 and Figure 67).

The curve equations highlighted in Figure 64 are as follows:

- Li-ion $y = 145.71x^{-0.6844}$
- PbA (flooded) $y = 18.889x^{-0.7671}$
- PbA AGM $y = 14.84x^{-0.565}$
- NiMH $y = 151.5x^{-0.65}$

The equation for NiMH is available, but it will not be used in this report.

The supplied data showed DOD as a function of cycle lifetime and these needed to be transposed to give cycle lifetime as a function of DOD.

Hence, from the curve equations, the proposed cycle life (C_F) equations are:

Equation 1: Cycle life of a Li-ion battery

$$C_F = \exp\left(\frac{-Ln(DOD)}{0.685 + 7.25}\right)$$

Equation 2: Cycle life of a PbA (flooded) battery

$$C_F = \exp\left(\frac{-Ln(DOD)}{0.7671 + 3.826}\right)$$

Equation 3: Cycle life of a PbA (AGM) battery

$$C_F = \exp\left(\frac{-Ln(DOD)}{0.565 + 4.76}\right)$$

Where 0<=DOD<=1

Li-ion worked example:

A DOD swing of 0.5 would mean a SOC swing of 50%, e.g. SOC changing from 70% to 20%, or 90% to 40%, etc).

$$C_F = \exp\left(\frac{-Ln(0.5)}{0.685 + 7.25}\right) = 3950$$

Therefore, a Li-ion battery that was exercised through a SOC swing of 50% would have a cycle lifetime of 3950 cycles before it needed replacing. This ignores calendar lifetime factors, which are considered later in the report (Section 2.6).

2.3.3 Facinelli Miner Rule:

The Facinelli Miner Rule states that the wear-out damage done during a given single cycle is assumed to be $1/C_F$. After sufficient cycles have passed that the fractions multiplied by the number of cycles (i.e. the 'damage') reach 1.0, the battery is assumed to be spent and a new one must be substituted.

This approach allows the estimation of the summation of wear-out damage caused by subjecting the battery to different DOD over its lifetime. This allows MERGE partners to use the technique to model the effects of different combinations of charge/discharge cycles.

For example, if 20 different cycles were run on a battery, then the damage done (D) is the summation of the individual damage done by each cycle and is given in Equation 4:

Equation 4: Facinelli Miner Rule

$$D = \sum_{i=1}^{20} N_i \frac{1}{C_{F,i}}$$

2.3.4 Charge/Discharge Rate Limits

Cell manufacturers provide cells with charging limitations. Typical charging characteristics are carried out using a combination of constant current (CC) and constant voltage (CV) modes as illustrated in Figure 68 (described in further detail in Section 3 of this report).

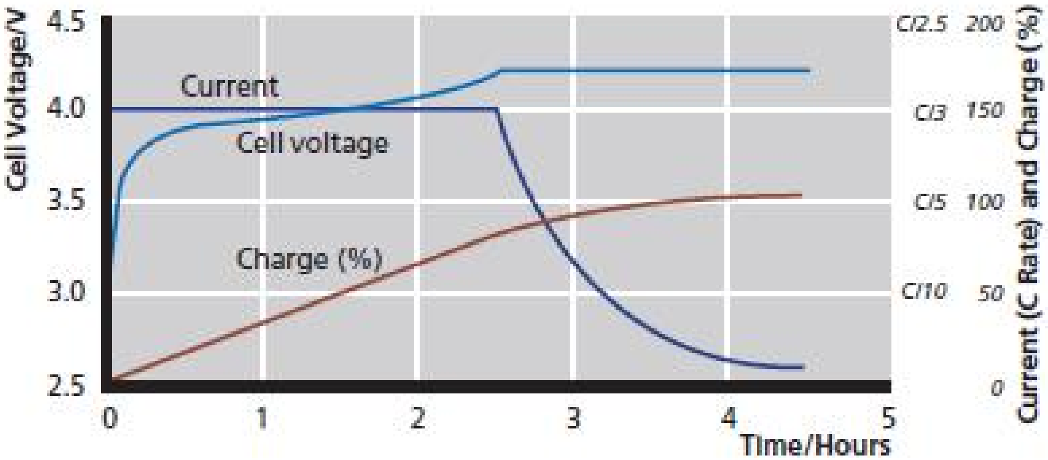


Figure 68: Charging method: CC-CV [24]

Figure 69 illustrates the range of possible discharging/charging rates for a typical EV battery cell [25].

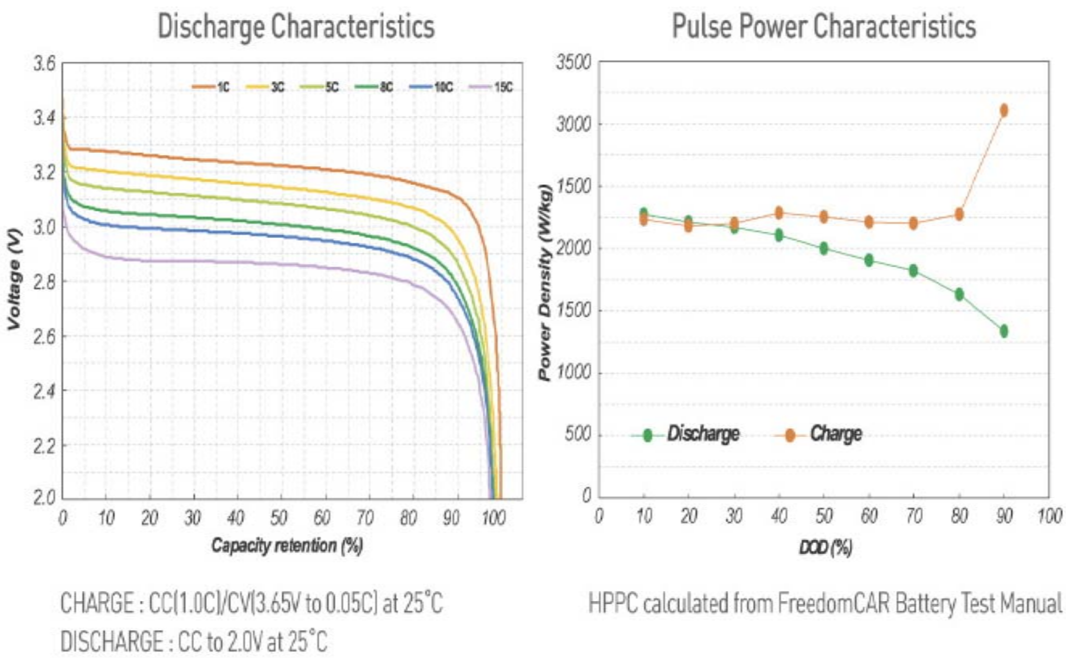


Figure 69: Charging characteristics of an EIG 'ePLB F014' battery [25]

Long term discharging of this cell (Figure 69, left-hand graph) starts at 1C rate until the cell voltage is reached. Then the voltage is maintained until the cell current drops off to 0.05C.

Short-term charging or ‘pulse’ charging depends on the DOD of the cell. Maximum rates for pulse charging can be from 15C up to 20C if the cell was nearly discharged.

Charge rates between these extremes are possible, but the final cell charge rate is dependant on factors such as cell temperature, DOD and SOH.

2.3.5 Battery Internal Resistance

As part of the battery model to be employed by the MERGE partners, the equivalent internal resistance of the vehicle battery is required.

An EV battery is typically made up of several ‘strings’ of cells, where the battery capacity defines total number of cells and the required battery voltage defines the number of cells in series.

So for a battery of a known capacity and voltage (such as the examples surveyed in the EV database, Section 2.2) it is possible to estimate the internal resistance.

A method of estimating the size and hence the internal resistance of the battery is described as follows:

- **Number of cells per string**. The number of battery cells per string is given by the vehicle system voltage divided by the nominal cell voltage (using cell data supplied from cell manufacturer). This is represented in Figure 70.

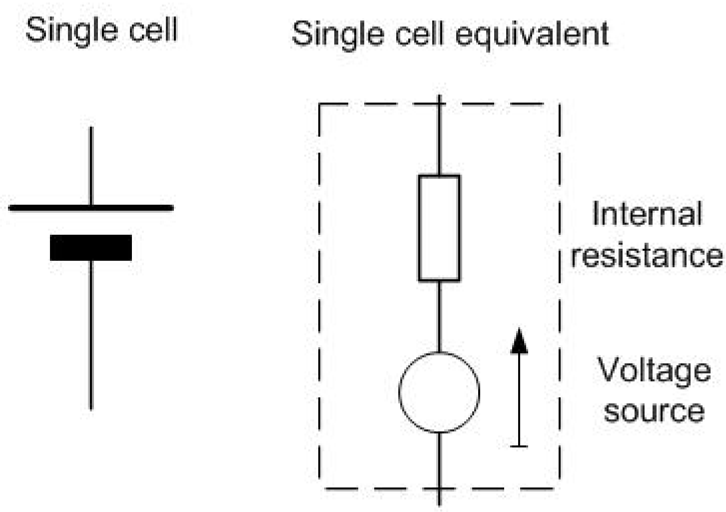


Figure 70: Schematic of a cell (Source: Ricardo analysis)

  The equivalent resistance per string is then given by the internal resistance per cell times the number of cells per string.

- **Number of parallel strings**. Most EV batteries use a number of parallel strings of cells to make up the power and energy that the vehicle requires, as can be seen in Figure 71.

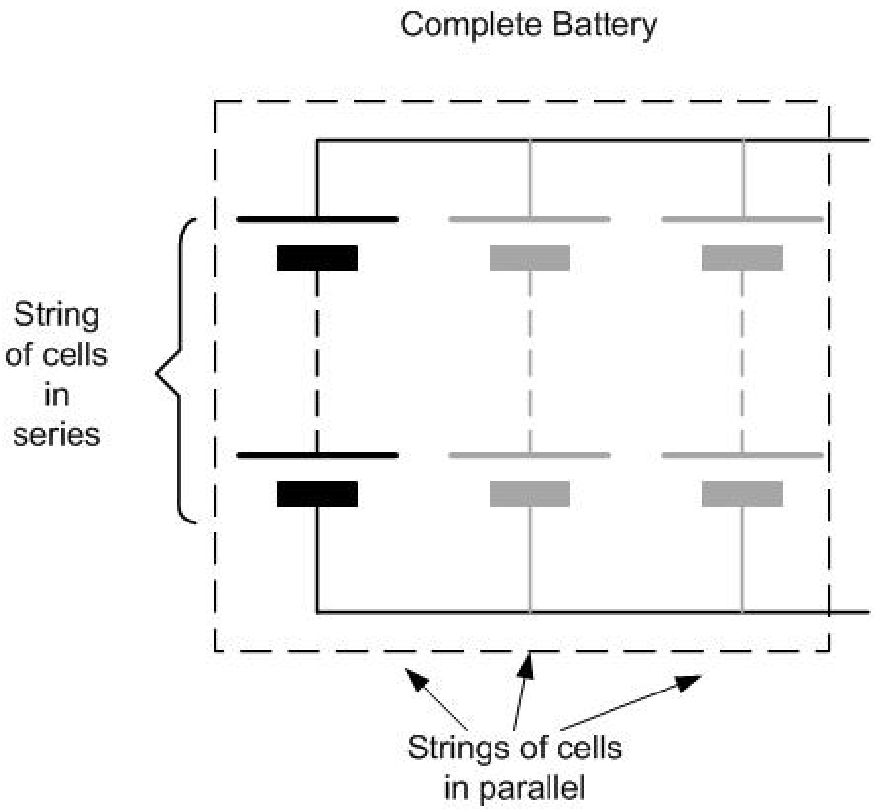


Figure 71: Schematic of a string of cells (Source: Ricardo analyisis)

The number of parallel strings that will give the required **power** is estimated; then the number of parallel strings that will give the required **energy** is also estimated. The number of parallel strings required is the larger of these two estimates.

- **Power calculation**. At full power, the voltage drop across the internal resistance of each string is given by the maximum current per cell multiplied by the internal resistance of the string.

  Then, the maximum power per string is equal to the nominal string voltage minus the voltage drop per string, multiplied by the maximum cell current.

  The vehicle power requirement is then made up by a number of strings, each contributing to the total power.
- **Energy Calculation**. The battery capacity divided by the capacity per cell gives a minimum total number of cells required. Obviously, cells can only be added to the battery in integer numbers of strings, so the actual number of cells required to provide the energy requirement will be a multiple of the number of cells per string.

Battery resistance worked examples:

- A typical cell, the EiG F014 Li-ion cell [25] has the following characteristics,
  - Cell nominal voltage 3.2V

  - Cell capacity 14Ah (equals 46.2Wh)
  - Cell internal resistance 5mOhm
  - Maximum cell current 280A (short term maximum)

- For a 30kWh, 100kW, 300V battery, typical for an **M1** application,
  - Number of cells per string = 300/3.2 = 94 cells
  - Number of strings per battery (power calculation) = 47kW per string, so needs at least 3 strings
  - Number of strings per battery (energy calculation) = 650cells, or at least 7 strings
  - So the battery would have 94 cells per string and 7 parallel strings
  - Battery total resistance equals 94 multiplied by 5mOhm per string (0.47 Ohms per string), with 7 strings in parallel, equals 67mOhm.

- For a 10kWh, 10kW, 72V battery, typical for an **L7e** application,
  - Number of cells per string = 72/3.2 = 23 cells
  - Number of strings per battery (power calculation) = 11kW per string, so needs only 1 string
  - Number of strings per battery (energy calculation) = 216 cells, or at least 10 strings
  - So the battery would have 23 cells per string and 10 parallel strings.
  - Battery total resistance equals 23 multiplied by 5mOhm per string (0.115 Ohms per string), with 10 strings in parallel, equals 11mOhm.

These nominal resistance values will increase with battery age, as discussed later in Section 2.6.

2.3.6 Battery Size Developments

Ricardo was asked to predict the likely changes in vehicle battery parameters that would be likely to occur over the next 10 years. Figure 72 shows estimations of expected changes in battery technology during the period requested for different vehicle types.

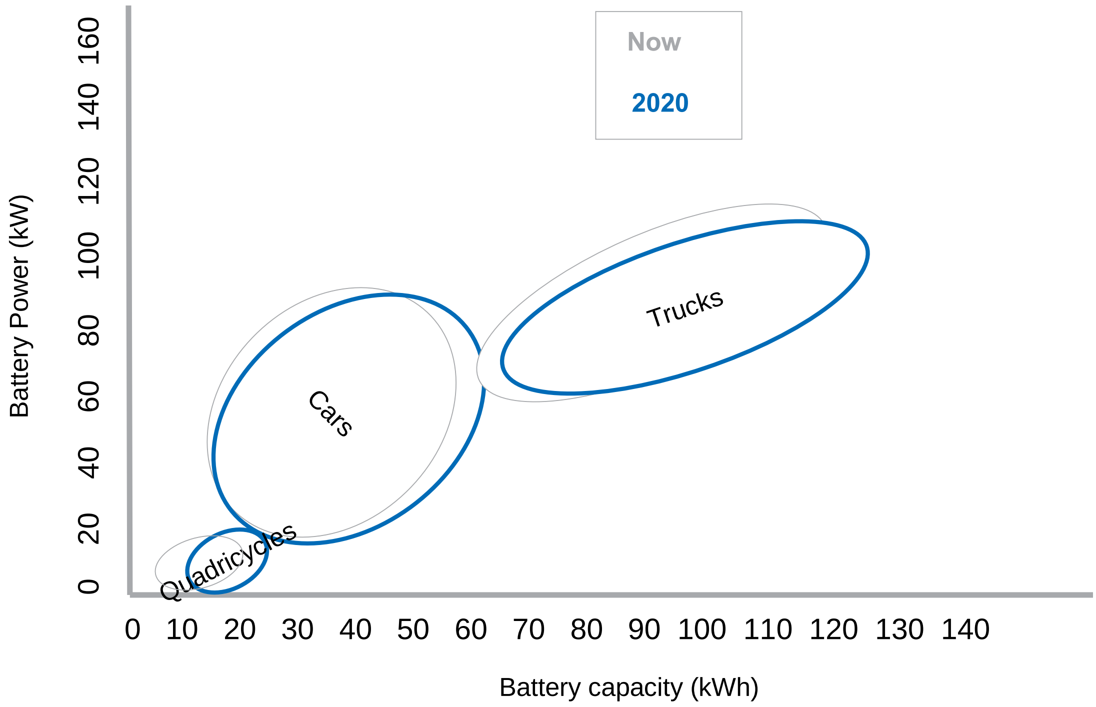


Figure 72: Expected battery technology changes 2010-2020 (Source: Ricardo analysis)

Although Li-ion technology is progressing quickly, the main barrier to greater usage is the high cost of batteries. For this reason, the main developments predicted would be to reduce the cost of batteries, rather than increasing their capacity or power. Hence, only minor growths in capacity are expected. However, where there is growth in capacity it is mainly where lead-acid batteries have been phased out in favour of Li-ion batteries.

Similarly, power levels are expected to remain constant; a vehicle that needs 50kW now will still need 50kW in 2020.

2.4 EV Market Data

2.4.1 Vehicle age by class

This section introduces some key information about the EV vehicle market. Since very few EV were sold across Europe during the period that this report was written, the market data collected mainly shows the information on current ICE vehicles. Average lifetime and attrition rates of these vehicles are discussed below.

It is important to note that there are discrepancies between different data collection organisations as the data collected is vast and has many variables depending on each individual country as will be seen in the following discussions.

The average age of road vehicles is determined by the vehicles in the European stock. This is made up of existing vehicles, new car sales and vehicles that are at their 'end of life'. End of life vehicles (ELV) are those that have come to the end of their usable life, or that have been in an accident and as a result have to be taken of the road. These vehicles are then taken to the scrap yard and recycled, in most cases up to 80% of their mass [26]. The rate at which vehicles or ELV are taken of the road is called a 'scrappage rate'. It is also known as the attrition curve of the vehicle stock (Figure 73).

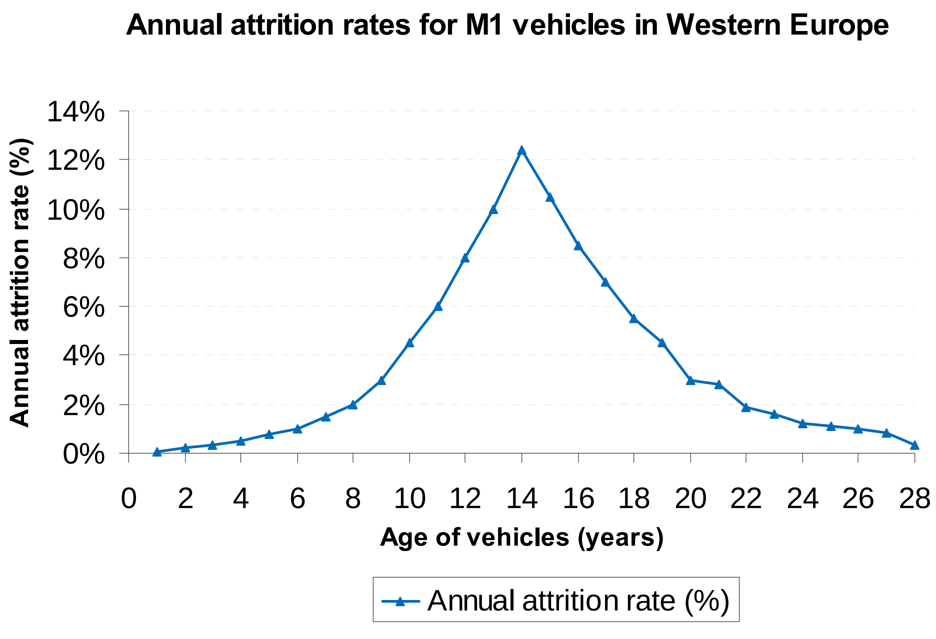


Figure 73: Average vehicle attrition curve for Europe (Source: Ricardo analysis)

Each country has its own unique attrition rate which can be affected by many variables including transport infrastructure, climate and economy. However, a single profile will be used in this analysis which is an average of all the countries.

The Western European countries that are considered in this curve include Germany, Greece, Portugal, Spain and the UK. From this curve it is possible to see that the average life of European vehicles is circa 14 years.

Please refer to MERGE Task 3.2 report by Ricardo for more information on the attrition curves used in this report.

2.5 EV Usage Data

2.5.1 Vehicle distance by vehicle class

This section introduces EV usage data. In order to provide a baseline for comparison, some typical key usage data for current vehicles is provided. The data has been used from Section 2.4. However, because of the available data at the time of this study, this data covers predominantly ICE vehicles. Figure 74 below gives information on the typical distance travelled by a European passenger car (M1) in 2008, as well as other vehicle classes.

