Programme Area: Energy Storage and Distribution

Project: Consumers, Vehicles and Energy Integration (CVEI)

Title: D1.4. Stage 2 Trial Design, Methodology and Business Case

Abstract:

This report represents Deliverable 1.4: Stage 2 Trial Design, Methodology and Business Case. The purpose of this report is to communicate the proposed design of research activities to be conducted in Stage 2 of the project. There are six parts to this report: Part 1: Overview of Stage 2, Part 2: Consumer Uptake Trial, Part 3: Consumer Charging Trial, Part 4: Fleet Study, Part 5: Analytical Tool, Part 6: Commercial Submission.

Part 1 provides an overview of the work package and task structure of work to be completed in Stage 2 of the CVEI project, together with the approach to health and safety, to data privacy and security management. In addition, the dissemination strategy is included, describing the approach for maximising the impact of the project outputs. The proposal for Stage 2 reflects collaborative development involving TRL, Baringa, Element Energy, Cenex, EV Connect, EDF, Behavioural Insights (BIT), Shell and the ETI. The detailed rationale and technical design of each element of the work are presented in Parts 2 to 5. Full details of the project timeline and costs were provided as Part 6 of this deliverable (Commercial Submission), but are not included in this document.

Context:

The objective of the Consumers, Vehicles and Energy Integration project is to inform UK Government and European policy and to help shape energy and automotive industry products, propositions and investment strategies. Additionally, it aims to develop an integrated set of analytical tools that models future market scenarios in order to test the impact of future policy, industry and societal choices. The project is made up of two stages:

• Stage 1 aims to characterize market and policy frameworks, business propositions, and the integrated vehicle and energy infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles, using the amalgamated analytical toolset.

• Stage 2 aims to fill knowledge gaps and validate assumptions from Stage 1 through scientifically robust research, including real world trials with private vehicle consumers and case studies with business fleets. A mainstream consumer uptake trial will be carried out to measure attitudes to PiVs after direct experience of them, and consumer charging trials will measure mainstream consumer PiV charging behaviours and responses to managed harging options.

THE FUTURE OF TRANSPORT

PROJECT REPORT

D1.4 Stage 2 Trial Design, Methodology and Business Case

Part 1 - Stage 2 Overview

N. Kinnear, R. Jenkins and G. Beard

Report details

Report prepared for:	ETI
Project/customer reference:	TR1006 Consumers, Vehicles and Energy Infrastructure (CVEI) project
Copyright:	
Report date:	March 2017
Report status/version:	
Quality approval:	

H. Al-Katib (Project Manager)		S. Skippon (Technical Reviewer)	

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	10/06/16	Draft delivered to client	GB	SS
2.0	14/12/16	Second version to client	HAK	SS
3.0	14/02/17	Third version to client	HAK	SS
4.0	13/03/17	Final version to client	HAK	SS

Document last saved on:	13/03/2017 14:45
Document last saved by:	Al-Katib, Hannah

Table of Contents

Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics
ESME	Energy System Modelling Environment

ESOS	Energy Savings Opportunity Scheme
EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
ISO	International Organization for Standardization
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Charge Point Protocol

OEM	Original Equipment Manufacturer
ONS	Office for National Statistics
OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
UMC	User Managed Charging
VAT	Value Added Tax
VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services

WP	Work Package

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.

Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)
Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
S Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how you see yourself and how one perceives others see them.
Social norms	Similar to injunctive norms but mores specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.
Symbolic meaning/ attitudes	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

STATUS OF TRIAL DESIGN INFORMATION

THIS DOCUMENT WAS PRODUCED IN STAGE ONE OF THE CVEI PROJECT, TO SET OUT THE PROPOSED TRIAL DESIGN AT THAT POINT.

IN STAGE TWO, THE TRIAL DESIGN HAS BEEN FURTHER DEVELOPED, AND SOME ASPECTS OF THE TRIAL DESIGN HAVE EVOLVED FROM THE PROPOSAL SET OUT IN THIS DOCUMENT.

THE FULL AND FINAL DESIGNS OF THE CONSUMER UPTAKE AND CONSUMER CHARGING TRIALS ARE DOCUMENTED IN DELIVERABLE D5.1 "SUPPLEMENTARY DETAILS OF DESIGN, MATERIALS AND MANAGEMENT ARRANGEMENTS FOR CONSUMER TRIALS".

PARTS 2 AND 3 IN PARTICULAR OF THIS DELIVERABLE D1.4 ARE SUPERSEDED BY D5.1

1 Introduction

1.1 Project overview

The purpose of the Consumers, Vehicles and Energy Integration (CVEI) project is to investigate challenges and opportunities involved in transitioning to a secure and sustainable low carbon vehicle fleet. The project explores how the integration of vehicles with the energy supply system can benefit vehicle users, vehicle manufacturers and those involved in the supply of energy.

The objective of the project is to inform UK Government and European policy and to help shape energy and automotive industry products, propositions and investment strategies. In addition to developing new knowledge and understanding, the project aims to develop an integrated set of analytical tools that can be used to model future market scenarios in order to test the impact of future policy, industry and societal choices. An amalgamation of analytical tools was therefore developed in Stage 1 of this project. This toolset was then used to characterise market and policy frameworks, business propositions, and the integrated vehicle and energy infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles (see D1.3).

The effectiveness of the analytical tools for meeting the objective of the project is dependent on the accuracy of the data entered into them. Complementary research activities were conducted in Stage 1 to inform the data and assumptions applied to the analytical tools[1]. These activities included:

- A literature review of consumer demand for electric vehicles and consumer acceptance of demand management.
- Interviews with current users of BEVs and PHEVs, and those who have had experience of but do not own an EV, to explore EV adoption and acceptance of demand management when charging.
- Interviews with fleet managers regarding the adoption of EVs and exploration of their initial response to future demand management options.
- Assessment of vehicle energy supply management systems and battery technology.
- Exploration of energy infrastructure management systems and technologies to aid development of a market framework.

Stage 1 also sought to develop the most relevant market and policy scenarios for testing and identify knowledge gaps and limitations of the analytical tools where further research can be used to inform or validate data or assumptions.

Stage 2 of the project aims to test and as far as possible validate the solutions identified in Stage 1, and address these gaps in knowledge, , by conducting scientifically robust research, including real-world trials with private vehicle consumers, and in-depth research with business fleets. The results of the research activities conducted in Stage 2 will be used to

[1] The results of these research activities are reported separately; the results were used to inform this deliverable and are referred to where relevant.

update and improve the analytical tools developed in Stage 1. The improved framework will be used to update and further develop the system analysis. The final analysis will highlight prominent policy and industry strategies to enhance energy integration between consumers, vehicles and energy systems in the future.

1.2 This report

This report is Deliverable 1.4: Stage 2 Trial Design, Methodology and Business Case, and details the proposed design of research activities for Stage 2 of the CVEI project.

There are six parts to this report:

- Part 1: Overview of Stage 2 (this document)
- Part 2: Consumer Uptake Trial
- Part 3: Consumer Charging Trials
- Part 4: Fleet Study
- Part 5: Analytical Tools
- Part 6: Commercial Submission

This document covers Part 1, the overview of Stage 2. The purpose of this document is to provide an overview of the work package and task structure of work which will be completed in Stage 2 of the CVEI project. The proposal for Stage 2 reflects collaborative development involving TRL, Baringa, Element Energy, Cenex, EV Connect, EDF, Behavioural Insights (BIT), Shell and the ETI.

This document details the Stage 2 Work Packages and tasks, alongside the roles and responsibilities of each of the consortium members within each Work Package. It also details the approach to health and safety and to data privacy and security management that has fed into the Stage 2 research design. Finally, details of the dissemination strategy are included; this describes the steps which will be employed during Stage 2 to maximise the impact of the project outputs.

Parts 2 to 6 of Deliverable 1.4 are provided in separate documents. The detailed rationale and technical design of each element of the work are presented in Parts 2 to 5. Full details regarding the project timeline and costs are provided in Part 6 (Commercial Submission).

2 Work package structure

Figure 1 provides an overview of the Work Package and task structure for Stage 2.

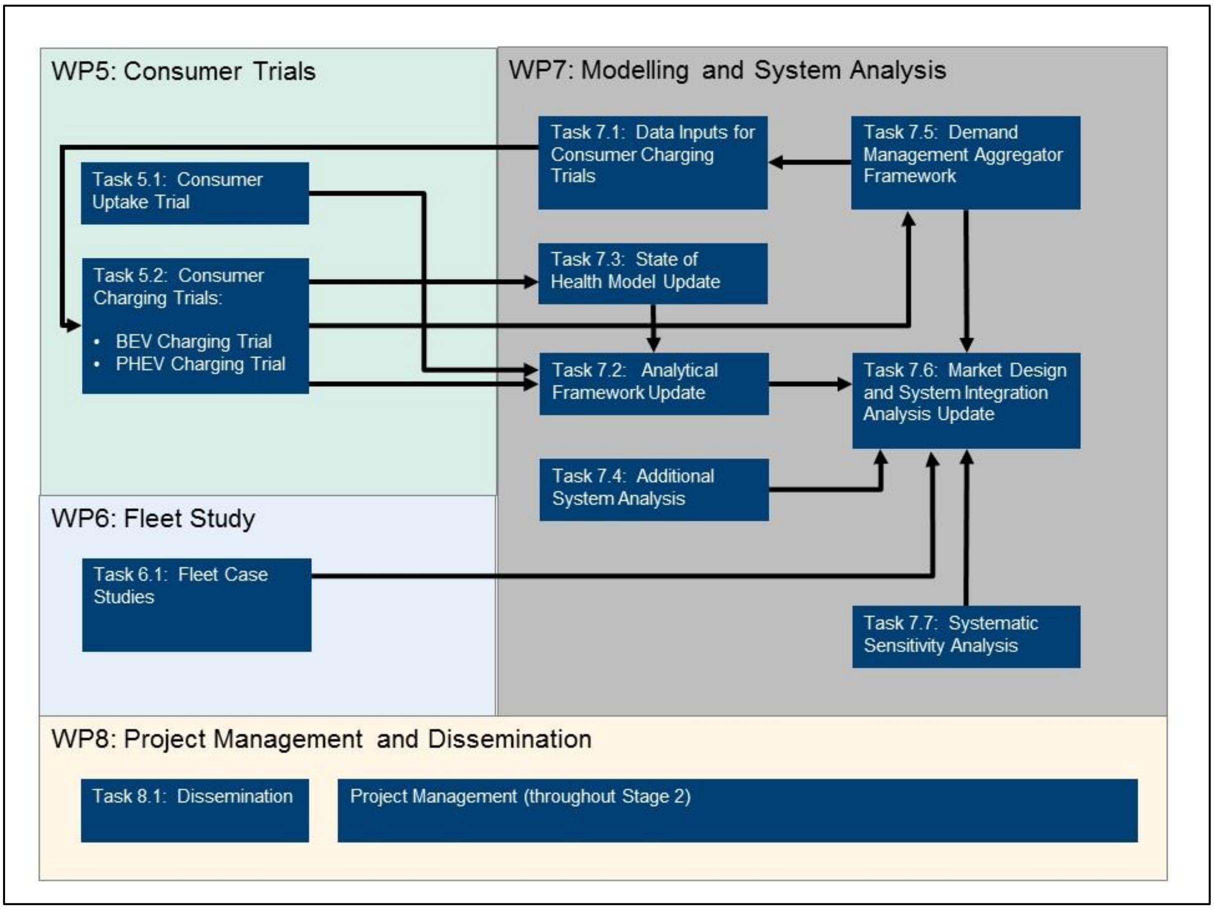

Figure 1: Overview of Stage 2 Work Packages and Tasks

Stage 2 will consist of three Work Packages (WPs):

WP5: Consumer Trials (Parts 2 and 3)

WP6: Fleet Study (Part 4)

WP7: Modelling and System Analysis (Part 5)

WP8: Project Management and Dissemination (Part 1)

Work Packages 5 and 6 will collect data from consumer and fleet participants[2] via real-world trials and in-depth case studies to meet the defined research needs identified from Stage 1; full details of these WPs are provided in Parts 2 to 4.

Modelling using the analytical tools developed in Stage 1 will provide parameters to be set within the Consumer Charging Trials. The data and research findings from WPs 5 and 6 will be used to update the analytical tools in WP7 and to update and further develop the system analysis. To meet the objective of the project, the updated modelling of future scenarios

[2] Where references are made to "participants" or "participant", this refers to trial participants, as opposed to a contracted organisation. /

and the results of the research will be used to develop policy evidence and recommendations (WP7). The results will be disseminated (WP8) to academic, industry and Government stakeholders; the dissemination strategy is outlined in Section 6.

The following sections detail the objectives, deliverables and roles and responsibilities for each task within each Work Package.

2.1 WP5: Consumer Trials

Work Package 5 will be led by TRL with input and support from Baringa, Cenex, Element Energy, EV Connect, EDF and Behavioural Insights (BIT). It will consist of the following two tasks:

- Task 5.1: Consumer Uptake Trial
- Task 5.2: Consumer Charging Trials

These tasks are described in more detail in the following sections.

2.1.1 Task 5.1 Consumer Uptake Trial

Task Lead: TRL	**Key Support: CENEX, EE, EV Connect, BIT**
Task Aims, Objectives and Value	
Aims	To provide high validity measures of attitudes towards adoption of PiVs by Mainstream Consumers who have had real-world experience of using a BEV and a PHEV. This will provide robust inputs to the Analytical Framework to allow more accurate prediction of the likely future uptake of PiVs by the Mass-Market, and the resulting impact on UK aggregated EV charging demand.
Objectives	• To give a sample of Mainstream Consumers sufficient experience of both BEV and PHEV vehicles to reduce their psychological distance to such vehicles; • To measure their attitudes towards adoption of such vehicles following this experience, in order to inform modelling of likely Mass-Market uptake; • To implement the Consumer Uptake Trial design while ensuring the health and safety and privacy of Trial Participants (see sections 4.2 and 5); and • To provide data in the required format for input into WP7.
Value	The Consumer Uptake Trial is unique in its application of a controlled scientific experimental design to measure Mainstream Consumers' willingness to adopt PHEVs and BEVs following experience with a mid-sized family vehicle of both types, and an equivalent ICE car as control, reducing their psychological distance before measurement. The data collected will advance understanding of Mainstream Consumers'

	willingness to adopt and will ensure that the outputs of modelling the uptake of PiVs are as valid as possible.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D5.1** – Supplementary Details of Design, Materials and Management Arrangements for Consumer Trials; (This Deliverable covers both Task 5.1 and Task 5.2); and • **D5.2** – Consumer Uptake Trial Report: Mainstream Consumers' Attitudes and Willingness to Adopt BEVs and PHEVs.
Dependencies	• Recruitment of required sample of Trial Participants; and • Availability of suitable vehicles.
Constraints	• The design provides maximum robustness and validity within the project's budget; and • In the event that a requirement is identified for analysis beyond that set out in the research questions section below, this may be subject to a Variation Request.
Assumptions	• Direct experience of using a BEV or a PHEV will provide sufficient reduction in Trial Participants' psychological distance from these categories of vehicle.
Roles and Responsibilities	
TRL	• Manage and implement Trial design, leading engagement with Subcontractors and the ETI; • Design and pilot questionnaire materials (excluding Choice Experiment items by EE below); • Pilot Trial procedures and vehicle telematics systems; • Obtain ethics approval; • Recruit Trial Participants and obtain informed consent; • Run Trial from TRL headquarters, managing Trial Participants in line with ethical, health and safety and privacy protection protocols; • Ensure standardisation of Trial procedures run by CENEX; • Cross-reference data from EV Connect with questionnaire data and share with Baringa and Element Energy; and • Analyse and report on attitudinal responses to PiVs, including segmentation of Mainstream Consumers based on responses of Trial Participants.
CENEX	• Continual support and engagement with TRL trials team during Trial procedure development and preparation phase; • Follow standardised Trial procedure developed by TRL; • Pilot Trial procedures and vehicle telematics systems as required by

	TRL; and • Run Trial from CENEX headquarters, managing Trial Participants in line with ethical, health and safety and privacy protection protocols.
Element Energy	• Design and pilot Choice Experiment; and • Analyse and report the results of the Choice Experiment for input into Deliverable D5.2 and use in WP7.
EV Connect	• Set-up data management system to collect telematics data from Trial vehicles; • Input into and support of piloting; • Data collection, processing and cleaning during Trial; and • Provide cleaned data in agreed format to TRL.
BIT	• Review of results and deliverables to ensure input into policy analysis and WP7.

2.1.2 Task 5.2 Consumer Charging Trials

Task Lead: TRL	**Key Support: CENEX, EE, EV Connect, Shell, EDF, BIT**
Task Aims, Objectives and Value	
Aims	To investigate Mainstream Consumer charging behaviour with PHEVs and BEVs, and their responses and attitudes to alternative customer propositions which aim to manage energy demand associated with charging PHEVs and BEVs. This will provide robust inputs to the Analytical Framework to allow more accurate prediction of the likely charging behaviour and use of Demand Management schemes by the Mass-Market, and the resulting impact on UK aggregated EV charging demand.
Objectives	• To give samples of Mainstream Consumers sufficient experience of using either a BEV or PHEV vehicle, along with either a User-Managed Charging scheme or a Supplier-Managed Charging scheme, to reduce their psychological distance to use of such vehicles and charging schemes; • To measure their charging behaviour and attitudes towards such schemes following this experience, in order to inform modelling of likely Mass-Market engagement with Managed Charging schemes; • To test selected elements of the systems required to implement successful Demand Management; • To test Consumer responses to key elements of the market structures, customer propositions, energy supply management and technology options that are reflected in the Managed Charging conditions experienced by Trial Participants and in the choice options offered in the Choice Experiment;

	• To implement the Consumer Charging Trials designs (see Part 3) while ensuring the health and safety and privacy of Trial Participants (see sections 4.2 and 5); • To assess the impact of unavailability (or prohibitively high cost) of electricity on PHEV users and the potential for liquid fuel to act as a buffer; and • To provide data in the required format for input into WP7.
Value	The Consumer Charging Trials are unique in their application of a controlled scientific experimental design to measure Mainstream Consumers' charging behaviour and their acceptance of and behavioural response to propositions to control energy demand when charging a PiV. There will be two similar but separate Trials; one to test Mainstream Consumer charging behaviour and responses to Managed Charging schemes when using a PHEV, and the other to test the same when using a BEV. The Trial methods will be similar except that different sampling strategies will be used in the two Trials. Two distinct types of Managed Charging scheme, plus a control condition that enables measurement of charging behaviour in the absence of Managed Charging schemes, will be included in the design. No other study has used these participant samples and this study design. The data collected will advance understanding of Mainstream Consumers' charging behaviours and responses to Managed Charging schemes and ensure that representation of Mainstream Consumer behaviour in the Analytical Framework is as valid as possible. Additional analysis of PHEV Trial data by Shell will provide an understanding of utility factors (UF, the fraction of mileage covered under electric power) which will enable estimation of the impact of the unavailability (or prohibitively high cost) of electricity (due, for instance, to variability in the provision of renewable power) on the PHEV component of a future, de-carbonised, light-duty road transport vehicle parc in the UK.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D5.1** – Supplementary Details of Design, Materials and Management Arrangements for Consumer Trials; (This Deliverable covers both Task 5.1 and Task 5.2); • **D5.3** – Consumer Charging Trials Report: Mainstream Consumers' Attitudes and Behaviours under Managed Charging Schemes for BEVs and PHEVs; and • **D5.4** – Potential Impact of PHEVs on the Ability of Liquid Fuels to Act as a Buffer in the Energy Supply System.
Dependencies	• Recruitment of required sample of Trial Participants. • Successful development and integration of technologies to simulate Managed Charging schemes and collect vehicle use and charging

	behaviour data. • Successful collection of required telematics data at suitable frequency.
Constraints	• The design provides maximum robustness and validity within the project's budget; and • In the event that a requirement is identified for analysis beyond that set out in the research questions section below, this may be subject to a Variation Request.
Assumptions	None.
Roles and Responsibilities	
TRL	• Manage and implement Trial design, leading engagement with Subcontractors and the ETI; • Design and pilot questionnaire materials (except Choice Experiment items by EE below); • Pilot Trial procedures and vehicle telematics system; • Test and aid development of Charge Point Management System (CPMS) and User Interface smartphone application; • Obtain ethics approval; • Recruit Trial Participants and obtain informed consent; • Run Trial, managing Trial Participants in line with ethical, health and safety and privacy protection protocols; • Cross-reference data from EV Connect with questionnaire data and provide to Baringa and Element Energy; and • Analyse and report on attitudinal and behavioural responses.
CENEX	• Engage closely with TRL trials team during Trial procedure development and preparation phase; • Follow standardised Trial procedure developed by TRL; • Pilot Trial procedure and vehicle telematics system as required by TRL; and • Run Trial from CENEX headquarters, managing Trial Participants in line with ethical, health and safety and privacy protection protocols.
Element Energy	• Design and pilot Choice Experiment; and • Analyse and report the results of the Choice Experiment for input into Deliverable D5.3.
EV Connect	• Set-up data management system to collect telematics data from Trial vehicles; • Develop and test User Interface smartphone application, providing on-going support throughout the Trials to TRL; • Input into and support of piloting;

	• Data collection, processing and cleaning during Trial; and • Provide cleaned data in agreed format to TRL.
Shell	• Analyse in-trip telematics data, assess impact of electricity availability/cost, and report as per D5.4.
EDF	• Provide advice and assistance during development and testing from the consumer business team.
BIT	• Review of results and deliverables to ensure input into policy analysis and WP7.

2.2 WP6: Fleet Study

Work Package 6 will be led by TRL and will consist of one task:

- Task 6.1: Fleet Case Studies

This tasks is described in more detail below.

2.2.1 Task 6.1 Fleet Case Studies

Task Lead: TRL	**Key Support: None**
Task Aims, Objectives and Value	
Aims	To inform appropriate sensitivity analyses in WP7 based on in-depth qualitative insights into the processes influencing vehicle choice, and into likely charging profiles, in those categories of Fleets where ULEV uptake could potentially have most impact on the wider energy system.
Objectives	• To undertake five (5) in-depth case studies, each involving appropriate combinations of business activity study, data analysis, face to face interviews with staff involved in decision-making at strategic, operational, and personal levels, process and activity observations; • Two of the case studies will involve User-Chooser Fleets; two will involve Centralised-Chooser Fleets whose vehicles are predominantly based overnight at users' homes (one of those to be operating vans); and one will involve a Car-Sharing Fleet; and • To provide insights that will inform interpretation of the modelling and analysis in WP7, including sensitivity analyses that will explore the effects of varying the modelling assumptions in ways suggested by the organisational perspectives identified in the Fleet Study where those effects are potentially material.
Value	Outputs of case study research, like all qualitative approaches, should be treated as hypotheses to be further evaluated, not as firm conclusions. Hypotheses generated will be tested via sensitivity analyses using the Analytical Framework updated in Task 7.2.

	Specific information on PiV uptake decision processes are expected to inform sensitivity analyses in WP7 that explore the impacts of the decision-making factors that the case studies suggest may be material. The deeper insight will enhance interpretation and discussion of the final CVEI modelling outputs in Deliverable D7.4 – for instance, limits of validity – and will enable a better informed view of their strengths and limitations.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D6.1** – Fleet Study Report.
Dependencies	None.
Constraints	• Successful recruitment of participating Fleets that meet the recruitment criteria; • Achievement of sufficient relational depth with each participating Fleet to gain useful insights; and • Participating Fleets remain fully engaged for duration of case studies.
Assumptions	• The methodology assumes that valuable insights into the research questions will be generated if sufficient relational depth can be achieved in each case study.
Roles and Responsibilities	
TRL	• Develop interview materials. • Conduct recruitment. • Carry out such of the following as are appropriate for each individual case study and are agreed with the participating Fleet: ○ desk based research on vehicle selection options available to each organisation (including purchase and lease); ○ face to face interviews with a variety of organisational staff involved in decision-making at strategic, operational, and where appropriate, personal levels, across departments; ○ business process studies; and ○ business activity studies. • Analysis of data gathered, interpretation and synthesis, and reporting.

2.3 WP7: Modelling and System Analysis

Work package 7 will be led by Baringa and supported by Element Energy, TRL, EDF, Route Monkey and Behavioural Insights (BIT). It will consist of the following seven tasks:

- Task 7.1: Data Inputs for Consumer Charging Trials
- Task 7.2: Analytical Framework Update
- Task 7.3: State of Health Model Update

- Task 7.4: Additional System Analysis
- Task 7.5: Demand Management Aggregator Framework
- Task 7.6: Market Design and System Integration Analysis Update
- Task 7.7: Systematic Sensitivity Analysis

These tasks are discussed in more detail in the following sections.

2.3.1 Task 7.1: Data Inputs for Consumer Charging Trials

Task Lead: Baringa	**Key Support: TRL**
Task Aims, Objectives and Value	
Aims	To provide supporting data inputs related to User-Managed and Supplier-Managed Charging scheme costs and incentives that Consumers will see as part of the Consumer Charging Trials.
Objectives	Drawing on Stage 1 analysis and supplementary analysis (e.g. PLEXOS), to produce datasets for use in WP5.
Value	Required to facilitate delivery of the Consumer Charging Trials, ensuring that the values tested in the Trials are reflective of how the customer proposition could evolve in future and hence that the Trial results are valid for use in the modelling and analyses (throughout WP7).
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.1** – Data Inputs for Consumer Charging Trials
Dependencies	• Decision on final design of Trial parameters (e.g. seasonal period which Trial covers, number of periods for User-Managed Charging scheme), (TRL, Deliverable 5.1); and • Insights from the initial work on the Demand Management Aggregator framework in Task 7.5 to help inform Consumer cost savings offered as part of the tariff structure.
Constraints	• The input data will include a degree of variability (within year and within day) but not so much as to make interpretation of Consumer responses excessively difficult. The effect of further variability will be explored in the Choice Experiments at the end of WP5.
Assumptions	• Data will represent potential conditions for Consumers in a future year (e.g. 2030/35).
Roles and Responsibilities	
Baringa	Task lead.
TRL	Technical integration and coordination (as Prime Contractor).

2.3.2 Task 7.2: Analytical Framework Update

Task Lead: Baringa	Key Support: TRL, EE
Task Aims, Objectives and Value	
Aims	To update the Analytical Framework and Additional Tools based on the results and insights gained from the Consumer Trials and other Tasks within WP7.
Objectives	• To update and enhance the complete toolset to better reflect Consumer behaviour (with both refined data inputs and potentially enhanced logic within the tools) based on analysis of Trial results and insights from them, as well as any significant changes in external conditions (such as changes in battery costs or performance since they were reported in D3.1 from Stage 1); and • To enable (in Task 7.6) the updating of Narratives and their use in updating the analysis and learning in respect of system design, technologies, market structures, business models and other aspects; and • To correct any residual errors in the Analytical Framework and/or Additional Tools. For the avoidance of doubt, it is noted that the Fleet Study will generate qualitative (rather than quantitative) results, and consequently that these results will be used to inform sensitivity analyses (in Task 7.6), but will not directly inform updates to the Analytical Framework itself.
Value	Essential to inform the update of the system analysis (in Task 7.6), based on a better real world understanding of Mainstream Consumers.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.2** – Analytical Framework (Updated) • PowerPoint summary of updates.
Dependencies	• Processed, cleaned and quality assured data from WP5 in convenient electronic format (e.g. SQL database); and • Supporting information from Task 7.3 State of Health Model Update.
Constraints	• Availability of data and insights from WP5 in a timely manner to facilitate update of the Analytical Framework and Additional Tools.
Assumptions	• Output data from Trials are sufficiently comprehensive and of sufficient quality to facilitate update of the Analytical Framework and Additional Tools.
Roles and Responsibilities	
Baringa	Task lead, responsible for updates to all tools apart from the ECCO Model

	(Consolidated).
Element Energy	Support, responsible for updates to the ECCO Model (Consolidated).
TRL	Technical integration and coordination (as Prime Contractor).