	Class	Average distance (km/year)
EU15	**L7e**	-
	M1	13,985
	N1	20,457
	N2	49,647

Figure 74: Average distance travelled per annum [27], [28]

This gives an overview of the make-up of vehicles on the road network in any one year. The following section will look more specifically at vehicle journeys of an M1 class vehicle in a day.

2.5.2 Vehicle trips by distance

In order to illustrate the effects of daily usage of an EV, vehicle range data from the EV database and from MERGE Task 1.5 was analysed. This was carried out to give a percentage of daily trips made according to the average distance. Figure 75 and Figure 76 are the outputs from this and represent typical week day trips and weekend trips correspondingly.

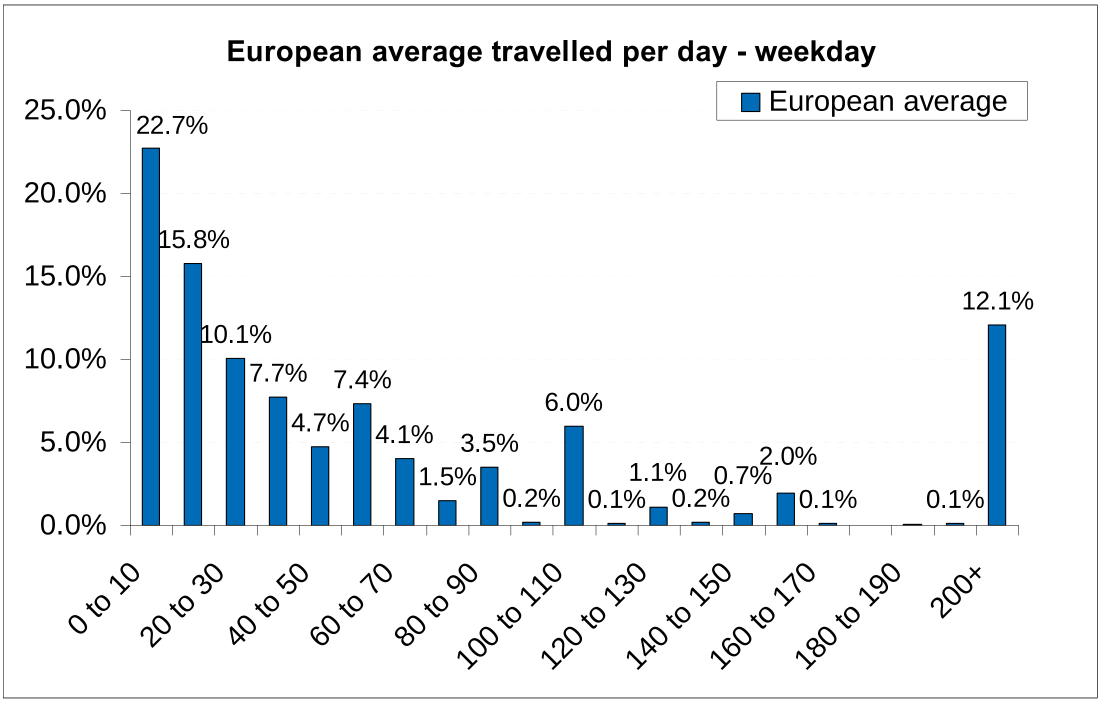


Figure 75: European average travelled per day – week day (Source: Ricardo analysis)

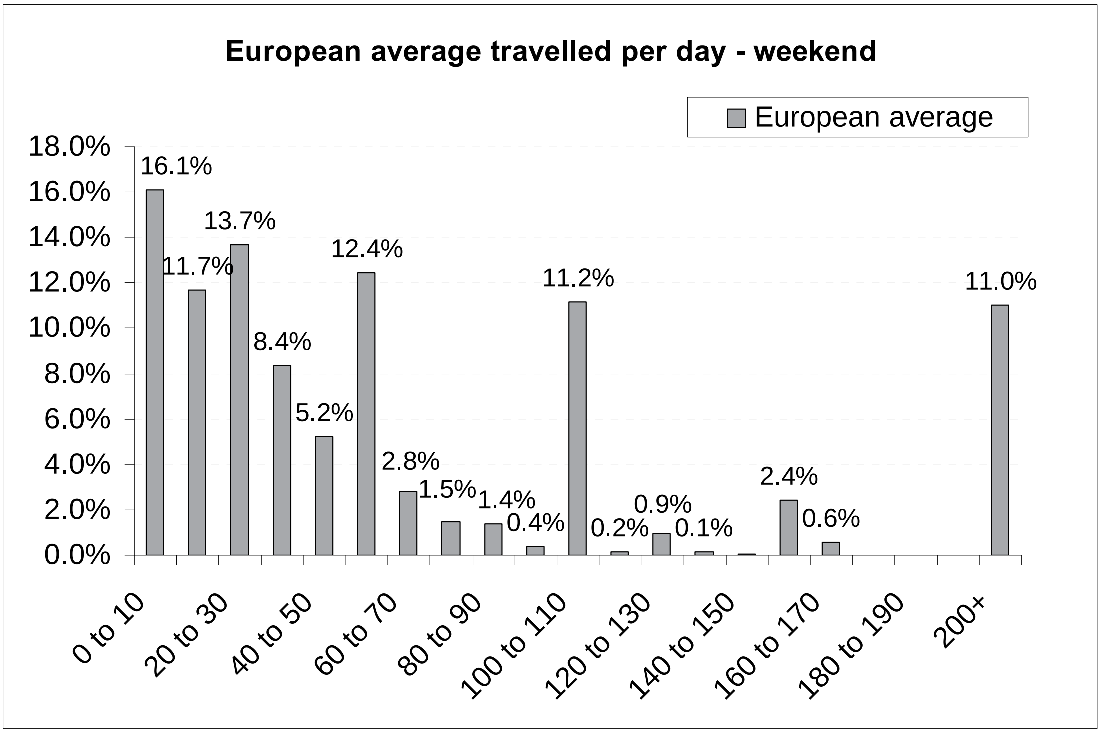


Figure 76: European average travelled per day – weekend (Source: Ricardo analysis)

From this data, it is possible to consider three vehicle scenarios in order to quantify their suitability: EV with a maximum operating range of (i) 160km, (ii) 80km, and (iii) 50km making daily journeys according to the vehicle usage data stated above.

2.5.3 160 km range EV

- 48.6% of all weekday journeys are **30 km** (return) or less, *87.6% are 160km or less* (Figure 77).

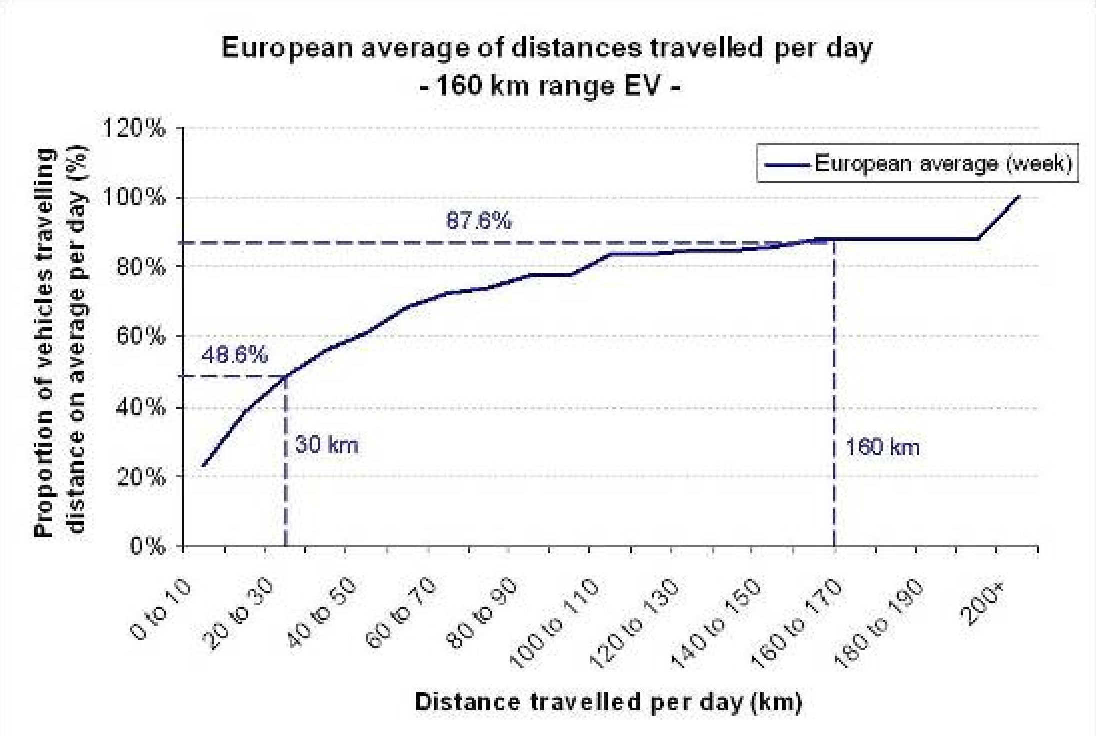


Figure 77: Suitability of a 160 km range EV for European journeys (week days) (Source: Ricardo analysis)

- 49.9% of all weekend journeys are **40 km** (return) or less, *88.4% are 160km or less* (Figure 78).

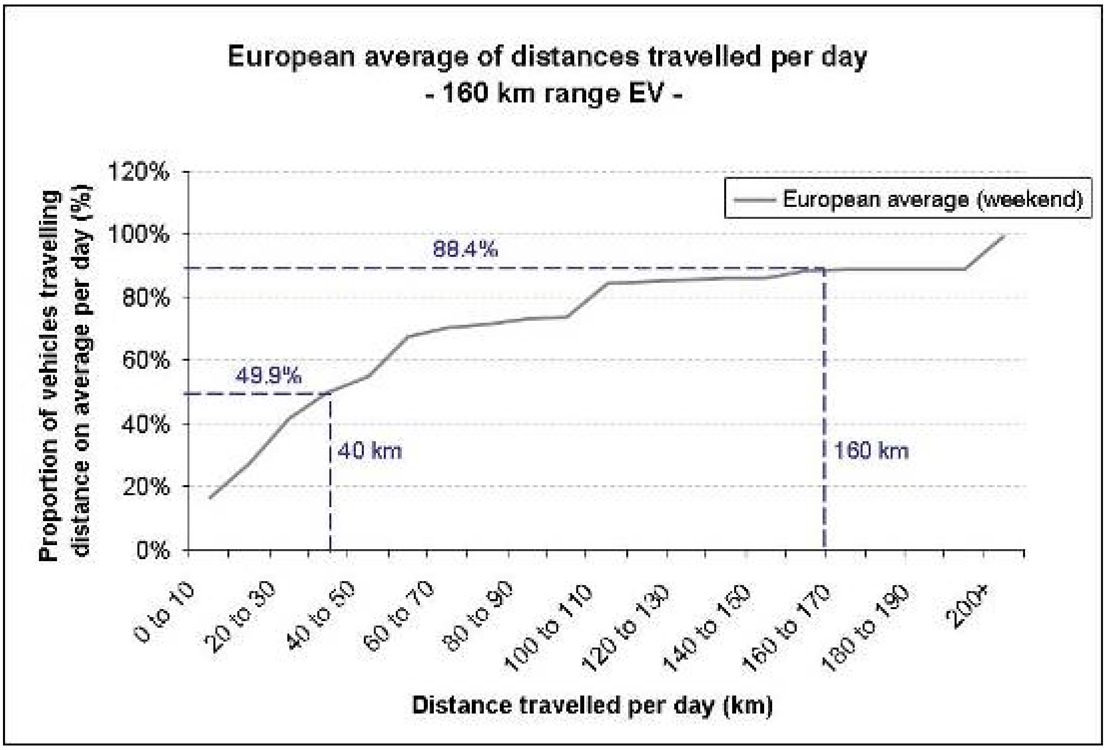


Figure 78: Suitability of a 160 km range EV for European journeys (weekend) (Source: Ricardo analysis)

- Thus, for a 160 km range EV this would require a daily SOC reduction of up to 30/160*100 = **18.75%** on week days.
- At the weekend, it would require a daily SOC reduction of up to: 40/160*100 = **25%**

Therefore it can be said that an EV with a 160 km range capacity is more than sufficient for the majority of short-range journeys within Europe, depending on the duty cycle, requiring relatively small charge amounts to fully recharge the batteries.

2.5.4 80 km range EV

- 48.6% of all weekday journeys are **30 km** (return) or less, *74.0% are 80km or less* (Figure 79).

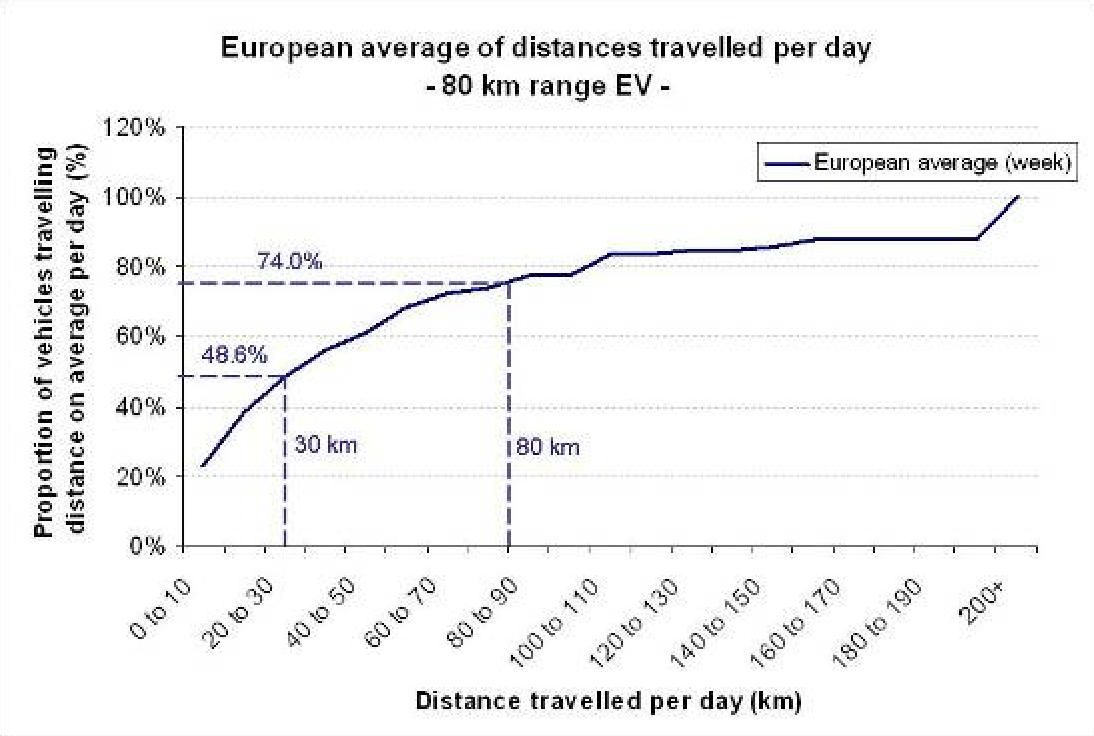


Figure 79: Suitability of an 80 km range EV for European journeys (week days) (Source: Ricardo analysis)

- 49.9% of all weekend journeys are **40 km** (return) or less, *71.8% are 80km or less* (Figure 80).

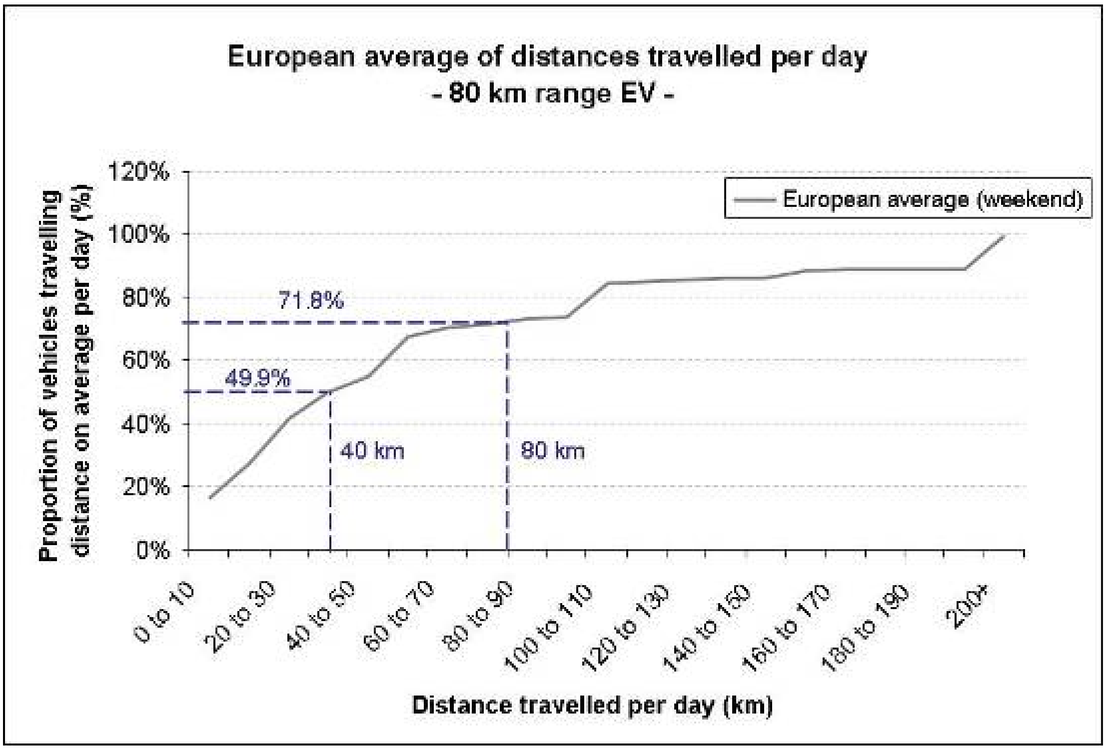


Figure 80: Suitability of an 80 km range EV for European journeys (weekend) (Source: Ricardo analysis)

- Thus, for an 80 km range EV this would require a weekday daily SOC reduction of up to 30/80*100 = **37.5%**
- At the weekend, it would require a daily SOC reduction of up to: 40/80*100 = **50%**

As with the 160 km range EV (Section 2.5.3), the 80 km range EV is also suitable for a large proportion of vehicle journeys within Europe. However, the batteries will require larger charging amounts due to the increased depletion of the charge during the journey.

2.5.5 50 km range EV

- 61.1% of all weekday journeys are **50 km** (return) or less (Figure 81).

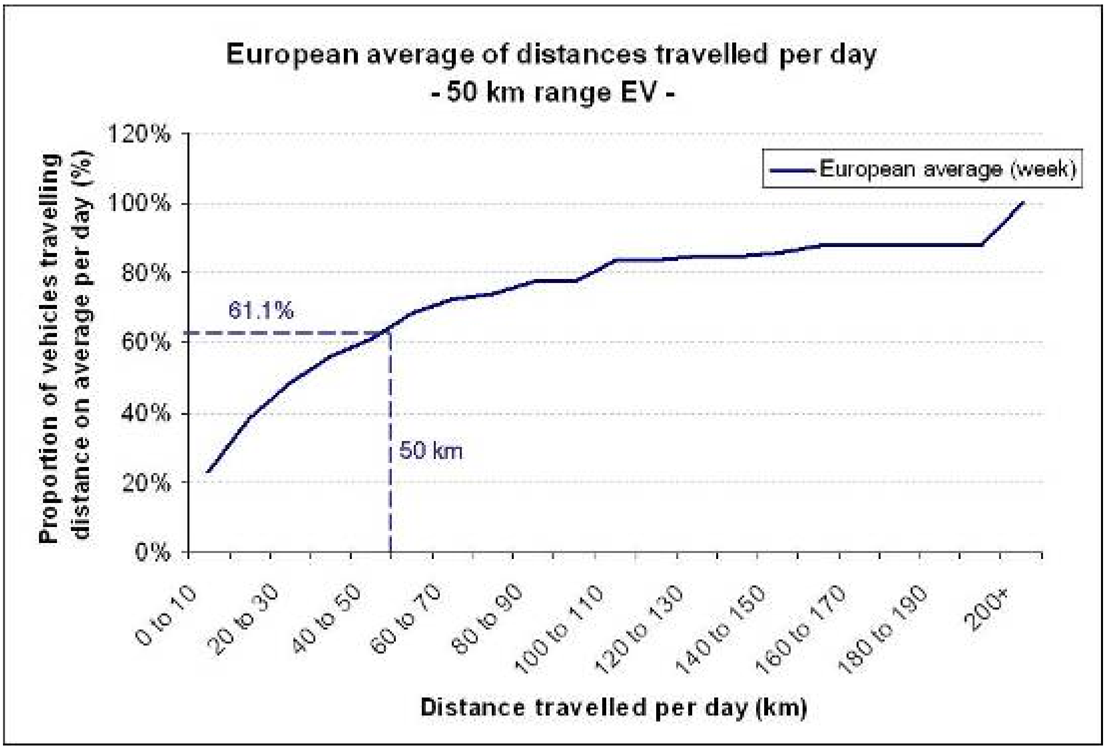


Figure 81: Suitability of a 50 km range EV for European journeys (week days) (Source: Ricardo analysis)

- 55.1% of all weekend journeys are **50 km** (return) or less (Figure 82).