2.3.3 Task 7.3: State of Health Model update

Task Lead: EE	**Key Support: TRL**
Task Aims, Objectives and Value	
Aims	To estimate the impact of Managed Charging on the EV battery lifetime to inform Demand Management pricing strategies and quantify the 'cost', if any, to the user of participating in Demand Management services in terms of battery impact.
Objectives	To use real world data on battery usage during the Trial (e.g. energy throughput, charging rate, average state of charge under various Managed Charging configurations) to analyse the impact of Demand Management strategies on battery health.
Value	Impact of Managed Charging on battery life, in particular for PHEVs, has not been studied (to the Project Team's knowledge) with the benefit of Trial data revealing 'real' battery usage and charging patterns.
Deliverables, Dependencies, Constraints and Assumptions	

Deliverables	• Part of **D7.2** – Analytical Framework (Updated):
	    ○ Updated State of Health model to include a set of inputs derived from the WP5 data analysis, and updated accompanying report.
	• A Chapter in the report for **D7.3** – Demand Management Aggregator Framework:
	    ○ Findings from analysis of impact of Managed Charging, including battery degradation costs that should be accounted for in the customer proposition.

Dependencies	• Use of the SOH model developed in Stage 1 (D3.2); and • Processed, cleansed and quality assured data from WP5 Consumer Charging Trials in convenient electronic format (e.g. SQL database or Excel file).
Constraints	• Availability of relevant data from WP5 in a timely manner.
Assumptions	• Output data from Trial is sufficiently comprehensive and of sufficient quality to be used in the SOH model update.

Roles and Responsibilities	
Element Energy	Task lead.
TRL	Technical integration and coordination (as Prime Contractor).

2.3.4 Task 7.4: Additional System Analysis

Task Lead: Baringa	**Key Support: TRL (and potentially EE)**
Task Aims, Objectives and Value	
Aims	To carry out (at/from the start of Stage 2) additional analysis of the System, with amendments to the Analytical Framework and Additional Tools if required, to address key areas of value to be specified in detail by the ETI.
Objectives	To carry out tool amendments and analysis to be specified in detail by the ETI during Task 7.4, and agreed with the Prime Contractor and Baringa, up to a value of £50k.
Value	There are key areas of valuable analysis, and potentially enhancements to the Analytical Framework and Additional Tools, which the ETI wishes to see completed, beyond those delivered during Stage 1. A budget of £50k has been allocated to this Task 7.4. The ETI, Prime Contractor and Baringa will agree the specific activities required, subject to a maximum cost not exceeding this budget. In the event that the full budget is not required for this Task 7.4, then the ETI, Prime Contractor and Baringa will agree whether to transfer the remaining budget to another Task or whether the Prime Contractor will invoice the ETI for a sum less than the corresponding Milestone Payment specified in Part 4 of this Schedule 1.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.6** – Additional System Analysis (concise slide pack detailing work undertaken and findings from the analysis, for initial reporting); • Chapter in Deliverable D7.4, with details in an appendix of D7.4, for subsequent capture (to enable dissemination with other reported material); and Models and tool results files consistent with the analysis.
Dependencies	Resubmission and acceptance of deliverables D1.3 and D4.2 under the Stage 1 Agreement.
Constraints	Task budget, as set out above.
Assumptions	None.

Roles and Responsibilities	
Baringa	Task Lead.
TRL	Technical integration and coordination (as Prime Contractor).
EE	Potential supporting contribution to technical analysis, if and as expressly agreed by the ETI in writing.

2.3.5 Task 7.5: Demand Management Aggregator Framework

Task Lead: Baringa	**Key Support: TRL**
Task Aims, Objectives and Value	
Aims	To provide a more detailed understanding of the structure and potential commercial issues for a Demand Management Aggregator. A variety of revenue streams (wholesale market, ancillary services, etc.) with different contractual requirements and risk profiles are available to Demand Management Aggregators. The cost and risks associated with engaging Consumers in Supplier-Managed Charging are also uncertain, but will be informed by the Consumer Charging Trials, and this analysis will help improve understanding of the potential strategies available to the Demand Management Aggregator (given uncertainty over both their costs and revenue streams).
Objectives	To develop a logical decision structure for the commercial entity that is managing the flexibility provided by a Managed Charging customer proposition and analysis of what this means for the entity given the likely variation in Consumer response observed in the Trial (and costs of engaging this) versus (simplified) simulation of potential revenue streams.
Value	The Trial is focused on Consumer behaviour insights. This task will help provide more informed insights in relation to a key new commercial entity that will need to interact directly with the Consumer.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.3** – Demand Management Aggregator Framework: ○ Full Report and supporting Excel workbook of analysis
Dependencies	Direct findings and analysis from WP5 in a timely manner to facilitate the Demand Management Aggregator analysis.
Constraints	Simulation of potential revenue streams is intended to be a simplified representation appropriate to understanding the potential risks faced by the Demand Management Aggregator (as opposed to a detailed representation of the current market framework which may change in future).

Assumptions	Output data from the Trial is sufficiently comprehensive and of sufficient quality to facilitate new WP7 analysis.
Roles and Responsibilities	
Baringa	Task lead.
TRL	Technical integration and coordination (as Prime Contractor).

2.3.6 Task 7.6: Market Design and System Integration Analysis Update

Task Lead: Baringa	**Key Support: EE, TRL, EDF and BIT**
Task Aims, Objectives and Value	
Aims	Update the market design and system integration analysis from Stage 1, and review policy implications.
Objectives	• To update the modelling, system design and analysis, using the updated Analytical Framework and Additional Tools with updated data based on the Trial results, to incorporate the findings from the Trials; This will include re-running of the Narratives and Sensitivities; and • To carry out further analysis informed by the Fleet Study.
Value	Focal point for final CVEI project analysis incorporating 'real world' findings of how Mainstream Consumers are likely to behave and more detailed understanding of the potential Demand Management Aggregator role.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.4** – Market Design and System Integration Report (Updated)
Dependencies	• Updated analytical tools and dataset from Task 7.2. • Insights from Demand Management Aggregator framework analysis from Task 7.5. • Direct findings/analysis from WP5. • Successful delivery of the Fleets Study in WP6.
Constraints	• Availability of data from WP5&6 in a timely manner to facilitate WP7 analysis.
Assumptions	• Output data from Trials is sufficiently comprehensive and of sufficient quality to facilitate new WP7 analysis.
Roles and Responsibilities	
Baringa	• Task lead.
TRL	• Ensure direct WP5 findings/analysis are integrated with WP7.

	• Technical integration and coordination (as Prime Contractor).
Element Energy	• Support to undertake updated analysis using Analytical Framework and Additional Tools, and drafting of final report.
BIT	• Ensure direct WP5 findings/analysis are integrated with WP7 with a particular focus on policy implications for Consumers.
EDF	• Review of Deliverables.

2.3.7 Task 7.7: Systematic sensitivity analysis

Task Lead: Baringa	**Key Support: TRL, EE**
Task Aims, Objectives and Value	
Aims	To provide a more structured view of the factors driving uncertainty in ULEV uptake and use, beyond the more Narrative-specific sensitivities undertaken in Stage 1. Insights from this analysis (using the toolset as delivered from Stage 1, prior to updates during Stage 2) will be used to inform the report on updated market design and system integration analysis in Task 7.6.
Objectives	To iteratively define and undertake a series of runs for both individual tools and across the suite of tools to understand the key drivers of uncertainty.
Value	Further inform the robustness of the modelling and analysis results and provide insights for the ETI on potential further analysis that it may wish to undertake in-house.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D7.5** – Systematic Sensitivity Analysis (concise slide pack detailing approach and insights from the analysis for initial reporting); • Chapter in Deliverable D7.4, with details in an appendix of D7.4, for subsequent capture (to enable dissemination with other reported material); and • Tool results files consistent with the analysis.
Dependencies	None.
Constraints	The timescales require that this analysis be undertaken with the tools as they stand at the end of Stage 1, rather than the updated set of tools at the end of Stage 2. However, insights from this task will feed into the final report for Task 7.6.
Assumptions	It is not plausible to explore the 'full' set of all possible combinations of inputs. This task aims to explore as much of the solution space across the modelling tools as is reasonable within the available budget allocated to

	the task, to better inform the understanding of uncertainty. The systematic sensitivity analysis will be undertaken with the Stage 1 tools and will not be repeated using the updated Stage 2 tools. However, insights from this analysis will feed into Task 7.6.
Roles and Responsibilities	
Baringa	Task lead.
Element Energy	Support in the definition of sensitivities/tests and analysis of results, with a particular focus on the ECCO Model.
TRL	Technical integration and coordination (as Prime Contractor).

2.4 Work Package 8: Project Management and Dissemination

The Prime Contractor (TRL) will carry out project management activities throughout Stage 2 to coordinate all project activities, in accordance with the Project Management Plan. Dissemination activities as set out in the Dissemination Strategy will be undertaken throughout Stage 2.

2.4.1 Task 8.1 – Dissemination

Task Lead: TRL	Key Support: Subcontractors as appropriate
Task Aims, Objectives and Value	
Aims	To ensure that the Project has the intended impact amongst stakeholders by communicating the findings and supporting information.
Objectives	Produce Final Project Summary Report. Maintain Dissemination Plan. Deliver activities according to the Dissemination Plan. Leverage the market position, credibility and stakeholder relationships of TRL and its Subcontractors to maximise impact of the Project.
Value	This is a critical activity to ensure that the Project Objectives are met and that real benefits are realised from the Project outputs, Deliverables and Required Outcomes.
Deliverables, Dependencies, Constraints and Assumptions	
Deliverables	• **D8.1** – Final Project Summary Report
Dependencies	Deliverables from all WPs.
Constraints	None.
Assumptions	None.

Roles and Responsibilities	
TRL	Working collaboratively with the ETI, maintain Dissemination Plan
Subcontractors	Support TRL and ETI, and where appropriate engage themselves in dissemination activities.

2.5 Deliverables

The proposed main deliverables for Stage 2 are:

- D5.1 - Supplementary Details of Design, Materials and Management Arrangements for Consumer Trials
- D5.2 - Consumer Uptake Trial Report: Mainstream Consumers' Attitudes and Willingness to Adopt BEVs and PHEVs
- D5.3 - Consumer Charging Trials Report: Mainstream Consumers' Attitudes and Behaviours under Managed Charging Schemes for BEVs and PHEVs
- D5.4 - Potential Impact of PHEVs on the Ability of Liquid Fuels to Act as a Buffer in the Energy Supply System
- D5.5 - Confirmation of Successful Completion of Piloting of Consumer Uptake and Charging Trials
- D5.6 - Confirmation of Successful Completion of 50% of Recruitment and Installation for Consumer Uptake and Charging Trials
- D6.1 - Fleet Study Report
- D7.1 - Data Inputs for Consumer Charging Trials
- D7.2 - Analytical Framework (Updated)
- D7.3 - Demand Management Aggregator Framework
- D7.4 - Market Design and System Integration Report (Updated)
- D7.5 - Systematic Sensitivity Analysis
- D7.6 - Additional System Analysis
- D8.1 - Project Final Summary Report
- D8.2 - Stage Gate Review 2.1 Passed

In addition to these main deliverables, and subject to approval and sign-off of the final reports from the ETI, where appropriate, separate papers will be written for submission to peer-reviewed academic journals (e.g. Renewable and Sustainable Energy, Transportation Research Part D: Transport and Environment, Energy Policy or International Journal of Electric and Hybrid Vehicles). The reporting process will form part of the dissemination strategy to ensure that the knowledge gained from the project is appropriately published into the wider academic community. Full details of the dissemination strategy are provided in Section 6. Further details of each of these Deliverables are provided in the following sections.

2.5.1 Work Package 5 Deliverables

2.5.1.1 D5.1: Supplementary Details of Design, Materials and Management Arrangements for Consumer Trials

Deliverable No:	**D5.1**		
Deliverable Name:	**Supplementary Details of Design, Materials and Management Arrangements for Consumer Trials**		
Work Package:	WP5	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	Report to supplement, and where relevant update, the information in the Stage 1 deliverable D1.4, providing all necessary additional details of the design of the Consumer Trials, the printed / electronic materials to be used with Trial Participants, and the management arrangements and detailed plans. The printed / electronic materials should ideally be inserted as appendices to the report. This Deliverable must address all appropriate details set out in Task 5.1 and Task 5.2. This Deliverable D5.1 will also be accompanied by Deliverable D7.1. It is intended that the Prime Contractor will supply the majority of the information that makes up the main content of this Deliverable ahead of formal submission of this Deliverable, in order to secure the ETI's agreement to details on a progressive basis in advance of Stage Gate Review 2.1, and thus to enable the ETI to authorise commencement of delivery of the Trials at Stage Gate Review 2.1.		
Deliverable Purpose(s):	• The purpose of the deliverable is to report on remaining details of the Consumer Trials, to facilitate agreement and provide a record.		
Deliverable Objective(s):	• To report on completed design details of the Consumer Trials, materials to be used, management arrangements and detailed plans; and • To summarise concisely the risks to validity of the Trial results, the measures taken to mitigate each of these risks, and the residual level of each of these risks.		
Dependent on:	• Timely completion of Trial design details.		
Prerequisite to:	• This Deliverable D5.1, along with Deliverable 7.1, must be agreed with the ETI at of before Stage Gate Review 2.1; and • Delivery of Consumer Trials in WP5 (following Stage Gate Review 2.1).		

Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • details must be sufficiently comprehensive to provide a useful record and to give confidence in the Trial validity and management; and • information must be provided in sufficient time to enable final agreement at or before Stage Gate Review 2.1.

2.5.1.2 D5.2: Consumer Uptake Trial Report: Mainstream Consumers' Attitudes and Willingness to Adopt BEVs and PHEVs

Deliverable No:	**D5.2**		
Deliverable Name:	**Consumer Uptake Trial Report: Mainstream Consumers' Attitudes and Willingness to Adopt BEVs and PHEVs**		
Work Package:	WP5	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	Report detailing the delivery of the Consumer Uptake Trial and the resultant state-of-the-art understanding of Mainstream Consumers' attitudes and behaviours to BEV and PHEV adoption, following real world experience. This Deliverable must address all appropriate details set out in Task 5.1. Prior to submission of the written report, and as soon as possible after conclusion of the Consumer Trials, a slide pack will be presented to the ETI and its project review panel to give an overview of the key results and conclusions for discussion and comment. A final version of this presentation will be resubmitted (for future use) along with the written report.		
Deliverable Purpose(s):	The purpose of the deliverable is to report on: • the method employed for the Consumer Uptake Trial; • the data obtained and the analysis performed; • the results of full statistical analysis of the key data obtained from the Trial; • answers to the research questions defined in the Consumer Uptake Trial design; and • evidence-based conclusions from the Trial with regard to how the data have advanced understanding of Mainstream Consumer attitudes to uptake of BEVs and PHEVs, and therefore what the new state-of-the-art understanding of this area is.		
Deliverable Objective(s):	• To update understanding of Mainstream Consumer attitudes towards BEV and PHEV adoption, including detail of existing		

	and newly-identified barriers to adoption; • To provide robust data inputs into the Analytical Framework; and • To enable more accurate prediction of the likely future uptake of EVs by the Mass-Market.
Dependent on:	• Successful recruitment of Trial Participants (TRL); • Successful implementation of the Trial design for the Consumer Uptake Trial (TRL, CENEX, EV Connect); and • Successful and robust collection and analysis of Trial data (TRL, Element Energy, EV Connect).
Prerequisite to:	Update of Analytical Framework in Work Package 7.
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the analysis and reporting of the Consumer Uptake Trial results must include a comprehensive exploration of the research questions and interpretation of the Trial results, and must set out robust findings, conclusions and recommendations supported by the analysis.

2.5.1.3 D5.3: Consumer Charging Trials Report: Mainstream Consumers' Attitudes and Behaviours under Managed Charging Schemes for BEVs and PHEVs

Deliverable No:	**D5.3**		
Deliverable Name:	**Consumer Charging Trials Report: Mainstream Consumers' Attitudes and Behaviours under Managed Charging Schemes for BEVs and PHEVs**		
Work Package:	WP5	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	Report detailing the delivery of the Consumer Charging Trials and the resultant state-of-the-art understanding of Mainstream Consumers' attitudes and behaviours when engaging with Managed Charging schemes for BEVs and PHEVs. This Deliverable must address all appropriate details set out in Task 5.2. Prior to submission of the written report, and as soon as possible after conclusion of the Consumer Trials, a slide pack will be presented to the ETI and its project review panel to give an overview of the key results and conclusions for discussion and comment. A final version of this presentation will be resubmitted (for future use) along with the written report.		
Deliverable Purpose(s):	The purpose of the deliverable is to report on:		

	• the method employed for the Consumer Charging Trials; • the data obtained and the analysis performed; • the results of full statistical analysis of the key data obtained from the Trials; • answers to the research questions defined in the Consumer Uptake Trial design; • evidence-based conclusions from the Trials with regard to how the data have advanced understanding of Mainstream Consumer charging behaviour and responses to the Managed Charging schemes investigated, and therefore what the new state-of-the-art understanding of this area is; and • testing of selected elements of the systems required to implement successful Demand Management; and • testing of Consumer responses to key elements of the market structures, customer propositions, energy supply management and technology options that are reflected in the Managed Charging conditions experienced by Trial Participants and in the choice options offered in the Choice Experiment.
Deliverable Objective(s):	• To provide understanding of Mainstream Consumer charging behaviour and attitudes and behaviours in response to Managed Charging schemes for BEVs and PHEVs; • To provide robust data inputs into the Analytical Framework; and • To enable more accurate prediction of the likely future charging behaviour and use of Managed Charging schemes by the Mass-Market, and the resulting impact on UK aggregated EV charging demand.
Dependent on:	• Successful recruitment of Trial Participants (TRL); • Successful implementation of the Trial designs for the Consumer Charging Trials (TRL, CENEX, EV Connect); and • Successful and robust collection and analysis of Trial data (TRL, Element Energy, EV Connect).
Prerequisite to:	Update of Analytical Framework in Work Package 7.
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the analysis and reporting of the Consumer Charging Trials results must include a comprehensive exploration of the research questions and interpretation of the Trial results, and must set out robust findings, conclusions and recommendations supported by the analysis; and • conclusions and recommendations must be derived in respect

	of the testing of (in particular) the propositions and technologies used to provide Managed Charging.

2.5.1.4 D5.4: Potential Impact of PHEVs on the Ability of Liquid Fuels to Act as a Buffer in the Energy Supply System

Deliverable No:	**D5.4**		
Deliverable Name:	**Potential Impact of Plug-In Hybrid Electric Vehicles on the Ability of Liquid Fuels to Act as a Buffer in the Energy Supply System**		
Work Package:	WP5	**Deliverable Lead:**	Shell
Deliverable Description & Scope:	Report on the impact of the unavailability (or prohibitively high cost) of electricity (due, for instance, to variability in the provision of renewable power) on the PHEV component of a future, de-carbonised, light-duty road transport vehicle parc in the UK. This will include an analysis of utility factors (the fraction of mileage using electric power) for different Managed Charging schemes, at present and for future PHEVs with longer All Electric Ranges, and the consequent impact on the ability of liquid fuels to act as a buffer to the electricity system. This Deliverable must address all appropriate details set out in Task 5.2. Prior to submission of the written report, and as soon as possible after conclusion of the Consumer Trials, a slide pack will be presented to the ETI and its project review panel to give an overview of the key results and conclusions of this analysis for discussion and comment. A final version of this presentation will be resubmitted (for future use) along with the written report.		
Deliverable Purpose(s):	The purpose of the deliverable is to report on: • the method employed for the data collection; • the data obtained and the analysis performed; • the results from the statistical analysis of the key data obtained; and • the conclusions and predictions regarding the impact of the unavailability (or prohibitively high cost) of electricity on the PHEV component of a future, de-carbonised, light-duty road transport vehicle parc in the UK, and the ability of liquid fuels to act as a buffer the electricity system.		
Deliverable Objective(s):	• To calculate mean utility factors (the fraction of mileage using electric power) for all Trial Participants in the PHEV Charging Trial, and mean utility factors for each group in it; • To estimate utility factors for future PHEVs with longer All Electric Ranges; and		

	• To report on the potential for the use of liquid fuels as a buffer in the energy system, considering effects both at the short-term / individual level (will an individual vehicle have enough fuel in it to provide an immediate buffer?) and at the long-term / regional level (will the retail network be large enough to provide a longer-term buffer?).
Dependent on:	• Successful and robust collection of in-trip telematics data at suitable frequency (TRL, EV Connect).
Prerequisite to:	None.
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the analysis must provide an evidence-based assessment of PHEV utility factors and the impact of these with variable electricity availability on the ability of liquid fuels to act as a buffer to the electricity system.

2.5.1.5 D5.5: Confirmation of Successful Completion of Piloting of Consumer Uptake and Charging Trials

Deliverable No:	**D5.5**		
Deliverable Name:	**Confirmation of Successful Completion of Piloting of Consumer Uptake and Charging Trials**		
Work Package:	WP5	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	• Letter from the Prime Contractor to the ETI confirming that the piloting activities for both the Consumer Uptake Trial and the Consumer Charging Trials have been successfully completed (in accordance with the Acceptance Criteria below), and reporting briefly on any findings and/or lessons from the piloting.		
Deliverable Purpose(s):	• To ensure successful piloting, de-risking of the Trials, implementation of lessons learnt, management of risks and issues, and readiness to commence Trial activities with Trial Participants.		
Deliverable Objective(s):	• To review and control progression of the Project between piloting and activities involving Trial Participants.		
Dependent on:	• Completion of piloting activities in Tasks 5.1 and 5.2.		
Prerequisite to:	• Commencement of activities involving Trial Participants.		
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and		

	• all piloting activities must have been completed; • any minor lessons learnt must have been implemented (or be ready to implement) and there must be no major unmitigated risks or issues identified in the course of the piloting activities which would jeopardise the Trials.

2.5.1.6 D5.6 - Confirmation of Successful Completion of 50% of Recruitment and Installation for Consumer Uptake and Charging Trials

Deliverable No:	**D5.6**		
Deliverable Name:	**Confirmation of Successful Completion of 50% of Recruitment and Installation for Consumer Uptake and Charging Trials**		
Work Package:	WP5	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	Letter from the Prime Contractor to the ETI confirming that: • the first 50% of Trial Participants for each of the Consumer Uptake Trial and the Consumer Charging Trials have been successfully recruited, with details of segmentation of those recruited to date and evidenced confirmation that recruitment remains on track to achieve the full required sample size and segmentation; • Mode 2 charge points for the first 50% of Trial Participants for the Consumer Uptake Trial and Mode 3 charge points for the first 50% of Trial Participants for the Consumer Charging Trials have all been successfully installed and signed off as safe by a competent person on behalf of the Prime Contractor.		
Deliverable Purpose(s):	• To ensure that recruitment and charge point installation is on track to complete successfully and on time.		
Deliverable Objective(s):	• To provide confirmatory evidence that both recruitment and charge point installation are meeting all requirements.		
Dependent on:	• Completion of 50% of both recruitment and charge point installation.		
Prerequisite to:	• None.		
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; • recruitment of Trial Participants and their segmentation must demonstrably be on a credible path to achievement of both the required numbers and required segmentation, taking account of potential drop-out rates; and • installation of charge points must be certified by a competent person, on behalf of the Prime Contractor, to be compliant		

	with all relevant technical and health, safety and environmental requirements, specifications, codes, standards, regulations, codes of practice and other documents as set out in the Health, Safety and Environmental Plan and in the agreements between the Prime Contractor and the charge point installation subcontractor.

2.5.2 Work Package 6 Deliverables

2.5.2.1 D6.1: Fleet Study Report

Deliverable No:	**D6.1**		
Deliverable Name:	**Fleet Study Report**		
Work Package:	WP6	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	A report summarising the methods employed, the findings from the five individual case studies, and a synthesis of insights gained across the case studies considered collectively. This Deliverable must address all appropriate details set out in Task 6.1. Prior to submission of the written report, and as soon as possible after conclusion of the Fleet Study, a slide pack will be presented to the ETI and its project review panel to give an overview of the key results and conclusions for discussion and comment. A final version of this presentation will be resubmitted (for future use) along with the written report.		
Deliverable Purpose(s):	To report to the ETI and stakeholders on: • the methods employed; • the findings from the five individual case studies; • a synthesis of insights gained across the case studies considered collectively; • answers to the research questions defined in the Fleet Study design; and • evidence-based conclusions from the Fleet Study with regard to how the findings have advanced understanding of Fleets, their potential impact on the energy system and integration into it (based on qualitative data), and therefore what the new state-of-the-art understanding of this area is.		
Deliverable Objective(s):	• To inform appropriate sensitivity analyses in WP7 based on in-depth qualitative insights into the processes influencing vehicle choice, and likely charging profiles, in those categories of Fleets where ULEV uptake could potentially have most impact on the wider energy system.		

Dependent on:	• No dependencies with other WPs.
Prerequisite to:	• Sensitivity analyses to be conducted in WP7.
Acceptance Criteria:	• the Generic Acceptance Criteria; and • the Deliverable must satisfy its defined description & scope, purpose and objectives.

2.5.3 Work Package 7 Deliverables

2.5.3.1 D7.1 - Data Inputs for Consumer Charging Trials

Deliverable No:	**D7.1**		
Deliverable Name:	**Data Inputs for Consumer Charging Trials**		
Work Package:	WP7	**Deliverable Lead:**	Baringa
Deliverable Description & Scope:	Excel workbook of supporting data inputs related to User-Managed Charging Scheme prices and Supplier-Managed Charging Scheme cost savings, complete with supporting documentation. This Deliverable must address all appropriate details set out in Task 7.1.		
Deliverable Purpose(s):	To provide input values related to the different charging tariffs to be used in the Consumer Charging Trials.		
Deliverable Objective(s):	• To provide supporting Trial data inputs under the User-Managed Charging Scheme and Supplier-Managed Charging Scheme tariff options that Consumers will experience as part of the Consumer Charging Trials, which are reflective of how the customer proposition might appear at a given point in the future (e.g. 2030/35) and hence to ensure that the Trial results are valid for use in the modelling and system analysis throughout WP7.		
Dependent on:	• Decision on final Trial design parameters, to be agreed as early as possible in order to facilitate Task 7.1 and to be reported in Deliverable D5.1 (TRL, Baringa); and • Early insights from more detailed structuring of the Demand Management Aggregator framework in Task 7.5 (Baringa).		
Prerequisite to:	• This Deliverable D7.1, along with Deliverable 5.1, must be agreed with the ETI at of before Stage Gate Review 2.1; and • Delivery of Consumer Charging Trials in WP5 (following Stage Gate Review 2.1).		
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and		

	• all details and assumptions must be clearly documented, explained, justified and traceable.

2.5.3.2 D7.2 - Analytical Framework (Updated)

<table>
<tr><th>Deliverable No:</th><th colspan="3">D7.2</th></tr>
<tr><th>Deliverable Name:</th><th colspan="3">Analytical Framework (Updated)</th></tr>
<tr><td>Work Package:</td><td>WP7</td><td>Deliverable Lead:</td><td>Baringa</td></tr>
<tr><td>Deliverable Description & Scope:</td><td colspan="3">Updated complete Analytical Framework, including updated assumptions book(s), input data, output sheets, user instructions, and any additional components or modules.
Updated versions of any of the Additional Tools which have been modified during Stage 2.
This will include the updated State of Health Model and an updated version of the associated State of Health Report (previously delivered together under D3.2).
This Deliverable must address all appropriate details set out in Tasks 7.2, 7.3 and 7.4.
PowerPoint summary of updates made.</td></tr>
<tr><td>Deliverable Purpose(s):</td><td colspan="3">• To enable complete system analysis (as set out in Task 7.6), with an updated and enhanced toolset using the outputs from the Consumer Trials, in particular with respect to how Mainstream Consumers and Fleets are likely to:
    o make ULEV purchase decisions, including the range of financial and non-financial parameters that influence this; and
    o operate PiVs, including in particular their response to different tariffs under User-Managed Charging Schemes and Supplier-Managed Charging Schemes;
• To use outputs from the Trial to update the State of Health Model (Task 7.3); and
• To provide a complete toolset to the ETI for its future use.</td></tr>
<tr><td>Deliverable Objective(s):</td><td colspan="3">• To update the set of analytical tools and input data in a manner which makes appropriate use of the insights gained from the set of Trial outputs and to reflect any significant changes in external factors (such as battery prices or performance); and
• The analysis of the Trial outputs will inform both refined data inputs and potentially enhanced logic within the tools which better reflect Consumer behaviours.</td></tr>
<tr><td>Dependent on:</td><td colspan="3">• Relevant processed, cleaned and quality assured data from WP5 and WP6 Trial outputs in convenient electronic format (TRL, Element);</td></tr>
</table>

	• Output data from Trial being sufficiently comprehensive and of sufficient quality to facilitate update of analytical tools (TRL); • Data and logic updates to ECCO Model incorporating relevant WP5 and WP6 outputs (Element Energy); and • State of health model update from Task 7.3 (Element Energy).
Prerequisite to:	D7.4 Market Design and System Integration Report (Updated)
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • All updates to the Analytical Framework and Additional Tools including data, assumptions and functionality, must be fully documented.

2.5.3.3 D7.3 - Demand Management Aggregator Framework

Deliverable No:	**D7.3**		
Deliverable Name:	**Demand Management Aggregator Framework**		
Work Package:	WP7	**Deliverable Lead:**	Baringa
Deliverable Description & Scope:	• Concise standalone report documenting the framework developed (early in Stage 2), and the analysis undertaken with Trial data and its conclusions (after the Consumer Charging Trials); with • Supporting Excel workbook of analysis. • This Deliverable must address all appropriate details set out in Tasks 7.3, 7.4 and 7.5.		
Deliverable Purpose(s):	To develop a logical decision structure for the commercial entity that is managing the flexibility provided by a Supplier Managed Charging customer proposition and analyse what this means for the entity given the likely variation in Consumer response observed in the Trial (and costs of engaging this) versus a (simplified) simulation of potential revenue streams.		
Deliverable Objective(s):	To provide a more detailed understanding of the structure and potential commercial issues for a Demand Management Aggregator given: • the variety of generic revenue streams (wholesale market, ancillary services, etc.) with different contractual requirements and risk profiles which might be available to Demand Management Aggregators; and • the cost and risks associated with engaging Consumers in Supplier-Managed Charging which are also uncertain, but which will be informed by the Trial, and this analysis will help to understand better the potential strategies available to the		

	Demand Management Aggregator (given uncertainty over both their costs and revenue streams).
Dependent on:	• Relevant processed, cleaned and quality assured data from Consumer Charging Trials in WP5 (TRL).
Prerequisite to:	D3.4 Market Design and System Integration Report (Updated).
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the Excel workbook must be fully documented with assumptions, any necessary instructions.

2.5.3.4 D7.4 - Market Design and System Integration Report (Updated)

Deliverable No:	**D7.4**		
Deliverable Name:	**Market Design and System Integration Report (Updated)**		
Work Package:	WP7	**Deliverable Lead:**	Baringa
Deliverable Description & Scope:	• Report covering the updated market design and system integration analysis, as set out in this Agreement; • Results files to accompany report; • This Deliverable must address all appropriate details set out in Task 7.6 • A chapter will also be included, with details in an appendix, to report the process and results of the systematic sensitivity analysis carried out in Task 7.7 (initially reported previously by the Deliverable D7.5 slide pack), and this must make clear that the sensitivity analyses was carried out with the toolset from Stage 1 rather than the updated toolset from Stage 2; and • Updated complete set of Building Blocks and accompanying updated version of the associated report (previously delivered together under D4.2).		
Deliverable Purpose(s):	To use the updated Analytical Framework, Additional Tools and updated data from D7.2 to update the system modelling and analysis from Stage 1 to incorporate the findings from the Trials; (this will include re-running of the Narratives and sensitivities).		
Deliverable Objective(s):	To understand the extent to which the original insights from the Stage 1 analysis and policy implications may change given real world findings of how Mainstream Consumers and Fleets are likely to behave. This will be informed by: • updated analysis using the refined Analytical Framework and Additional Tools and data from D7.2; • other relevant insights from the WP5 and WP6 Deliverables,		

	including (given greater understanding of Consumers resulting from the Trial) whether some or all of the previous policy recommendations for Consumers should be updated; • insights from the analysis of the Demand Management Aggregator framework in D7.3; and • insights from the systematic sensitivity analysis in D7.5.
Dependent on:	• Updated Analytical Framework and Additional Tools from D7.2 and analysis using the tools to inform final report (Baringa, Element); • Output data from WP5 and WP6 being sufficiently comprehensive and of sufficient quality to facilitate update of analytical tools (TRL, Element); and • Integration of other relevant WP5 and WP6 insights (TRL, BIT).
Prerequisite to:	n/a.
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; • the analysis of the energy infrastructure must be sufficiently comprehensive to address all relevant aspects set out throughout Schedule 1 (including setting out the means by which the value of tight integration of vehicles into the energy infrastructure can be realised, such as addressing the issues at Section 1.4 of Part 1); and • the Deliverable must be a standalone document (apart from the updated Building Blocks report) reflecting the methodology and combined learning from both Stage 1 and Stage 2, and must cover all the information previously covered by Deliverable D1.3, (so that this Deliverable D7.4 supersedes D1.3 for the purposes of communicating with stakeholders, and thus stakeholders do not need to read D1.3).

2.5.3.5 D7.5 - Systematic Sensitivity Analysis

Deliverable No:	**D7.5**		
Deliverable Name:	**Systematic Sensitivity Analysis**		
Work Package:	WP7	**Deliverable Lead:**	Baringa
Deliverable Description & Scope:	• Concise slide pack detailing approach and insights from the analysis. • Tool results files consistent with the analysis. • This Deliverable must address all appropriate details set out in Task 7.7.		

Deliverable Purpose(s):	To report initially on the series of runs undertaken, for both individual tools and across the suite of tools, to understand better the key drivers of uncertainty in the system level analysis results.
Deliverable Objective(s):	• Provide a more structured view of the factors driving uncertainty in ULEV uptake and use beyond the more Narrative-specific sensitivities undertaken in Stage 1; and • Generate insights from this analysis (using the toolset as delivered from Stage 1) which can be used to inform the report on updated market design and system integration analysis in Deliverable D7.4.
Dependent on:	• Support to undertake and write up the analysis (Element Energy).
Prerequisite to:	• D7.4 Market Design and System Integration Report (Updated), which will include a chapter and appendix to report the process and results of the sensitivity analysis more formally (in a manner suitable for dissemination).
Acceptance Criteria:	• the Generic Acceptance Criteria; and • the Deliverable must satisfy its defined description & scope, purpose and objectives.

2.5.3.6 D7.6 - Additional System Analysis

Deliverable No:	**D7.6**		
Deliverable Name:	**Additional System Analysis**		
Work Package:	WP7	**Deliverable Lead:**	Baringa
Deliverable Description & Scope:	• Concise slide pack detailing the additional system analysis undertaken in Task 7.4 and findings from the analysis. • Models and tool results files consistent with the analysis. • This Deliverable must address all appropriate details set out in Task 7.4, including the specific scope to be agreed during the Task.		
Deliverable Purpose(s):	To report initially on the tool amendments and system analyses undertaken in order to address key areas of valuable analysis identified.		
Deliverable Objective(s):	• To report on additional analyses completed.		
Dependent on:	• Resubmission and acceptance of Stage 1 deliverables.		
Prerequisite to:	• D7.4 Market Design and System Integration Report (Updated), which will include a chapter (and if appropriate appendices) to report the analysis and findings more formally (in a manner suitable for dissemination).		

Acceptance Criteria:	• the Generic Acceptance Criteria; and • the Deliverable must satisfy its defined description & scope, purpose and objectives.

2.5.4 Work Package 8 Deliverables

2.5.4.1 D8.1 - Project Final Summary Report

Deliverable No:	**D8.1**		
Deliverable Name:	**Final Project Summary Report**		
Work Package:	WP8	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	• Concise report which summarises the Project and its key findings, to be used for dissemination to key stakeholders. • This Deliverable must align with the Dissemination Plan.		
Deliverable Purpose(s):	• To communicate a summary of the Project and its findings in an accessible format to a range of stakeholders		
Deliverable Objective(s):	• To provide an overview of the Project, the activities undertaken and the key findings; and • To be publishable as a standalone, single, short summary report and also to be usable alongside other documents in the Dissemination Plan (such as the planned targeted communications (in written form and presented in person) to inform policy makers, influencers within government and regulators, and other critical stakeholders and key forums).		
Dependent on:	• Approval of other Deliverables (ETI).		
Prerequisite to:	• None.		
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the report must be concise, clear and suitable for a range of stakeholders.		

2.5.4.2 D8.2 - Stage Gate Review 2.1 Passed

Deliverable No:	**D8.2**		
Deliverable Name:	**Stage Gate Review 2.1 Passed**		
Work Package:	WP8	**Deliverable Lead:**	TRL
Deliverable Description & Scope:	• Stage Gate Review 2.1 held and passed (under the terms set out in Schedule 5).		
Deliverable	• To ensure readiness to commence the delivery of the Trial, as		

Purpose(s):	set out in more detail in Schedule 5.
Deliverable Objective(s):	• To review and control progression of the Project as set out in more detail in Schedule 5.
Dependent on:	• Completion of Stage 2.1 and successful pass of Stage Gate Review 2.1.
Prerequisite to:	• Commencement of Stage 2.2.
Acceptance Criteria:	• the Generic Acceptance Criteria; • the Deliverable must satisfy its defined description & scope, purpose and objectives; and • the Stage Gate Review must have been passed.

3 Project team structure

The project team for Stage 2 follows from the successful delivery of Stage 1 of this CVEI project and draws upon a wealth of experience and expertise in research, policy, regulation, economics, energy supply, distribution, low carbon energy and vehicles, charging infrastructure, fuels, consumer usage, behaviour and adoption.

As lead partner, TRL will be the Prime Contractor to ETI. The organisations brought together have the capacity and competence to fulfil Stage 2 of this project. The overall structure of the Stage 2 team and the roles of key individuals are outlined in Figure 2.

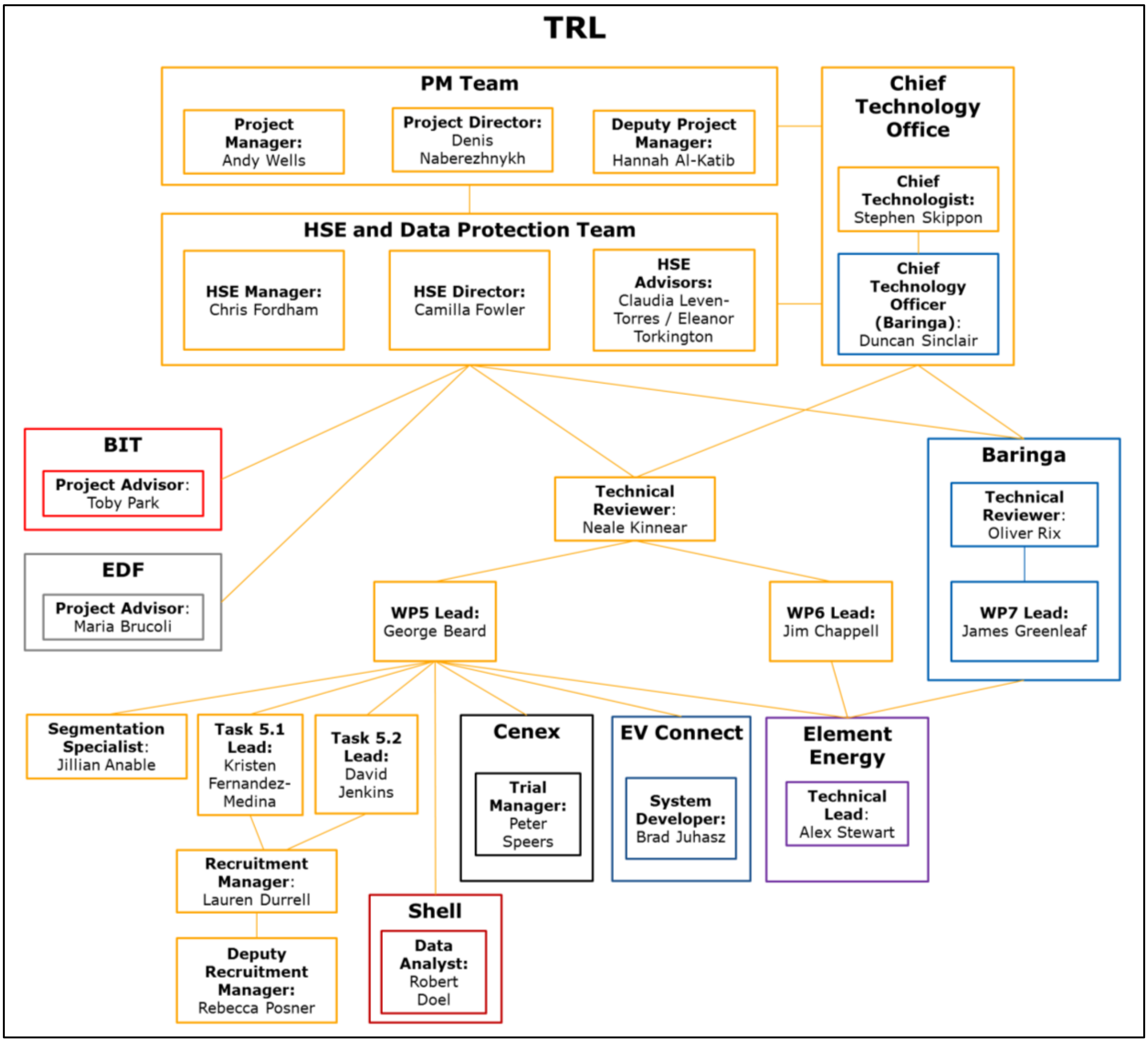

Figure 2: Project team structure

The project will also utilise the services of a number of suppliers. These will include, but may not be limited to:

- Supplier of Mode 2 and Mode 3 chargepoints, and associated electrical installation services, to ensure participants in Consumer Uptake Trial and Consumer Charging Trials can charge their vehicles safely from their home
    - Following a review of potential suppliers in the UK, Rolec Services Limited have been selected as the preferred supplier for Stage 2.
    - A letter of support from Rolec can be provided upon request.
- Supplier of vehicles (BEV, PHEV and ICE types) and vehicle telematics system
    - VW Group Leasing (VGL) will be providing lease vehicles for the purposes of the Consumer Uptake Trial and Consumer Charging Trial.
    - VW Financial Services (VWFS) are working with the RAC to develop the vehicle telematics system to deliver data for the Consumer Uptake Trial and Consumer Charging Trials.

- A letter of support from VGL can be provided upon request.

- Supplier of online survey hosting services
    - Accent Limited will provide online hosting services for the questionnaire and choice experiment elements of the Consumer Uptake Trial and Consumer Charging Trials.

4 Health, safety and ethics

The purpose of this section is to detail the Health and Safety and research ethics considerations that have underpinned the design of Stage 2 trials for the CVEI project. The section is structured to present:

- Our approach to Health and Safety and the key Health and Safety considerations for Stage 2.
- A detailed assessment of the risks associated with use of Mode 2 charging as part of the Consumer Uptake Trial.
- A HAZID methodology to be undertaken at the start of Stage 2 to ensure the safety of all affected parties throughout the life cycle of both the Consumer Uptake Trial and Consumer Charging Trials.
- Research ethics considerations

In addition, a detailed assessment of the risks associated with the non-electrical elements of the Stage 2 trial design has been developed; this can be provided upon request. In Stage 2, TRL will develop a Health and Safety Plan which will further build on and develop on this Section.

4.1 TRL's approach to health and safety

TRL operates an Integrated Management System (IMS) which is independently audited and certified by NQA to ISO 9001, ISO 140001, OHSAS 18001, ISO/IEC 27001 and ISO/IEC 17025. Our IMS describes the processes and procedures that are followed in order to ensure our activities are delivered safely, sustainably and in accordance with all regulatory requirements. The IMS is managed by a dedicated Compliance team, which comprises the Compliance Manager, the Health, Safety and Environment (HSE) Manager, the Laboratory Standards Manager and two SHEQ (Safety, Health, Environment and Quality) Advisors. These individuals have the appropriate levels of experience and relevant qualifications to provide competent advice to the business. TRL's IMS is audited both externally and internally on an annual basis. Senior Management reviews are held annually to ensure the effectiveness and continual improvement of the systems.

The implementation of Stage 2 will be governed by the TRL Project Management Process. This process ensures regular review of activities undertaken and includes specific requirements for the assessment of risk. This process includes a number of review points and cross-checks to ensure the quality and timeliness of outputs, and is audited regularly by the Compliance Team. TRL personnel proposed for Stage 2 have been assigned to the project based on their specific expertise and relevant transferable skills.

Our subcontractors and suppliers will be added to the TRL Approved Suppliers list. This list is maintained by the Purchasing Manager and approvals are based on a number of factors including HSE performance and processes, data protection processes, relevant insurances and demonstrable track records in the areas of expertise claimed. Subcontractors are managed in accordance with the TRL Procedure for the Management of Contractors and the responsibility for the management of TRL appointed subcontractors, including communication and performance management rests with the TRL Project Manager.

The experience gained in previous projects such as the Consumer Response to Electric Vehicles project undertaken on behalf of the ETI in 2010, and a study of electric vehicles and mass market consumers for Shell in 2013, has informed our approach to managing health, safety and environment within Stage 2. A number of key health, safety and environment considerations have been built into the trial design for Stage 2 – these are discussed in the following sections.

4.2 Health, Safety and Environment considerations for Stage 2 design

4.2.1 Selection of participant drivers

TRL has extensive experience of running participant-based trials and has a database of over 2,000 volunteers. Relevant experience specific to this CVEI project includes a number of studies that have involved lending vehicles to volunteer participants, including a previous EV uptake study undertaken for the ETI. TRL has been successful in completing projects which have used a mix of recruitment methods, including targeted advertising and social media, to help recruit participants according to specific criteria.

All potential participants will be required to complete a recruitment screening questionnaire that will help determine whether they are a suitable candidate for participating in the study. The questionnaire will be used to obtain information relevant to the specific recruitment criteria and sampling approach for each trial. It will include items related to aspects of participants' driving, for example how long they have held a licence, how many miles they drive a year on average, length of their daily commute, etc. Specific details about the recruitment criteria can be found in Part 2 (Consumer Uptake Trial), Part 3 (Consumer Charging Trial) and Part 4 (Fleet Study).

All drivers will be requested to provide permission for TRL to electronically access their DVLA records to ensure that their licence is valid and meets trial insurance requirements in terms of penalty points and previous claims.

4.2.2 Driving standards

All participants will undertake a familiarisation drive in the trial vehicle prior to commencing the trial. This will introduce participants to the main controls and features of the vehicle and will allow TRL staff to explain the positioning and functionality of any telemetry on the vehicle. The familiarisation drive will also be used to confirm that they are comfortable with driving the vehicle and to establish whether the participant's driving is of an acceptable standard. On completion of the familiarisation drive, the participant will be given the option to withdraw from the study if they do not feel comfortable or safe driving the vehicle (they will also be advised that they are free to withdraw from the trial at any time without giving a reason as part of the research ethics requirements). The researcher may also decide that the participant is not suitable for the study based on their performance during the familiarisation drive (e.g. if they are seen to be breaking the speed limit).

All participants will receive a full briefing as part of the trial procedure. This briefing will include a reminder of appropriate driving standards, draw attention to the fact that their driving is bound by the Highway Code, and make clear that any fines or penalty points are solely the liability of the participant. Prior to being entrusted with the vehicle, participants will be asked to sign a document making it clear they understand their responsibilities and liabilities over the duration of the trial. It will also be made clear that the telematics systems that are fitted to the vehicles will record information about the location of the vehicle and some elements of driving behaviour. Participants will be fully informed about the types of data which will be collected, and why, how those data will be used and shared, and how long the data will be retained. Participants will be informed that data will not be used for any purposes other than research unless TRL is explicitly asked to hand over the data to the police.

4.2.3 Vehicle safety

All vehicles to be used in this study will be new. TRL will arrange servicing and maintenance of all vehicles to the manufacturer's guidelines. Vehicle maintenance and servicing will be carried out by manufacturer-approved garages in line with manufacturer's recommendations. A planned preventative maintenance schedule will be drawn up for each vehicle prior to the vehicle being issued to trial participants. Each vehicle will be visually inspected against a standard vehicle inspection check sheet by the participant and a member of TRL staff prior to issue and at return. Any concerns or faults highlighted by the participant, either during the trial period, or at the vehicle return will result in the vehicle being withdrawn from service if required. The vehicle will inspected and the fault rectified by a TRL-appointed competent person prior to the vehicle being returned to service. Records will be maintained of all inspections, services and fault reports.

Tyres will be inspected as part of the issue and return inspections. Any tyres which are identified as nearing an acceptable limit will be replaced prior to the vehicle being issued to the participant. This limit will be in excess of the legal minimum[3]. Tyres will also be inspected for damage and, if any is found, will be replaced. Participants will be requested to carry out regular visual inspections of the vehicle and to report any faults or concerns immediately to a dedicated 24/7 report line. Where the trial dictates that participants will be in possession of the vehicle for longer than seven days, participants will be asked to record these checks on a sheet provided with the vehicle.

Wherever possible, the aim will be to use OEM telematics systems that are already integrated into the vehicle and comply with all relevant technical and safety standards. If manufacturer systems are unable to provide the necessary data, a third party solution may be required. Where this is the case, all telemetry fitting and any required adaptations will be undertaken by a TRL-appointed competent person prior to the release of any trial vehicle. Due consideration will be given to the interaction of any after-market fittings with the vehicle as supplied by the manufacturer. Any fittings inside the vehicle will be positioned to ensure the potential to cause harm to the driver/passengers either in general use or in the

[3] The law requires car tyres to have a minimum tread depth of 1.6mm in a continuous band around the central three quarters of the tyre.

event of a crash is minimised. Any fitting to the exterior of the vehicle will be made in such a way that there is no risk to third parties either during general use or in the event of a crash.

4.2.4 Vehicle charging

4.2.4.1 Consumer Uptake Trial

It is anticipated that the majority of vehicle charging will be undertaken at the participant's place of residence. As a part of the selection process we will confirm with all participants that:

- They have off-street parking (e.g. driveway or garage) for the vehicle which is segregated from any public rights of way – the charging cable presents a risk of slips, trips and falls, and therefore it is a requirement that cabling cannot go across public footpaths.
- They have a suitable 3-PIN socket on a dedicated RCD-protected circuit, in line with Section 722 BS 7671 (17th Edition) of the UK wiring regulations, which can be used for the purpose of charging a BEV and PHEV.
    - Where an approved contractor ascertains that there is no such suitable socket in the participant's home, the participant will be asked whether they would be willing for a dedicated socket to be installed for the purposes of the trial. If the participant is not willing to accept this, they will be required to withdraw from the study.

If the arrangements are not suitable then the participant will not be allowed to continue with the trial. All Mode 2 charging cables for connecting the vehicle to the charging point will be manufacturer approved and supplied by TRL. Cables will be bought specifically for each vehicle, in accordance with the manufacturer's recommendations, at the beginning of the trial. The cables will be visually inspected at the collection and return of the vehicle and arrangements will be made for them to be tested by a TRL-appointed competent person once every three months. The cables provided (which will be mandated for use by participants) will have their own RCD cut off to provide extra electrical safety to the charging. Participants will be briefed on safe use of the cables, including making sure that they are fully uncoiled prior to use, not turning current on/off until cable is fully connected/disconnected and also slip/trip hazards.

A full risk assessment of Mode 2 charging for the Consumer Uptake Trial is detailed in Section 4.3.

4.2.4.2 Consumer Charging Trials

Due to the nature of the Consumer Charging Trials, participation will require the installation of dedicated Mode 3 electric vehicle chargepoints at participants' homes; this will ensure that the vehicle charging can be undertaken safely and that the objectives of the trial can be met.

During the trial design phase of Stage 1, a 'Request for Quotation' (RFQ) process has been undertaken to select an appropriate chargepoint supplier for the Stage 2 Consumer

Charging Trials. The RFQ detailed the technical specification, quantities, timeframes, and safety criteria that will need to be met by the supplier. The key specification is;

- Provision of chargepoints to the specification required by the vehicle and for collection of data relevant to the trial.
- Installation of the chargepoints at participants' homes by a qualified and approved contractor.
- Technical support for the chargepoint hardware for the duration of the trials.
- Possible removal of the chargepoints (and associated remedial work) at the end of the trial, if the participants request it.

The RFQ was distributed to 25 different chargepoint manufacturers and suppliers along with a supplier questionnaire that asked a range of questions relating to the management, financial position and Health and Safety culture of the company.

Responses were assessed on the criteria above, along with the cost of the chargepoints and the associated installation (and potential removal) processes. At the beginning of Stage 2, a chosen supplier from a shortlist of responses and will be required to sign a contract agreeing that they will supply and install the chargepoints in the timeframe specified and for the cost quoted. The chargepoint manufacturer will also be directly responsible for the management of any subcontractors included in their bid.

TRL will request that the chargepoint supplier is responsible for the installation of chargepoints at the residences of participants. Installations will only take place after a survey has been carried out by a qualified electrician to make sure that the chargepoint can be safely installed and integrated into the domestic wiring system. Installations will be carried out in line with all relevant safety guidelines. The chargepoint will also come with a minimum three year warranty.

The chargepoint will include a tethered cable (i.e. one that is attached to the chargepoint) of the correct specification to charge the vehicle being used. As the chargepoint is being affixed to the outside of the property, the participant must either be the property owner or have the permission of the property owner for such an installation to take place.