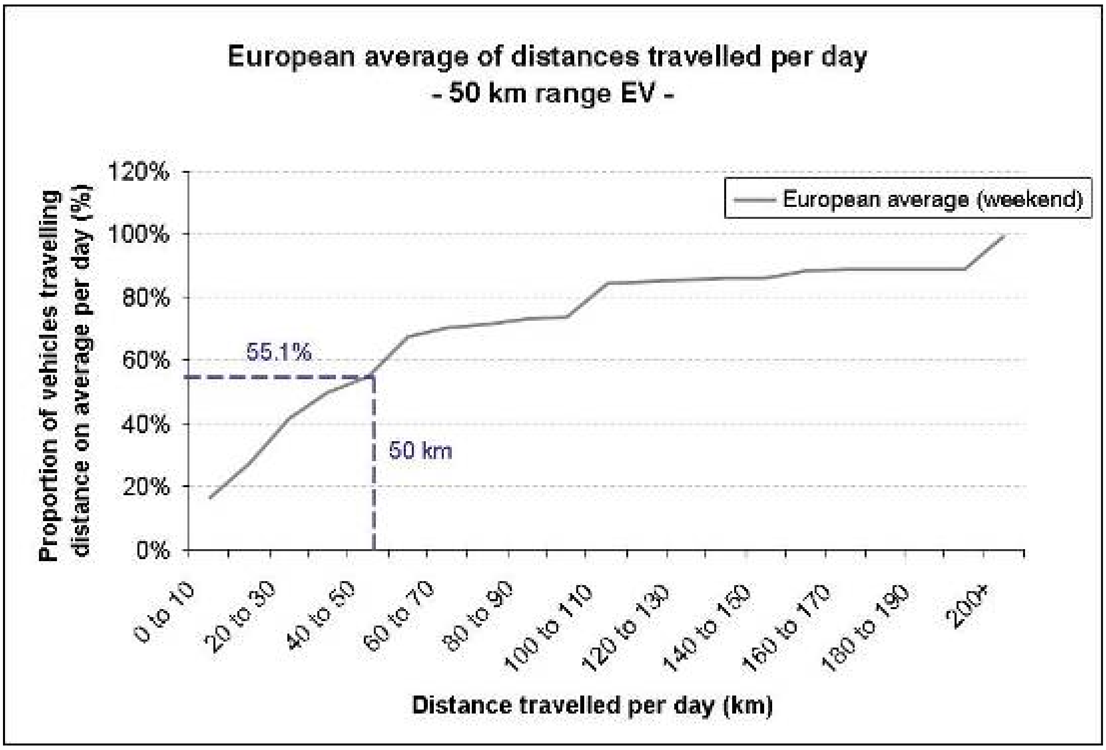


Figure 82: Suitability of a 50 km range EV for European journeys (weekend) (Source: Ricardo analysis)

- Thus, for a 50 km range EV, this would require a daily (weekday and weekend) SOC reduction of up to 50/50*100 = **100%**

For a 50 km range EV, the journeys are much more limited due to the battery capacity. Roughly half the journeys made are 50 km, so this would mean that the battery would be discharged fully for a journey of this length. It is important to note however that for most battery types, a discharge of below 80% of their initial charge is not advisable due to the detrimental effects on the battery lifetime and capacity.

2.6 Battery Ageing Effects

2.6.1 Current technology - Li-ion batteries

A battery's life is directly linked to the depth and number of charge/discharge cycles it experiences (as described in Section 2.3.1). In order to achieve an adequate cycle lifetime, usable capacity is often considered to be only 50% of the rated capacity (although for an EV the vehicle user is the final decider of journey length and hence depth of discharge).

Due to ageing, a linear reduction in battery capacity to 80% of initial capacity and linear growth of internal resistance to 120% of the initial value will occur over the lifetime of the battery. Hence these degraded capacity and internal resistance values can be substituted in MERGE partners' simulations of an ageing population of EV.

Life is determined by a combination of energy passing in/out of the battery and calendar life (e.g. the battery ages even if not used). In 2010 a life of approximately 1000 cycles of the battery's rated energy or 6 years calendar life is reasonable. Note these factors are additive, so a pack will be worn out after a combination of 3 years and 500 cycles of the battery's rated energy.

A more accurate calculation is given in Equation 5. Adding the calendar age factor to the Li-ion cycle life equation given in Section 2.3.2 (Equation 1) gives:

Equation 5: Calculation of battery life

$$Damage = \frac{N°cycles * 1}{\exp\left(-Ln(DOD) \big/ 0.685 + 7.27 \right)} + age \big/ 6$$

- Where 0<=DOD<=1 and Damage starts from 0 (new) and increases to 1 (worn-out)
  - Capacity % = 100 - (20*Damage)
  - Internal resistance % = 100 + (20*Damage)

2.6.2 Future developments - 2020 Li-ion batteries

Developments are continuing in Li-ion battery technology and it is predicted that usable capacity should increase to 80% of rated capacity in 10 years time.

Also, a life of 5000 cycles or 10 years should be available in 10 years time.

Adding this calendar age factor to the Li-ion cycle life, Equation 1, gives the approximate relationship in Equation 6:

Equation 6: Calculation of battery life - 2020

$$Damage = \frac{N°cycles * 1}{\exp\left(-Ln(DOD)\big/0.5 + 7.27\right)} + {age}\big/{10}$$

- Where 0<=DOD<=1 and Damage starts from 0 (new) and increases to 1 (worn-out)
  - Capacity % = 100 - (20*Damage)
  - Internal resistance % = 100 + (20*Damage)

2.6.3 User Acceptance of Battery Ageing

The battery industry typically uses the ‘80% of rated capacity’ as the threshold at which the battery is declared worn-out. But with an EV battery currently costing circa $1000/kWh, EV users will be tempted to continue using the battery past this point (although its deterioration is likely to accelerate). Figure 83 illustrates the non-linear effects of ageing on capacity reduction and that once the ‘end of life’ point is reached, there is little useful operation remaining.

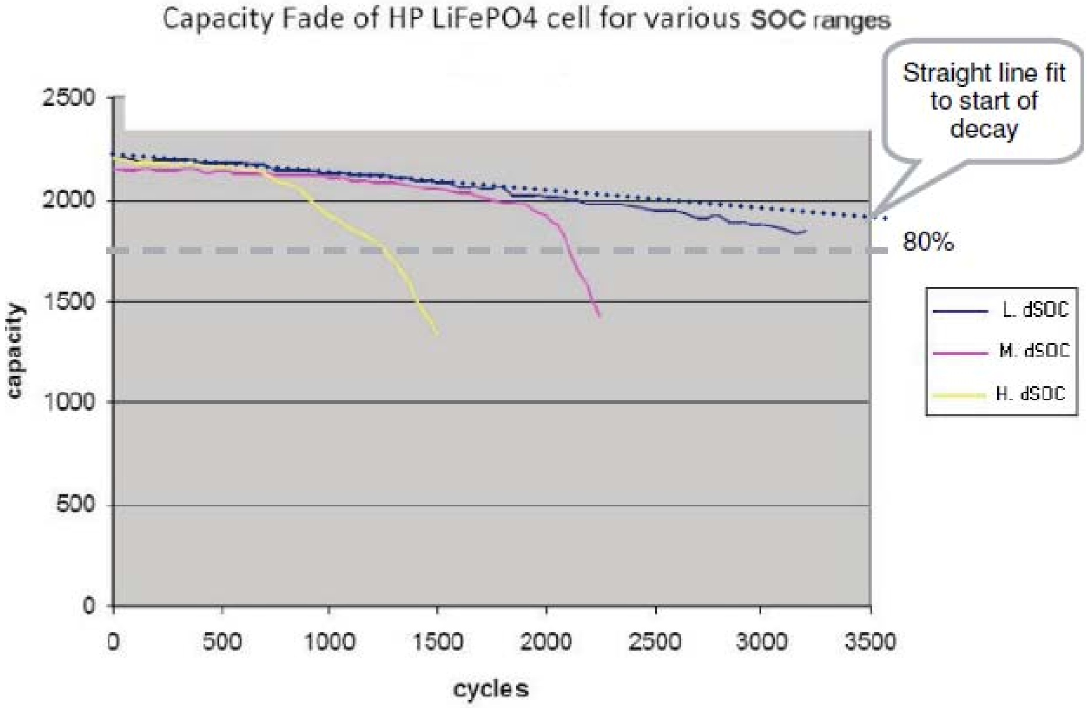


Figure 83: Effect of using cells to different SOC limits [29]

The vehicle user may notice the reduction in available range and choose to modify their usage of the vehicle (more frequent charging, choosing to make only shorter journeys) but ultimately the Battery Management System (BMS) will declare the worn-out battery to be faulty and prevent further usage.

2.7 Temperature Effects

2.7.1 European temperature extremes

Due to the strong dependence of the EV battery performance on temperature, data was collected on the prevailing ambient temperatures that would be experienced in European countries.

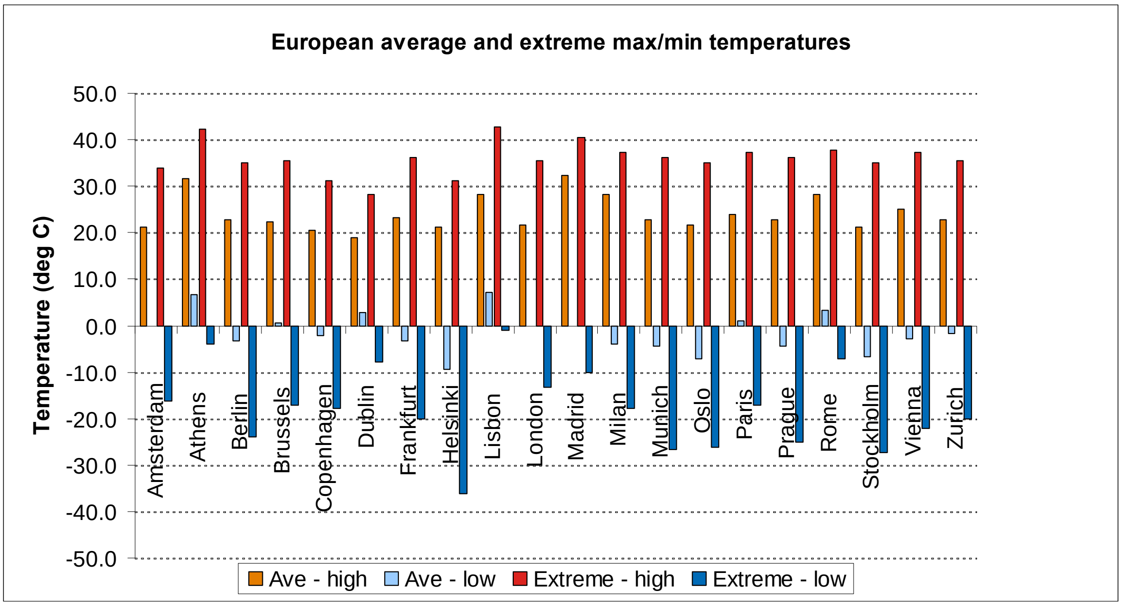


Figure 84: European average and extreme max/min temperatures [30]

In this figure, the terms ‘Ave – high’ and ‘Ave – low’ refer to the highest average monthly temperature in entire year and the lowest average monthly temperature in entire year respectively.

In particular, low temperatures will potentially cause problems to EV; with some battery manufacturers recommending that no charging is carried out at temperatures below 0°C. Progressively lower temperatures produce progressively more severe limitations, as described later.

From the data analysed (Figure 84), 9 out of 20 extreme low temperatures are below -20°C. These temperatures occur in Germany, Finland, Norway, Czech Republic, Sweden, Austria and Switzerland.

Sub -20°C temperatures occurred mainly in January, but may occur from November to March in Scandinavian countries.

Daily minimum January temperatures can be seen visually from the map produced by the European Commission Joint Research Centre [31] (Figure 85).

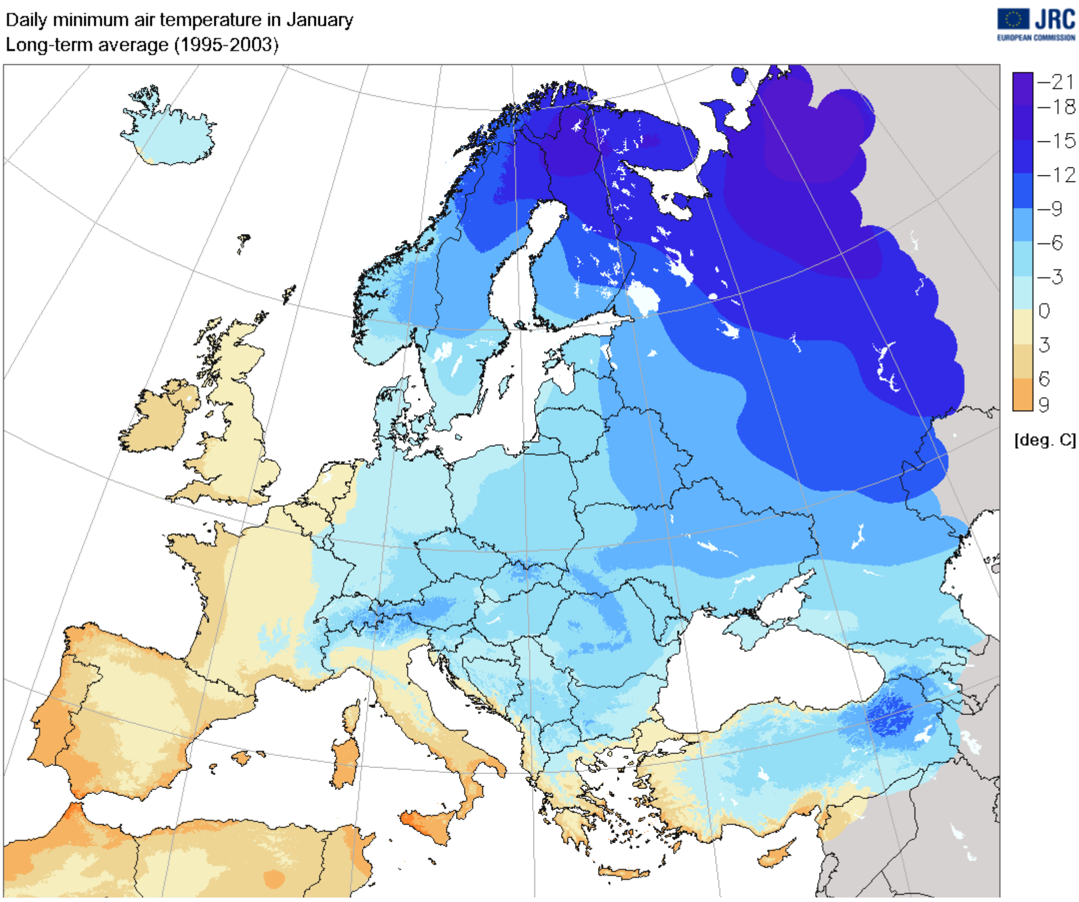


Figure 85: Daily minimum air temperature in January 1995-2003 [31]

2.7.2 Battery behaviour at low temperatures

The effects of the low temperatures stated in Section 2.7.1 are quantified below. The most significant effects are a loss of discharge capacity and inability to charge at low temperatures.

Considering the Valence RT series cells [32] at a nominal 25°C as an example (Figure 86):

- At 10°C, their capacity will reduce to approximately 95%
- At 0°C, their capacity will reduce to approximately 83%
- At -10°C, their capacity will reduce to approximately 70%
- The minimum charge temperature is circa 0°C

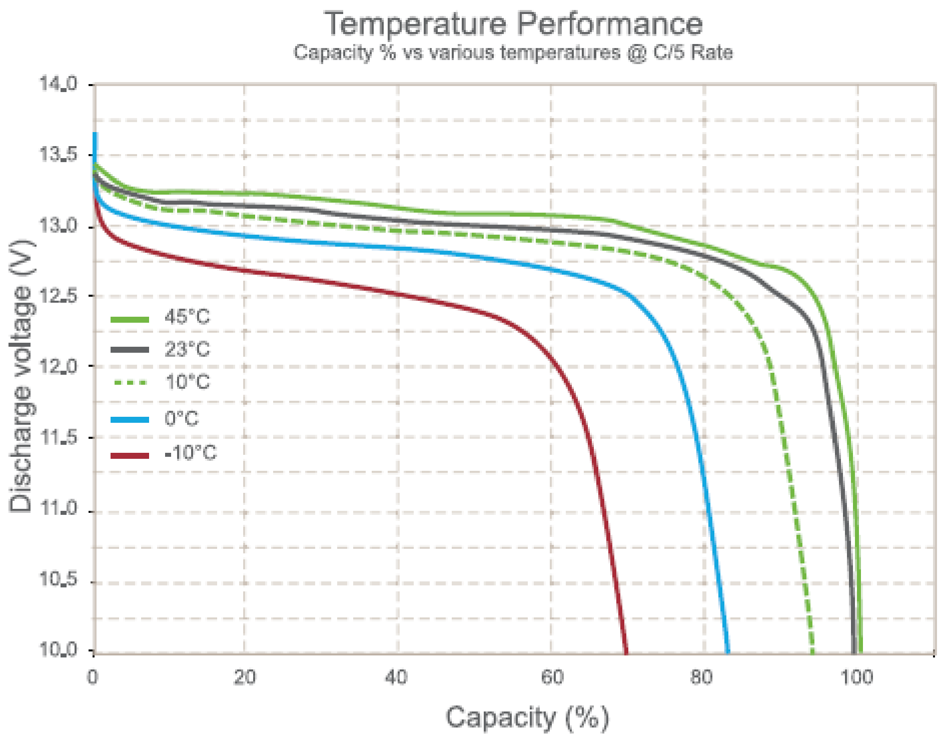


Figure 86: Valence 'u-charge' temperature performance [32]

Possible remedial factors may be to externally heat the battery, or to use the battery while it still has residual heat energy from its previous usage, for example soon after arrival at a charging point.

2.8 Journey Energy Estimation

MERGE partners requested an estimate of the initial SOC of EV at the time they connected up to a charging point. In order to be able to estimate the initial SOC at the start of charging, it has been assumed that the initial SOC at start of charging is equal to the SOC at the end of the previous journey.

From the vehicle user data discussed in Section 2.5.2, the effects of carrying out 'typical' journeys of today with either a 160km range EV, a 80km range EV, or a 50km range EV were made. The vehicle SOC at the end of a weekday usage would be given by the graph shown in Figure 87.

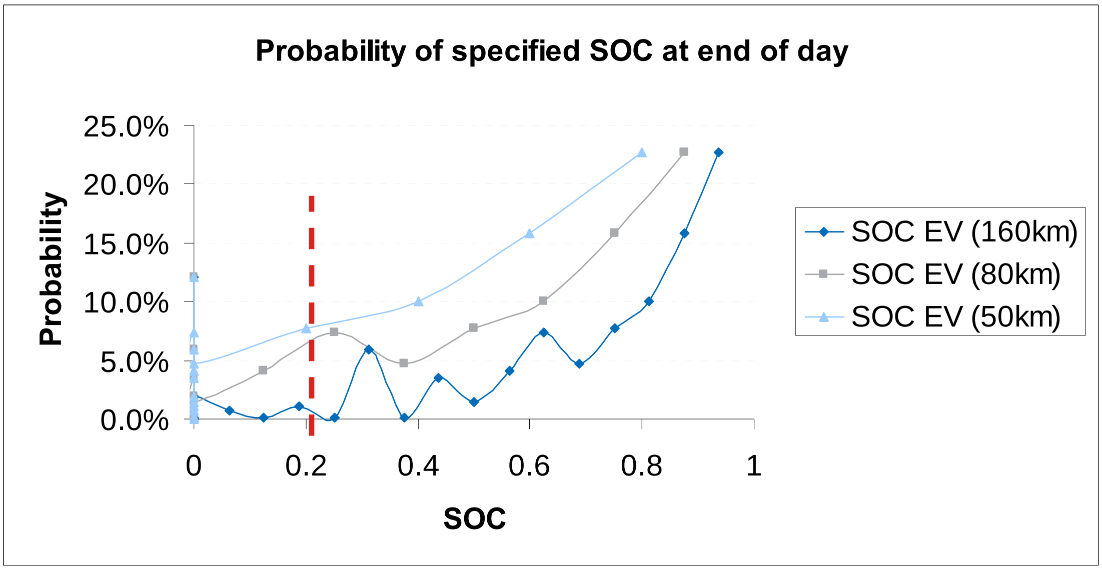


Figure 87: Probability of specified SOC at end of day. Note the cut-off point at 0.2 SOC for the majority of batteries (Source: Ricardo analysis)

The data used in Section 2.5.2 supplies an analysis of a 'typical' journey. Using the data for existing ICE usage indicates that there are high probabilities of EV having high SOC when connecting to the charging point. It can be seen in Figure 87 that it is likely that the majority of EV will be connecting up to the CP with a SOC that is already above 50%. However, it is important to note that battery manufacturers suggest that the batteries are only used up to 80% DOD, which is 0.2 SOC (illustrated by the red line in Figure 87).