The chargepoint must be installed in such a location that when the vehicle is being charged, the cable does not cross any public land. On completion of the trial, the participant or homeowner may opt to have the chargepoint removed from their property and for any necessary rectification work to be undertaken. This work will be carried out by either the chargepoint supplier, or an appropriate contractor identified by them, at no cost to the participant.

TRL will provide participants with information about how to locate charging points while they are away from their place of residence. A 24/7 helpline will be made available to all participants to provide assistance with any charging or vehicle related issues.

4.2.5 Vehicle use

Fully comprehensive insurance will be arranged by TRL and the details provided to the participant during the vehicle collection briefing. The insurer's accident reporting procedures will be clearly detailed and the participant will be made aware of these. Road

Fund Licence (or 'road tax') will be included as part of the vehicle leasing contract, and will be automatically renewed by the leasing agent. As all vehicles will be new they will not require an MOT over the course of the trial. Wherever possible any scheduled servicing will be undertaken between participants having the vehicle; however if this is not possible a collection and return service or courtesy car will be offered.

Breakdown cover for the vehicle will also be provided to participants. This cover will be extensive and will include home start and recovery (including in the event of a vehicle running out of charge).

If the vehicle breaks down or requires a prolonged period of maintenance due to a fault with the vehicle, the participant will be offered a courtesy car.

4.3 Risk Assessment for Mode 2 Charging

This section examines the suitability of using Mode 2 charging equipment during the Consumer Uptake Trial. The section provides a high level comparison of Mode 2 and Mode 3 safety features and an evidence review of the suitability of Mode 2 charging for the purpose of these trials.

4.3.1 Mode 2 charging overview

Mode 2 charging uses a standard 3-pin socket outlet, with the chargers complying with UK plug standards BS1363. Mode 2 chargers do not have a dedicated power supply, using power drawn from the same source as the rest of the electrical appliances in the house, but the charger does have an integral in-cable control and protective device (IC-CPD). This provides RCD protection and control pilot function. On the vehicle side of the Mode 2 cable is a dedicated EV connector that facilitates the use of the control pilot function. Mode 2 charging is limited to 13A single phase supply through the BS1363 plug, but in practice, many vehicle manufacturers restrict the supply via Mode 2 to 10A, as an additional precaution.

In terms of safety risk, Mode 3 represents the optimal solution for domestic charging of EVs. This risk assessment therefore focuses on identifying the relative risks of Mode 2 charging compared with Mode 3 charging, in order to establish whether the Mode 2 charging can be used without introducing an intolerable level of risk to participants.

Mode 3 chargers utilise a dedicated connection to the power supply with a control pilot function extending to the control systems in the vehicle supply equipment. Mode 3 is the preferred solution for charging Electric Vehicles (EVs) because it guarantees a dedicated circuit for the charger and as such, is independent from any existing domestic wiring. The main difference between Mode 2 and Mode 3 charging is, therefore, at the interface to the domestic wiring / power supply. Whereas Mode 3 is guaranteed to have a separate, dedicated circuit, Mode 2 (although also recommended to have a separate dedicated circuit installed[4]) is unlikely to have a dedicated socket on a dedicated circuit in a typical domestic charging environment. Portable socket-outlets are not permitted by section 722 of BS 7671

[4] For new installations, when installing a socket outlet for EV charging, section 722 of the wiring regulations requires that a separate dedicated circuit is installed.

(17th Edition) of the UK wiring regulations, implying that extension cables must not be used for Mode 2 charging. However, since Mode 2 charging utilises a standard 3-pin socket outlet, in practice it is possible for a user to plug this into an extension cable when charging via Mode 2. This therefore adds an additional risk compared with Mode 3 charging which has an enclosed connection to the mains supply, not accessible to the user and thus does not have a BS1363 plug interface

Table 1 below shows the respective safety features for Mode 2 and Mode 3 chargers. The latest Mode 2 charging cables provide the majority of the safety features available with Mode 3 charging, including over current protection, RCD protection and an ability to control the current flow, which helps to minimise the risk of raised temperatures (over-heating). Furthermore, as most manufacturers limit Mode 2 current flow to 10A (including VW, who will be providing vehicles for this project); this minimises the risk of overheating and unwanted overloading on the circuit.

The lack of a dedicated circuit for Mode 2 and non-tethered cable (allowing potential use of extension cables) appear to be the only safety feature differences between Mode 2 and Mode 3 charging.

Table 1: Comparison between Mode 2 and Mode 3 Safety Features

Main safety feature	Mode 2	Mode 3
Dedicated power supply (via a dedicated circuit)	No. Recommended and possible but not guaranteed.	Yes. Guaranteed via installation.
Over Current protection	Yes	Yes
RCD	Yes	Yes
Contactor/switching	Yes (between the in-cable box and the vehicle)	Yes
Control pilot function	Yes (between the in-cable box and the vehicle)	Yes. Control pilot function extending to control of equipment in Electric vehicle supply equipment (EVSE)
Protective casing/design (IP rating)	Yes (BS1363 and IEC 62196)	Yes (IEC 62196)
Interlocking mechanism (mechanical or electric)	Not for BS1363 domestic plug. Same as Mode 3 for vehicle connector	Yes
Tethered lead	No (use of extension cables possible)	Yes

4.3.2 Risk assessment

Table 2 details the risk assessment for Mode 2 charging focusing only on the risks which are not present with Mode 3 charging. It can be seen that most of the risks are not electric shock related but are in fact a potential fire hazard, caused by potential failure of the household wiring or extension cables. Each risk is described in more detail under Table 2. It should also be noted that although the primary risk of cables overheating is a fire hazard, there is also a potential for electric shock if parts of the conductor are exposed to touch. However, the presence of an RCD within the Mode 2 cable and as part of domestic wiring should prevent any serious risk to human health.

Table 2: Risk Analysis for Mode 2 charging; risks that are additional to those associated with Mode 3 charging (L = Low, M = Medium, High = High)

Risk number	Risk	Relevant Design Item	Probability	Impact	Risk rating
1	Burns	No interlocking plug. Heat damage to BS1363 plugs	L	L	L
2	Fire Hazard	Wiring harness of household	L	H	M
3	Fire Hazard	Extension cables	L	H	M

Risk 1: It would be possible to perform a "hot disconnect" of the 3-pin plug from the mains supply (disconnection of charger by removing the plug from the socket when in use), which can cause arcing and pitting of the contact surfaces (pins) of the plug. Over many occurrences, this could lead to increased surface resistance and result in the heating up of these contacts in the connector (the plug). This could lead to an increased risk of suffering minor burns when attempting to handle the plug. This risk is further increased by the possibility of using extension cables with Mode 2 charging. It should be noted that during the short time span of this trial, the probability of this risk creating a hazard is deemed to be very low; it is very unlikely that a sufficient number of 'hot disconnects' would be performed during the short trial period to cause higher than normal surface resistance on the plug pins.

Risk 2: Mode 2 charging draws power directly from a domestic socket, thereby producing a potential fire hazard due to a possible overheating of the wiring between the wall socket and house circuit breaker (if the wiring is not sufficient to withstand the current draw over prolonged time periods). It is possible to draw 10A continuously for up to 13 hours via Mode 2 charging of a BEV – this is anticipated to be the worst case in the trials, assuming longest charging time of the e-Golf as per manufacturer's specification. For a given domestic socket, the thickness of the cable used for that spur combined with the Miniature Circuit Breaker (MCB) rating upstream will determine whether the domestic wiring for a particular plug can safely cope with the EV charging demand. The situation for every house and socket is likely to be different. If the Mode 2 cable is plugged into a socket that is on a spur where cabling is not adequate to deal with the current load of EV charging, and any existing load on that spur, and the upstream MCB is not rated sufficiently low to detect hazardous levels of overcurrent, then there is potential for the cable to overheat. Overheating cables could result in melted insulation and exposed metal conductors, which will present a fire hazard if in contact with potentially flammable material. Probability of this occurring is relatively low as most domestic properties are likely to use the 2.5mm^2 cable size for power circuits, in line with IET Wiring Regulations. The current rating of a cable this size will vary depending on a number of factors, such as temperature, type of cable and its location and placement in the property. However, the current rating is likely to be somewhere between 18A and 30A. It is therefore unlikely that adding an additional 10A load to the cable for Mode 2 charging will exceed its rating, unless there are other high-current, continuous loads connected to the same cable spur. So, although the potential impact of a fire hazard can be highly severe – e.g. a house fire, the likelihood of this occurring, to this level of severity, is very low, resulting in an overall risk rating of medium.

Risk 3: Extension cables should never be used with Mode 2 charging. However, as Mode 2 cables use a standard BS1363 3-pin plug, it would be possible, in practice, for users to use extension cables during the trial. If a Mode 2 cable is plugged into an extension cable that is not able to tolerate prolonged current draw, either due to other devices being plugged into the same extension cable or an inadequately rated cable, then the cable could be subject to overcurrent and potential overheating, as described in Risk Number 2. If the extension cable is fused then this risk is much lower, as current in the cable should never exceed the load of the fuse rated to the cable capacity (maximum rating of 13A). The use of extension cables could increase the likelihood of Risk Number 2 if they are plugged into sockets with multiple loads already present. Most extension cables are rated to 13A and are fused. Therefore, the likelihood of occurrence is low. However, given the potentially high severity that a resulting fire hazard could present in extreme cases, the overall risk rating is deemed to be medium.

4.3.3 Risk mitigation

This section describes possible mitigation measures for each of the risks identified in Table 2 above.

Table 3: Risk mitigation table

Risk number	Risk	Design Item	Mitigation	Residual Risks	Further Mitigation	Level of remaining residual risk
1	Burns	No interlocking plug. Heat damage to BS1363 plugs	Produce a user guide for participants in the trial that clearly advises them to turn off power supply at the socket prior to unplugging the Mode 2 cable.	Some users may still choose to hot disconnect	The relatively short length of trial will mean that it's highly unlikely that hot disconnecting will increase resistance of the connectors.	Low
2	Fire Hazard	Wiring Harness of household	Two options are possible: Option 1 – Undertake an inspection of the suitability of the household wiring for use with domestic Mode 2 charging using a suitably qualified	Potential for users to use non-surveyed or non-dedicated socket.	Ensure the user guide for participants in the trial clearly advises them to use the dedicated socket / only sockets checked by the electrician.	Low

			electrician, for each household taking part in the trial. Option 2 – Provide a dedicated socket on a dedicated circuit, in each participant's house for use with Mode 2 charging (this is the preferred option and is in line with section 722 of the wiring regulations)			
3	Fire Hazard	Extension cables	Ensure the user guide for participants in the trial clearly advises them to not use any extension cables. Seek a signature from participants to verify that they have read and understood this requirement.	User may choose to ignore guidance and warning about using extension cables.	The relatively short length of trials will mean that it's unlikely that users will have the opportunity or the perceived need to use an extension cable in addition to the dedicated socket provided.	Low

4.3.4 Supporting evidence

This section outlines evidence gathered from other reputable sources that describe acceptable usage of Mode 2 charging. The use of Mode 2 charging for occasional use is permitted and accepted by professional organisations and industry standards.

- The European Automobile Manufacturers' Association (ACEA) recommends Mode 3 charging for publicly accessible charging stations. ACEA recommends using Mode 3 charging for charging at home, but Mode 2 is an acceptable form of charging during Phase 1 should no Mode 3 charging station be available (Phase 1 is considered as a transitional period lasting up to 2017 and reflecting the current situation) (ACEA, 2012).

- BEAMA (British Electrotechnical and Allied Manufacturers' Association) recommends that Mode 2 may be a satisfactory charging solution for some types of EVs and their operators i.e. for those with modest charging requirements such as some two wheelers and Plug-in Hybrid Electric Vehicles (PHEVs). Some vehicles will be supplied new with a Mode 2 cable with Mode 3 as an optional extra. Mode 2 is also an important backup for any compatible vehicle in locations where there is no dedicated charging installation. BEAMA recommends that regular Mode 2 charging should only be carried out using a dedicated EV circuit although occasional charging from a non-dedicated circuit is acceptable (BEAMA, 2015).

- CEN-CENELEC (European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) Recommendation 7.3 states that Mode 2 can be used to charge vehicles occasionally. However, Recommendation 7.11 does not recommend use of Mode 2 chargers in publicly accessible places (CENELEC, 2011).

4.3.5 Recommendations

Having reviewed the risks, possible mitigation measures and supporting evidence from other sources, there is strong evidence to support the safe use of Mode 2 charging in the Consumer Uptake trial of this project. There is no evidence to suggest that the risks associated with Mode 2 charging instead of Mode 3 charging will be increased to an intolerable level. All evidence reviewed suggests that for occasional use, Mode 2 charging can be used without any additional intervention. Given that over the course of the short-term trial period, most participants are unlikely to charge their vehicle more than 4 times (i.e. twice per BEV and twice per PHEV), this is considered as occasional use.

Mode 2 charging provides most of the same safety features as Mode 3 charging, with the main exception being the lack of a guaranteed dedicated circuit that connects the charger to the domestic supply.

Having identified how specific risks related to this issue can be mitigated in a practical manner that should be reasonable within the scope of the project and the trial, the following steps are recommended to ensure that risks associated with Mode 2 charging during the trial are reduced to ALARP levels:

1. During the recruitment process TRL will administer a screening questionnaire to prospective participants which will include questions to ascertain whether the participant's household meets the required safety standards for EV charging (i.e. in accordance with Section 722 of the IET's 17th Edition wiring regulations).
    - This will include high-level questions to screen which participants may require additional electrical works at their property to ensure safe EV charging. Questions will seek to identify whether the participant has an existing EV charging point or a suitable socket outlet (i.e. a dedicated, RCD-protected circuit; rated to at least 10Amps; with a EV-appropriate Mode 2 socket[5], in an appropriate location for EV charging).
2. If the responses to the questionnaire indicate that the participant may already have appropriate provision for safe EV charging, then a TRL-appointed electrical contractor will be asked to inspect the premises and certify the existing charging infrastructure as safe and fit for purpose.

[5] An 'EV-appropriate Mode 2 socket' is defined as one which is consistent with the IET's 17th Edition wiring regulations. One example of a product conforming to these requirements can be found here:

http://assets.rolecserv.com/files/products_document/63ced5ffd0986e107c741f80265b912c/EVWPD001%20-%20WALLPOD%20EV%20Ready.pdf

3. If the participant is found to lack the necessary electrical infrastructure (either via the screening questionnaire or a subsequent electrical inspection) then they will be offered an installation as part of the project.

4. Installation of an EV-appropriate Mode 2 socket on a dedicated RCD-protected circuit will be completed by the TRL-appointed contractor. The installation will be in accordance with Section 722 of the IET's 17th Edition wiring regulations.

    - Prior to installation, the TRL-appointed electrical contractor will engage with participants to ascertain the specifics of the existing electrical wiring in the household (via remote interviews and photos of the electrical components, such as sockets, consumer unit, parking location, etc.). Based on this remote assessment a recommendation will be made by the contractor on the best way to proceed.

5. In the event that a participant is not willing for the required installation work to take place, they will be ruled out from taking part.

6. Participants will only be allowed to take part in the trial upon satisfactory certification from the TRL-appointed electrical contractor that the necessary electrical installation has been completed and is fit for the purpose of the trial.

In addition to the above mitigating steps, all trial participants will be provided with a concise guide on plug-in vehicle charging that clearly describes relevant safety considerations and good practice, such as prohibited use of extension cables. The contents of this guide will be fully explained during the vehicle handover process. All participants will be asked to sign a form to indicate that they have read and understood the recommendations for safe use of Mode 2 charging equipment during the trial.

As evidenced in this report, implementation of these control measures is likely to reduce the risks associated with Mode 2 charging a level that is ALARP.

4.4 Stage 2 Hazard Identification (HAZID) study

Ensuring the safety of all affected parties throughout the life cycle of the trials is paramount. It is therefore proposed that a hazard identification (HAZID) study is conducted during the preparation phase of Stage 2. This will complement the Health and Safety considerations outlined in this document, and feed into a comprehensive risk assessment to ensure *all* hazards, throughout the life cycle of the trial, are identified, assessed, and mitigated against through implementation of appropriate control measures to ensure risks to all affected parties are reduced to a level that is ALARP.

4.4.1 Approach

It is proposed that a top-down approach is adopted whereby initially key undesired events are identified and subsequently linked to a specific hazard and activity. Key undesired events will be identified through a review of existing literature, relevant risk assessments from appropriate technical specialists (such as the Mode 2 charging risk assessment) presented in Section 4.3), previously recorded incidents and documented lessons learned, where available. A workshop will also be held with relevant technical experts to ensure all hazards are systematically identified.

A comprehensive risk assessment will then be undertaken for each undesired event, identifying the stage in the life cycle (pre-installation, installation, use, and removal), persons affected, consequences and proposed mitigations. The level of risk will be calculated using a modified risk calculator that combines probability of occurrence, exposure duration and consequence severity on a nomogram (a diagram representing the relations between three or more variable quantities) to calculate a risk level. The risks will be categorised into four levels: high, substantial, moderate and low. Additional mitigation measures will be identified where necessary to ensure risks are ALARP.

A separate risk assessment will be conducted for Mode 3 charging to build upon the Mode 2 charging risk assessment documented in Section 4.3.

The assessment of risks will be conducted by risk specialists at TRL informed by literature and available data. Risk decisions will be validated in a workshop setting by relevant technical experts.

4.4.2 Outcome

The HAZID and associated risk assessment will feed into the practical implementation of the Stage 2 trial design to ensure risks to all affected parties are eliminated, where possible, or reduced to levels that are ALARP.

4.5 Research ethics

Ethical approval is required for all projects using human participants. This includes all projects that involve observation of human participants or collection of information from them or about them. It also includes projects that require access to information on identifiable individuals that is already held by TRL or another organisation. Projects in which human beings participate in other ways – for example, by being subjected to experimental situations or driving instrumented vehicles – are also covered.

TRL has a rigorous ethics procedure informed by EPSRC’s Guide to Good Practice in Science and Engineering Research. All staff at TRL are required to comply with ethical guidelines to protect and enhance the ethical and professional reputation of research activities performed by TRL. The standard of this ethical procedure is designed to satisfy the ethical standards of relevant professional bodies, government and other clients, and other funding bodies.

The TRL ethics process is summarised in Figure 3 below. TRL projects involving human participants are first formally assessed by the Project Manager and Technical Reviewer using a simple ethics checklist. Proposals that appear to follow recognised ethical principles will then be judged by a "light touch" internal Mini Ethics Panel. Potentially problematic projects require approval from the TRL Research Ethics Committee. The TRL Research Ethics Committee involves an external participant and also monitors the decisions of the Mini Ethics Panels.

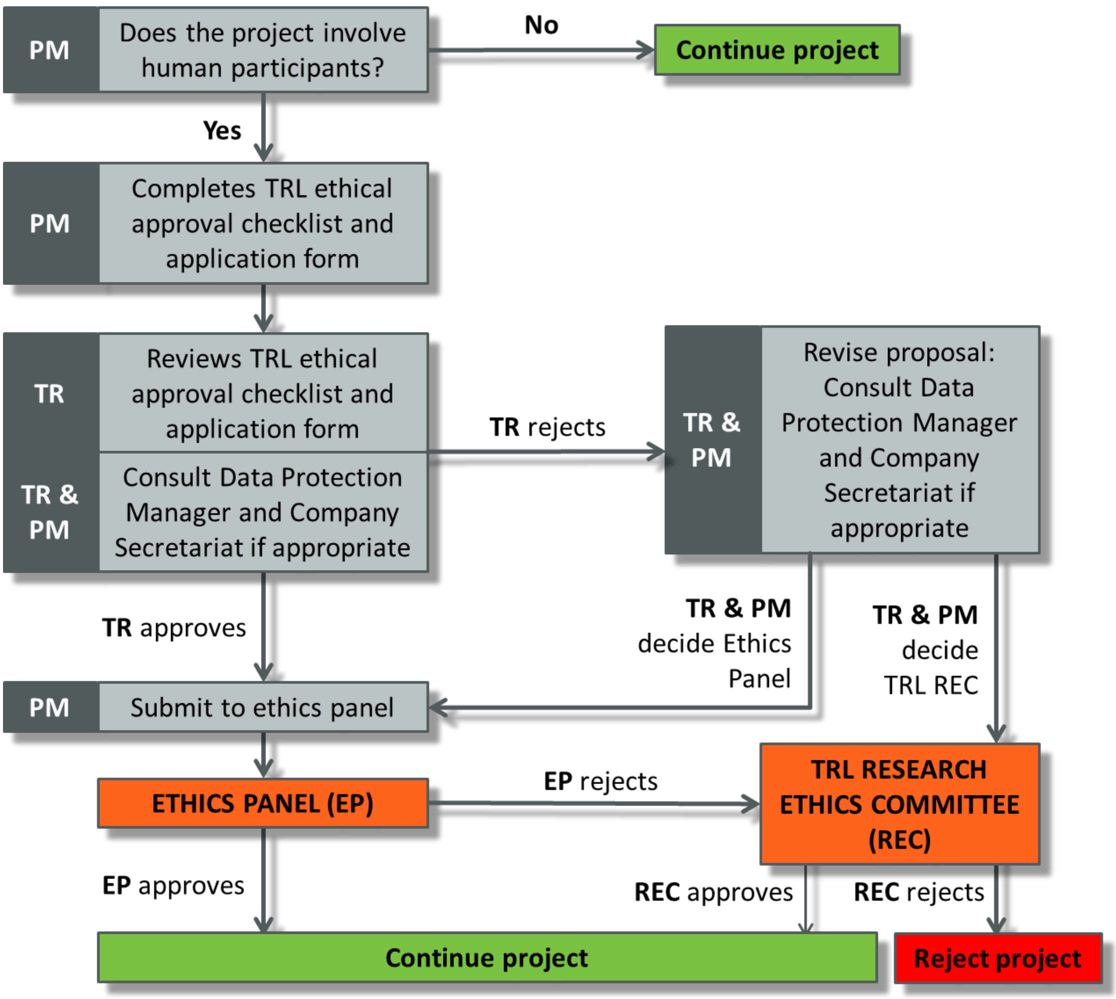

Figure 3: TRL Ethics Process

The Chair of the TRL Ethics committee has been consulted with and early indications are that all of the research procedures planned for Stage 2 will fall under review by mini ethics panel.

5 Data privacy and security management

We regard the lawful and sensitive treatment of personal information as critical to the success of our operations, and have implemented formal procedures since 1988. Our Data Protection and Information Security Policy covers our obligations under the Data Protection Act, Freedom of information Act and Environmental Information Regulations. Our Procedures comply with the information security standard ISO/IEC 27000 and reflect government publications such as the Data Handling Procedures in Government Report and the Data Sharing Review. They also comply with the Cross Government Actions: Minimum Mandatory Measures as outlined by the Cabinet Office.

Data will be stored on TRL's electronic data storage systems. This is a centrally based (server) system with high security. In addition, all access to this data will be via computers that have hard disk encryption, ensuring that there will be no unauthorised access or unlawful processing. All data will be fully anonymised and securely stored by TRL (including all completed questionnaires, vehicle telematics and chargepoint data) for a minimum of seven years.

On completion of the first recruitment survey, all participants will be assigned a Participant ID. All subsequent data collected will be linked to the Participant ID, rather than a participant's name or other personal details, in order to anonymise data. Any data which need to be shared between consortium members will be transmitted using secure media. The preferred method of this will be through TRL's secure FTP site. This service is compliant with the required security standard (FIPS 140-2) and can only be accessed by those who are required to access it. If secure FTP is not an appropriate mechanism for transferring data then secure removable media (such as encrypted memory sticks) will be used. Any data transferred in this way will also be compliant with the required security standard. No personal or sensitive data will be shared between consortium members unless it is necessary (e.g. for the purpose of running trials). In all other circumstances data will be anonymised prior to sharing. It is not expected that any personal or sensitive data will be shared outside of the consortium. Other than to the ETI it is not expected that any anonymised data will need to be shared outside of the consortium. Specific data which will be collected as part of the Stage 2 trials are detailed in Part 2 (Consumer Uptake Trial), Part 3 (Consumer Charging Trials), and Part 4 (Fleet Study).

TRL has a comprehensive Code of Practice relating to handling personal and sensitive information. This Code of Practice meets or exceeds the requirements of the Data Protection Act (1988). A copy can be provided upon request. Key features and areas covered in the Code of Practice include:

- Protective marking of data
- Outline of the principles of the Data Protection Act
- TRL's legal responsibilities for personal information
- Explanation of, and guide to completing, a Privacy Impact Assessment
- Physical and logical protection of information
- Relationships with contractors and partners
- Personal data transfer and movement
- Disposal of personal data or media
- Incident reporting

To ensure that all requirements under the Data Protection Act are appropriately met, upon recruitment for the trials participants will be fully informed of:

- The nature of the data which will be collected
- How data will be anonymised
- Who the data will be shared with
- What we will be doing with the data
- How long we will be keeping the data for

- What data will be published

This will ensure complete transparency in our data privacy management processes and will allow participants to provide full informed consent for data to be collected and used as part of the trials.

During Stage 2, TRL will further update the Privacy Impact Assessment and undertake a Data Protection Review with the ETI prior to Trial commencement, which will include review of the flow and management of data in the project, and review of all partners data protection protocols in place to ensure data is appropriately managed.

6 Dissemination strategy

The dissemination of the research activities and project findings is a critical component for the success of Stage 2 of this project and will be managed under Work Package 8. This section summarises the ways in which the activities and findings will be showcased and communicated with relevant stakeholders throughout the project timeline. This is further detailed in the Dissemination Strategy agreed with the ETI during the preparation phase of Stage 2. It is recommended that the approach includes a varied mix of dissemination techniques in order to maximise the potential reach for the key target audiences.

An overview of this mixed method approach is provided in Table 4.

Table 4: Dissemination strategy

	Target audience						
	ETI	Other research organisations/ academia	Government organisations/ other policy makers/ regulators	Fleet operators	Trial participants	The public, in particular vehicle consumers	OEMs/DNOs/utilities
Publication of reports / graphical summaries	✓	✓	✓	✓	✓	✓	✓
Press releases (e.g. via TRL's 'News Hub')	✓	✓	✓	✓	✓	✓	✓
Technical articles (e.g. via TRL's 'e-News')	✓	✓	✓	✓	✓	✓	✓
Project website	✓	✓	✓	✓	✓	✓	✓
Conference presentations (e.g. Cenex-LCV, Hybrid and Electric Vehicle Conference)	✓	✓	✓	✓			✓
Industry events (e.g. Cenex event days, Capital Greenfleet)	✓	✓	✓	✓			✓
Academic journal articles (e.g. Transportation Research Part D: Transport & Environment, Energy Policy or International Journal of Electric & Hybrid Vehicles)	✓	✓	✓				
Project symposiums (e.g. 'dissemination day' at TRL)	✓	✓	✓				✓
Utility/DNO client breakfast event	✓						✓
Baringa Viewpoint (website) article	✓		✓				✓

6.1 Case study example: GATEway project

TRL will draw upon marketing expertise and experience gained from disseminating research findings from other large research programmes, such as the GATEway project, to inform the dissemination strategy. TRL is the lead partner in the GATEway project, with overall responsibility for management and technical direction of a consortium of 14 companies. As part of this large-scale project, TRL coordinated development of new project-specific branding. This branding is used on all dissemination streams, including on the project specific website which was developed to provide a dedicated portal for disseminating research activities (see Figure 4). This website provides a valuable, dedicated resource for sharing information with regards to:

- Project aims and objectives
- Showcase photos and video demonstrations of the project activities
- FAQs about the project
- Contact details for the project team
- Opportunities for members of the public to participate in the research.

Figure 4: Illustration of GATEway project website

In addition to the website, project-specific social media accounts were set up to further increase the reach of the project dissemination. These include dedicated GATEway Facebook and Twitter accounts. The success of this varied approach is directly measurable; to date the project has accumulated:

- Over 10,000 website visits
- Nearly 120,000 views of the GATEway promotional video on social media
- More than 800 press articles in a range of regional, national and international media within the first month of project launch
- Over 30 TV/radio appearances by the TRL Technical Director of the project
- Over 100 Facebook followers, 700 Twitter followers and 40 YouTube subscribers.

These approaches have been proven to reach the varied target audience required by the project, including residents and businesses local to the project trial area in the Royal Borough of Greenwich, prospective trial participants, and project stakeholders.

References

ACEA. (2012). *ACEA position and recommendations for the standisation of the charging of electrically chargeable vehicles.*

BEAMA. (2015). *A Guide to Electric Vehicle Infrastructure.*

CENELEC. (2011). *Focus Group on European Electro-Mobility: standisation for road vehicles and associated infrastructure.*

D1.4 Stage 2 Trial Design, Methodology and Business Case

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN

ISBN

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THE FUTURE OF TRANSPORT

PROJECT REPORT

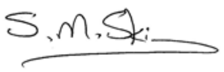
D1.4 Stage 2 Trial Design, Methodology and Business Case

Part 2 - Consumer Uptake Trial

G. Beard, N. Kinnear & S. Skippon

Report details

Report prepared for:	ETI
Project/customer reference:	TR1006 Consumers, Vehicles and Energy Integration (CVEI)
Copyright:	© Energy Technologies Institute
Report date:	March 2017
Report status/version:	4.0
Quality approval:	

H. Al-Katib (Project Manager)		S. Skippon (Technical Reviewer)	

Disclaimer

This document is provided to the ETI under, and is subject to the terms of, the Energy Technologies Institute's Agreement for the Consumers, Vehicles and Energy Integration (CVEI) Project – Stage 1.

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	10/06/16	Draft delivered to client	GB/NK	SS/SH
2.0	14/12/16	Edited version addressing comments from ETI	HAK/NK	SS
3.0	14/02/17	Third version to Client	HAK/NK	SS
4.0	13/03/17	Final version	HAK	SS

Document last saved on:	13/03/2017 14:00
Document last saved by:	Al-Katib, Hannah

Table of Contents

Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics
ESME	Energy System Modelling Environment
ESOS	Energy Savings Opportunity Scheme

EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
ISO	International Organization for Standardization
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer

ONS	Office for National Statistics
OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
UMC	User Managed Charging
VAT	Value Added Tax
VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services
WP	Work Package

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.

Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)
Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how you see yourself and how one perceives others see them.
Social norms	Similar to injunctive norms but mores specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.
Symbolic meaning/ attitudes	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

STATUS OF TRIAL DESIGN INFORMATION

THIS DOCUMENT WAS PRODUCED IN STAGE ONE OF THE CVEI PROJECT, TO SET OUT THE PROPOSED TRIAL DESIGN AT THAT POINT.

IN STAGE TWO, THE TRIAL DESIGN HAS BEEN FURTHER DEVELOPED, AND SOME ASPECTS OF THE TRIAL DESIGN HAVE EVOLVED FROM THE PROPOSAL SET OUT IN THIS DOCUMENT.

THE FULL AND FINAL DESIGNS OF THE CONSUMER UPTAKE AND CONSUMER CHARGING TRIALS ARE DOCUMENTED IN DELIVERABLE D5.1 "SUPPLEMENTARY DETAILS OF DESIGN, MATERIALS AND MANAGEMENT ARRANGEMENTS FOR CONSUMER TRIALS".

PARTS 2 AND 3 IN PARTICULAR OF THIS DELIVERABLE D1.4 ARE SUPERSEDED BY D5.1

1 Introduction

1.1 This report

This report is part of Deliverable 1.4: Stage 2 Trial Design, Methodology and Business Case. There are six parts to this deliverable:

- Part 1: Overview of Stage 2
- Part 2: Consumer Uptake Trial (this document)
- Part 3: Consumer Charging Trials
- Part 4: Fleet Study
- Part 5: Analytical Tools
- Part 6: Commercial Submission

This report covers Part 2, the rationale, methodology, conceptual design, and practical design that will be employed for the Consumer Uptake Trial (Work Package 5; Task 5.1). The trial design reflects collaborative development involving TRL, Baringa, Element Energy, Cenex, EV Connect, EDF, the Behavioural Insights Team and the ETI.

The other parts of Deliverable D1.4 are provided in separate documents. Part 1 includes an overview of the CVEI project as a whole.

1.1.1 Scope

The contents of this report provide details of the proposed design for the Consumer Uptake Trial. There are areas of the design where there is more than one option and areas where specific details will be confirmed during the development phase at the start of Stage 2.

The report discusses the rationale behind the proposed method of addressing the research questions. Research design inevitably involves trade-offs, for instance between internal and external validity, and stakeholders may have different areas of priority. Accordingly, several alternative design options are offered. These are summarised at the end of this document, alongside an explanation of the budget implications and scientific advantages and disadvantages associated with these alternatives. The full impact of alternative design options on cost and participant[1] numbers is provided in Part 6: Commercial Submission.

[1] Where references are made to "participants" or "participant", this refers to trial participants, as opposed to a contracted organisation.

2 Background and rationale

2.1 Measuring attitudes, responses, and choice

Quantitative measurement of attitudes and responses is most commonly carried out using self-report methods in questionnaires (e.g. Ajzen, 2005; Oppenheim, 1992; Saris & Gallhofer, 2007). However when considering choice between alternatives that vary in respect of independent attributes, people may hold different and potentially conflicting attitudes towards those attributes, so must trade them off against each other. For instance, many attributes come at a cost; increased AER in an EV, for instance, may involve higher purchase cost. Different people will place different relative importance on these attributes, and trade them off differently in considering choices between alternatives. If we simply measure attitudes towards AER and attitudes towards cost, we would be likely to find agreement, with most people preferring more AER and less cost. When required to trade these off, however, peoples' attitudes are less likely to be convergent.

The most appropriate method to characterise choice between alternatives that differ in respect of multiple attributes is the choice experiment (e.g. Anderson, de Palma, & Thisse, 1992; Louviere, Henscher, & Swait, 2000). However there are practical constraints in choice experiments; it is difficult for participants to deliberate on choice options that differ in respect of more than eight or so attributes. This limits the range of research questions that can be addressed together in a single choice experiment.

Accordingly our preferred methodology will be measurement using a choice experiment, but supplemented by self-report questionnaires to provide a richer dataset addressing supplementary research questions that cannot practically be accommodated within the choice experiment alone.

2.2 Adoption of electric vehicles by the mass-market

Across a broad range of technological and other innovations, adoption behaviours differ widely; times to adoption across a population are typically normally distributed, with a few adopting early, a majority adopting on similar timescales and a few only adopting much later.

The most widely accepted and used theory of adoption, "Diffusion Theory" (Rogers, 2003), proposes that these differences are driven by an individual characteristic termed "innovativeness". In Diffusion Theory, adopters are segmented operationally not by a direct measure of innovativeness (such as a psychological scale measure) but by a behavioural measure – their time to adoption. The theory defines a segment called "Innovators" as people who adopt innovations early, largely without direct social influence from others because they have particular personal goals (motives) that are supported by such behaviour. "Innovators" are statistically defined as people whose times to adoption lie earlier than two standard deviations before the population mean time to adoption; that is, they represent the first 2.5% (approximately) of the eventual adopter population, assuming a normal distribution.

In the UK there are approximately 30 million cars (DfT, 2016a). If all of these were replaced by EVs, "Innovators" would represent the first 750,000 to adopt. At present, there are around 310,000 "alternative fuel vehicles"[2] (DfT, 2016a), representing approximately 1% of the total car fleet. Therefore, according to Diffusion Theory, *all* present owners/users of EVs are Innovators, and this will remain the case for some time.

Rogers (2003) showed that, across a wide range of categories of innovation, Innovators' attitudes to adoption cannot be used to predict the adoption behaviour of the majority of the population. The literature review conducted during Stage 1 of this CVEI project (Deliverable D2.1) confirmed that all present and previous trials measuring responses to, attitudes to, use of, or charging behaviour using participants' own EVs have been with Innovators rather than 'mainstream consumers' (i.e. the non-Innovator majority), and those in which EVs were provided to participants have also used samples biased towards those with substantial pro-EV motivations. It follows that none of these studies can be used to make valid predictions regarding mainstream consumers' responses to EVs, attitudes towards adoption of EVs, use of EVs, or charging behaviour.

The primary value of this Consumer Uptake Trial will be to provide valid measures of responses to EVs, attitudes towards adoption of EVs, and use of EVs, by mainstream consumers. This will provide robust inputs to the anaytical framework to allow more accurate prediction of the likely future uptake of EVs by the mass market and the resulting impact on UK aggregated EV charging demand, and to enable the project to deliver appropriate recommendations concerning policies and market structures.

2.3 Alternative types of electric vehicle

The ETI PiV project (Anable, Kinnear, Hutchins, Delmonte, & Skippon, 2011) indicated that Mainstream consumers are more likely to adopt PHEVs than BEVs over the period to 2050. PHEVs have substantially smaller batteries than BEVs: and thus smaller individual charging demands. However, a greater willingness of Mainstream consumers to adopt PHEVs than BEVs (as suggested by Anable *et al.*, 2016) may imply that, collectively, PHEVs could make a much bigger contribution to overall EV charging demand than BEVs.

Nevertheless, because of their relatively later introduction to the vehicle market, there has been very little empirical research with PHEVs, and none which has investigated the responses, attitudes, behaviour and likely adoption of PHEVs by Mainstream consumers.

The primary value of the Consumer Uptake Trial can only be realised by measuring Mainstream consumer responses to PHEVs as well as BEVs.

2.4 Psychological distance

Research with mainstream consumers has so far been restricted almost exclusively to qualitative methods, survey methods, and choice experiments with people who have had no direct experience of EVs (see Deliverable D2.1). Assessment of consumers' preferences for "really new" product categories can be methodologically challenging (Hoeffler, 2003).

[2] "Alternative fuel vehicles are those able to use a range of alternatives to purely petrol or diesel fuel, including gas, electricity, or a combination such as gas bi-fuel and hybrid electric" (DfT, 2016a)

Construal Level Theory (Liberman, Trope, & Stephan, 2007; Trope & Liberman, 2003) proposes that psychological distance affects the level of abstraction with which a product is construed. An object is psychologically distant when it is detached from a person's direct experience; the more psychologically distant an object, the more it is construed in high-level, abstract terms, rather than low-level, concrete terms that relate directly to lifestyle. This suggests that research in which participants have not directly experienced EVs may be subject to large uncertainties and therefore have limited validity.

One previous study, by TRL on behalf of Shell (Skippon, Kinnear, Lloyd, & Stannard, 2016), has addressed this issue by measuring the responses and attitudes of Mainstream consumers following direct experience of using a BEV. Results of this study challenged a common assumption that experience of an EV would result in more positive attitudes towards EVs, and therefore a greater likelihood of adoption. The trial found that while attitudes towards EVs were more positive following experience of a BEV, willingness to adopt a BEV reduced. This shows the crucial importance of addressing psychological distance in research on the uptake of EVs. Unfortunately at the time that research was carried out, PHEVs were not yet available in the UK market, so were not included. Thus, there remains no research into the uptake of EVs with mainstream consumers whose psychological distance to both BEVs and PHEVs has been reduced following direct experience of using them.

Previous evidence from the TRL-Shell BEV trials suggests that 36 hours is sufficient to elicit a substantial shift in willingness to consider having a BEV (downwards) and a substantial shift in evaluation of the driving experience and performance of a BEV (upwards) (Lloyd *et al*., 2012; Skippon *et al*., 2016).

The Consumer Uptake Trial will take a unique approach by reducing the psychological distance of a sample of Mainstream consumers by providing them with direct experience of using both BEVs and PHEVs.

2.5 Control of "Hawthorne" effects

All field research is vulnerable to "Hawthorne" effects which can bias findings due to participants changing their behaviours, attitudes or preferences because they are aware that they are being observed, rather than in response to the research stimuli. Observed effect sizes in uncontrolled studies are often substantially larger than those in studies using research designs that control for Hawthorne effects (Graham-Rowe, Skippon, Gardner & Abraham, 2011) because uncontrolled designs measure the sum of two effects (i.e. any effects due to the independent variable *plus* the Hawthorne effect). To yield valid results, research must be designed so as to control for Hawthorne effects. The literature review performed during Stage 1 of this project confirmed that most field trials measuring consumer responses and attitudes to EVs have used uncontrolled designs, thus meaning their findings are likely to be biased.

Because of the potential for Hawthorne effects to bias the findings, the primary value of the Consumer Uptake Trial can only be realised by measuring Mainstream adopter responses in a controlled research study.

2.6 Research questions

The CVEI project aims to model the potential integration of UK aggregated EV charging demand into the wider UK energy system to 2050. The validity of that modelling depends on having a clear picture of the prospective patterns of adoption of both BEVs and PHEVs by mainstream consumers over the coming decades.

Published research on potential adoption of EVs, carried out in the UK and elsewhere, was reviewed in WP2.1 of this project (Kinnear, Anable, Delmonte, Tailor, & Skippon, 2016). The literature review identified substantial weaknesses in previous research that limit the value of the findings as inputs into the CVEI modelling framework. The ETI's previous PiV project developed a set of predictions of BEV and PHEV uptake, grounded in research with mainstream consumers. This remains one of very few studies that has researched the attitudes of mainstream consumers, rather than EV Innovators (see Section 2.1), so its findings represent an important basis for modelling future adoption. It found that mainstream consumers were likely to adopt many more PHEVs than BEVs. However, at the time it was conducted, there were few EVs available in the UK market, and participants were not given direct experience of using either a BEV or a PHEV: thus, they were "psychologically distant" from EVs (see Section 2.2). Skippon, Kinnear, Lloyd, and Stannard (2016) subsequently measured mainstream consumers' responses and attitudes towards BEVs in a rigorous RCT that involved reduction of psychological distance through direct experience of using a BEV. However, their study did not address responses and attitudes towards PHEVs, which the PiV project has suggested are likely to be the most widely adopted category of EV in the decades leading up to 2050.

There is thus a substantial gap in current knowledge, leading to the primary research question for this Consumer Uptake Trial:

> **What will be the rates of adoption of BEVs and PHEVs by Mainstream consumers between 2016 and 2050?**

Clearly, it is not possible to answer this question *directly*, as it is not possible to conduct research with future consumers. However, research can be conducted into the responses and attitudes of today's mainstream consumers to a range of potential future EV configurations, with a range of attributes. The literature review and PiV project have identified a range of EV attributes such as AER, cost, and recharge time, plus external factors such as availability of public charging, as relevant to consumer uptake, and these considerations generate further, more specific research questions to be addressed. Other research questions have been identified in Stage 1 as a result of a stakeholder workshop to discuss the purpose of the trial and desirable outcomes, findings of the Task 2.1 qualitative interviews with EV Innovators, and identification of other knowledge gaps and assumption limitations identified from the analytical tools. Accordingly, the key research questions to be addressed by the Consumer Uptake Trial are:

1. How much does the potential All Electric Range (AER) of a BEV or PHEV influence willingness to consider adoption?
2. How much does the potential purchase cost of a BEV or PHEV influence willingness to consider adoption?

3. How much does the potential running cost saving associated with using a BEV or PHEV influence willingness to consider adoption?
4. How much does the recharge time associated with a BEV or PHEV influence willingness to consider adoption?
5. How much are personal characteristics (personality, innovativeness, liminality, self-congruity, driving style, demographic variables, etc.) predictive of willingness to consider adoption of a BEV or PHEV?
6. How much are personal-situational variables (e.g. income, annual mileage) predictive of willingness to consider adoption of a BEV or PHEV?
7. What effect does varying the perceived level of access to public charging stations (e.g. density, type of location, type of charger) have on willingness to adopt BEVs or PHEVs?
8. What effect does convenient access to public transport options for longer journeys have on willingness to consider adoption of a BEV?
9. What effect does the rate of depreciation of residual value have on willingness to consider adoption of a BEV or PHEV?
10. What effect does access to additional ULEV benefits (e.g. access to bus lanes, free congestion charge, free parking) have on willingness to consider adoption of a BEV or PHEV?
11. What other factors might compensate users for lack of long-range mobility sufficiently for them to consider adoption of a BEV?
12. What effect does convenient access to a long-range vehicle (whether within the household or hired) for longer journeys have on willingness to consider adoption of a BEV?

3 Proposed method

3.1 Experimental design

The proposed Consumer Uptake Trial will utilise a within-participants design, in which a sample of mainstream consumers will be given direct experience of using three types of vehicle, for 48 hours each[3]:

- A Battery Electric Vehicle (BEV);
- A Plug-in Hybrid Electric Vehicle (PHEV), and;
- An Internal Combustion Engine (ICE) vehicle, for control purposes.

The vehicles will be three variants of the Volkswagen (VW) Golf hatchback (see Section 3.4):

- ICE: VW Golf hatchback (1.4 TSI DSG GT Edition 5dr, 2016 model)
- BEV: VW e-Golf hatchback (5dr, 2016 model)
- PHEV: VW Golf GTE hatchback (1.4 TSI 5dr, 2016 model)

The use of three alternative models of VW Golf will minimise the impact of any differences between vehicle types that are associated with vehicle characteristics other than the powertrain configuration.

Experience in the TRL-Shell BEV trial (Skippon *et al.*, 2016) suggests that the majority of participants will make substantial use of the trial vehicles. To ensure that this happens, a number of steps will be taken. Daily vehicle mileage will be assessed through the recruitment screening questionnaire to ensure that potential participants' normal vehicle usage is substantial enough to facilitate a trial experience which sufficiently reduces their psychological distance from EVs.

In addition, participants will be requested to store their own vehicle with the research team for the duration of the trial. This will increase the likelihood that participants will use the trial vehicle for their regular day-to-day journeys. This will also ensure that participants with limited parking space at home will still be able to participate in the trial. Where the household has multiple vehicles, preference will be given to replacing the participant's main vehicle (i.e. the vehicle they usually drive), or the vehicle in the household which is a closest match to the C-segment VW Golf. Participants will be requested to drive each vehicle at least once per day, using the vehicle as a replacement for their normal vehicle, and recharge the BEV and PHEV at least twice[3] each during the trial period.

Replacement of participants' vehicles will encourage participants to gain experience of using and charging the BEV and PHEV during the two day period; this is crucial for reducing psychological distance and allowing robust study of attitudes towards EVs.

[3] Alternative design options regarding the duration of the trial experience are discussed in Section 6. Note that the ETI has confirmed selection of Alternative Design 1. All references to 48 hours / 2 days throughout section 3 should therefore be read as 4 days.

Participants will be asked to complete a series of questionnaires at different time points:

- **Recruitment**: Screening questionnaire to select eligible participants
- **Time point 1**: Before selected participants are provided with Vehicle 1
- **Interim time points**: Between Vehicle 1 and 2, and between Vehicle 2 and 3
- **Time point 2**: After they experience Vehicle 3

Data related to journeys, driving performance, battery state of charge (SOC) and fuel consumption will be collected from vehicle telematics (see Section 3.6).

Upon receipt of completed 'Time point 2' questionnaires at the end of the trial, participants will receive £200 compensation for their participation in the trial. In addition, they will be entered into a prize draw for a chance to win £2,500.

An overview of the trial methodology[3] is provided in Figure 1.

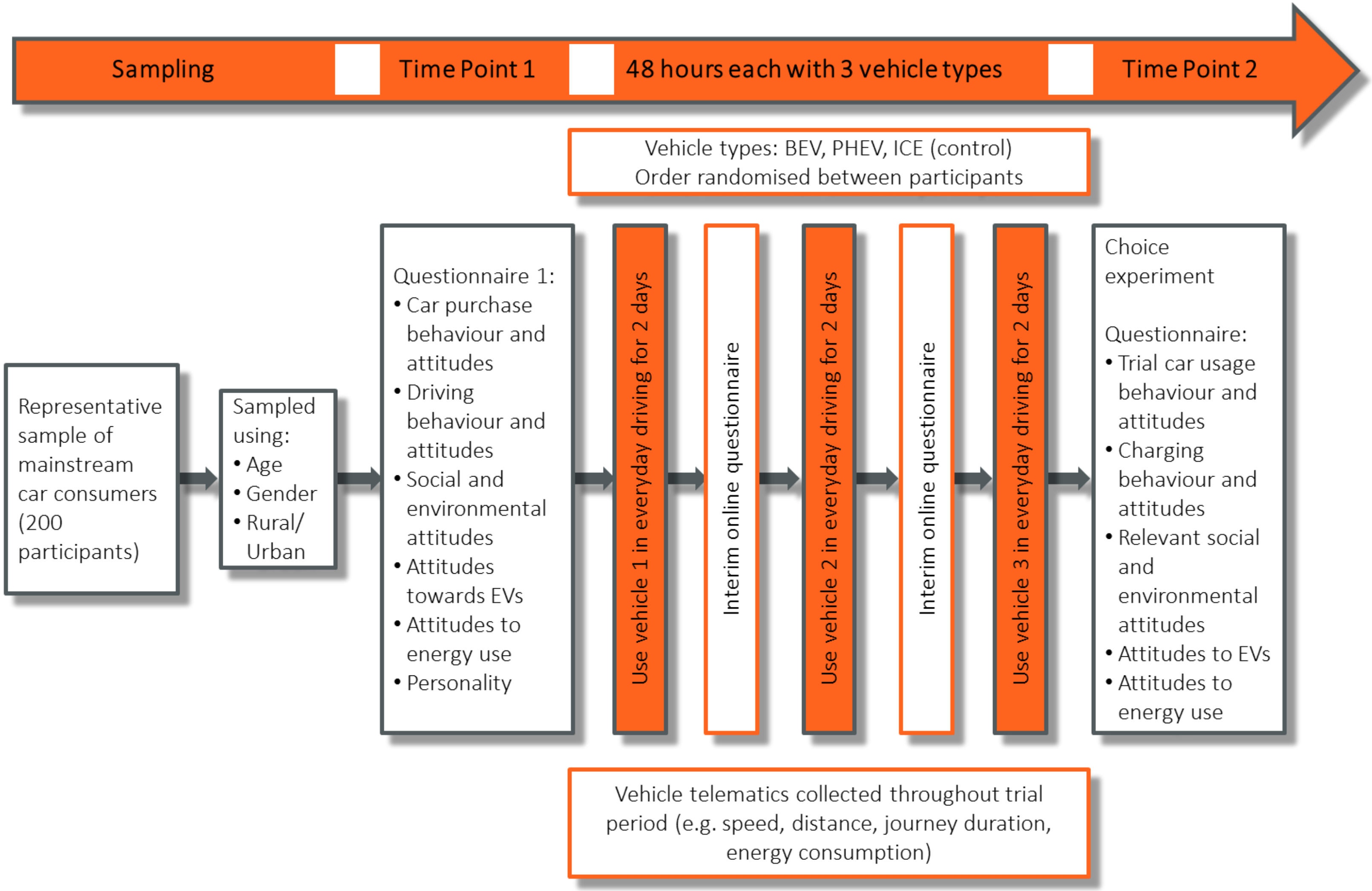


Figure 1: Overview of methodology proposed for Consumer Uptake Trial

3.2 Procedure

3.2.1 Piloting

Data collection and the trial procedure will be piloted ahead of the main trial. The aim of piloting is to identify issues and mitigate potential confounds during data collection, ensuring maximum internal validity during the trial. The piloting process will be as follows:

- In addition to ETI approval prior to application in the trial, all questionnaires and the choice experiment will undergo 'cognitive testing' to ensure that the wording of questions is understandable for participants, that the questions can be answered in a reasonable timeframe, and that the delivery methods are suitable. The principle aim of 'cognitive testing' is to sense check the questions to ensure that wording is clear and free from errors, that comprehension of questions is correct, and that scale and multiple-choice items are logical and appropriate. Participants will be asked to read each question (and their answer) aloud, so that researchers can consider the clarity of the survey wording and the appropriateness of language used. At least five participants will be interviewed upon completion of the survey to gauge their general response (e.g. how long it felt to complete, appropriateness, etc.) and discuss any specific questions that stood out (e.g. that may have caused some confusion or didn't represent their answer). Feedback from the cognitive interviews will be used to refine and update the survey as necessary.
- As part of this process, the survey will be administered online to check for technical errors and ensure the platform works as it is intended. This process and attention to detail is vital to ensure that the final survey design is robust and appropriate for this project and for future application.
- The vehicle telematics data collection system (and post-processing procedure) will be fully tested to ensure that all required data are obtained from the vehicles as expected and to identify any errors.
- The full trial procedure (including questionnaires and telematics) will be piloted with naïve participants. Full pilots will be run at both TRL and Cenex. The pilots will recruit up to three participants at each location and will provide an opportunity to fully test all data collection tools and trial procedures.

Pilot participants will be separate from the main sample as changes to the procedure or materials are to be expected. Where changes are minimal and do not affect the validty of participant responses, these data may also be used in the final analyses. This piloting process will ensure the methodology is fit-for-purpose before starting data collection for the full trial.

3.2.2 Trial locations

The trial will be run from two separate locations in the UK:

- TRL headquarters (Crowthorne House) in Wokingham, Berkshire
- Cenex headquarters in Loughborough, Leicestershire

The use of two locations will allow recruitment of participants from a wider geographical area than if only one location was used; this will increase the representativeness of the participant sample and aid recruitment.

3.2.3 Day-to-day running of the trial

An overview of the trial procedure is provided below:

Recruitment

1. TRL will identify potential participants through use of recruitment databases and a variety of advertising methods (see Section 3.3.2). Participants will be recruited from within a 50-mile radius of either TRL or Cenex headquarters.
2. TRL will screen potential participants, using an online screening questionnaire, to determine eligibility for the trial (see Sections 3.3 and 3.7).
3. TRL will invite eligible participants to take part in the trial.
4. TRL will provide participants who agree to take part with an online trial information pack and consent form so that informed consent can be obtained. All communication materials will be approved by the ETI before use.
5. TRL will assign each participant who consents to take part with a unique reference number.

Electrical safety check and installation of dedicated circuit

6. If the participant's household does not meet the required minimum safety standards for Mode 2 charging (see Section 3.5)[4], in order for participant to proceed with the trial they will be required to consent to installation of a new EV-appropriate 3-PIN socket on dedicated RCD-protected circuit to enable safe Mode 2 charging. Installation work will be completed by a TRL-approved electrical contractor.
7. TRL will obtain evidence from the Contractor that appropriate measures have been implemented to allow safe Mode 2 charging (i.e. via a dedicated RCD-protected circuit).