2.9 Section Conclusions

The anticipated use by the MERGE partners of the battery model for an example simulation would be as follows:

- The data from the EV Database in Section 1.2 and from the data contained within Section 2 of this report will be used to represent a population (L7e class shown here as an example).
- The parameters given in this section can be put into a 'Monte-Carlo' simulation in order to carry out many simulations of the model using the sample data from the input distributions. The outputs are then combined to give an output distribution.
- This feeds into the model as illustrated in Figure 88.

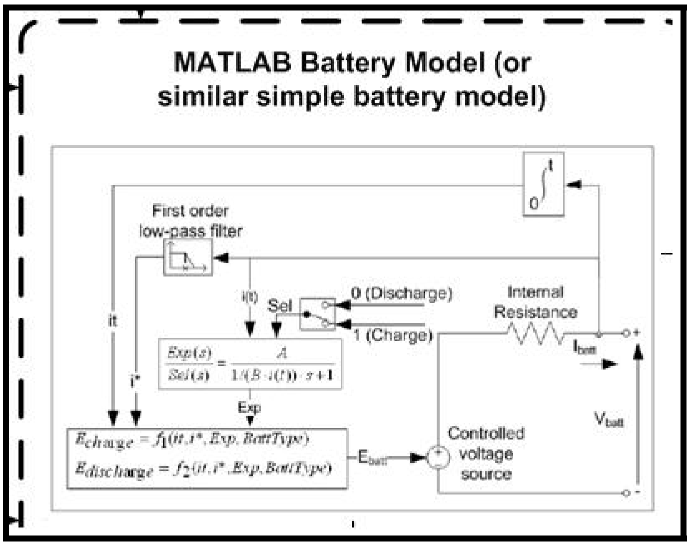


Figure 88: Battery model output (Source: Ricardo analysis)

- An experimental charge/discharge profile can be given as an output which is required by the partners for the various modelling tasks. The output will be given as a probability graph much like the one in Figure 89 which would show the resulting voltage current, SOC or battery life.

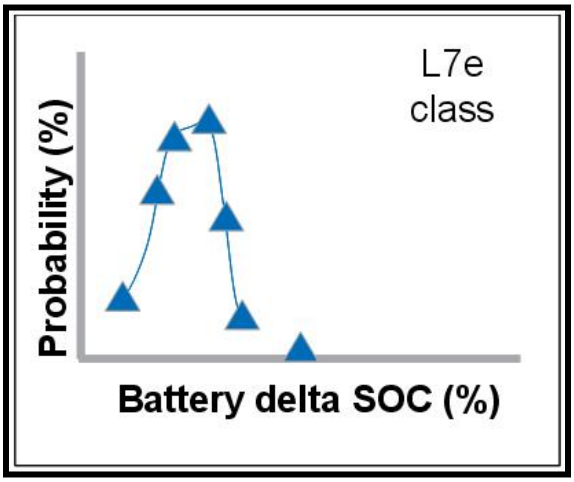


Figure 89: Representative output of the battery SOC (Source: Ricardo analysis)

- The user would run the simulation many times, each time with the user picking a random set of parameters according to their probability distributions presented here. In this way, an equivalent set of outcomes will be derived.

The aim is for the user to be able to evaluate the effects of different charge and discharge profiles, on different vehicles, with the various parameters given in the report.

Table 18 gives the summary of the battery capacities to be used in the model. Minimum, maximum and mean values are provided to be used by the model users as required.

Type		Battery Capacity (kWh)		
		Mean	Min	Max
L7e	BEV	8.7	3	15
M1	BEV	29	10	72
	PHEV	8.2	2.2	13
	EREV	17	12	23
N1	BEV	23	9.6	40
	PHEV	8.2	2.2	13
	EREV	17	12	23
N2	BEV	85	51	120

Table 18: Summary table of battery capacity for use in model

Another key output required by the model users is the maximum charging rate of EV. The charge rate will vary between zero and the value shown in Table 19 whilst the vehicle is connected and the battery is charging. The minimum, maximum and the mode values are given which gives an idea of the available ranges. For standard charging, the rate is constant at 3kW for all classes except N2, which has the higher charge rate due to the size of the batteries. Fast charge rates have been provided in this table so that model users can see the difference in power required from the grid depending on the charge rate.

Type		Standard Battery Charging Rates (kW)			Fast Charge Rate* (kW)
		Mode	Min	Max	Range
L7e	BEV	3	1	3	3-7.5
M1	BEV	3	2	9	3-240
	PHEV	3	3	5	11
	EREV	3	3	5	-
N1	BEV	3	1	3	10-45
	PHEV	3	3	3	11
	EREV	3	3	5	-
N2	BEV	10	-	-	35-60

Table 19: Summary table of battery charging rates for use in model. (*Maximum value of fast charge rate may exceed charging point capabilities, so maximum values if used in modelling should be used with caution)

The numbers given as fast charge rate are estimates obtained from the drivetrain power of the vehicles studied. It is assumed that the maximum fast charge rate for EV is half the battery power of the EV. However, these rates are not constant rates as the rate would reduce as the battery nears full capacity, as explained in Section 2.3.4.

It is important to note, however, that the information collected is current up to the first quarter of 2010. This means that charging rates may change with new developments in charge technology. This could mean that the charge rates are higher than the rates stated. However, there are current limitations in order to ensure battery safety and longevity. Another finding in MERGE Task 1.5 is that the majority of EV users (80%) would prefer to charge their vehicle at home. This means that the majority of the vehicle fleet, M1, will use the standard 3kW charge rate which is available at home.

3 ENERGY STORAGE DEVICES AND THEIR INFLUENCE ON THE DESIGN OF CHARGING POINTS

3.1 Introduction

The purpose of this section of the report is to provide the data to support the use of the MERGE battery model. It comprises the following sub-topics:

- Estimating maximum battery charge/discharge power
- Charge/discharge regimes
- Electrical energy measurement for (cost) charging purposes
- Charging time prediction, effects on SOC calculation accuracy
- User constraints (time to be ready to drive away)
- Section conclusions

In this section, the term ‘charge rate’ or ‘C-rate’ will be used. The explanation of C-rate [33] is given as:

- The current required to charge or discharge a cell fully in one hour. For example a 1C charge rate means that a 1000mAh battery would provide 1000mA for one hour if discharged at a 1C rate.
- 0.5C means that the same battery discharged at 0.5C would provide 500mA for two hours.
- 2C means that the same battery discharged at 2C would deliver 2000mA for 30 minutes

3.2 Maximum Charge / Discharge Rates

The EV Database (Section 1.2) contains data on the drivetrain maximum power, together with the manufacturer's expected battery charge rate through the existing charger(s). This explanation shows how the maximum charge rate of the battery, with a more powerful charger, might be evaluated.

EVs for use in Europe											
Technology	Vehicle type	status	Manufacturer	Model	battery technology	battery capacity (kWh)	Drivetrain power (kW)	charge rate (kW)	fast charge rate (kW)	battery voltage (V)	plug in type
EV	M1	concept	Audi	R4 e-tron	Li-ion	45	268	3.0	12.8		230V AC (16A 3 KV
EV	M1	concept	Audi	R8 e-tron (Frar	Li-ion	53	230	3.0	25.0		230v - 16A / 400V - 32
EV	M1	concept	Audi	R8 e-tron (Det	Li-ion	45	150	3.0	25.0		230v - 16A / 400V - 32

Figure 90: Snapshot of EV Database from Section 1 (Source: Ricardo analysis)

As highlighted in red in Figure 90, the battery's maximum short-term discharge limit is likely to be similar to maximum drivetrain power (for BEV and EREV, but not PHEV). This is because the vehicle designer tries to size the maximum power of drive motor and battery to be similar, for best overall efficiency.

Highlighted in blue on Figure 90 are the available charge rates, normal and fast.

Also, at a first approximation, the battery's maximum charge rate is similar to its maximum discharge rate (Figure 91 shows the maximum charge and discharge rates available from a typical cell for a range of DOD). MERGE partners will be able to use the maximum drivetrain power specified in the EV database as an indication of the short-term maximum charging power of the batteries.

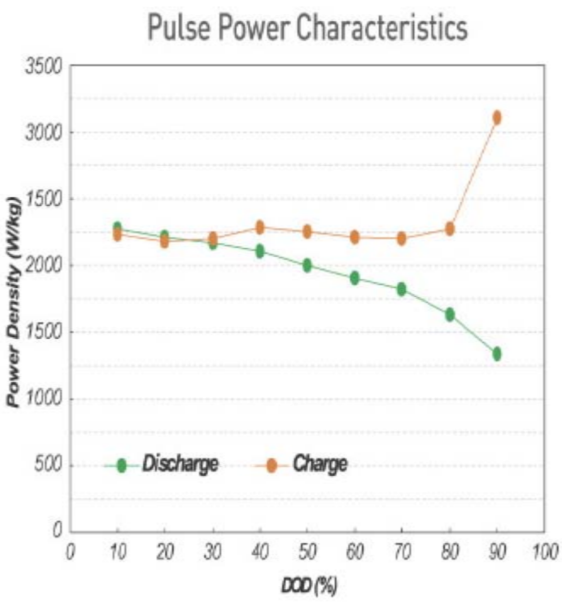


Figure 91: Pulse power characteristics of EiG battery [25]

As an example, the Li-ion cell shown in Figure 91, with a peak (10 second) discharge power rating of 20C has a continuous discharge rating of only 10C.

However, the maximum discharge power is often specified as a very short-term duration (for example 10 seconds), so the equivalent peak charge power is also only available for similarly short durations.

So, for short-term 'pulse charging' it is possible to charge or discharge the battery at a high rate, but to charge for a longer period, other factors need to be considered, such as the heating of the battery that occurs as a by-product of the high charge rate. To mitigate this, either cooling of the battery is required or the charge rate must be reduced to prevent the battery overheating.

Also, as the battery SOC increases, the ability of the battery to accept charge reduces and the charging power must be reduced further. This is illustrated in Figure 92.

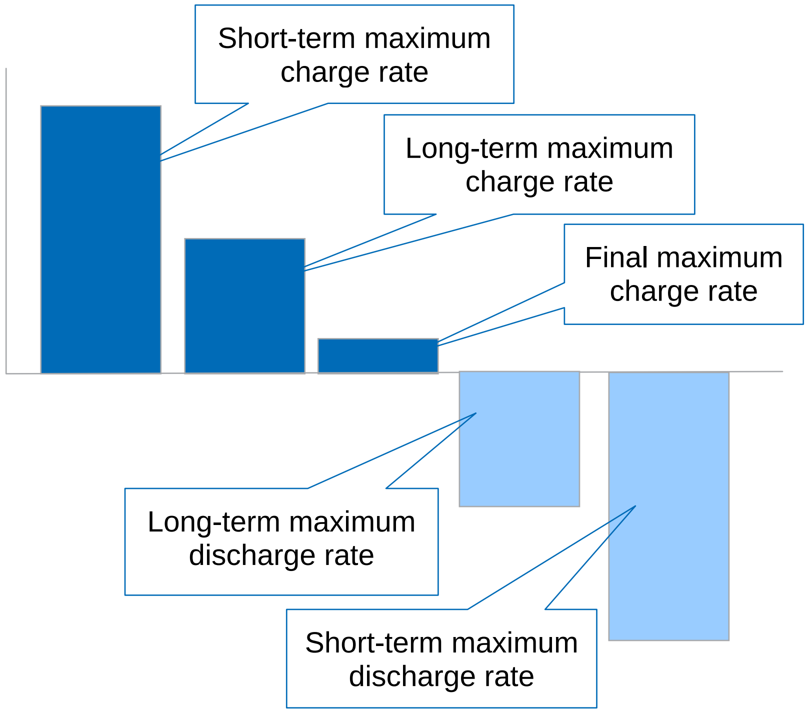


Figure 92: Representation of charging/discharging capabilities (Source: Ricardo analysis)

So for example; if the battery had a maximum power rating quoted of 70kW, it is likely that it would be able to accept very short-term (less than 10 seconds) charging at 70kW, but the maximum continuous charge rate would probably be half that.

The cell manufacturers usually recommend that the final stages of charging (approximating to 80%-100% SOC) are done using a constant voltage (CV) charge, rather than a constant current (CC), with the result that charging is done at a gradually-reducing rate, much more slowly. This is covered in more detail in the following section.

3.3 Li-ion Cell Charging/Discharging

3.3.1 Charge profile

The usual Li-ion battery charge profile is to charge at a constant current (CC) until a specified voltage is reached, then maintain that constant voltage (CV) until the battery is ‘full’ (defined as current dropping to a low level or timing-out).

Interruptions to the charging process can be accommodated by stopping and restarting the process.

Charging needs to be controlled by the BMS as it depends on battery voltage and battery temperature.

Figure 93 shows a generic charge profile for a Li-ion battery [24]. It illustrates the CCCV charging and puts it in context with the cell charge (dark blue line). The CC is active until the cell reaches its optimum voltage and then drops off (gray line). The light blue line shows the CV stage which remains constant until the cell current has dropped to the predetermined level. Once this process is completed, the cell is fully charged.

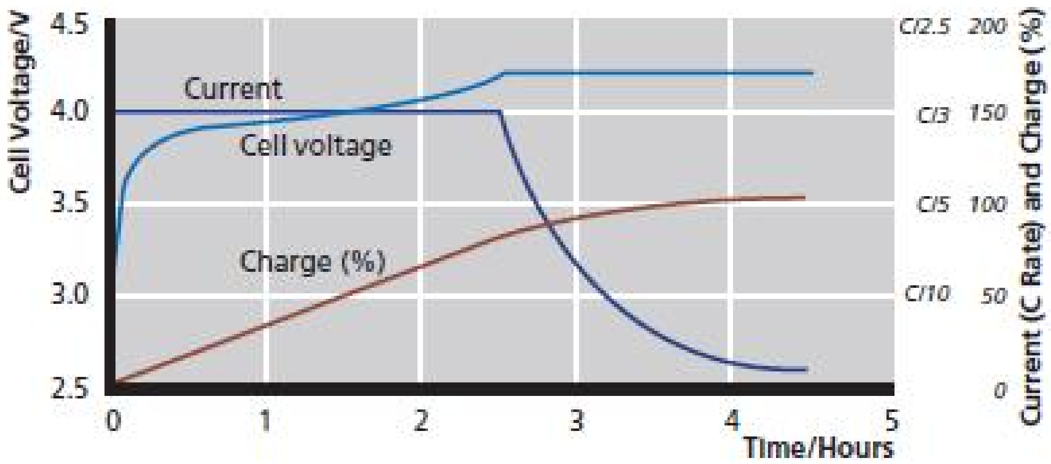


Figure 93: CCCV charging protocol of a Li-ion battery [24]

3.3.2 Discharge profile

The battery can be discharged using any chosen profile (as requested by the grid), but within the limitations mentioned in Section 3.2, namely that short-term power delivery can be at a higher rate than long-term power delivery.

Again, the BMS needs to be able to limit the maximum discharge rate (as it depends on battery SOC and battery temperature).

3.4 Lead-acid Cell Charging/Discharging

3.4.1 Charge profile

Lead-acid cells are usually charged using constant-current (CC) constant voltage (CV) as described for Li-ion cells (Section 3.3).

Lead-acid (PbA) cells are rather different to Li-ion cells; however VRLA / AGM cells have some characteristics that are quite similar to Li-ion, since these cells also get hot on overcharge and have a thermal runaway mechanism that is similar to Li-ion. For these batteries, 'pulse' charging (Figure 94) is an alternative option that can actually significantly improve cell life. CCCV charging is still the normal method of charging at moderate rates.

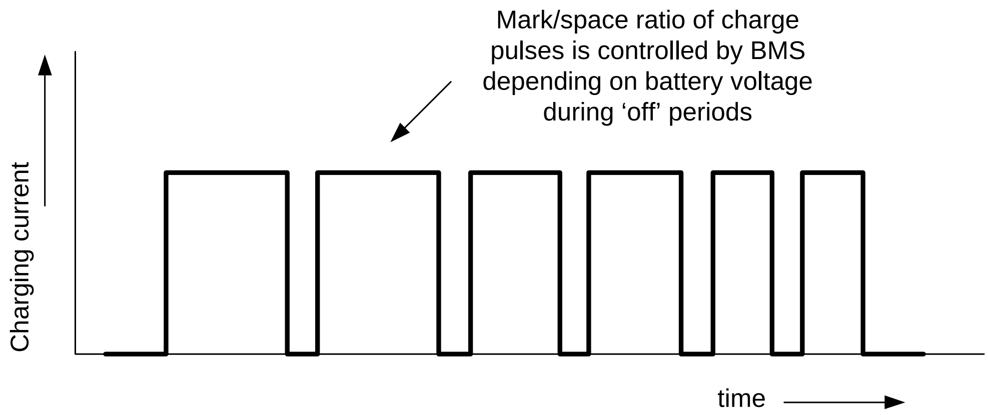


Figure 94: Representation of 'pulse' charging of a PbA battery (Source: Ricardo analysis)

3.4.2 Discharge profile

The Battery Management System (BMS) will be limiting discharge rates to keep the battery within temperature, minimum voltage and maximum current limits.

The BMS will need to avoid discharging to below approximately 30% SOC to preserve battery life (for PbA).

3.5 Implications for Charging Points

As described previously, the BMS is best-placed to understand the:

- Battery's maximum available charge power
- Battery's maximum available discharge power

The discharge rate (for vehicle to grid (V2G)) is likely to be requested through the Charging Point (CP) from the grid, yet the implications of the choice of discharge rate have a big impact on the battery in terms of energy losses within the battery and bi-directional charger (see Section 3.5.2).

The charge rate is likely to be requested by the BMS and limited by the grid through the CP.

3.5.1 Electrical energy measurement for (cost) charging purposes

Owing to the energy losses during the charging and discharging process, the CP and vehicle battery are likely to see different amounts of energy transferred. Figure 95 illustrates the communication process between EV, CP and the grid. It can be seen that there are inevitable energy losses between the EV battery and the grid.

The typical efficiency of the charger is approximately 85% and the battery is approximately 90% efficient (more explanation in Section 3.5.2).

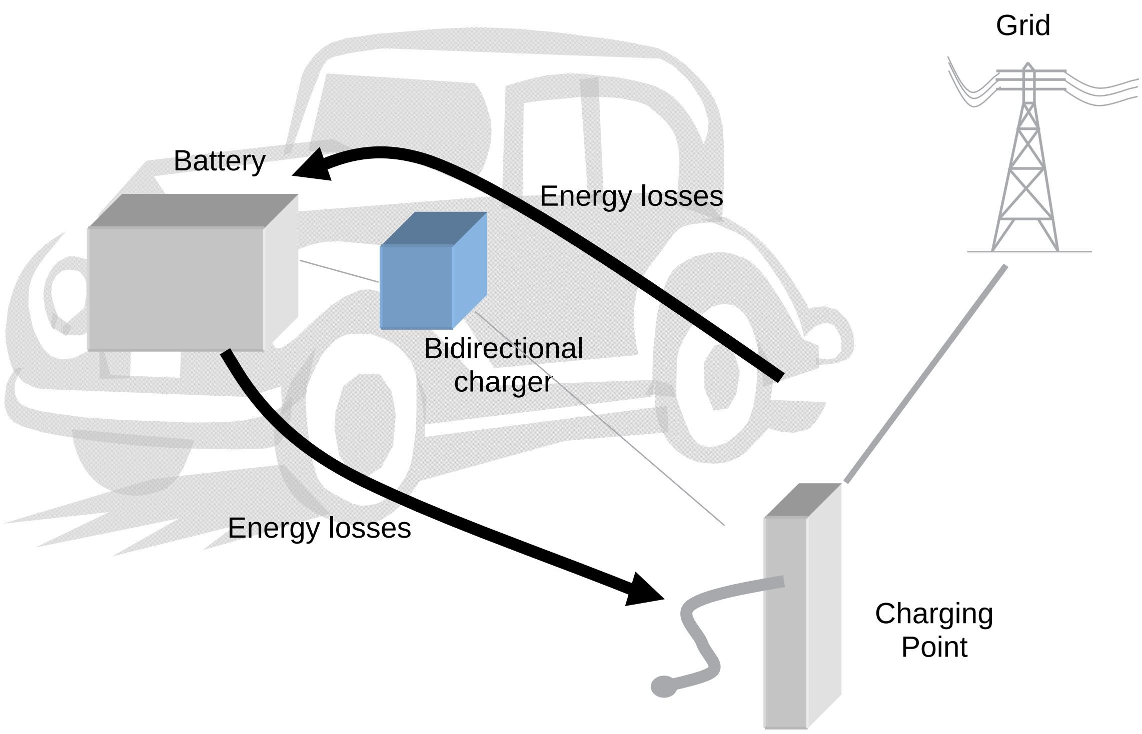


Figure 95: Charge process of an EV (Source: Ricardo analysis)

Hence the transfer of 5kWh of energy through the CP will only result in 3.8kWh of energy available for use in the vehicle. This situation also applies for V2G transactions. In this case, the charge point borrows 5kWh for V2G purposes, and then returns 5kWh of energy to the vehicle, but the battery SOC will be lower than it was originally.

Additional consideration needs to be given to the possibility of needing to heat the battery to operating temperature to accept charge during cold weather.

The vehicle owner may also need to be compensated for any reduction of battery lifetime resulting from additional V2G discharge/charge cycles.

3.5.2 Charge Efficiency

The charge efficiency can be represented as the losses - chemical and resistive - within a cell. In Figure 96, the charge efficiency is shown by the area between the cell charging curve and the cell discharging curve.

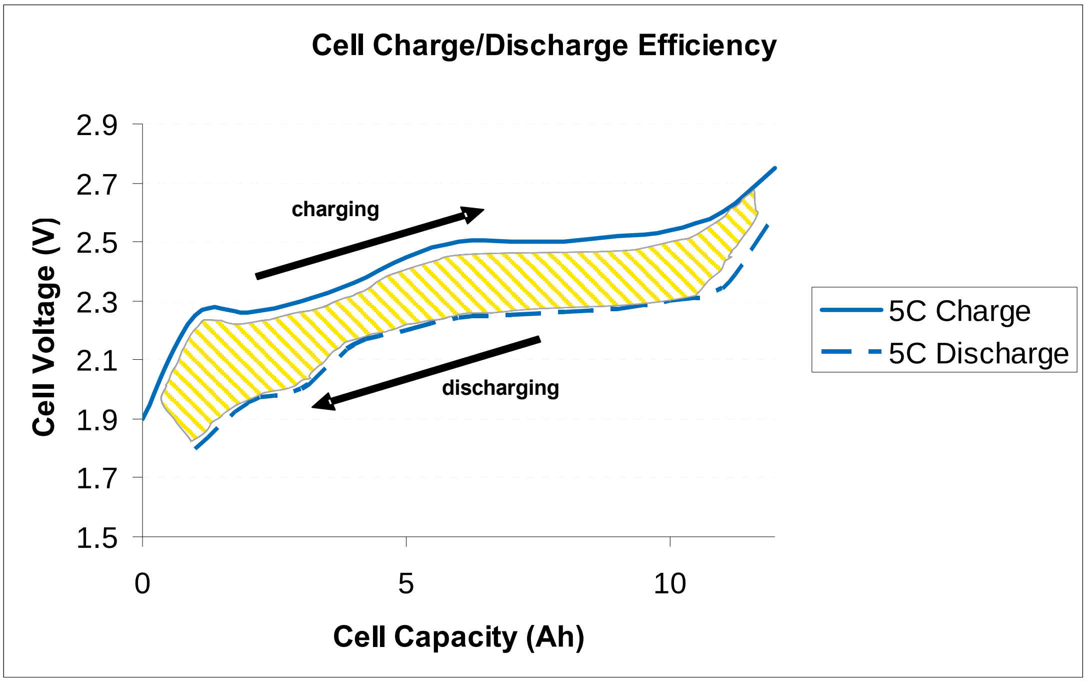


Figure 96: Charge efficiency for an Altair nano lithium titanate 11Ah cell [34]

Battery inefficiencies result from differences between the charge and discharge characteristics defined by the cell chemistry, as shown above (Figure 96). Additionally, there will be some resistive losses within the battery pack and connecting cables.

However, higher power charge and discharge cycles give poorer battery efficiency. Figure 97 shows that by increasing the charge and discharge rates, the direct results are increased losses within the cells.

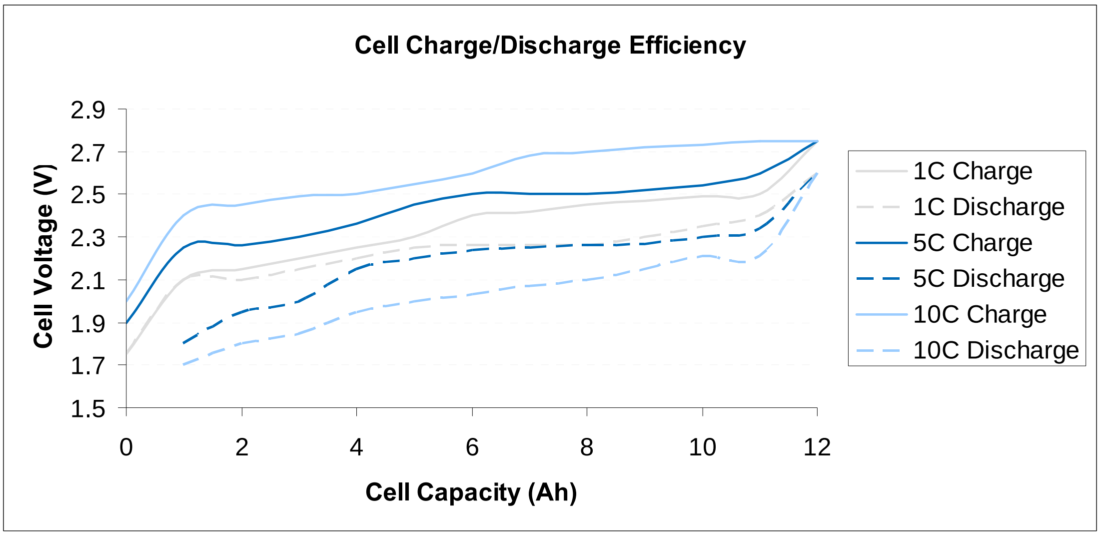


Figure 97: Cell charge and discharge efficiency for Altair nano lithium titanate 11Ah cell [34]

It can be seen in Figure 97 that the shaded area that was shown in Figure 96, which represents the losses within the cell, gets larger with larger C-rates. For example, for a charge rate of 10C, the losses would be double that of a 5C charge rate. Therefore, 'fast charging' will provide lower efficiency than 'slow charging'.

3.5.3 Data Transfer Needs – from BMS to grid through CP

A set of communications signals are proposed here to illustrate the type and complexity of communication required between the BMS and the grid through the CP. These would allow both the suspension of charging and V2G operation, as well as 'controlled' charging.

- BMS to grid through CP:
  - Battery nominal capacity (kWh).
  - Battery estimated SOC (%).
  - Battery available charge (kWh).
    - "Available charge" declared by vehicle from 'drive away' calculations.
  - Battery estimated maximum available discharge power (5 minute rating) (kW).
    - 5 minute rating chosen as being compatible with grid requirements for Spinning Reserve.
  - Battery estimated maximum possible charge power (5 minute rating) (kW).
  - Operating mode (Charging, Discharging, Passive, and Battery heating).
  - Request charge and requested charge rate (kW).
    - Either the grid or BMS can request charging.
  - Request heating.
- Grid to BMS through CP:
  - Request charge and requested charge rate (kW).
    - Either the grid or BMS can request charging.

- Request V2G discharge and requested discharge rate (kW).
- Requests pause/suspend charging.

3.6 Section Conclusions

- The vehicle and the grid need to communicate effectively, through the CP, in order to charge/discharge the vehicle battery safely and reliably at higher rates.
- Charging/discharging at higher rates is less efficient and loses energy as heat (both within the battery and the bi-directional charger).
- The vehicle battery and grid will ‘see’ different calculated battery energy levels, due to losses in the charging & discharging processes.
- The vehicle or its owner need the ability to declare an ‘available energy’ for V2G purposes, the remainder of the battery’s energy being unavailable for V2G due to the vehicle owner’s journey time and expected journey distance needs.
- The vehicle BMS will be able to estimate ‘damage’ caused by each charge/discharge cycle. This would allow an assessment of loss of battery lifetime from cycles carried out for purely V2G reasons.

4 ENERGY STORAGE DEVICES AND THEIR INFLUENCE ON THE DESIGN OF BATTERY MANAGEMENT SYSTEMS

4.1 Introduction

This section of the report covers factors that will require consideration in the design of the BMS. It comprises the following sub-sections:

- Battery manufacturer/OEM relationships.
- Typical Battery Management System (BMS) functions.
- Additional BMS features to support controlled charging.
- Additional BMS features to support V2G.
- BMS implications.
- Safety requirements.
- Section conclusions.

For the purpose of this report it is important to note the different stages of interaction between the grid and the EV. Figure 98 shows the likely progression from ‘dumb charging’ through to ‘V2G’.

Figure 98: The four key stages of development of power grid infrastructure. V2G is the long term goal (Source: Ricardo analysis)

1) By ‘dumb charging’ it is understood that the EV is plugged in whenever possible and is charged until it has reached maximum charge or the owner has to leave.
2) ‘Manually deferred charging’, for example, refers to when the EV user sets a timing device to charge the EV in order to take advantage of reduced electricity rates during the night hours.
3) ‘Controlled charging’ involves some autonomy between the EV and the grid (i.e. without input from the EV user). There is an increase in the communication between the EV and the grid. In this case, the grid can control when the EV is charged, for example, to maximise the use of renewable energy sources (RES) or for load balancing.
4) ‘V2G’ is when ‘controlled charging’ is combined with the use of the EV as a source of distributed energy that the grid can access.

4.2 Battery Supplier / Joint Venture and OEM Li-ion Relationship 'Map'

It is important to note that the battery manufacturers develop the BMS alongside their battery technology. This is then supplied to the OEM as a packaged item. Figure 99 shows the relationships that exist between said OEMs and the battery manufacturers.

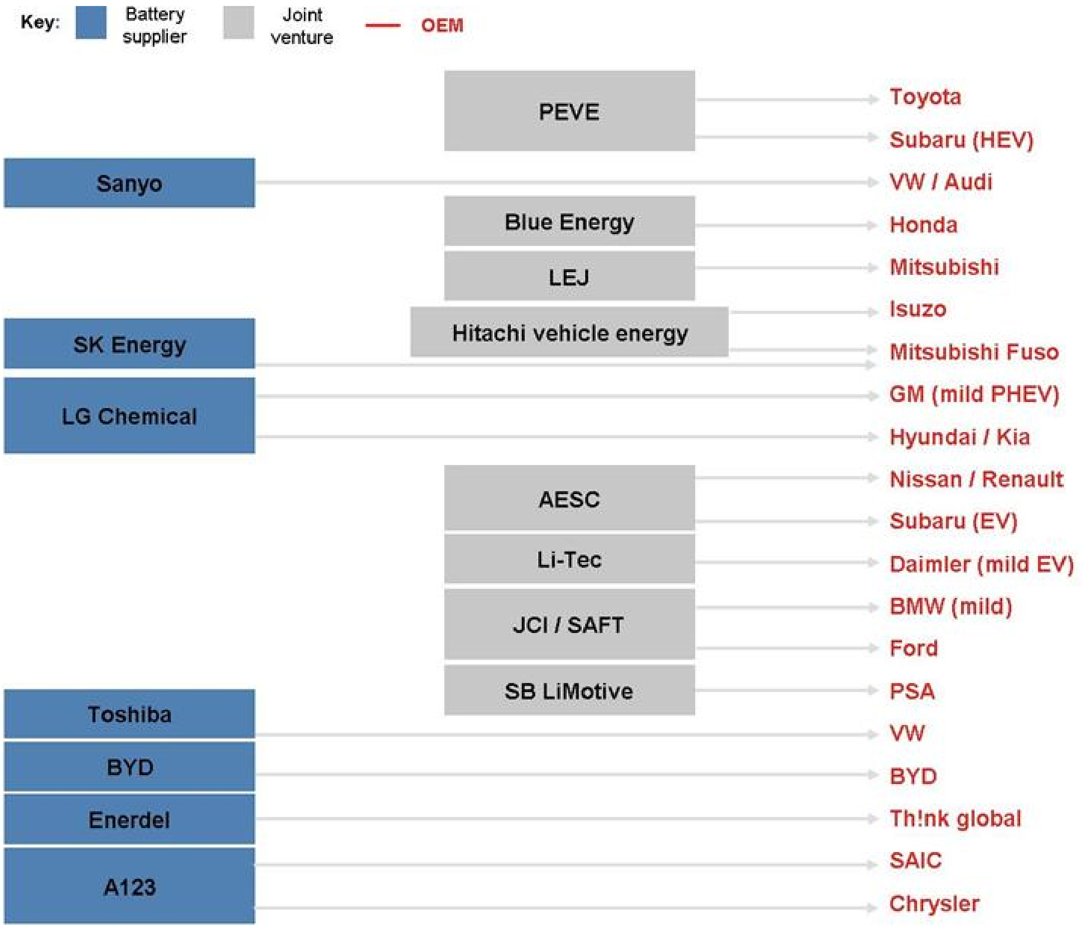


Figure 99: Battery manufacturer/OEM relationship map (Source: Ricardo analysis)

4.3 The Battery Management System (BMS)

The BMS has several vital functions [1], these are:

- Maintain the battery in a state suitable for EV performance requirements.
- Prolong the life of the battery.
- Protect the cells or the battery from damage.
- Provide an interface with the host application.

Figure 100 shows a typical battery set up with the BMS being an integral part of the package.

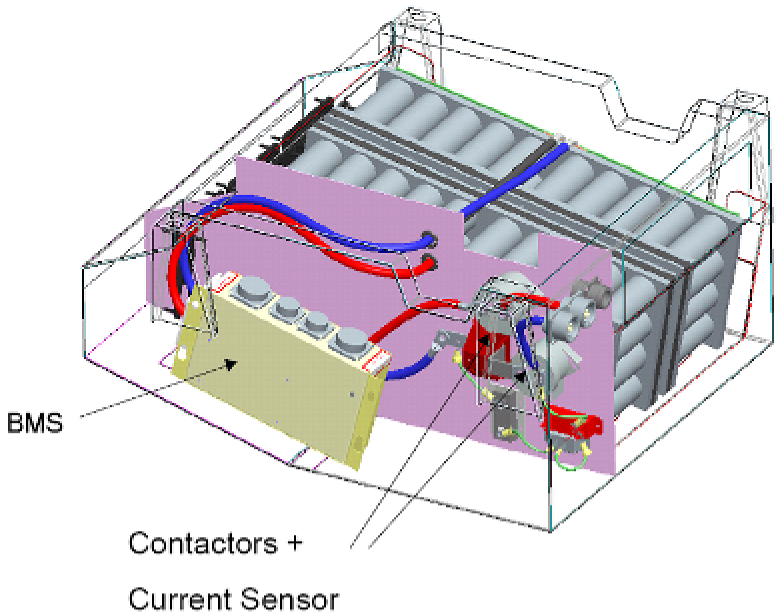


Figure 100: Schematic of a battery package (Source: Ricardo)

Battery lifetime is critically influenced by how the EV is used (power demand & DOD) and charged (fast/slow), therefore:

- The BMS controls these parameters within safe limits and it prevents damage to the battery cells, the systems and vehicle users.
- There are current and temperature sensors for control.
  - Contactors can disconnect power from pack to make external system safe.

The BMS also provides information for external control:

- To the vehicle electronic control unit (ECU).
- And to the external Charging Point (e.g. on-street chargers).

4.4 Typical BMS Functions

A typical vehicle BMS currently supports the following features [35]:

- *Charge/discharge control* - This is essential for BMS as batteries are often damaged by inappropriate charging.
  - Heating/cooling of cells. Currently usually only during driving, but high-rate discharging/charging to and from the grid will also need thermal control by the BMS.
  - Pre-charge circuit. This is a ‘soft-start’ facility used when the vehicle powers up. An equivalent may be needed for the fast charger connection.
  - Current and voltage measurements. These are made at the battery, for safety and SOC calculations and reported to the vehicle to ensure the batteries are not abused.
  - SOC estimation. It is necessary to give the user an indication of the available capacity left in the battery or to be used to optimise the charging process.
  - State of Health (SOH) determination. Is a measure of the battery capability to deliver the specified output; can be used to assess the need for maintenance.
  - Demand management. Used to minimise the current drain on the battery by utilising power saving techniques in between charges.
  - Cell balancing. Compensates cells with manufacturing flaws or weaker cells to extend battery life. This is done by equalising the charge on all the cells in the chain.
- *Safety* – This covers the hazards for human safety.
  - Detecting vent gasses. It would shut-down the battery for safety reasons if gases were detected.
  - Detecting short circuits to vehicle chassis. The battery terminals are normally isolated from vehicle ground and earth; any loss of isolation shows insulation problems.
  - Isolating battery for switch-off, servicing and in emergencies. Functionality will need extending to cover high-rate discharges into the grid and consideration of all the failure cases that could arise from this new mode.
  - Current limiting in an emergency. The BMS can open the battery main contactors, isolating the battery.
- *Communication* – Is required so that the vehicle user and/or CP know the requirements of the battery. More in depth detail is given in the MERGE - Task 1.1 report.
  - Communication with vehicle controller. Reporting battery status and demands for power or any alarms.
  - Communication between battery and charger. Provision of optimal charge algorithms for the battery.
  - Access to the BMS control parameters for diagnostics and tests.
  - History or logbook function. In order to monitor the usage of the battery. Required for estimating the SOH but can also log any failures or abuse that the battery has undergone for evaluation.

4.5 Additional BMS Features to Support 'Controlled Charging'

Envisaged new BMS features to support 'Controlled Charging' include:

- Communication via CP
  - This will include functional, safety and commercial data. If this contains financial data, this is likely to be encrypted. The CP acts as the conduit for information that is to be exchanged with the grid, allowing the grid to exercise both local and national control of the EV load
- Drive-away timing calculations
  - This is discussed further in Section 4.7.4
- Safety functions
  - This is addressed in Section 4.8
- The sharing of control between the BMS, CP and grid will need to be subject to analysis to find a robust solution that provides safe, high rate charging and discharging while the vehicle is unattended. The chosen solution will also need to be flexible enough to support the whole range of EV

4.6 Additional BMS Features to Support 'V2G'

In addition to the 'Controlled Charging', new features have to be included to enable the EV to be used as a distributed energy source in a V2G scenario. These are:

- Calculation of V2G costs
  - This is likely to be based on the calculated energy passing through the CP. It will need to take into account losses at each stage in the energy conversion 'chain'
- Calculation of battery lifetime reduction due to V2G cycling
  - As part of the above, it is important to consumer confidence to be able to evaluate the incremental cost of 'lending' energy to the grid, taking account of the gradual reduction of battery lifetime and the high cost of replacing the vehicle battery
- Again, to build customer confidence, it is important that the BMS is able to ensure that the vehicle is available for the owner to drive away by a requested time, regardless of any V2G energy transfers

4.7 BMS Implications

4.7.1 Required communications with the CP:

The BMS and CP will need to have a defined standard for communication between them. This will need to be adopted by all battery manufacturers/vehicle manufacturers and Charging Points. The suggested contents for this interface are shown in Sections 4.4, 4.5 and 4.6.

4.7.2 Calculation of V2G costs

In order to calculate the costs of V2G usage, it is necessary to understand the energy that is used during the process. As can be seen in Figure 101, there are inherent energy losses in the battery and charger. However, at present the CP does not see these losses which lead to some important questions concerning the use of EV in V2G.