Time point 1 questionnaires

8. Upon receipt of evidence confirming electrical safety compliance, TRL will ask participants to complete the 'Time point 1' online questionnaires, quoting their unique reference number so that responses can be identified.
9. TRL will randomly assign participants to one of six groups which will determine the order in which they experience the three vehicles (see Table 2).
10. TRL will assign each participant to a dedicated Trial Manager (at either TRL or Cenex as appropriate) to arrange the collection and return of vehicles.

[4] It is expected that the majority of households will NOT have a pre-existing dedicated charging circuit and socket, and these will therefore be installed in most households.

Vehicle 1

11. The Trial Manager will arrange the date and time for collection and return of Vehicle 1 from the trial headquarters (TRL or CENEX).
12. Participants will collect Vehicle 1 from trial headquarters at the date and time specified. BEVs and PHEVs will be charged to at least 80% maximum state of charge (SOC) on collection. The Trial Manager will take the participant through the vehicle handover process (see Section 3.2.5).
13. The Trial Manager will log the date and time of collection, the Participant ID and the Vehicle ID.
14. Participants will use the vehicle during their normal day-to-day activities for a period of two[3] days.
15. Participants will return Vehicle 1 to trial headquarters at the end of the two-day[3] period and complete an interim online vehicle assessment questionnaire.
16. The Trial Manager will log the date and time of return, the Participant ID and the Vehicle ID.
17. The Trial Manager will complete a vehicle 'walk-around' to record the condition of the vehicle.

Vehicle 2

18. Participants will collect Vehicle 2 from trial headquarters. BEVs and PHEVs will be charged to at least 80% maximum SOC on collection. The Trial Manager will take the participant through the vehicle handover process.
19. The Trial Manager will log the date and time of collection, the Participant ID and the Vehicle ID.
20. Participants will use the vehicle during their normal day-to-day activities for a period of two[3] days.
21. Participants will return Vehicle 2 to trial headquarters at the end of the two-day[3] period and complete an interim online vehicle assessment questionnaire.
22. The Trial Manager will log the date and time of return, the Participant ID and the Vehicle ID.
23. The Trial Manager will complete a vehicle 'walk-around' to record the condition of the vehicle.

Vehicle 3

24. Participants will collect Vehicle 3 from trial headquarters. BEVs and PHEVs will be charged to at least 80% maximum SOC on collection. The Trial Manager will take the participant through the vehicle handover process.
25. The Trial Manager will log the date and time of collection, the Participant ID and the Vehicle ID.
26. Participants will use the vehicle during their normal day-to-day activities for a period of two[3] days.

27. Participants will return Vehicle 3 to trial headquarters at the end of the two-day[3] period and complete an interim online vehicle assessment.
28. The Trial Manager will log the date and time of collection, the Participant ID and the Vehicle ID.
29. The Trial Manager will complete a vehicle 'walk-around' to record the condition of the vehicle.

Time point 2 questionnaires and trial end

30. The Trial Manager will ask participants (via email) to complete the 'Time point 2' online questionnaire (approximately 24 hours after return of Vehicle 3).
31. TRL will remunerate participants for their involvement in the trial upon completion of the final questionnaire.

This trial procedure will be standardised to minimise any potential bias resulting from differences in vehicle handovers between the two locations (TRL and Cenex).

All staff will receive identical training on the trial procedure to ensure that it is fully understood before the trial commences.

3.2.4 Research team training

TRL will run a training workshop with TRL and Cenex staff prior to the trial commencing to ensure that all staff involved in the trial procedure are fully briefed. This will include specific training on the vehicles from VW representatives.

At the start of the trial, the TRL Trial Manager will attend the first few trial days at Cenex to ensure consistency across the two trial locations.

3.2.5 Vehicle handover process

The vehicle handover process will include a 'walk-around' of the vehicle to check for scratches and dents, an explanation of how to use key instruments (e.g. lights, climate control, etc.), a demonstration of charging (PHEV and BEV only), a briefing on the materials in the vehicle information pack, and a short familiarisation drive with the Trial Manager. Specific tasks will include:

- Ensuring the interior and exterior of vehicles are clean and tidy before participant collection (a professional valet service will be utilised to ensure all vehicles are fit for purpose before being given to participants).
- Ensuring BEV and PHEV vehicles have a minimum of 80% charge. It is desirable for all BEVs and PHEVs to have 100% charge at participant collection but this may not be possible in some circumstances depending on the time available and level of charge on previous participant return.

- Fully briefing participants on the vehicle, including providing them with information on the official stated range and the likely range when operating the BEV and PHEV under various driving conditions (e.g. urban driving vs. motorway driving)[5].
- Performing routine safety and maintenance checks on the vehicles to ensure the vehicles are safe and fit for purpose, i.e. F-L-O-W-E-R:
    - **Fuel**: Check fuel/charge levels.
    - **Lights**: Clean all exterior lights and check they are working.
    - **Oil**: Check oil and other fluid levels (as appropriate).
    - **Water**: Check coolant and windscreen washer levels.
    - **Electrics**: Check for highlighted warning signs on vehicle ignition.
    - **Rubber**: Check tyre pressure and tyre condition.

3.3 Trial Participants

The statistical power of a research design reflects its capacity to avoid Type I and Type II errors[6]. Statistical power depends on the sample size, anticipated effect size, and required criterion for statistical significance.

The design of this Consumer Uptake Trial was informed by sample power calculations using data obtained in the previous TRL-Shell BEV uptake trial (Lloyd, Kinnear, Stannard, Scoons, Delmonte & Hutchins, 2012; Skippon, *et al*., 2016). In the TRL-Shell BEV uptake trial 200 experimental group participants experienced use of a Nissan Leaf BEV for 36 hours, while 200 control group participants experienced use of an equivalent unfamiliar ICE car (Ford Focus diesel) for 36 hours.

The Consumer Uptake Trial will adopt a different experimental design to the TRL-Shell BEV trial because participants must be given direct experience of both a BEV and a PHEV, and, to control for Hawthorne effects (see Section 2.5) an equivalent unfamiliar ICE car. Accordingly a within-participants design is proposed, rather than the between-participants design used by Lloyd *et al*. (2012). On the basis of this design and the sample power calculations using data from Lloyd *et al*. (2012), it is proposed to target a sample of 200 Mainstream consumers (excluding pilot participants). For the purpose of this trial "Mainstream consumers" will be represented by a sample of the driving population of Great Britain limited by specific qualifying conditions (e.g. non-adopters of EVs).

Based on the size of effect and variability observed in the study (Lloyd et al., 2012), it is estimated that a sample size of 200 should enable, for example, a 3km difference in average journey distance between ICEs, BEVs and PHEVs to be detected as statistically significant.

[5] This will be also included in the information pack provided to participants which will provide general advice on factors that can affect range like acceleration, weather etc.

[6] In statistical hypothesis testing, a type I error is the incorrect rejection of a true null hypothesis (a "false positive"), while a type II error is incorrectly retaining a false null hypothesis (a "false negative")

Reducing sample size below this would mean that larger differences would be required to reach statistical significance and this could pose a threat to the validity of the trial.

To ensure that the sample is representative of this population, the 200 participants will be stratified according to driving licence, population and travel data from the National Travel Survey (NTS) and the Office of National Statistics (ONS). The key metrics which have been used for this stratification process are age, gender and the resident area (i.e. rural or urban[7]).

Recruiting a sample of 200 mainstream consumers will ensure:

- **The sample is sufficiently large to provide robust statistical power**
- **The sample is representative of the typical characteristics of drivers in Great Britain, avoiding the biases commonly associated with EV research which has traditionally recruited Innovators only**
- **The sample is sufficiently large to provide an adequate data set for the Choice Experiment**
- **The sample is sufficiently large to perform a segmentation analysis**

The resulting target sample matrix is shown in Table 1.

Table 1: Target sample matrix[8]

Resident area	Age group[9]	Gender		Total
		Male	Female	
Rural	19-29	2	2	**4**
	30-49	6	6	**12**
	50+	12	11	**23**
Urban	19-29	14	12	**26**
	30-49	34	30	**64**
	50+	39	32	**71**
Total		**107**	**93**	**200**

To control for order effects, participants will be randomly allocated to one of six groups which will determine the order in which they experience the vehicle types (Table 2). The trial will also be scheduled so as to balance the experiences of each of the vehicle types across weekdays and weekend days. In other words, an equal number of participants will experience the BEV on a weekend as those who experience it on weekdays; likewise for the PHEV and ICE.

[7] The ONS defines urban areas as 'settlements of more than 10,000 people' and rural areas as 'smaller towns (less than 10,000 people), villages, hamlets or isolated dwellings '(Defra Rural Statistics, May 2015).

[8] It has been suggested that consideration is given to increasing the proportion of younger participants in the sample. The impact on external validity of doing this will be explored at the start of Stage 2.

[9] 17-18 year olds will be excluded to mitigate increased crash risk associated with young and novice drivers.

Table 2: Counterbalancing for vehicle order effects

Group	Vehicle 1	Vehicle 2	Vehicle 3	Number of participants
1	ICE	BEV	PHEV	34
2	PHEV	ICE	BEV	33
3	BEV	PHEV	ICE	33
4	ICE	PHEV	BEV	34
5	BEV	ICE	PHEV	33
6	PHEV	BEV	ICE	33
			Total	**200**

The randomisation of participants into experimental groups and counterbalancing in the trial schedule will ensure that the trial data are not biased by order effects or differences between weekend and weekday experiences.

3.3.1 Recruitment criteria

A recruitment screening questionnaire will be administered to prospective participants in order to check their eligibility for the trial. The key eligibility criteria which participants must meet will be as follows:

- Full UK driving licence with fewer than 5 points, held for a minimum of two years[10].
- Currently owns and regularly drives an ICE car[11]. Where possible, preference will be given to recruits currently using a C-segment medium family hatchback, followed by those who self-report that a C-segment car will meet their functional needs.
- Live within ~50 miles of TRL or Cenex.
- Able to charge an EV during the trial (e.g. at home, work or in public location).
- Must not have had a plug-in or alternatively fuelled car (e.g. LPG, CNG) in the household in the last five years.

The screening questionnaire will also be used to obtain information relevant to the stratified sampling approach, and other key demographics which will be used to understand more detailed characteristics of the final participant sample:

- Age
- Gender
- Rurality (urban or rural) (obtained via home postcode)

[10] Terms subject to final agreement and acceptance by AVIVA insurance

[11] Ownership to include all forms (e.g. outright, lease, hire-purchase, personal contract purchase, user-chooser company car)

- Annual mileage
- Number of cars in household
- Current domestic energy supplier and tariff

Use of the recruitment screening questionnaire will ensure that:

- **The final sample of participants matches as far as practicable the target stratification matrix described in Table 1.**
- **The sample is not biased by potential confounding factors identified during Stage 1 (such as the use of solar panels, Economy 7 energy tariffs, or previous recent experience with ULEVs)**

3.3.2 Recruitment strategy

Recruitment adverts will be used to promote the study in the target geographical locations (i.e. Wokingham, Loughborough and surrounding areas). The adverts will provide a URL to direct interested individuals to an online screening survey.

Adverts will be distributed via several media:

- **TRL's participant database**:

  A database containing over 2,000 members of the public, local to TRL, who have registered to take part in research.

- **Social networking**:

  Use of LinkedIn, Facebook and Twitter to target adverts by location, age and gender.

- **Company websites**:

  Large businesses local to TRL and Cenex will be asked to disseminate details of the study amongst their staff.

- **Local newspapers**:

  Publication of adverts in print and online newspapers.

- **Local noticeboards and forums**:

  Publication of adverts in supermarkets, community centres, local online forums, etc.

- **Word of mouth**:

  Participants will be asked to inform friends and family of the trial. Participants will be limited to one per household, but otherwise, friends and family of current or previous participants will be permitted to take part (assuming they fall within the recruitment criteria listed in Section 3.3.1).

This varied approach has been developed by TRL over many years of experience in recruiting large samples of participants for research trials. Use of a variety of methods will

maximise the opportunity to target and secure the required participant sample, whilst minimising self-selection bias as far as possible.

3.4 Vehicles

A market analysis of BEVs and PHEVs currently available in the UK was performed to identify possible vehicles for the trial.

B- and C-segment vehicles account for approximately 35% and 25% of the UK vehicle fleet, respectively (Society of Motor Manufacturers and Traders [SMMT], 2016). As such, focus was given to developing a shortlist of B and C-segment BEVs and PHEVs currently available in the UK market (as of April 2016). This shortlist is summarised in Table 3.

Table 3: B- and C-segment BEVs and PHEVs[12] in the UK market (April 2016).

Make	Model	Base variant	Segment	Electric range (miles)	List price (£)
Plug-in Hybrid Electric Vehicles (PHEVs)					
Audi	A3	Sportback e-tron 1.4 TFSI 150PS S Tronic	C	31	35,690
Volkswagen	Golf	1.4 TSI GTE DSG	C	31	33,995
Battery Electric Vehicles (BEVs)					
BMW	i3	127kW Auto	B	118	30,980
Ford	Focus	107kW Auto	C	100	31,145
Kia	Soul	EV 81.4kW Auto	B	132	29,995
Mercedes-Benz	B-Class	Electric Drive B250 eSport Auto	C	124	32,275
Nissan	Leaf	Visia 24kWh Auto	C	124	25,790
Renault	Zoe	Expression Nav 65kW Auto	B	149	18,445
Volkswagen	Golf	e-Golf 85kW Auto	C	118	31,650

The key difference between the three vehicle types (BEV, PHEV, ICE) is in the powertrain configurations. Any other differences, e.g. in trim levels, liquid fuel used (ICE and PHEV) or performance, could potentially confound the trial. Accordingly, it is desirable that the three vehicles be matched as closely as possible in all respects other than powertrain configuration.

The market analysis identified eight models of BEV and two models of PHEV (with an electric range of at least 50km) which are currently available in the UK and are classified as either B-

[12] PHEVs were limited to those with at least 50km of electric range.

or C-segment vehicles (as shown in Table 3). The two models of PHEV are C-segment, therefore in order to ensure the study offers a comparable experience across vehicle types, it is also necessary for the ICE and BEV to be C-segment.

The VW Golf is the only vehicle to offer comparable models of BEV, gasoline PHEV, and gasoline ICE. Accordingly, this vehicle represents the most appropriate vehicle selection. Other choices would compromise the internal validity of the trial by introducing a confounding variable (vehicle model).

The number and type of vehicles required for the trial is shown in Table 4[13].

Table 4: Number and type of vehicles required for consumer uptake trial

Vehicle type	Number required
BEV (VW e-Golf)	8
PHEV (VW Golf GTE)	8
ICE (VW Golf 1.4 TSI DSG)	8
Total	**24**

OEM-provided statistics regarding the range and charging specifications of the VW e-Golf and VW Golf GTE are summarised in Table 5 below:

Table 5: OEM-statistics on BEV and PHEV range and charging specifications

Range / charging specification	Golf GTE	e-Golf
Maximum range (miles)	31	118
Expected range (miles)	25	90
Charge time from 0-100% (AC) 2.3kW (hours)	3.75	13
Charge time from 0-100% (AC) 3.6kW (hours)	2.25	8
Charge time from 0-80% (DC) (hours)	n/a	0.5

Previous trials have used different vehicle makes and models for control (ICE) and experimental (PHEV/BEV) conditions. This was largely driven by market availability at the time of the trials; nevertheless consumer feedback may have been influenced by differences between vehicle types other than the drivetrain. Using identical models of vehicle that differ only by drivetrain removes the possibility of these potential confounding influences.

[13] Alternative design options regarding the duration of the trial experience are discussed in Section 6. Note that the ETI has confirmed selection of Alternative Design 1, whilst retaining overall uptake trial duration. Consequently the number of vehicles is increased from 24 to 36 (being 12 of each type).

3.5 Vehicle charging

When experiencing the BEV and PHEV, participants will be asked to charge the vehicle (at home or at public chargepoints) at least twice during their time with each vehicle.

For long-term use of plug-in vehicles, Mode 3 charging (involving the use of a dedicated EV charging station with its own circuit) is ordinarily the recommended method for domestic charging. However, given the time, cost and practical constraints of this short-term trial, it was necessary to assess whether use of Mode 2 charging would be a suitable alternative charging solution for use in this trial. Mode 2 charging involves the use of a dedicated charging cable equipped with a residual current device (RCD) that can be connected to a domestic ring main socket, and which is suitable for occasional use. Cables suitable for Mode 2 charging are commonly supplied with vehicles sold in the UK, and available separately as spares from car dealerships, EVSE outlets and other stores.

Safety is of paramount importance. A risk assessment was conducted to identify the relative risks of Mode 2 charging compared with Mode 3 charging, and establish whether Mode 2 charging could be used safely. The full details of this risk assessment can be found in Appendix A.

The findings from this risk assessment support the safe use of Mode 2 charging in the Consumer Uptake Trial. There was no evidence identified to suggest that the use of Mode 2 charging instead of Mode 3 charging would increase risks to an intolerable level. However, to ensure that any residual risks associated with Mode 2 charging are reduced ALARP, the following steps are recommended:

1. The trial participant will be asked whether they would be willing for the Mode 2 charging socket to be installed for the purposes of the trial. If the trial participant is not willing to accept this or if the arrangements are not suitable then the trial participant will not be allowed to continue with the trial. 200 trial participants will be recruited for the trial;
2. Participation in the Consumer Charging Trials will require an initial survey of trial participants' homes to understand if premises are suitable for chargepoint installation.

   Remote surveys (for screening purposes) will predominantly be used, with trial participants asked to take photographs and respond to specific questions about their property. Participants will not be required to examine any electrical equipment in detail and this will only be asked of a trial participant if it does not expose them to unnecessary risks, such as working at height. Alternatively, if there is a risk to participants or they feel unable to do this, approved contractors will visit trial participants' premises to carry out those activities in person.
3. Regardless of whether a trial participant carries out an initial screening survey, chargepoint installation will only take place after a survey has been carried out by a qualified electrician to make sure that the chargepoint can be safely installed and integrated into the domestic wiring system. This survey will be undertaken as part of the installation process alongside the site specific risk assessment. Electricians carrying out the surveys will be competent and trained up to 17th Edition of the UK wiring regulations.

4. Participants will only be allowed to take part in the trial upon satisfactory certification from the TRL-appointed electrical contractor that the necessary electrical installation has been completed and is fit for the purpose of the trial.

In addition to the above mitigating steps, all trial participants will be provided with a concise guide on plug-in vehicle charging that clearly describes relevant safety considerations and good practice, such as prohibited use of extension cables (to be approved by the ETI). The contents of this guide will be fully explained during the vehicle handover process. All participants will be asked to sign a form to indicate that they have read and understood the recommendations for safe use of Mode 2 charging equipment during the trial.

3.5.1 Public charging

To encourage participant use of the trial vehicles and provide a representative experience of EV ownership, participants will be given access to a public charging scheme in the relevant trial areas (TRL or Cenex).

The schemes that are in use in these areas are:

- **Chargemaster Polar Plus:** a membership-based scheme with a flat monthly charge, giving access to over 4000 chargepoints across the country. The majority of these chargepoints are free to use; some charge about 9p/kWh.
- **Chargemaster Polar Instant:** a Pay-As-You-Go system, managed and operated through a smartphone app. Users are required to register and load their account with a minimum of £20 credit. They can then access Polar network chargepoints for a fee of £1.20 per use, plus any electricity costs.
- **Charge Your Car:** a Pay-As-You-Go network accessible either through a £20 swipe card or a smartphone app (for free), providing access to over 2000 chargepoints, as well as a number of regional networks. These include a mixture of free-to-use and priced chargepoints.
- **Ecotricity Electric Highway:** free-to-use chargepoints managed by Ecotricity along the motorway network, mainly at motorway service areas. Access requires a swipe card which is provided free upon registration.

Both the Chargemaster options, and the Charge Your Car option, offer coverage in the two geographical areas in which the trials will be run. The Ecotricity network offers easy to locate charging options if participants choose to travel longer distances or regularly use the motorway network.

The schemes to be provided to participants during the trial will be determined at the start of Stage 2 based on an assessment of geographical coverage, administrative impact on the trial and support offered by scheme providers.

3.5.2 Access to VW, or other, apps

In order to ensure that the experience of using and charging the vehicle during the trial is representative of normal EV ownership, participants will be free to utilise the VW Car-Net mobile phone application, or other third-party applications, if they wish to do so. Items will be included in the Time point 2 questionnaires to ask participants about which apps they used, if any, and what their experience was like.

3.6 Vehicle data

A vehicle telematics system will be used to collect vehicle data from the Controller Area Network (CAN) bus via the on-board diagnosis (OBD) port. It is proposed that the following core data are collected:

Table 6: Core telematics dataset

Field	Description
Journey start date & time	Date and time of start of journey (i.e. ignition on)
Journey end date & time	Date and time of end of journey (i.e. ignition off)
Max speed (km/h, or mph)	Maximum speed reached during journey
Journey start mileage	Odometer reading at start of journey
Journey end mileage	Odometer reading at end of journey
Journey distance (km, or miles)	Total journey distance
Journey start SOC (%)	Battery State of Charge (SOC) at start of journey
Journey end SOC (%)	Battery SOC at end of journey
Energy consumed during journey (kWh)	Amount of energy used by vehicle during journey
Journey start liquid fuel level (%, or litres)	Liquid fuel level (petrol) at start of journey - PHEV and ICE only
Journey end liquid fuel level (% or litres)	Liquid fuel level (petrol) at end of journey - PHEV and ICE only
GPS coordinates	Lat / Long, OSGR or .shp or .tab file

Analysis of these data will enable:

- **Understanding of vehicle usage patterns**
- **Comparison of vehicle usage and driving behaviour between the three vehicle types (ICE, BEV, PHEV)**

These vehicle data will be collected via one of two methods:

- Integration with VW on-board telematics system
- Installation of third-party OBD ‘dongle’

The former option is the preferred route as it will enable direct collaboration with and support from the vehicle OEM. In the event that the required data are not available from the VW on-board telematics system, a third-party telematics solution specialist (such as FleetCarma) will be contracted to extract data from the vehicle CAN Bus via the OBD port.

The availability of all vehicle data, and the method of extraction, will be confirmed during the preparation phase of Stage 2.

3.6.1 Vehicle telematics

Vehicle telematics data will be collected either directly from the vehicle through the OEM's telematics system (which communicates with the automotive manufacturer's network system) or through a third-party 'dongle' that is attached to the vehicle's OBD port.

If the data are collected from the automotive manufacturer's network system, then no additional hardware will be required. The following requirements shall be met:

- Data must be downloadable on a regular basis (to be defined during the preparation phase of Stage 2)
- Data must be collected and transmitted even when the vehicle ignition is off and the vehicle is charging
- Data transmitted to the vehicle manufacturer's network must be accessible via a well-defined API which allows periodic polling of data from the CPMS.

If an OBD dongle is used, the device shall have the following capabilities:

- Conforming to published OBD-II (USA) or EOBD (European) standards
- Conforming to SAE J1962 (specification for type A and/or type B connector), SAE J1850 (serial communication protocol), J1978 (minimum operating standards), or their ISO equivalent standards
- Powered from the vehicle system with minimal electrical draw
- On-board battery backup
- Capable of functioning even when the vehicle ignition is off
- Capable of collecting all of the data outlined in Section 3.6
- Capable of communication to a data collection system in real time through a cellular connection
- Small enough to fit within the vehicle without obstructing driver interaction or vehicle operation
- Connected to a network system which is accessible by the CPMS via a well-defined API which allows periodic polling of vehicle data

3.7 Questionnaires

In addition to vehicle telematics data, information on participant demographics, vehicle ownership, personality, and attitudes will be collected from questionnaires. Four sets of questionnaires will be developed for use in the trial. These will be administered at five distinct time points during the trial, as illustrated in Table 7.

The purpose of these questionnaires is as follows:

- **Recruitment questionnaires:**
    - To determine the eligibility of prospective participants to take part in the trial (see recruitment screening, Section 3.3.1).
    - Questionnaire will include a number of items relating to the demographics of participants, including age, gender, postcode, education, marital status and income, as well as questions related to vehicle use, parking availability and travel patterns.
- **Segmentation and personality questionnaires:**
    - To understand the characteristics of the sample population, including how they fit into consumer segments investigated in previous research (e.g. Anable *et al*., 2011; Lloyd *et al.,* 2012; DfT, 2016b) and currently in use within ECCo.
    - This will include the Multi-Dimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari, Mikulincer, & Gillath, 2004), a measure of personality such as the IPIP-NEO personality inventory (Costa & McCrae, 1992), and a set of questions on previous vehicle ownership, personal travel and attitudes to new technology.
- **Attitudinal questionnaires:**
    - To understand participants' attitudes towards EVs, ICE vehicles, their likely uptake of EVs in the future, and how these attitudes change following direct experience with the vehicles in this trial.
    - This questionnaire set will include items related to attitudes towards driving and the environment, for example, using the 20-item Attitudes to Driving and the Environment Inventory (Schuitema, Anable, Skippon & Kinnear, 2013), instrumental, symbolic and affective attitudes to EVs, attitudes towards associated behaviours such as recharging and likelihood to choose an EV in future.
- **Evaluation of vehicle performance:**
    - To understand participants' ratings of the performance and driving experience associated with each vehicle experienced during the trial.
    - This questionnaire set will include items related to acceleration, responsiveness, smoothness, noise, comfort, safety, enjoyment and overall performance, measured using the CR-10 Category-Ratio scales developed by Borg (1998); Skippon, 2014).

Table 7: Administration of participant questionnaires.

Questionnaire set	Recruitment screening	Time point 1 (before vehicles received)	Interim data collection point 1	Interim data collection point 2	Time point 2 (after vehicles returned)
Recruitment questionnaires: - **Participant demographics, vehicle use and parking availability at home**	✓				
Segmentation questionnaires: - **MDSI, vehicle ownership and use, personal travel and attitudes to new technology**		✓			
Attitudinal questionnaires: - **Attitudes towards EVs, ICE vehicles and likelihood to purchase EVs**		✓	✓ **Core Qs only**	✓ **Core Qs only**	✓
Evaluation of vehicle performance: - **Borg Category-ratio scales of vehicle acceleration, responsiveness, comfort, noise**			✓	✓	✓

3.8 Choice experiment

The preferred way to assess consumer choice between alternative vehicle options is through a choice experiment. This methodology involves presenting participants with a series of choices between options that enable exploration of the way that choice is influenced by a range of attributes. To date the best available choice experiment data related to uptake of EVs in the UK has come from the ETI PiV project and subsequent update work for ECCo carried out by Element Energy (EE). However in both cases, participants were psychologically distant from BEVs and PHEVs.

The choice experiment for this Consumer Uptake Trial will build on recent work conducted for DfT (DfT, 2016b), taking advantage of the increased BEV/PHEV awareness and reduced psychological distance of the trial participants to increase the validity of the modelling of consumer choice in ECCo. The primary research questions to be addressed by the choice experiment are as follows:

1. What is the relative attractiveness of ICEs, PHEVs and BEVs (and hence their likely uptake) among mainstream consumers who have exposure to these vehicles?
2. What are mainstream consumers' attitudes to different aspects of ULEVs (e.g. performance, cost, infrastructure availability) once they have real-world experience?
3. How are these choices affected by different purchase models (e.g. lease versus outright purchase)?
4. What are the impacts of ULEV policies on choice (e.g. interventions relative to the narratives such as incentives, access restrictions)?