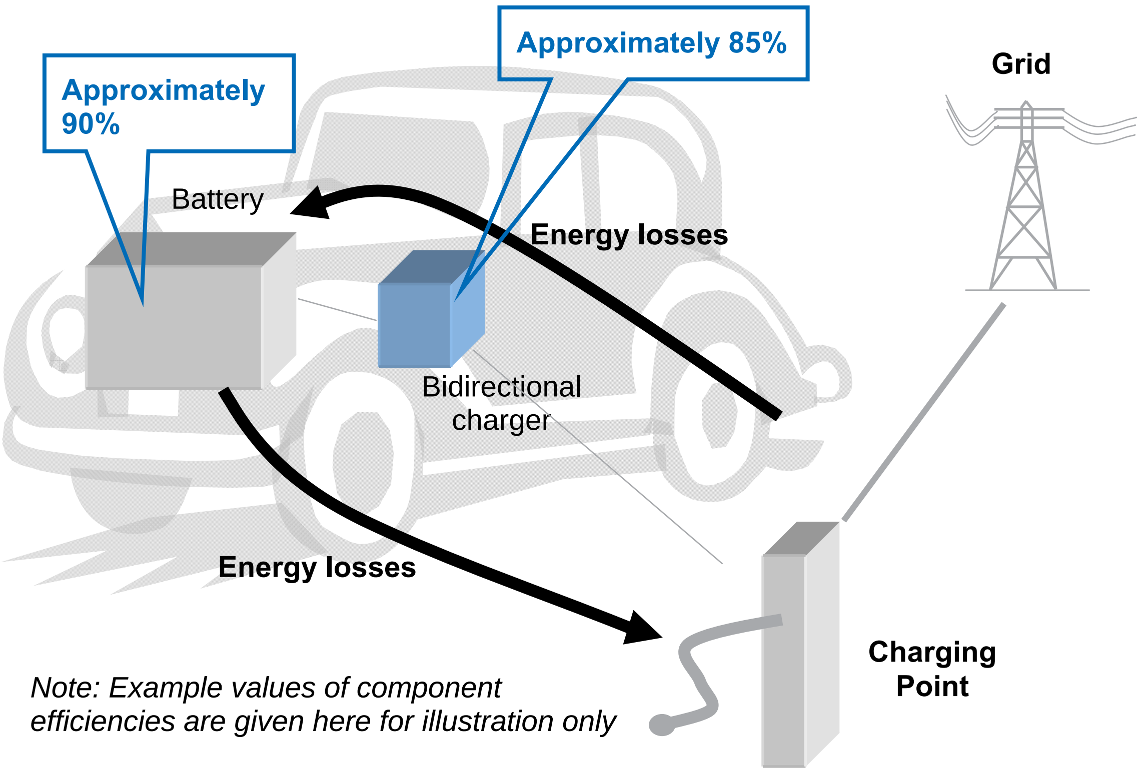


Figure 101: Representation of EV in V2G operation (Source: Ricardo analysis)

Questions to be resolved arising from Figure 101:

- Who pays for the ‘wasted’ energy? That is to mean the energy that is lost as heat in the Bidirectional Charger and Battery. (For example, if the CP takes 5kWh of energy from the car for V2G, then returns 5kWh to the car, the battery SOC will be lower than it was originally).
- Who pays to heat the battery to operating temperature if needed? As shown earlier in the report (Section 2.7), the ambient temperature may be low enough to prevent charging from occurring without using a battery heater. Alternatively,

the start of charging may need to be restricted to a short period of time after the car arrives at the CP and while the battery is still warm.

- Who pays for the reduction of battery lifetime from additional cycles? Although the V2G ‘loan’ of energy to the grid could be made transparent to the user, by taking the previous restrictions into account, there remains the reduction of battery life each time the battery is cycled. As a minimum, the BMS needs to maintain a record of ‘additional’ V2G cycles and be able to attribute a financial loss to each.

4.7.3 Calculation of battery lifetime reduction due to V2G cycling

As discussed previously, additional charge/discharge cycles will reduce the battery’s remaining lifetime. This will be more pronounced when the charge/discharge cycles utilise a large change of SOC of the battery.

The BMS will need to estimate the incremental reduction in lifetime and hence the incremental cost of additional V2G charge/discharge cycles. From the example vehicle usage data given in Section 2.5, a V2G cycle could be as significant as the actual nightly recharging cycle (37.5% SOC swing for an 80km range EV in weekday use).

4.7.4 Drive-away timing calculations

It is assumed that the vehicle owner will programme the required range and drive-away time required as the vehicle is plugged into the charger. For example, 70km range required for the next journey and a given drive-away time of 09:05am the following day.

There are two situations in which these drive-away calculations will be made: (a) controlled charging where charging is deferred by charge point as an interruptible load and (b) V2G operation.

These will now be discussed.

(a) Controlled Charging where charging is deferred by CP as an interruptible load

The BMS converts the owner's journey requirements (1) into a minimum SOC to be reached for a particular time of day (2). From this 'end point', the BMS calculates the latest charge profile (3) that will allow the battery to reach the chosen end point.

When the CP requests to 'defer charging' at arrival (4), the BMS is able to judge whether it can support these requests. This is illustrated in Figure 102.

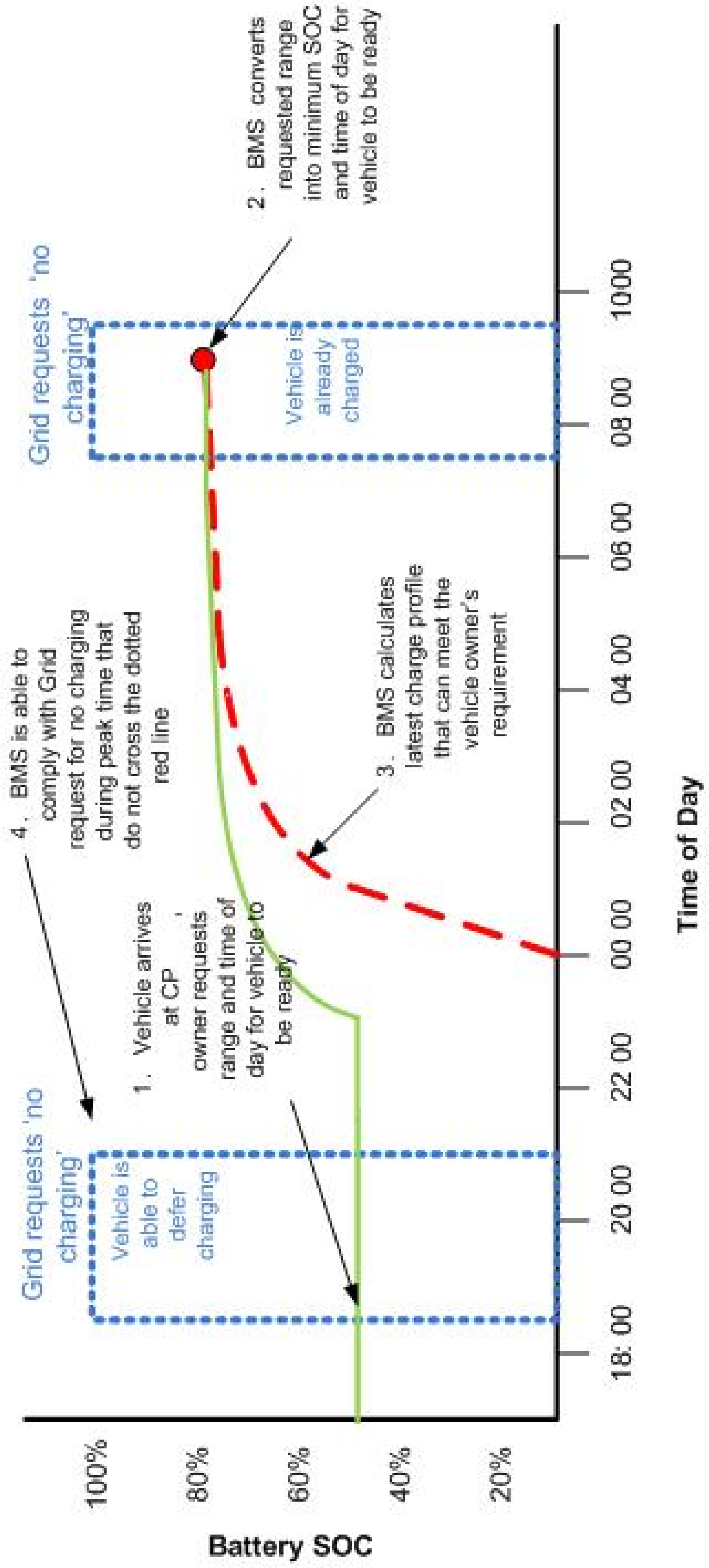


Figure 102: Drive-away timing calculation (controlled charging where charging is deferred) (Source: Ricardo analysis)

(b) V2G operation

In Figure 103, the BMS converts the owner's journey requirements (1) into a minimum SOC to be reached for a particular time of day (2). From this 'end point', the BMS calculates the latest charge profile (3) that will allow the battery to reach the required end point. This approach is shared with the Controlled Charging scenario.

However, the BMS is now able to judge requests from the CP as achievable or not achievable and can schedule the appropriate charge profile (4).

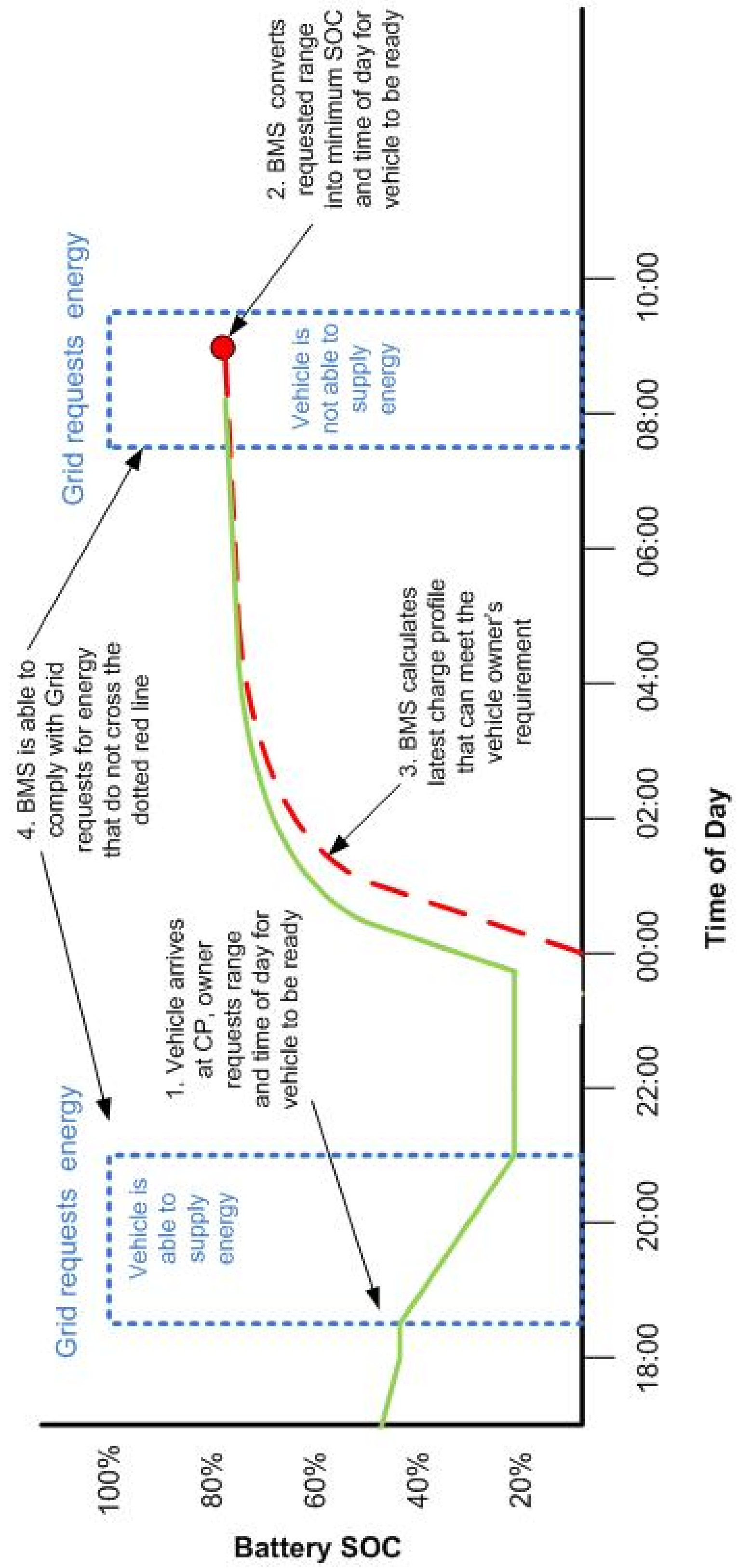


Figure 103: Drive-away timing calculation (V2G) (Source: Ricardo analysis)

Further considerations for drive-away timing calculations

For the preceding calculations, the maximum battery charge rate needs to be predicted by the BMS (as it is dependent on several factors).

In order to calculate this, the BMS is likely to maintain an internal mathematical model of its battery, with outputs such as:

- Usable capacity
- Internal resistance
- Internal temperature
- Battery cycle count

4.8 Safety Requirements

The CP will have the ability to request high rate discharges or charges to or from the battery.

In normal vehicle operation, safety monitoring of the battery is provided by both the BMS and the vehicle supervisory controller (and by a driver being present). However during charging, control is exercised jointly by the BMS and CP and is likely to be carried out while unattended.

Hence the design of the CP must incorporate sufficient controls to ensure the safety of the vehicle and battery while the vehicle is connected.

For example, if the BMS reports high battery temperatures, the charge/discharge rate must be reduced, or stopped. If the BMS detects an isolation failure, the CP should halt charging and switch off the battery. If charging is in progress and the charge plug is removed, or the cable severed, both the battery and CP must be immediately placed into a safe state (and both must be able to withstand the voltage surge produced by the disconnection).

In the event of a mains power cut, the CP must be able to reliably re-establish communication with the vehicle, determine the battery status and where possible, resume planned actions to make the vehicle available at the planned time.

4.8.1 Security requirements

For the scenarios discussed earlier, the CP and the BMS will need to share information that has commercial and privacy implications. If users are to have confidence in the billing for electricity used for charging their vehicles, communications between BMS and CP must be resistant to attempts to intercept or alter their contents. Similarly, personal data stored within the CP (e.g. historical vehicle movements, intended times of departure) must be secured from unauthorised access.

4.9 Section Conclusions

- The BMS and CP need to communicate to charge/discharge safely and reliably at high charge/discharge rates.
- The BMS and CP will ‘see’ different calculated battery energy levels, due to losses in the charging & discharging processes.
- The vehicle or its owner will need the ability to declare a ‘drive away time’ and ‘drive away energy’ for Controlled Charging and V2G purposes. This will aim to ensure the battery has a sufficient SOC at the stated time in order to meet the vehicle owner’s next journey needs.
- The vehicles’ BMS will be able to estimate ‘damage’ (reduction in remaining lifetime) caused by additional charge/discharge cycles. This additional cost may be considered as part of any commercial V2G transaction.

5 EV PENETRATION SCENARIO DATA TO USE WITH EV BATTERY PARAMETERS IN ELECTRICITY GRID SYSTEM MODELLING

5.1 Introduction

This Section intends to satisfy the requirement of the description of work for deliverable 2.1.5 of the MERGE project which states the following:

"Analysis of said energy storage models to simulate EV penetrations of the transport sector and the potential impact on European energy grid. Incorporation into this model of the through life characterisation and end-of-life conditions, plus usage implications for use with the modelling of the energy grid when using EV as distributed stored energy"

This links closely to other work carried out by Ricardo in MERGE Task 3.2 and Task 5.1; some of the key outputs from these Tasks are shown in this Section. Separate reports will be generated to communicate the full findings of the other two Tasks.

A summary of the key information (from Scenario 2 in Task 3.2) that can be used to help in modelling the impact of mass integration of EV on the grid from 2010-2030 is provided. The sub-sections include:

- EV uptake scenarios
- Forecasted EV sales in Europe
- EV car parc
- Section conclusions

5.2 M1 EV Uptake Scenarios

In Task 3.2, EV penetration scenarios were developed specifically for MERGE project partners to use. Please refer to the MERGE Task 3.2 report for full details of all the scenarios. An overview is provided below focusing on Scenario 2.

The penetration scenarios are composed of assumptions from technology roadmaps (MERGE Task 5.1), public domain reports and forecasts, non-public domain reports and forecasts and Ricardo expertise.

Three uptake scenarios have been considered for EV: Scenario 1, Scenario 2 and Scenario 3 (Figure 104). The uptake scenarios have been plotted in one-year increments from 2010 to 2030.

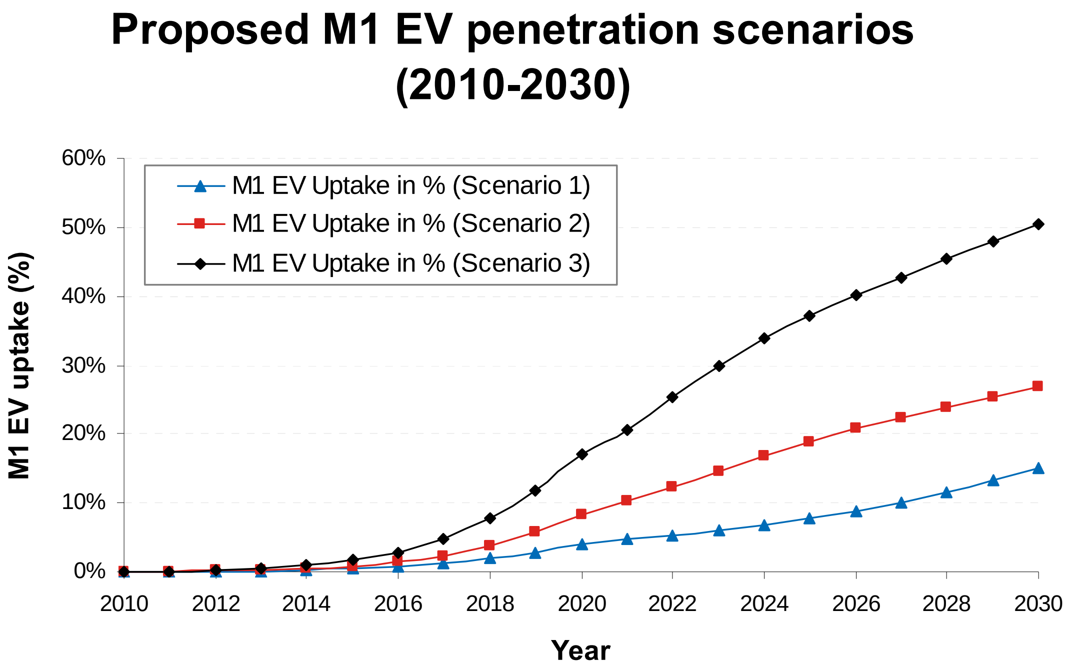


Figure 104: Predicted M1 class EV sales percentages from 2010 to 2030. Scenario 1 is a sensible estimate of EV uptake, however Scenario 2 should be used by MERGE project partners to assess the impact of mass integration of EV on the grid (Source: Ricardo analysis)

These three scenarios have been identified to give an upper bound limit and lower bound estimate for the uptake of EV.

- Scenario 1 – a sensible estimate of EV uptake that is the most likely of the three scenarios to occur in reality. However, the needs of the MERGE project require information on the effects of mass integration of EV on the grid and this scenario, whilst likely in reality, may not be sufficiently high to assess the future needs of the grid.
- Scenario 2 – whilst being a more aggressive EV uptake scenario than is expected in reality, this scenario is the most appropriate for use in the project. It is recommended as the prime focus for the MERGE project partners to use in

their studies as it will provide better information on the effects of mass integration of EV on the grid.

- Scenario 3 – a very aggressive EV uptake scenario which could be used as an alternative scenario by the MERGE project partners if necessary. It is highly unlikely that these values will be exceeded at a national level.

It should be noted that all scenarios are estimates and real world figures may lie outside of these boundaries.

Figure 105 shows that the majority of the longer-term (post 2020) proposed target uptake figures obtained are below Scenario 2, with the majority being around Scenario 1.

For this reason Scenario 2 has been chosen as the prime focus for the MERGE project. Scenario 2 should be sufficient to model the effect of a significant uptake of EV on the European electricity demand.