EE will follow the process below for designing and implementing the choice experiment:

- Propose an initial set of 'attributes' to be tested in the choice experiment, reflecting the data needed by ECCo, evidence from the literature and the content of the wider questionnaires being administered in the trial. This will be based on knowledge from EE's previous choice experiments and the latest UK and international evidence from customer choice experiments. ETI approval of the proposed attribute set will be sought.
- Generate the choice experiment design, with individual choice questions and blocks to be provided to participants.
- Pilot the choice experiment. A short cognitive testing phase will ensure the questions are properly understood by trial participants. ETI approval will be sought for the finalised questionnaire.
- Deploy the choice experiment online. The choice experiment will be deployed to all participants following their exposure to the three trial vehicles.

The choice experiment analysis will be carried out using the NLogit software, which ensures that the resulting coefficients are fully compatible with the ECCo model. EE will generate choice coefficients for each of the attributes as well as expressing each one as an equivalent 'willingness to pay' value for ease of understanding in the reporting. Although the sample size is not sufficient to allow a full segmentation model to be developed, a high level 'mapping' of the new results to the different customer groups in ECCo will be conducted through comparison of consumers' profiles (e.g. attitudinal and demographic factors).

The primary output of the Consumer Uptake Trial will be a new set of consumer choice coefficients - based on a choice experiment carried out with mainstream consumers whose psychological distance from PHEVs and BEVs has been reduced by direct experience of them.

3.9 Data management

All data storage and handling will be performed in accordance with the International Standard for Information Security Management System (ISO 27001:2013). Full details about TRL's data privacy management policies and procedures are provided in Part 1 (Overview of Stage 2).

An overview of the key types of data which will be collected, along with the roles and responsibilities for cleaning, processing and analysis, is provided in Figure 2.

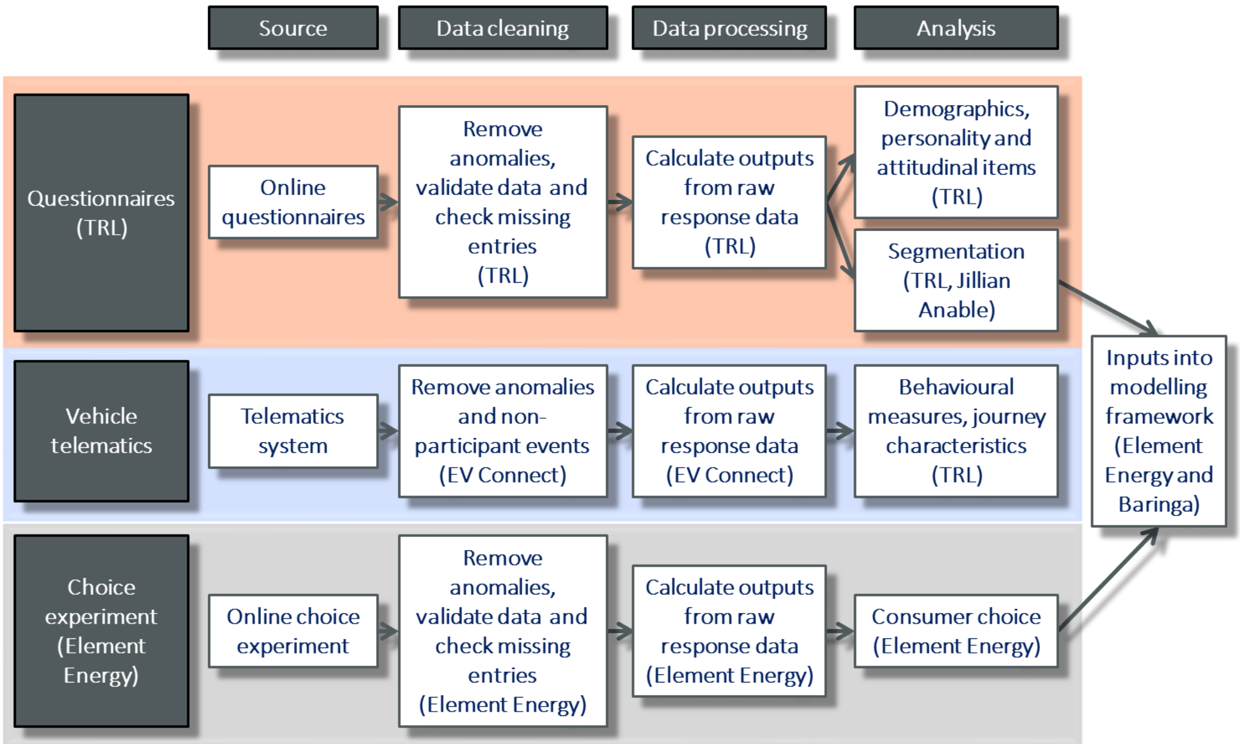


Figure 2: Overview of data management roles and responsibilities

On completion of the first recruitment survey, all participants will be assigned a Participant ID. All subsequent data collected will be linked to the Participant ID, rather than a participant's name or other personal details, in order to anonymise data. Where possible, all questionnaires will be administered to participants electronically via an online survey tool (such as 'SmartSurvey' or 'Survey Monkey'). Questionnaire data will be saved on the secure server of the survey tool, before being transferred onto secure TRL servers for cleaning, processing and analysis.

Vehicle telematics data will be remotely accessed by EV Connect via vehicle data loggers connected to the OBD link and saved on secure SQL servers. Vehicle telematics data will be linked to a Participant ID, not the name or other personal details of a participant. EV Connect will provide a cleaned and processed dataset, linked to participants' unique reference numbers, to TRL for subsequent analysis. Data cleaning and processing will ensure:

- Data are fully anonymised, with names and/or other types of personally identifiable information converted to unidentifiable user ID numbers.
- Data are filtered to remove non-participant events. These will be identified by removing very short trips (e.g. less than 0.1 miles in distance).
    - Examples of such could include events during which the driver turns on the vehicle, and then quickly turns off the vehicle to go and retrieve some forgotten item at home or office. This would also include periods when the research team operate the vehicles in between participant handover days at TRL or Cenex headquarters.

The choice experiment will be hosted and administered by a third-party online survey tool (to be confirmed during the preparation phase of Stage 2). EE will clean and process the raw data before undertaking the required consumer choice analyses.

Outputs from the segmentation analysis and consumer choice analysis will be fed into the modelling framework by Baringa and EE.

4 Analysis and reporting

4.1 Introduction

A number of statistical techniques will be used to analyse the data collected in this trial. An overview of these techniques is provided below.

4.2 Factor analysis

The questionnaire data will contain responses to numerous attitudinal items which aim to measure participants' attitudes and changes in attitudes towards EVs following their experience in the trial. Factor analysis, a powerful 'data reduction' technique, will be used to combine information from this large set of similar variables into a smaller set of factors.

This technique will be used to identify common factors within the multi-item attitudinal scales to allow comparison between attitudes before and after experience of each of the three vehicle types.

4.3 Statistical comparisons

Comparison of the factors will be conducted using repeated-measures statistical methods[14]. This will enable identification of differences in attitudes before and after experience of the three vehicles. Similar analyses will also be performed to identify differences in travel behaviour (e.g. average journey distance, or average speed) between each vehicle type.

These repeated-measures techniques will include (but may not be limited to):

- Analysis of Variance (ANOVA) or Generalised Estimating Equations (GEE)
- Paired t-tests or Wilcoxon matched-pairs tests
- Cochran's Q or the McNemar dichotomous variables test

As described in Section 3.3, the order in which participants receive the vehicles will be randomised. This will enable a sensitivity analysis to be performed using the 'Time point 1' and 'Interim 1' questionnaire responses from participants in Group 1 and Group 4 (who will receive the ICE vehicle first).

Any statistical differences in attitudes identified between these two time points will provide indication that participation in the trial alone is sufficient to result in a change in attitudes (a "Hawthorne" effect), regardless of whether or not that participation includes experience with an EV. In the event that this effect is observed, statistical techniques will be used to control for this bias.

[14] 'Within-subjects' or 'repeated measures' analysis is required since participants' attitudes and behaviours are measured at multiple time points.

Experienced statisticians will select the most appropriate statistical techniques for analysis of the various datasets collected during this trial. The techniques selected will depend on the characteristics of the data obtained. For example, parametric statistical tests such as ANOVA or t-test rely on underlying assumptions about the distribution of the data; tests will be performed to check these assumptions before analysis is carried out.

4.4 Segmentation

Anable *et al*. (2011) segmented consumers into groups according to their likelihood to adopt BEVs or PHEVs and their attitudes towards these vehicle types. Segmentation analysis of this kind allows identification of the demographic, attitudinal and behavioural characteristics of different groups in the population.

The previous segmentation by Anable *et al*. (2011) was based on responses to a large number of questions from drivers who had acquired new or nearly-new cars within the previous five years. The analysis resulted in the identification of eight segments:

- **Plug-in Pioneers**: excited about plug-in technology and optimistic about its suitability to their lifestyle and their image
- **Zealous Optimists**: highly enthusiastic and optimistic about the technology, including the driving experience
- **Willing Pragmatists**: extremely polarised in their opinions – being very enthusiastic about PHEVs and virtually the most pessimistic of all groups about BEVs
- **Anxious Aspirers**: enthusiastic about the technology and would be proud to own an EV, but have some of the greatest reservations about range, safety and reliability
- **Uninspired Followers**: unengaged with and/or lack knowledge about the technology
- **Conventional Sceptics**: very negative about all the functional aspects of EVs and do not believe EVs would suit their lifestyle or that they would find it easy to charge at home
- **Image-conscious Rejecters**: extremely negative about all aspects and do not believe that they associate with the type of people who own EVs
- **Company Car Drivers**[15]**:** have some concerns about performance, range, reliability and image of EVs, they are relatively open to the idea of plug-in vehicles, particularly as a second car.

In the TRL-Shell BEV trial (Lloyd *et al*., 2012; Skippon *et al*., 2016), a similar segmentation technique was employed using a subset of questionnaire items previously used by Anable *et al*. (2011). These “golden questions” were selected because they were found to be the most

[15] Participants who indicated that their ‘main car’ (the household car driven most often) was a company car.

useful for discriminating between the eight consumer segments shown above. In this case, four groups were identified from the segmentation:

- **Technology Pioneers**: defined as usually among the first to try new technology. Most likely group to choose an EV as their main car (21% agreed or strongly agreed), but highly likely to choose one as their second vehicle (58% agreed or strongly agreed), primarily male and youngest group.
- **Company Car Drivers**: defined as those whose main car was a company car. Second most likely group to choose an EV as their main car (18% agreed or strongly agreed), considerably higher mileage than other groups.
- **Plug-in Enthusiasts**: slightly older than Plug-in Sceptics, lower mileage group, and positive about practicalities of owning a BEV and a PHEV and environmental benefits.
- **Plug-in Sceptics**: younger, high mileage, least likely to choose an EV, concerned about charging practicalities and symbolism.

In addition to these studies, Element Energy surveyed 2,020 consumers in Great Britain, with the sample drawn from those who have bought or intended to buy a new or nearly new car (DfT, 2016b). The survey used similar questionnaire items to those of Anable *et al*. (2011) and Lloyd *et al*. (2012), complemented with a choice experiment. Participants were found to cluster into six customer segments based on attitudes towards several aspects such as new technologies, fuel cost savings, the environment or electric vehicle perceptions, in addition to factors such as demographics, car ownership, parking availability and travel patterns. The proportion of participants who fell into each of these segments is shown in Figure 3, along with a comparison to the results of Anable *et al*. (2011).

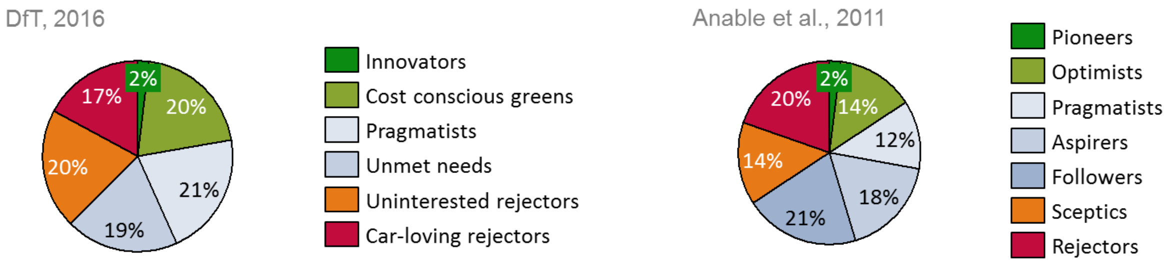


Figure 3: Proportion of consumer segments with comparison of Anable *et al*. (2011) and DfT (2016b)

Innovators, the cluster identified as most likely to adopt a plug-in electric vehicle in the short-term, constituted 2% of the sample, a proportion consistent with the previous consumer analysis. The clusters identified as early adopters ('Innovators' and 'Cost conscious greens'), constituted 22% of the sample in total. 'Pragmatists' and 'unmet needs' (40% of the sample) are considered as late adopters and around 37% of the sample, considered as 'rejectors', were formed by 'Uninterested rejectors' and 'Car-loving rejectors'.

The results of this survey were used to update the current ECCo model. The results of the previous segmentation surveys will be complemented by responses gained from participants following practical experience of a BEV and PHEV when further updating the ECCo model following the uptake trial.

Previous segmentation studies demonstrate that, in isolation, demographics are an incomplete indicator of plug-in vehicle uptake, supporting the use of a segmentation approach focused strongly on attitudinal factors designed to capture the complexities of consumer purchase decision making.

The segmentation analysis for this Consumer Uptake Trial will build on knowledge gained from previous studies. Segmentation of the Mainstream consumer sample will be performed according to their demographic, attitudinal and behavioural characteristics. This will provide knowledge of the Mainstream consumer segments which are most likely to adopt a BEV or a PHEV in the future.

4.5 Reporting

Full details of the methodology, analysis, results and conclusions from this trial will be documented in a final Consumer Uptake Report (Deliverable 5.1).

In addition to the final written report, a PowerPoint presentation will be produced in order to provide the ETI Review Panel with an overview of the key results and conclusions from the trial. This presentation will be delivered before the Consumer Uptake Report to allow for comments from the Review Panel to be incorporated into the written deliverable.

Subject to approval and sign-off of the Consumer Uptake Report from the ETI, a separate paper(s) will be written for submission to a peer-reviewed academic journal(s) (e.g. Renewable and Sustainable Energy, Transportation Research Part D: Transport and Environment, Energy Policy or International Journal of Electric and Hybrid Vehicles).

The reporting process will form part of a dissemination strategy to ensure that the knowledge gained from this trial is appropriately published into the wider academic community. Full details of the dissemination strategy are provided in Part 1 of this deliverable.

Deliverable 5.1 will document clear and concise evidence-based conclusions to the research questions, to provide robust inputs to the modelling framework to allow more accurate prediction of the likely future uptake of EVs by the mass-market, and the resulting impact on UK aggregated EV charging demand.

5 Timeline

An indicative timeline for the Consumer Uptake Trial is shown in Figure 4 below. This timeline is based on the selection of Alternative Design 1 (with a four day duration for participants with each vehicle), as agreed with the ETI. From project inception, a minimum of 15 months is required to allow sufficient time to prepare for and pilot the trial, recruit participants, collect, clean and analyse data, and report and disseminate the findings.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Trial preparation and piloting (TRL, EV Connect), including:															
Integration of vehicle telematics system (EV Connect)															
Vehicle procurement and delivery (TRL)															
Development of questionnaires & choice experiment (TRL, EE)															
Pilot and testing (TRL, EE, EV Connect)															
Recruitment (TRL)															
Run trial (TRL, Cenex)															
Data cleaning and processing (EV Connect, TRL, EE)															
Data analysis (TRL, EE)															
Reporting (TRL, EE)															

Figure 4: **Indicative timeline for Consumer Uptake Trial**

6 Options for trial design

6.1 Principles used to determine our recommended option

The methodology presented in this report represents our recommended approach and has been developed on the basis of the following principles:

1. It prioritises statistical power and internal validity (since research with low internal validity cannot generate meaningful answers to research questions)
2. It prioritises external validity where doing so does not unduly compromise internal validity
3. It does not require additional budget

The recommended trial design outlined in this document therefore represents the most scientifically robust solution for investigating mainstream consumer uptake, which is achievable within the budget of the project.

6.2 Alternative options

There are three possible alternatives to the recommended trial design which ETI might wish to consider. These relate to:

- Increasing the duration of the trial from 2 days to 4 days per vehicle, or;
- Increasing the duration of the trial from 2 days to 7 days per vehicle, and/or;
- Installing Mode 3 chargepoints in participants' homes, instead of an EV-appropriate 3-PIN socket on dedicated RCD-protected circuit for Mode 2 charging.

Selection of any of these alternative options would result in one of two consequences:

1. An increase in cost, or;
2. A reduction in the number of participants (to offset the increase in cost).

Full details regarding the impact of these options on cost and participant numbers are provided in Deliverable 1.4 (Part 6 – Commercial Submission).

The following sections outline the pros and cons associated with each of these alternative options.

Note: After considering the advantages and disadvantages of each option, the ETI has confirmed selection of Alternative Design 1 (i.e. 4-day duration with each vehicle), in accordance with supplementary information provided by TRL, and has confirmed that it does NOT wish to take up either Alternative Design 2 (i.e. 7-day duration with each vehicle) or Alternative Design 3 (i.e. Mode 3 chargers).

6.3 Alternative design 1 and 2: Increasing the trial duration to 4 days or 7 days per vehicle

A key part of the trial design is the ability to reduce participants' psychological distance from EVs by providing them with direct experience of using the vehicles for their day-to-day travel needs. Previous evidence from the TRL-Shell BEV trial suggests that 36 hours is sufficient to elicit a substantial shift in willingness to consider having a BEV (downwards) and a substantial shift in evaluation of the driving experience and performance of a BEV (upwards) (Lloyd *et al*. 2012; Skippon *et al*., 2016). Additionally, in a so-far unreported study at TRL, 15 mainstream car user participants were each given one week's direct experience of a Nissan Leaf BEV, Vauxhall Ampera E-REV (AER ~50-60km), Toyota Prius PHEV (AER ~20km), Toyota Prius gasoline HEV, and Peugeot 3004 diesel HEV, and then interviewed qualitatively about their experiences with each. This study investigated how far into the week's experience participants thought their responses had settled. The majority of participants reported that they formed their evaluations within the first 1-2 days and that subsequent days of use confirmed them but did little to change them.

The recommended approach for the current study (Consumer Uptake Trial) is to provide participants with a 2-day (48-hour) experience of each vehicle type. An important aspect of the EV experience is the time it takes to recharge a discharged vehicle battery. Consistent with the findings of the comparative vehicle experience study outlined above, a single experience of this charging process moves a participant from no appreciation of the length of charging, to a reasonably clear understanding. Setting the trial duration at 48-hours would allow for at least one and up to two opportunities for overnight charging, thereby providing a sufficient experience to reduce the psychological distance of participants.

It could be argued that usage behaviour for cars often differs at weekends and weekdays, and so any experience of using a car must include an even distribution across the days of the week. In the recommended design, this will be controlled for by evenly distributing the start days throughout the week.

Thus it may be concluded that whilst extension of the experience with each of the BEV and PHEV vehicle types may be desirable, it would add relatively little further psychological distance reduction at the sample-aggregated level (which includes both weekday and weekend day experience) compared with the 36 hours' experience in the TRL-Shell BEV trial. Extension of this period to two days will create opportunity for up to two overnight charging events (one extra than provided by the previous study).

Providing participants with each vehicle type for a period of two days is justified scientifically and will ensure that participants have sufficient opportunity to drive (and charge, where applicable) the vehicle as part of their daily routine. Experience in the TRL-Shell BEV trial (Skippon *et al*., 2016) suggests that the majority of participants will make substantial use of the trial vehicles. To ensure that this happens, a number of steps will be taken. Daily vehicle mileage will be assessed through the recruitment screening questionnaire to ensure that potential participants' normal vehicle usage is substantial enough to facilitate a trial experience which sufficiently reduces their psychological distance from EVs. In addition, participants will be requested to drive each vehicle at least once per day, using the vehicle as a replacement for their normal vehicle, and recharge the BEV and PHEV at least once each during the trial period.

Nevertheless, as an alternative option, the duration of the trial experience could be increased to either four days per vehicle or seven days per vehicle. The pros and cons associated with each of these options are as follows:

Table 8: Pros and cons associated with increasing the trial duration

Alternative design	Pros	Cons
Alternative design 1: Increased trial duration from 2 days to 4 days per vehicle	**Validity** • Increasing the duration of the trial from 2 days to 4 days per vehicle will increase the amount of driving and charging experience participants gain with each vehicle type; although, the scientific benefits of this are unfounded. **Practicality and cost** • None – this option will increase costs and timescales, although the impact will be lower than increasing the duration to 7 days per vehicle.	**Validity** • The increased burden on participants' time may limit the available participant pool; this could compromise the ability to recruit 200 participants thereby reducing statistical power. • There is no scientific evidence to suggest that providing a 4-day experience with each vehicle type will reduce psychological distance significantly more than a 2-day experience. **Practicality and cost** • Increased costs and timescales, although to a lesser extent than the 7 day option. • Could negatively impact the delivery of final reports if the end of the trial coincides with the end of the Consumer Charging Trials.

<u>Alternative design 2:</u> Increased trial duration from 2 days to 7 days per vehicle	**Validity** • Increasing the duration of the trial from 2 days to 7 days per vehicle will increase the amount of driving and charging experience participants gain with each vehicle type; although, the scientific benefits of this are unfounded. **Practicality and cost** None – this option will have the greatest impact on costs and timescales.	**Validity** • The increased burden on participants' time may limit the available participant pool; this could compromise the ability to recruit 200 participants thereby reducing statistical power. • There is no scientific evidence to suggest that providing a 7-day experience with each vehicle type will reduce psychological distance significantly more than a 2-day experience. **Practicality and cost** • Represents greatest increase in costs and timescales. • Could negatively impact the delivery of final reports if the end of the trial coincides with the end of the Consumer Charging Trials.

6.4 Alternative design 3: Mode 3 charging

A full risk assessment of Mode 2 charging in domestic properties is documented in Appendix A. This risk assessment notes that Mode 2 charging can be implemented in this trial with sufficient control measures to reduce any risks ALARP.

Nevertheless, rather than utilising Mode 2 charging from an EV-appropriate 3-PIN socket on a dedicated RCD-protected circuit, an alternative option could be to install a dedicated Mode 3 chargepoint in participants' homes. This would involve:

- Full installation of chargepoints at participants' homes prior to the trial commencing (adopting the same approach to domestic charging installation as the Consumer Charging Trials – see Deliverable 1.4 Part 3).
- Charging using a specific EV multi-pin socket with control and protection functions (e.g. in line with SAE J1772 or IEC62196).

The pros and cons of this alternative option are outlined below:

Table 9: Pros and cons associated with installing Mode 3 chargepoints.

Pros	Cons
Validity • Mode 3 is the optimal charging solution for EV owners – experience of Mode 3 charging during trial would be optimised for participants. **Practicality and cost** • None – this option will increase costs and timescales.	**Validity** • Mode 2 charging is the default charging solution offered to EV owners; this charging method is supported for occasional use by vehicle manufacturers and electrical safety institutions such as BEAMA. • The requirement to install Mode 3 chargepoints will limit the available participant pool; this could compromise the ability to recruit participants, thereby reducing statistical power. **Practicality and cost** • Expensive – not feasible within current budget; will either result in an increase in costs or a reduction in the number of participants (see Part 6 – Commercial Submission). • Logistically challenging – timescales will be increased considerably to arrange installation etc. • Limited safety advantage – Mode 2 charging with adequate control measures represents a very low level of risk.

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Appendix A Risk Assessment for Mode 2 Charging

A.1 Introduction

This risk assessment report examines the suitability of using Mode 2 charging equipment during the Consumer Uptake Trial of the CVEI project for the ETI. The report provides a high level comparison of Mode 2 and Mode 3 safety features and an evidence review of the suitability of Mode 2 charging for the purpose of these trials.

A.1.1 Context

The Consumer Uptake Trial will provide a sample of 200 participants with a short-term experience of driving three types of vehicle; a Battery Electric Vehicle (BEV), a Plug-in Hybrid Electric Vehicle (PHEV) and an Internal Combustion Engine (ICE) vehicle. The trial will be carried out[16] over a total period of six days, during which the participants will be loaned each of the vehicle types for a period of two days. In the case of the BEV and PHEV, participants will be asked to charge the vehicle (at home or at public chargepoints) at least once per two days.

For long-term use of plug-in vehicles, Mode 3 charging is ordinarily the recommended method for domestic charging. However, given the time, cost and practical constraints of this short-term trial, it is necessary to assess whether use of Mode 2 charging would be a suitable alternative charging solution for use in this trial. Safety is of principal importance; this risk assessment aims to establish whether Mode 2 charging can be used without introducing an intolerable level of risk to trial participants.

A.2 Mode 2 charging overview

Mode 2 charging uses a standard 3-pin socket outlet, with the chargers complying with UK plug standards BS1363. Mode 2 chargers do not have a dedicated power supply, using power drawn from the same source as the rest of the electrical appliances in the house, but the charger does have an integral in-cable control and protective device (IC-CPD). This provides Residual Current Device (RCD) protection and control pilot function. On the vehicle side of the Mode 2 cable is a dedicated EV connector that facilitates the use of the control pilot function. Mode 2 charging is limited to 13A single phase supply through the BS1363

[16] Note that selection of Alternative Design 1 has been confirmed by the ETI. Consequently, the durations will be adjusted to 4 days per vehicle and 12 days in total, and charging may be more than once per vehicle.

plug, but in practice, many vehicle manufacturers restrict the supply via Mode 2 to 10A, as an additional precaution.

In terms of safety risk, Mode 3 represents the optimal solution for domestic charging of EVs. This risk assessment therefore focuses on identifying the relative risks of Mode 2 charging compared with Mode 3 charging, in order to establish whether the Mode 2 charging can be used without introducing an intolerable level of risk to participants.

Mode 3 chargers utilise a dedicated connection to the power supply with a control pilot function extending to the control systems in the vehicle supply equipment. Mode 3 is the preferred solution for charging Electric Vehicles (EVs) because it guarantees a dedicated circuit for the charger and as such, is independent from any existing domestic wiring. The main difference between Mode 2 and Mode 3 charging is, therefore, at the interface to the domestic wiring / power supply. Whereas Mode 3 is guaranteed to have a separate, dedicated circuit, Mode 2 (although also recommended to have a separate dedicated circuit installed[17]) is unlikely to have a dedicated socket on a dedicated circuit in a typical domestic charging environment. Portable socket-outlets are not permitted by section 722 of BS 7671 (17th Edition) of the UK wiring regulations, implying that extension cables must not be used for Mode 2 charging. However, since Mode 2 charging utilises a standard 3-pin socket outlet, in practice it is possible for a user to plug this into an extension cable when charging via Mode 2. This therefore adds an additional risk compared with Mode 3 charging which has an enclosed connection to the mains supply, not accessible to the user and thus does not have a BS1363 plug interface

Table 10 shows the respective safety features for Mode 2 and Mode 3 chargers. The latest Mode 2 charging cables provide the majority of the safety features available with Mode 3 charging, including; over current protection, RCD protection and an ability to control the current flow, which helps to minimise the risk of raised temperatures (over-heating). Furthermore, as most manufacturers limit Mode 2 current flow to 10A (including VW, who will be providing vehicles for this project), this minimises the risk of overheating and unwanted over loading on the circuit.