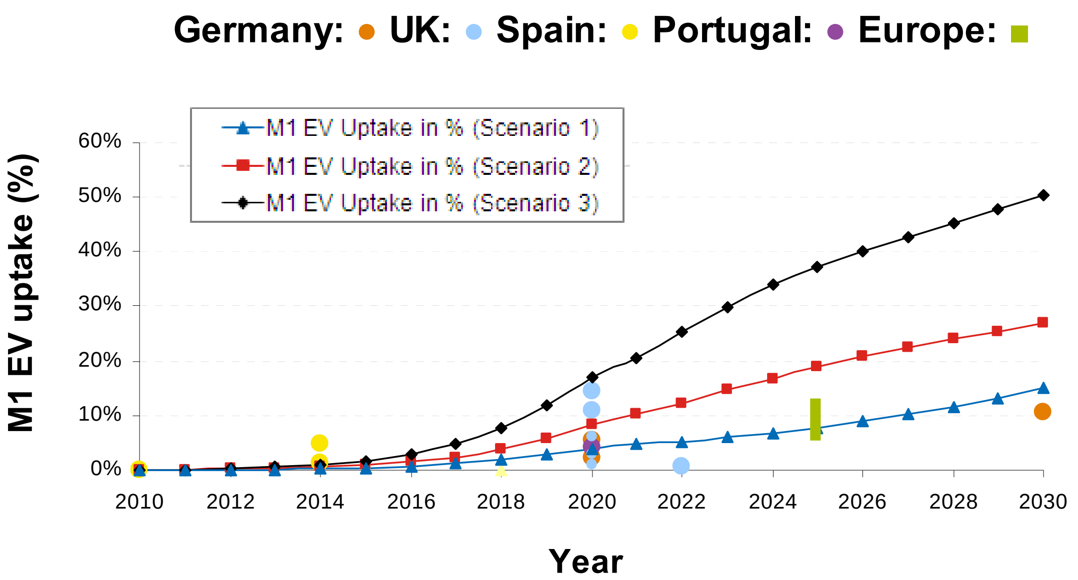


Figure 105: EV penetration scenarios versus EV targets (Source: Ricardo analysis)

It is important for the MERGE project partners to consider that the targets and projected uptake scenarios are current projections and may be subject to change.

5.3 Forecasted M1 EV Sales in Europe (Scenario 2)

Using M1 EV uptake Scenario 2, it is possible to make forecasts of the sales of EV within Europe. This has been split into the five countries that have been identified in the DoW for MERGE Task 3.1: Germany, UK, Spain, Portugal and Greece (Figure 106).

The data used to make these forecasts come from Schmidt's 2009 AUTO AID historic and projection data, from 1988 to 2013 [36]. From 2013 onwards, a single sales growth rate of 0.35% from EU27 data is considered for all countries [37].

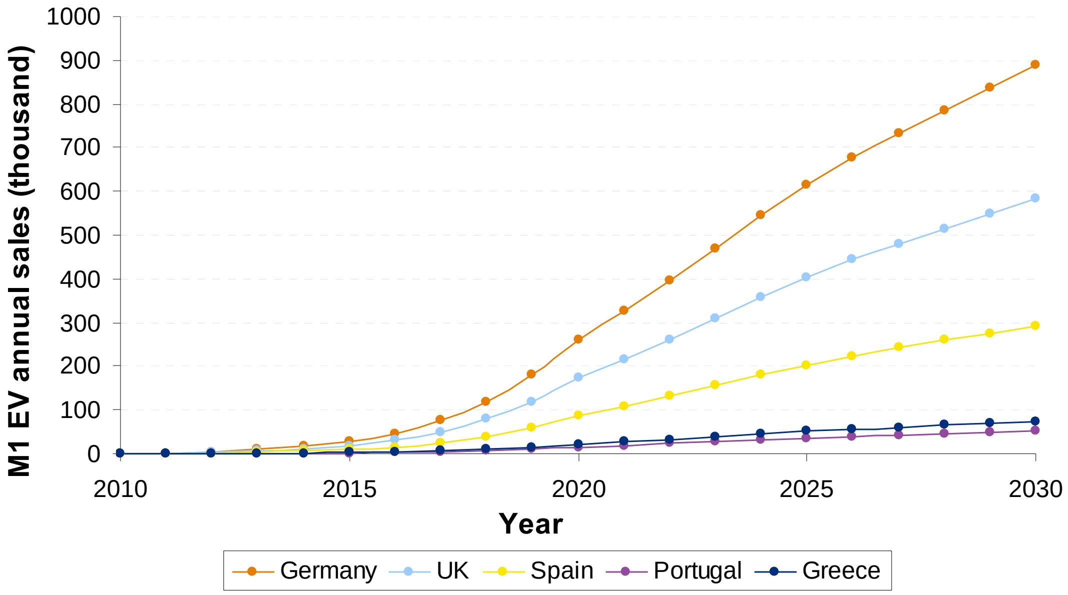


Figure 106: Scenario 2 EV sales per country (Source: Ricardo analysis, [36])

This forecast is required in order to estimate the composition of the vehicle fleet (from now on referred to as 'car parc') from 2010 to 2030.

5.4 Forecasted M1 EV Car Parc (Scenario 2)

The data from the previous sub-sections is used below to give an overview of the vehicle parc in the five key countries. The growth rate of the overall vehicle parc in each country has been estimated using the 20-year average growth rate, shown in Table 20, in order to provide values of the overall vehicle parc in each country.

	Average % change over last 20 years
Germany	1.6%
UK	1.8%
Spain	3.5%
Portugal	6.0%
Greece	6.5%

Table 20: Growth rate of the vehicle parc per country (Source: Ricardo analysis)

The attrition rate for new vehicles (Figure 73) is used with the EV sales (Figure 106) to give a forecast of the number of EV on the road in the period from 2010 to 2030. The percentage of EV as a proportion of the total vehicle parc has then been estimated, as shown in Figure 107.

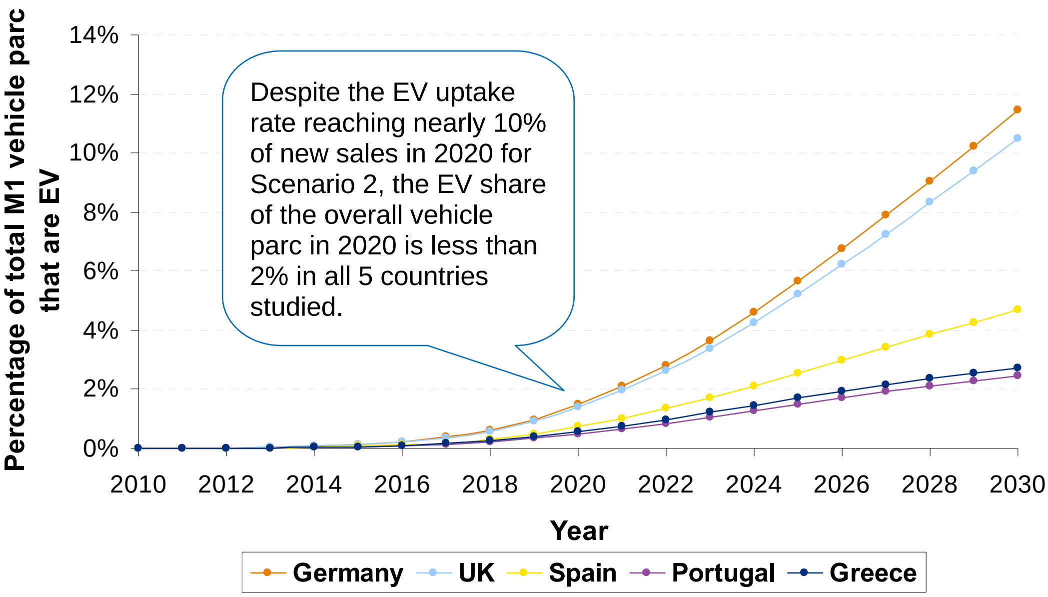


Figure 107: Percentage of the total M1 vehicle parc that are EV – Scenario 2 (Source: Ricardo analysis).

Figure 107 provides a very important conclusion, despite the M1 EV uptake rate reaching nearly 10% of new sales in 2020 for Scenario 2 (as shown in Figure 105), the M1 EV share of the overall M1 vehicle parc in 2020 is less than 2% in all five countries studied.

As the growth rate of the vehicle parc is higher than the predicted increase in new car sales (indicating an ageing vehicle parc), the relative M1 vehicle parcs of each country grow at noticeably different rates after 2016 (Figure 107).

The EV parc data shown above has been split into vehicle class (L7e, M1, N1 and N2) and by location (urban, sub-urban and rural) for the MERGE partners to use to model different requirements of the electricity grid across Europe. The full data set is provided in the MERGE Task 3.2 report.

5.4.1 E.g. Germany EV car parc (Scenario 2)

As stated above, EV uptake Scenario 2 is considered here. Figure 108 shows the composition of the vehicle parc from 2010 to 2030 in Germany. It is possible to see that the majority of the parc will be made up of M1 vehicles, with significant uptake of N1 as well. Values for N2 and L7e are shown but are barely distinguishable compared to M1 and N1.

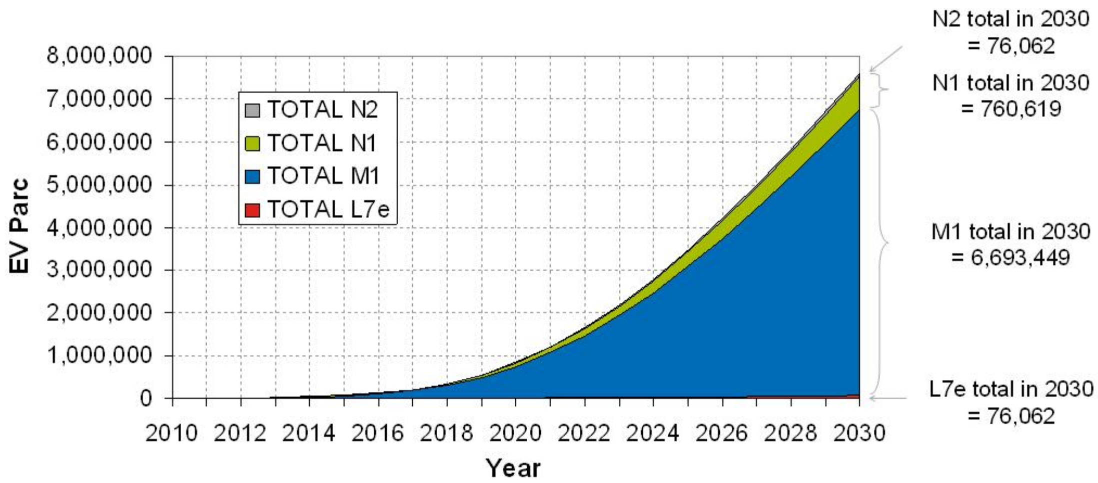


Figure 108: Number of vehicles in EV parc: Germany (Scenario 2). For Scenario 1 and Scenario 3 data, please see MERGE Task 3.2 report (Source: Ricardo analysis)

Germany EV car parc composition (Scenario 2)

The following plots illustrate graphically the split of the EV parc in Germany. The data supplied gives values for all the classes (L7e, M1, N1 and N2) and the sub-classification of these (BEV, PHEV and EREV).

For M1 and N1 the total values of EV in the parc have been split into the three categories specified.

Germany: Scenario 2: M1

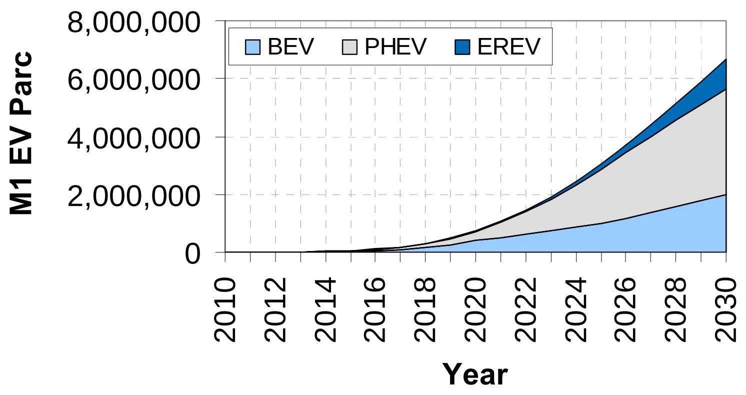


Figure 109: BEV, PHEV, EREV split for M1 Parc: Germany – Scenario 2

Germany: Scenario 2: N1

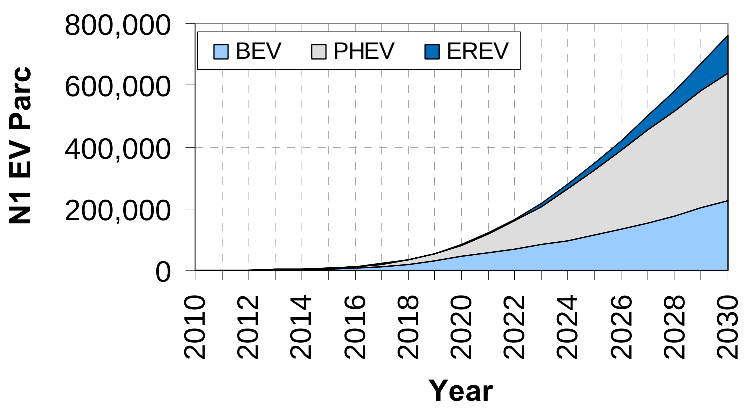


Figure 110: BEV, PHEV, EREV split for N1 Parc: Germany – Scenario 2

It is assumed that L7e and N2 vehicles will be 100% BEV.

Germany: Scenario 2: L7e

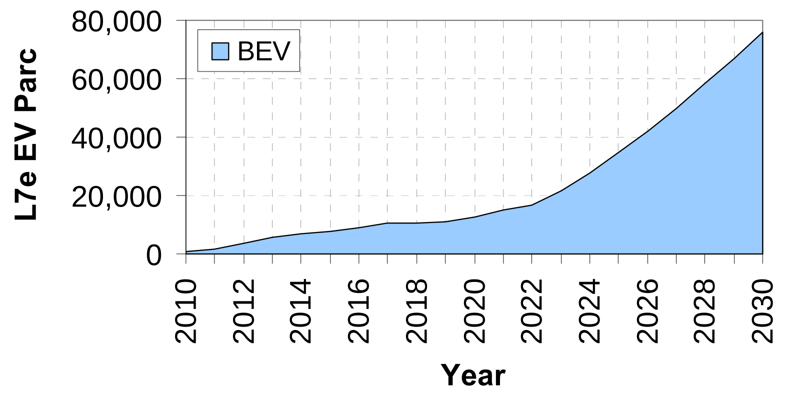


Figure 111: BEV, PHEV, EREV split for L7e Parc: Germany – Scenario 2

Germany: Scenario 2: N2

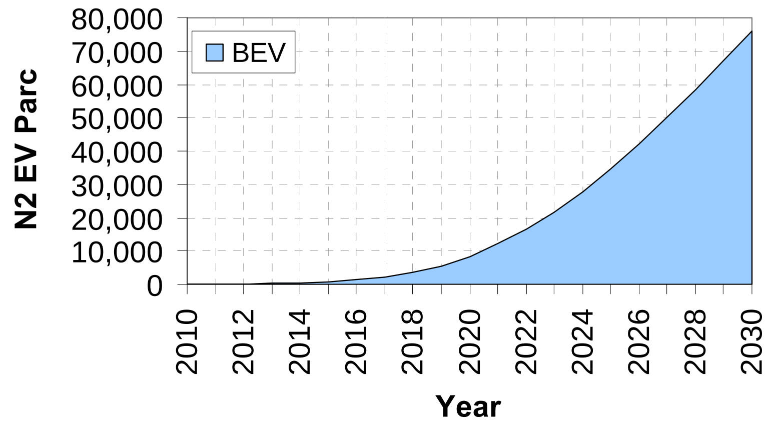


Figure 112: BEV, PHEV, EREV split for N2 Parc: Germany – Scenario 2

Figure 109 to Figure 112 illustrate the breakdown of the vehicle parc composition. For the subsequent countries (UK, Spain, Portugal and Greece) it has been assumed that they will follow the same proportional split. Therefore these plots have not been repeated in this report for those countries.

Distribution of Germany EV car parc

The following tables provide the estimated number of EV in the parc split by urban, sub-urban and rural. Each EV segment is identified in a separate table. These tables should be sufficient to enable MERGE project partners to model EV uptake.

As a snapshot to accompany the previous Ricardo penetration estimates, the information is at 2010, 2020 and 2030 only, but data for all years is available.

The data provided uses the Scenario 2 uptake only. For all the data, including Scenario 1 and Scenario 3 please see MERGE Task 3.2 report.

EV type	Charge location	2010			2020			2030		
		% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	254	55%	40%	162,166	30%	40%	795,302
	Sub-urban		55%	349		55%	222,978		55%	1,093,540
	Rural		5%	32		5%	20,271		5%	99,413
PHEV	Urban	0%	0%	0	42%	30%	93,843	54%	15%	544,323
	Sub-urban		0%	0		55%	172,046		55%	1,995,853
	Rural		0%	0		15%	46,922		30%	1,088,647
EREV	Urban	0%	0%	0	3%	25%	5,662	16%	15%	161,456
	Sub-urban		0%	0		60%	13,589		60%	645,823
	Rural		0%	0		15%	3,397		25%	269,093
Total number of M1 vehicles				634			740,873			6,693,449
M1 EV total as % of M1 Vehicle parc			0.00%			1.48%			11.44%	

Figure 113: M1 Germany – Scenario 2

EV type	Charge location	2010			2020			2030		
		% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	51	55%	40%	18,531	30%	40%	90,375
	Sub-urban		55%	70		55%	25,480		55%	124,266
	Rural		5%	6		5%	2,316		5%	11,297
PHEV	Urban	0%	0%	0	42%	30%	10,724	54%	15%	61,855
	Sub-urban		0%	0		55%	19,660		55%	226,801
	Rural		0%	0		15%	5,362		30%	123,710
EREV	Urban	0%	0%	0	3%	25%	647	16%	15%	18,347
	Sub-urban		0%	0		60%	1,553		60%	73,389
	Rural		0%	0		15%	388		25%	30,579
Total number of N1 vehicles				127			84,662			760,619

Figure 114: N1 Germany - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	75%	476	75%	9,461	75%	57,046
	Sub-urban	25%	159	25%	3,154	25%	19,015
	Rural	0%	0	0%	0	0%	0
Total number of L7e vehicles			634		12,615		76,062

Figure 115: L7e Germany - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	25%	4	25%	2,117	25%	19,015
	Sub-urban	75%	11	75%	6,350	75%	57,046
	Rural	0%	0	0%	0	0%	0
Total number of N2 vehicles			14		8,466		76,062

Figure 116: N2 Germany - Scenario 2

5.4.2 UK

The following plot identifies the EV category split for the UK. The same proportions applied to Germany have been applied to each of the other four countries considered. This plot can therefore be used to identify and compare the number of vehicles in the EV parc.

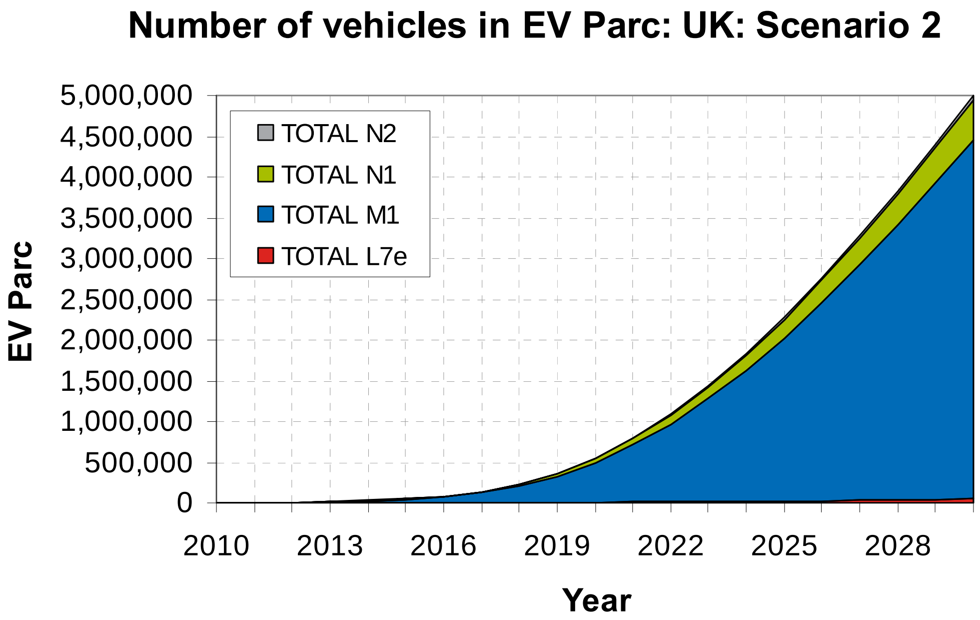


Figure 117: Number of vehicles in EV parc: UK (Source: Ricardo analysis)

Distribution of UK EV car parc

The following tables provide the estimated number of EV in the parc split by urban, sub-urban and rural. Again, each EV segment is identified in a separate table and information is provided for 2010, 2020 and 2030 only.

The data provided uses the Scenario 2 uptake only. For all the data, including Scenario 1 and Scenario 3 please see MERGE Task 3.2 report.

EV type	Charge location	2010			2020			2030		
		% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	157	55%	40%	106,453	30%	40%	522,543
	Sub-urban		55%	215		55%	146,372		55%	718,497
	Rural		5%	20		5%	13,307		5%	65,318
PHEV	Urban	0%	0%	0	42%	30%	61,603	54%	15%	357,641
	Sub-urban		0%	0		55%	112,939		55%	1,311,350
	Rural		0%	0		15%	30,801		30%	715,282
EREV	Urban	0%	0%	0	3%	25%	3,717	16%	15%	106,082
	Sub-urban		0%	0		60%	8,920		60%	424,330
	Rural		0%	0		15%	2,230		25%	176,804
Total number of M1 vehicles				392			486,341			4,397,847
M1 EV total as % of Vehicle parc			0.00%			1.38%			10.48%	

Figure 118: M1 UK - Scenario 2

EV type	Charge location	2010			2020			2030		
		% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	31	55%	40%	12,165	30%	40%	59,380
	Sub-urban		55%	43		55%	16,726		55%	81,647
	Rural		5%	4		5%	1,521		5%	7,422
PHEV	Urban	0%	0%	0	42%	30%	7,040	54%	15%	40,641
	Sub-urban		0%	0		55%	12,906		55%	149,017
	Rural		0%	0		15%	3,520		30%	81,282
EREV	Urban	0%	0%	0	3%	25%	425	16%	15%	12,055
	Sub-urban		0%	0		60%	1,019		60%	48,219
	Rural		0%	0		15%	255		25%	20,091
Total number of N1 vehicles				78			55,576			499,755

Figure 119: N1 UK - Scenario 2

EV type	Charge location	2010 %	2010 Number of vehicles	2020 %	2020 Number of vehicles	2030 %	2030 Number of vehicles
BEV	Urban	75%	294	75%	6,211	75%	37,482
	Sub-urban	25%	98	25%	2,070	25%	12,494
	Rural	0%	0	0%	0	0%	0
Total number of L7e vehicles			392		8,281		49,976

Figure 120: L7e UK - Scenario 2

EV type	Charge location	2010 %	2010 Number of vehicles	2020 %	2020 Number of vehicles	2030 %	2030 Number of vehicles
BEV	Urban	25%	2	25%	1,389	25%	12,494
	Sub-urban	75%	7	75%	4,168	75%	37,482
	Rural	0%	0	0%	0	0%	0
Total number of N2 vehicles			9		5,558		49,976

Figure 121: N2 UK - Scenario 2

5.4.3 Spain

The following plot identifies the EV category split for Spain.

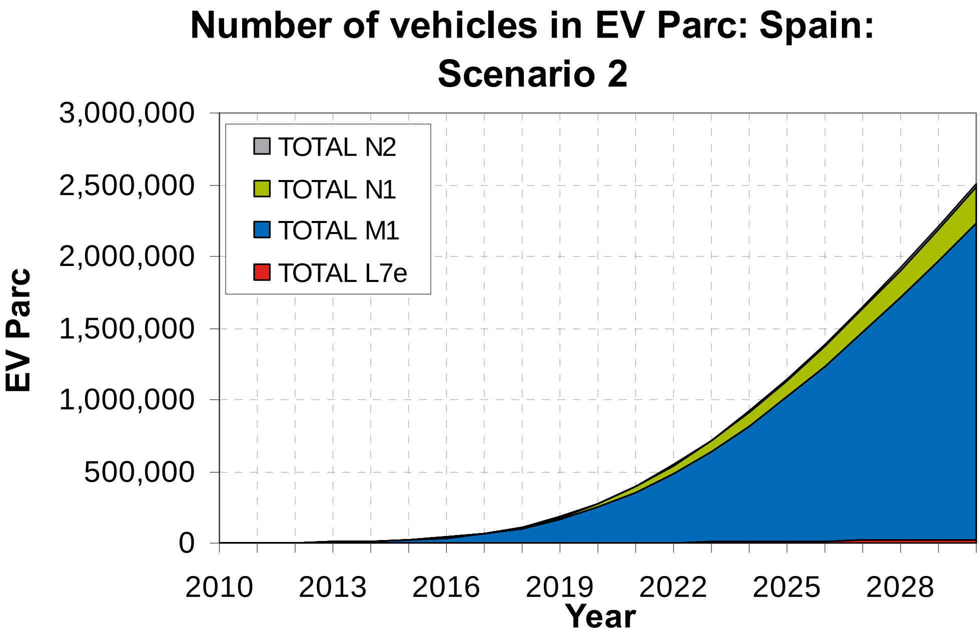


Figure 122: Number of vehicles in EV parc: Spain (Source: Ricardo analysis)

Distribution of Spain EV car parc

The following tables provide the estimated number of EV in the parc split by urban, sub-urban and rural. Each EV segment is identified in a separate table and information is provided for 2010, 2020 and 2030 only.

The data provided uses the Scenario 2 uptake only. For all the data, including Scenario 1 and Scenario 3 please see MERGE Task 3.2 report.

EV type	Charge location	2010 % of M1 vehicles	2010 %	2010 Number of vehicles	2020 % of M1 vehicles	2020 %	2020 Number of vehicles	2030 % of M1 vehicles	2030 %	2030 Number of vehicles
BEV	Urban	100%	40%	80	55%	40%	53,468	30%	40%	262,543
	Sub-urban		55%	110		55%	73,519		55%	360,997
	Rural		5%	10		5%	6,684		5%	32,818
PHEV	Urban	0%	0%	0	42%	30%	30,941	54%	15%	179,691
	Sub-urban		0%	0		55%	56,726		55%	658,867
	Rural		0%	0		15%	15,471		30%	359,382
EREV	Urban	0%	0%	0	3%	25%	1,867	16%	15%	53,299
	Sub-urban		0%	0		60%	4,480		60%	213,198
	Rural		0%	0		15%	1,120		25%	88,832
Total number of M1 vehicles				200			244,276			2,209,629
M1 EV total as % of Vehicle parc			0.00%			0.73%			4.68%	

Figure 123: M1 Spain - Scenario 2

EV type	Charge location	2010 % of N1 vehicles	2010 %	2010 Number of vehicles	2020 % of N1 vehicles	2020 %	2020 Number of vehicles	2030 % of N1 vehicles	2030 %	2030 Number of vehicles
BEV	Urban	100%	40%	16	55%	40%	6,110	30%	40%	29,834
	Sub-urban		55%	22		55%	8,401		55%	41,022
	Rural		5%	2		5%	764		5%	3,729
PHEV	Urban	0%	0%	0	42%	30%	3,536	54%	15%	20,419
	Sub-urban		0%	0		55%	6,482		55%	74,871
	Rural		0%	0		15%	1,768		30%	40,839
EREV	Urban	0%	0%	0	3%	25%	213	16%	15%	6,057
	Sub-urban		0%	0		60%	512		60%	24,227
	Rural		0%	0		15%	128		25%	10,095
Total number of N1 vehicles				40			27,914			251,094

Figure 124: N1 Spain - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	75%	150	75%	3,119	75%	18,832
	Sub-urban	25%	50	25%	1,040	25%	6,277
	Rural	0%	0	0%	0	0%	0
Total number of L7e vehicles			200		4,159		25,109

Figure 125: L7e Spain - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	25%	1	25%	1,357	25%	12,276
	Sub-urban	75%	3	75%	4,071	75%	36,827
	Rural	0%	0	0%	0	0%	0
Total number of N2 vehicles			4		5,428		49,103

Figure 126: N2 Spain - Scenario 2

5.4.4 Portugal

The following plot identifies the EV category split for Portugal.

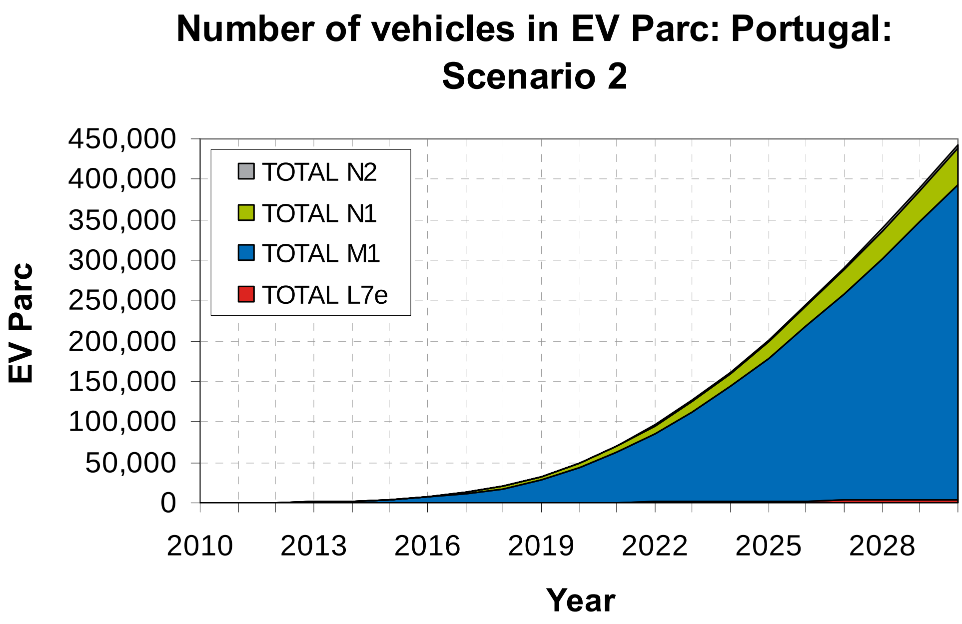


Figure 127: Number of vehicles in EV parc: Portugal (Source: Ricardo analysis)

Distribution of Portugal EV car parc

The following tables provide the estimated number of EV in the parc split by urban, sub-urban and rural. Again, each EV segment is identified in a separate table and information is provided for 2010, 2020 and 2030 only.

The data provided uses the Scenario 2 uptake only. For all the data, including Scenario 1 and Scenario 3 please see MERGE Task 3.2 report.

EV type	Charge location	2010			2020			2030		
		% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles	% of M1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	14	55%	40%	9,430	30%	40%	46,265
	Sub-urban		55%	0		55%	12,967		55%	63,614
	Rural		5%	0		5%	1,179		5%	5,783
PHEV	Urban	0%	0%	0	42%	30%	5,457	54%	15%	31,665
	Sub-urban		0%	0		55%	10,005		55%	116,104
	Rural		0%	0		15%	2,729		30%	63,329
EREV	Urban	0%	0%	0	3%	25%	329	16%	15%	9,392
	Sub-urban		0%	0		60%	790		60%	37,569
	Rural		0%	0		15%	198		25%	15,654
Total number of M1 vehicles				14			43,084			389,375
M1 EV total as % of Vehicle parc			0.00%			0.48%			2.44%	

Figure 128: M1 Portugal - Scenario 2

EV type	Charge location	2010			2020			2030		
		% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles	% of N1 vehicles	%	Number of vehicles
BEV	Urban	100%	40%	3	55%	40%	1,078	30%	40%	5,257
	Sub-urban		55%	4		55%	1,482		55%	7,229
	Rural		5%	0		5%	135		5%	657
PHEV	Urban	0%	0%	0	42%	30%	624	54%	15%	3,598
	Sub-urban		0%	0		55%	1,143		55%	13,194
	Rural		0%	0		15%	312		30%	7,197
EREV	Urban	0%	0%	0	3%	25%	38	16%	15%	1,067
	Sub-urban		0%	0		60%	90		60%	4,269
	Rural		0%	0		15%	23		25%	1,779
Total number of N1 vehicles				7			4,923			44,247

Figure 129: N1 Portugal - Scenario 2

EV type	Charge location	2010 %	2010 Number of vehicles	2020 %	2020 Number of vehicles	2030 %	2030 Number of vehicles
BEV	Urban	75%	27	75%	550	75%	3,319
	Sub-urban	25%	9	25%	183	25%	1,106
	Rural	0%	0	0%	0	0%	0
Total number of L7e vehicles			36		734		4,425

Figure 130: L7e Portugal - Scenario 2

EV type	Charge location	2010 %	2010 Number of vehicles	2020 %	2020 Number of vehicles	2030 %	2030 Number of vehicles
BEV	Urban	25%	0	25%	239	25%	2,163
	Sub-urban	75%	1	75%	718	75%	6,490
	Rural	0%	0	0%	0	0%	0
Total number of N2 vehicles			1		957		8,653

Figure 131: N2 Portugal - Scenario 2

5.4.5 Greece

The following plot identifies the EV category split for Greece.

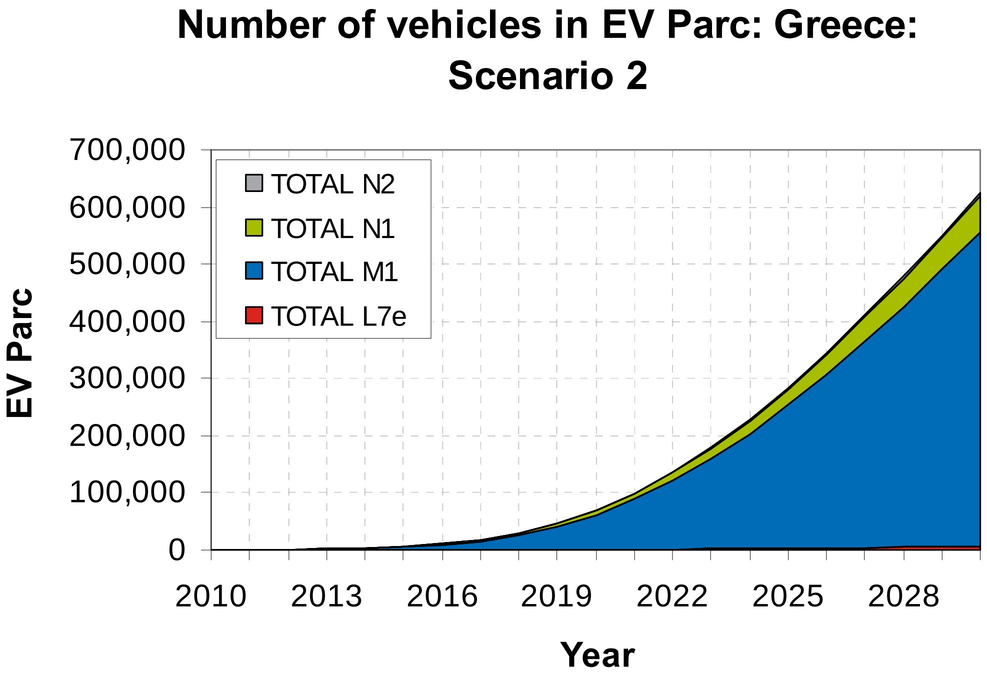


Figure 132: Number of vehicles in EV parc: Greece (Source: Ricardo analysis)

Distribution of Greece EV car parc

The following tables provide the estimated number of EV in the parc split by urban, sub-urban and rural. Again, each EV segment is identified in a separate table and information is provided for 2010, 2020 and 2030 only.

The data provided uses the Scenario 2 uptake only. For all the data, including Scenario 1 and Scenario 3 please see MERGE Task 3.2 report.

EV type	Charge location	2010 % of M1 vehicles	2010 %	2010 Number of vehicles	2020 % of M1 vehicles	2020 %	2020 Number of vehicles	2030 % of M1 vehicles	2030 %	2030 Number of vehicles
BEV	Urban	100%	40%	20	55%	40%	13,330	30%	40%	65,383
	Sub-urban		55%	27		55%	18,328		55%	63,614
	Rural		5%	2		5%	1,666		5%	8,173
PHEV	Urban	0%	0%	0	42%	30%	7,714	54%	15%	44,750
	Sub-urban		0%	0		55%	14,142		55%	164,082
	Rural		0%	0		15%	3,857		30%	89,499
EREV	Urban	0%	0%	0	3%	25%	465	16%	15%	13,273
	Sub-urban		0%	0		60%	1,117		60%	53,094
	Rural		0%	0		15%	279		25%	22,122
Total number of M1 vehicles				49			60,898			523,990
M1 EV total as % of Vehicle parc			0.00%			0.56%			2.59%	

Figure 133: M1 Greece - Scenario 2

EV type	Charge location	2010 % of N1 vehicles	2010 %	2010 Number of vehicles	2020 % of N1 vehicles	2020 %	2020 Number of vehicles	2030 % of N1 vehicles	2030 %	2030 Number of vehicles
BEV	Urban	100%	40%	4	55%	40%	1,523	30%	40%	7,430
	Sub-urban		55%	5		55%	2,094		55%	10,216
	Rural		5%	0		5%	190		5%	929
PHEV	Urban	0%	0%	0	42%	30%	881	54%	15%	5,085
	Sub-urban		0%	0		55%	1,616		55%	18,646
	Rural		0%	0		15%	441		30%	10,170
EREV	Urban	0%	0%	0	3%	25%	53	16%	15%	1,508
	Sub-urban		0%	0		60%	128		60%	6,033
	Rural		0%	0		15%	32		25%	2,514
Total number of N1 vehicles				10			6,959			62,531

Figure 134: N1 Greece - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	75%	37	75%	778	75%	4,690
	Sub-urban	25%	12	25%	259	25%	1,563
	Rural	0%	0	0%	0	0%	0
Total number of L7e vehicles			49		1,037		6,253

Figure 135: L7e Greece - Scenario 2

EV type	Charge location	2010		2020		2030	
		%	Number of vehicles	%	Number of vehicles	%	Number of vehicles
BEV	Urban	25%	0	25%	338	25%	3,057
	Sub-urban	75%	1	75%	1,015	75%	9,171
	Rural	0%	0	0%	0	0%	0
Total number of N2 vehicles			1		1,353		12,228

Figure 136: N2 Greece - Scenario 2

5.5 Section Conclusions

- Vehicle sales forecasts (from Task 3.2) from 2010 to 2030 and EV penetration scenarios (also from Task 3.2) were applied to identify EV car parc figures for Germany, UK, Spain, Portugal and Greece over this period.
- Despite the EV uptake rate reaching nearly 10% of new sales in 2020 for Scenario 2, the EV share of the overall vehicle parc in 2020 is less 2% in all countries.
- EV car parc figures were split by vehicle category (L7e, M1, N1, and N2), vehicle type (BEV, PHEV and EREV) and charge location (urban, sub-urban and rural split).
- The data presented here and in Section 2.9 can be used to form the basis of the input parameters for models to be run by MERGE partners. This data should enable the effects of the integration of EV on European electricity grids to be considered.
- Scenario 2 should be used as the prime focus for modelling, because whilst being a more aggressive EV uptake scenario than is expected in reality, this scenario is the most appropriate for use in the project. It is recommended as the prime focus for the MERGE project partners to use in their studies as it will provide better information on the effects of mass integration of EV on the grid.

Please refer to MERGE reports Task 3.2 and Task 5.1 for full data sets relating to the EV penetration scenarios shown in this Section.

6 CONCLUSIONS

There are four main vehicle categories that are applicable for vehicle electrification that are considered in this report, namely L7e, M1, N1 and N2. Currently, lead-acid battery technology predominates in the L7e class due to the need for a low-cost, short range city vehicle. However in all the other classes, Li-ion is already the most popular choice of battery chemistry. The trend is for Li-ion to become the dominant battery technology in all classes.

Considering the above, the modelling data, available vehicle ranges, usage profiles, charging characteristics and other assumptions contained within this report have therefore been based mainly upon Li-ion technology.

Consideration of the location of usage has also been given. It has been noted that temperature effects, especially at cold extremes, will have detrimental effects on the charging/discharging characteristics of the battery as well as apparent available capacity of the battery unit. This is an important consideration considering the extreme temperature differences that can occur across Europe and one which could have implications on the overall V2G strategy.

The energy storage devices will have a significant influence on the design of charging points. Effective communication between the vehicle and charger is of paramount importance for reasons of safety and reliability. The selection of charging rate is important due to inherent energy loss, especially at higher rates. Vehicle owners may need a method of securing enough energy within their storage device to cover their subsequent journey requirements and may also require compensation for any shortening of battery life incurred due to V2G discharging activity.

The design of future battery management systems will be crucial to the management of successful high rate charging/discharging regimes, especially when considering V2G activity. The BMS will provide information required on state of charge and state of health of the battery to the charging points and enable correct amounts and rates of energy transfer to occur. The BMS will also be the key to the assessment of wear-out damage incurred in the storage device resulting from additional V2G charging/discharging cycles applied.

The data supplied in this report (in conjunction with two other MERGE project reports - Task 3.2 and Task 5.1) will allow MERGE project partners to model the effects of mass penetration of EV on the electricity grid.

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