The lack of a dedicated circuit for Mode 2 and non-tethered cable (allowing potential use of extension cables) appear to be the only safety feature differences between Mode 2 and Mode 3.

[17] For new installations, when installing a socket outlet for EV charging, section 722 of the wiring regulations requires that a separate dedicated circuit is installed.

Table 10. Comparison between Mode 2 and Mode 3 Safety Features

Main safety feature	Mode 2	Mode 3
Dedicated power supply (via a dedicated circuit)	No. Recommended and possible but not guaranteed.	Yes. Guaranteed via installation.
Over Current protection	Yes	Yes
RCD	Yes	Yes
Contactor/switching	Yes (between the in-cable box and the vehicle)	Yes
Control pilot function	Yes (between the in-cable box and the vehicle)	Yes. Control pilot function extending to control of equipment in Electric vehicle supply equipment (EVSE)
Protective casing/design (IP rating)	Yes (BS1363 and IEC 62196)	Yes (IEC 62196)
Interlocking mechanism (mechanical or electric)	Not for BS1363 domestic plug. Same as Mode 3 for vehicle connector	Yes
Tethered lead	No (use of extension cables possible)	Yes

A.3 Risk Assessment

Table 11 details the risk assessment for Mode 2 charging focusing only on the risks which are not present with Mode 3 charging. It can be seen that most of the risks are not electric shock related but are in fact a potential fire hazard, caused by potential failure of the household wiring or extension cables. Each risk is described in more detail under Table 11. It should also be noted that although the primary risk of cables overheating is a fire hazard, there is also a potential for electric shock if parts of the conductor are exposed to touch. However, the presence of an RCD within the Mode 2 cable and as part of domestic wiring should prevent any serious risk to human health.

Table 11. Risk Analysis for Mode 2 charging; risks that are additional to those associated with Mode 3 charging (L = Low, M = Medium, High = High)

Risk number	Risk	Relevant Design Item	Probability	Impact	Risk rating
1	Burns	No interlocking plug. Heat damage to BS1363 plugs	L	L	L
2	Fire Hazard	Wiring Harness of household	L	H	M
3	Fire Hazard	Extension cables	L	H	M

Risk number 1: It would be possible to perform a "hot disconnect" of the 3-pin plug from the mains supply (disconnection of charger by removing the plug from the socket when in use), which can cause arcing and pitting of the contact surfaces (pins) of the plug. Over many occurrences, this could lead to increased surface resistance and result in the heating up of these contacts in the connector (the plug). This could lead to an increased risk of suffering minor burns when attempting to handle the plug. This risk is further increased by the possibility of using extension cables with Mode 2 charging. It should be noted that during the short time span of this trial, the probability of this risk creating a hazard is deemed to be very low; it is very unlikely that a sufficient number of 'hot disconnects' would be performed during the short trial period to cause higher than normal surface resistance on the plug pins.

Risk Number 2: Mode 2 charging draws power directly from a domestic socket, thereby producing a potential fire hazard due to a possible overheating of the wiring between the wall socket and house circuit breaker (if the wiring is not sufficient to withstand the current draw over prolonged time periods). It is possible to draw 10A continuously for up to 13 hours via Mode 2 charging of a BEV – this is anticipated to be the worst case in the trials, assuming longest charging time of the e-Golf as per manufacturer's specification. For a given domestic socket, the thickness of the cable used for that spur combined with the Miniature Circuit Breaker (MCB) rating upstream will determine whether the domestic wiring for a particular plug can safely cope with the EV charging demand. The situation for every house and socket is likely to be different. If the Mode 2 cable is plugged into a socket that is on a spur where cabling is not adequate to deal with the current load of EV charging, and any existing load on that spur, and the upstream MCB is not rated sufficiently low to detect hazardous levels of overcurrent, then there is potential for the cable to overheat. Overheating cables could result in melted insulation and exposed metal conductors, which will present a fire hazard if in contact with potentially flammable material. Probability of this occurring is relatively low as most domestic properties are likely to use the $2.5mm^2$ cable size for power circuits, in line with IEE Wiring Regulations. The current rating of a cable this size will vary depending on a number of factors, such as temperature, type of cable and its location and placement in the property. However, the current rating is likely to be somewhere between 18A and 30A. It is therefore unlikely that adding an additional 10A load to the cable for Mode 2 charging will exceed its rating, unless there are other high-current, continuous loads connected to the same cable spur. So, although the potential impact of a fire hazard can be highly severe – e.g. a house fire, the likelihood of this occurring, to this level of severity, is very low, resulting in an overall risk rating of medium.

Risk Number 3: Extension cables should never be used with Mode 2 charging. However, as Mode 2 cables use a standard BS1363 3-pin plug, it would be possible, in practice, for users to use extension cables during the trial. If a Mode 2 cable is plugged into an extension cable that is not able to tolerate prolonged current draw, either due to other devices being plugged into the same extension cable or an inadequately rated cable, then the cable could be subject to overcurrent and potential overheating, as described in Risk Number 2. If the extension cable is fused then this risk is much lower, as current in the cable should never exceed the load of the fuse rated to the cable capacity (maximum rating of 13A). The use of extension cables could increase the likelihood of Risk Number 2 if they are plugged into sockets with multiple loads already present. Most extension cables are rated to 13A and are fused. Therefore, the likelihood of occurrence is low. However, given the potentially high severity that a resulting fire hazard could present in extreme cases, the overall risk rating is deemed to be medium.

A.3.1 Risk Mitigation

This section describes possible mitigation measures for each of the risks identified in Table 11 above.

Table 12. Risk mitigation table

Risk no.	Risk	Design Item	Mitigation	Residual Risks	Further Mitigation	Level of remaining residual risk
1	Burns	No interlocking plug. Heat damage to BS1363 plugs	Produce a user guide for participants in the trial that clearly advises them to turn off power supply at the socket prior to unplugging the Mode 2 cable.	Some users may still choose to hot disconnect.	The relatively short length of trial will mean that it's highly unlikely that hot disconnecting will increase surface resistance of the connectors.	Low
2	Fire hazard	Wiring Harness of household	Two options are possible: Option 1 – Undertake an inspection of the suitability of the household wiring for use with domestic Mode 2 charging using a suitably qualified electrician, for each household taking part in the trial. Option 2 – Provide a dedicated socket on a dedicated circuit, in each participant's house for use with Mode 2 charging (this is the preferred option and is in line with section 722 of the wiring regulations).	Potential for users to use non-surveyed or non-dedicated socket.	Ensure the user guide for participants in the trial clearly advises them to use the dedicated socket / only sockets checked by the electrician.	Low

3	Fire hazard	Extension cables	Ensure the user guide for participants in the trial clearly advises them to not use any extension cables. Seek a signature from participants to verify that they have read and understood this requirement.	User may choose to ignore guidance and warning about using extension cables.	The relatively short length of trials will mean that it's unlikely that users will have the opportunity or the perceived need to use an extension cable in addition to the dedicated socket provided.	Low

A.4 Supporting evidence

This section of the risk assessment outlines evidence gathered from other reputable sources that describe acceptable usage of Mode 2 charging. The use of Mode 2 charging for occasional use is permitted and accepted by professional organisations and industry standards.

- The European Automobile Manufacturers' Association (ACEA) recommends Mode 3 charging for publicly accessible charging stations. ACEA recommends using Mode 3 charging for charging at home, but Mode 2 is an acceptable form of charging during Phase 1 should no Mode 3 charging station be available (Phase 1 is considered as a transitional period lasting up to 2017 and reflecting the current situation) (ACEA, 2012).
- BEAMA (British Electrotechnical and Allied Manufacturers' Association) recommends that Mode 2 may be a satisfactory charging solution for some types of EVs and their operators i.e. for those with modest charging requirements such as some two wheelers and Plug-in Hybrid Electric Vehicles (PHEVs). Some vehicles will be supplied new with a Mode 2 cable with Mode 3 as an optional extra. Mode 2 is also an important backup for any compatible vehicle in locations where there is no dedicated charging installation. BEAMA recommends that regular Mode 2 charging should only be carried out using a dedicated EV circuit although occasional charging from a non-dedicated circuit is acceptable (BEAMA, 2015).
- CEN-CENELEC (European Committee for Standardization, CEN, the European Committee for Electrotechnical Standardization, CENELEC) Recommendation 7.3 states that Mode 2 can be used to charge vehicles occasionally. However, Recommendation 7.11 does not recommend use of Mode 2 chargers in publicly accessible places (CENELEC, 2011).

A.5 Recommendations

Having reviewed the risks, possible mitigation measures and supporting evidence from other sources, there is strong evidence to support the safe use of Mode 2 charging in the Consumer Uptake trial of this project. There is no evidence to suggest that the risks associated with Mode 2 charging instead of Mode 3 charging will be increased to an intolerable level. All evidence reviewed suggests that for occasional use, Mode 2 charging can be used without any additional intervention. Given that over the course of the short-term trial period, most participants are unlikely to charge a vehicle more than four times (i.e. twice per BEV and twice per PHEV), this is considered as occasional use.

Mode 2 charging provides most of the same safety features as Mode 3 charging, with the main exception being the lack of a guaranteed dedicated circuit that connects the charger to the domestic supply.

Having identified how specific risks related to this issue can be mitigated in a practical manner that should be reasonable within the scope of the project and the trial; the following steps are recommended to ensure that risks associated with Mode 2 charging during the trial are reduced ALARP:

1. During the recruitment process TRL will administer a screening questionnaire to prospective participants which will include questions to ascertain whether the participant's household meets the required safety standards for EV charging (i.e. in accordance with Section 722 of the IET's 17th Edition wiring regulations).
    - This will include high-level questions to screen which participants may require additional electrical works at their property to ensure safe EV charging. Questions will seek to identify whether the participant has an existing EV charging point or a suitable socket outlet (i.e. a dedicated, RCD-protected circuit; rated to at least 10Amps; with a EV-appropriate Mode 2 socket[18], in an appropriate location for EV charging).
2. If the responses to the questionnaire indicate that the participant may already have appropriate provision for safe EV charging, then a TRL-appointed electrical contractor will be asked to inspect the premises and certify the existing charging infrastructure as safe and fit for purpose.
3. If the participant is found to lack the necessary electrical infrastructure (either via the screening questionnaire or a subsequent electrical inspection) then they will be offered an installation as part of the project.
4. Installation of an EV-appropriate Mode 2 socket on a dedicated RCD-protected circuit will be completed by the TRL-appointed contractor. The installation will be in accordance with Section 722 of the IET's 17th Edition wiring regulations.
    - Prior to installation, the TRL-appointed electrical contractor will engage with participants to ascertain the specifics of the existing electrical wiring in the household (via remote interviews and photos of the electrical components, such as sockets, consumer unit, parking location, etc). Based on this remote assessment a recommendation will be made by the contractor on the best way to proceed.

[18] An 'EV-appropriate Mode 2 socket' is defined as one which is consistent with the IET's 17th Edition wiring regulations. One example of a product conforming to these requirements can be found here:

http://assets.rolecserv.com/files/products_document/63ced5ffd0986e107c741f80265b912c/EVWPD001%20-%20WALLPOD%20EV%20Ready.pdf

5. In the event that a participant is not willing for the required installation work to take place, they will be ruled out from taking part.
6. Participants will only be allowed to take part in the trial upon satisfactory certification from the TRL-appointed electrical contractor that the necessary electrical installation has been completed and is fit for the purpose of the trial.

In addition to the above mitigating steps, all trial participants will be provided with a concise guide on plug-in vehicle charging that clearly describes relevant safety considerations and good practice, such as prohibited use of extension cables. The contents of this guide will be fully explained during the vehicle handover process. All participants will be asked to sign a form to indicate that they have read and understood the recommendations for safe use of Mode 2 charging equipment during the trial.

As evidenced in this report, implementation of these control measures is likely to reduce the risks associated with Mode 2 charging as low as reasonably practicable (ALARP).

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D1.4 Stage 2 Trial Design, Methodology and Business Case

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN

ISBN

THE FUTURE OF TRANSPORT

PROJECT REPORT

D1.4 Stage 2 Trial Design, Methodology and Business Case

Part 3 - Consumer Charging Trials

G Beard, N Kinnear and S Skippon

Report details

Report prepared for:	ETI
Project/customer reference:	TR1006 Consumers, Vehicle and Energy Infrastructure (CVEI) project
Copyright:	
Report date:	March 2017
Report status/version:	4.0
Quality approval:	

H. Al-Katib (Project Manager)		S. Skippon (Technical Reviewer)	

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	10/06/16	Draft delivered to client	GB/NK	SS/SH
2.0	14/12/16	Second version to client	HAK/NK	SS
3.0	14/02/17	Third version to client	HAK/NK	SS
4.0	13/03/17	Final version	HAK	SS

Document last saved on:	14/02/2017 14:08
Document last saved by:	Al-Katib, Hannah

Contents

Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics
ESME	Energy System Modelling Environment
ESOS	Energy Savings Opportunity Scheme

EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
ISO	International Organization for Standardization
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer

ONS	Office for National Statistics
OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
UMC	User Managed Charging
VAT	Value Added Tax
VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services
WP	Work Package

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)

Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how you see yourself and how one perceives others see them.
Social norms	Similar to injunctive norms but mores specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.
Symbolic meaning/ attitudes	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

STATUS OF TRIAL DESIGN INFORMATION

THIS DOCUMENT WAS PRODUCED IN STAGE ONE OF THE CVEI PROJECT, TO SET OUT THE PROPOSED TRIAL DESIGN AT THAT POINT.

IN STAGE TWO, THE TRIAL DESIGN HAS BEEN FURTHER DEVELOPED, AND SOME ASPECTS OF THE TRIAL DESIGN HAVE EVOLVED FROM THE PROPOSAL SET OUT IN THIS DOCUMENT.

THE FULL AND FINAL DESIGNS OF THE CONSUMER UPTAKE AND CONSUMER CHARGING TRIALS ARE DOCUMENTED IN DELIVERABLE D5.1 "SUPPLEMENTARY DETAILS OF DESIGN, MATERIALS AND MANAGEMENT ARRANGEMENTS FOR CONSUMER TRIALS".

PARTS 2 AND 3 IN PARTICULAR OF THIS DELIVERABLE D1.4 ARE SUPERSEDED BY D5.1

1 Introduction

1.1 This report

This report is part of Deliverable D1.4: Stage 2 Trial Design, Methodology and Business Case. There are six parts to this deliverable:

- Part 1: Overview of Stage 2
- Part 2: Consumer Uptake Trial
- Part 3: Consumer Charging Trials (this document)
- Part 4: Fleet Study
- Part 5: Analytical Tools
- Part 6: Commercial Submission

This report details Part 3, the proposed trial design and methodology which will be employed for the Consumer Charging Trials (Work Package 5; Task 5.2). The trial design reflects collaborative development involving TRL, Baringa, Element Energy, Cenex, EV Connect, EDF, Shell, Behavioural Insights (BIT) and the ETI.

The other parts of Deliverable D1.4 are provided in separate documents. Part 1 includes an overview of the CVEI project as a whole.

1.2 Scope

The contents of this report provide details of the proposed design for the Consumer Charging Trials.

The finalised study plan outlining all specific practical details about how the trial will be run will be developed at the start of Stage 2.

The report discusses the rationale and methodology that supports the proposed method as a means of addressing the research questions. Research design inevitably involves trade-offs, for instance between internal and external validity, and stakeholders may have different areas of focus. Accordingly, several alternative design options are offered. These are summarised at the end of this document, alongside an explanation of the budget implications and scientific pros and cons associated with these alternatives. The full impact of alternative design options on cost and participant numbers is provided in Part 6: Commercial Submission.

2 Background and rationale

2.1 Validity: a fundamental issue in experimental design

In discussing the rationale behind the recommended trial design and the various alternatives to this, frequent reference shall be made to the *validity* of the trial design. Validity refers to the ability of the research design to support causal inferences in relation to the research questions it is aimed at addressing. It has two major aspects: internal validity and external validity.

Internal validity is a property of experimental designs that reflects the extent to which a causal conclusion based on research using that design is warranted. That depends on the extent to which the study minimises systematic error, and the extent to which the study design excludes possible explanations for the findings, other than the one being hypothesised. Designing research to control for all possible confounding errors is the key to internal validity. Uncontrolled research designs have very low internal validity. Research with low internal validity cannot generate meaningful answers to research questions. Randomised Controlled Trials generally have the highest internal validity.

External validity refers to the validity of generalised causal inferences from the results of a study. In other words, it is the extent to which the results of a study can be generalised to other situations and to other people. One of the main threats to external validity is sample bias. For instance, it is not valid to infer that Mainstream consumers will show particular attitudes to adoption of EVs, based only on results from a study with “EV Innovators”. Research with low external validity can generate answers to research questions that are only applicable to a narrow set of circumstances, which might not apply to the ‘real world’.

2.1.1 Validity trade-offs in research design

In most scientific research designs involving human participants, there is an explicit trade-off to be made between internal validity and external validity. When control measures are implemented to increase the internal validity, these measures may also limit the generalisability of the findings (i.e. the external validity), and vice-versa. Budget and time constraints often play some part in the trade-offs that are eventually made.

2.2 Mainstream consumers

The rationale behind this trial design makes reference to a clear distinction between “EV Innovators” and “Mainstream consumers”. The distinction is based on Rogers’ (2003) ‘Diffusion Model’ for the adoption of innovations. The Diffusion Model suggests that, once an innovation has become available, individual differences in times to adopt are driven at least in part by differences in a specific trait (known as ‘Innovativeness’) which reflects a general behavioural tendency to engage with new experiences. It further suggests that adoption will proceed through a process of ‘diffusion’, in which awareness of, knowledge about, and positive attitudes towards the innovation diffuse through a population in a process of uni-directional influence. This starts with adoption by a few “Innovators” (i.e. people high in Innovativeness), progressing next to “Early adopters”, and then into the wider population, with the attitudes of low-Innovativeness “Laggards” being the last to shift.

This process gives rise to an ogive (cumulative normal) S-curve distribution of adoption with time (Figure 1), and a normal distribution of times to adoption (Figure 2).

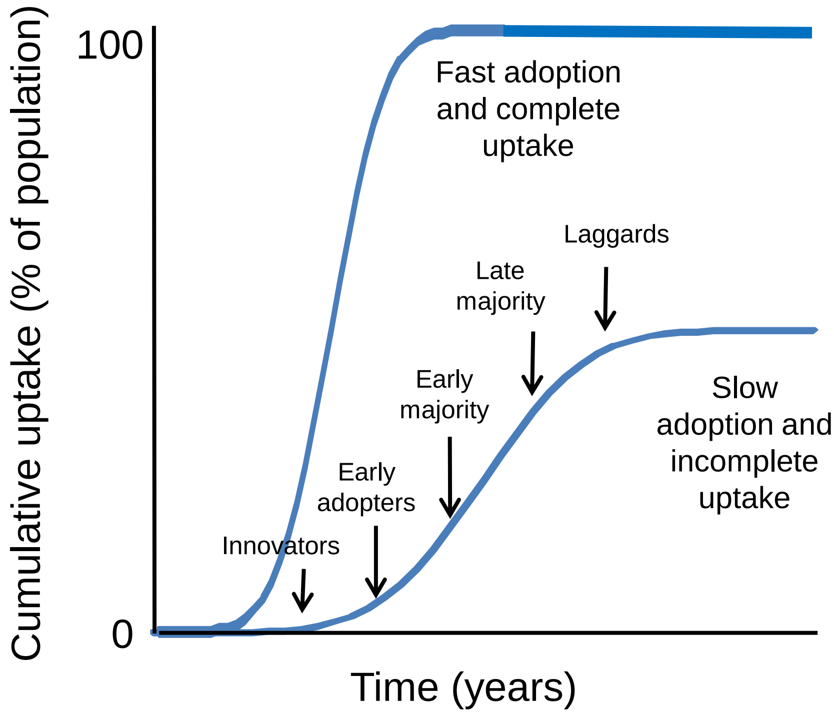

Figure 1: The Diffusion Model: cumulative uptake over time (Rogers, 2003)

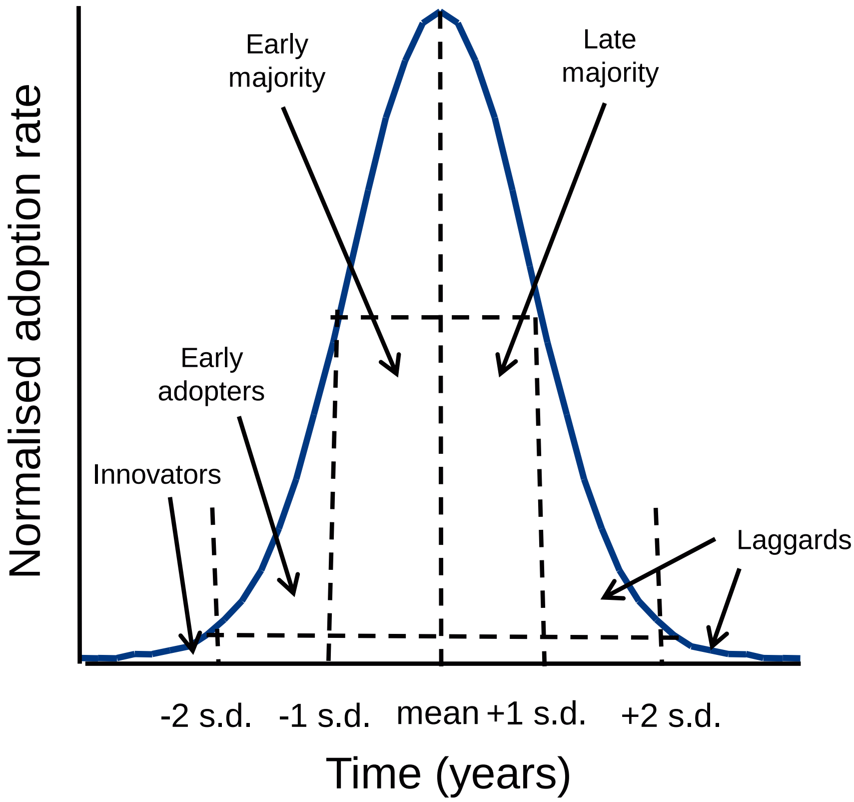

Figure 2: Diffusion Model: The normal distribution of times to adopt, and the statistical definition of adoption segments in terms of position relative to that distribution (Rogers, 2003)

Innovators are distinctive in the Diffusion Model in that they are the sources of awareness, knowledge, and positive attitudes towards the innovation. All others in the population act first as receivers of this information, and then become sources for further diffusion themselves. The last few to adopt are receivers only. It is useful to define a category of 'non-Innovators', that is, all those individuals whose adoption has been solely influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation. In the Diffusion Model, non-Innovators encompass all those in the Early adopter, Early majority, Late majority, and Laggard segments (see Figure 1): for the purposes of this report and the Consumer Charging Trials, they shall be referred to as *Mainstream consumers*[1].

The various segments in the Diffusion Model are defined statistically in terms of their position in relation to the normal distribution curve (see Figure 2). Innovators are those whose times to adoption are earlier than two standard deviations before the population mean time to adoption (around 2.5% of the population); Early Adopters are those whose times to adoption lie between two and one standard deviation earlier than the mean time to adoption (a further 13.5% of the population), and so on. In this report, the term *Innovator (or EV Innovator)* is used to refer to a consumer car user who is among the first 2.5% to adopt an EV.

In the UK there are approximately 30 million cars (DfT, 2016). If all of these were replaced by EVs, "Innovators" would represent the first 750,000 to adopt. At present, there are around 310,000 "alternative fuel vehicles" (DfT, 2016), representing approximately 1% of the total car fleet. Therefore, according to Diffusion Theory, all present owners/users of EVs are Innovators, and this will remain the case for some time.

2.3 Charging behaviour of Mainstream consumers

The diurnal time profile of aggregated EV charging demand is central to the CVEI modelling framework. The WP2 literature review (Kinnear, Anable, Delmonte, Tailor & Skippon, 2016) identified some research evidence regarding the charging behaviour of EV Innovators when using BEVs, but no research evidence about the charging behaviour of EV Innovators when using PHEVs. Furthermore, the literature review identified *no* research evidence regarding the charging behaviour of Mainstream consumers, whether using BEVs or PHEVs. Beyond the earliest stages of EV uptake, the diurnal time profile of aggregated EV charging demand will increasingly be determined by the charging behaviours adopted by Mainstream consumers.

The segmentation analysis performed for the ETI's PiV project (Anable, Kinnear, Hutchins, Delmonte & Skippon, 2011) provides very clear evidence that Innovators' attitudes towards EVs differ markedly from those of each of the variety of Mainstream consumer segments identified. Innovators' attitudes towards EVs, in general and particularly towards ownership of a BEV or PHEV, are much more positive than those of Mainstream consumer segments. While this information does not directly bear on the question of whether their charging

[1] Mainstream adopters, or Mainstream car users, may also be used interchangeably where this is contextually appropriate. In all cases, these terms shall refer to those non-Innovator car consumers, in relation to EV adoption.

profiles might differ, it does suggest considerable caution is needed in making assumptions of similarity between different consumer segments.

Further, the WP2.1 qualitative interviews with EV Innovators (Kinnear *et al.*, 2016) indicated that a majority exhibited pro-environmental motivations for their vehicle choice. It was also found that the main benefits Innovators could see in engaging with "supplier-managed charging" (i.e. a concept tariff in which the energy supplier would control EV charging) were that it would "benefit society" or "benefit the environment". A reasonable hypothesis might therefore be that Innovators would respond more positively than Mainstream consumers to these kinds of Managed Charging schemes, and would therefore be more willing to modify their charging behaviour in ways that confer a system-level benefit (because of their greater pro-environmental motivations).

In summary, all previous UK trials have measured *only* the charging profiles of Innovators, and there is no *a priori* case to assume that their charging behaviour will accurately reflect that of Mainstream consumers. This represents a major gap in knowledge. Evidence available to date casts serious doubt on the validity of assuming that Mainstream consumer charging profiles will be the same as those of Innovators. Accordingly, it would be ill-advised to base their charging profiles on those already measured in previous trials: this would pose a substantial, unquantified risk to the validity of the modelling outputs.

There is a clear scientific need to provide the modelling framework with new empirical data from measurements of the actual charging behaviours of Mainstream consumers.

One key value of the Consumer Charging Trials will be to provide valid measures of charging behaviour by Mainstream consumers and how this is affected by engagement in major classes of EV Managed Charging schemes. A further key value will be to provide valid measures of Mainstream consumer choice in relation to EV Managed Charging schemes.

This will provide robust inputs to the modelling framework to allow more accurate prediction of the likely UK aggregated EV charging demand in the future than is possible based on current evidence, which is derived from Innovators.

2.4 Factors influencing Mainstream consumer charging profiles

2.4.1 Type of EV

The ETI PiV study (Anable *et al*., 2011) indicated that Mainstream consumers are more likely to adopt PHEVs than BEVs over the period to 2050. Because of their relatively later introduction to the vehicle market, there has been very little empirical research with PHEVs, and none which has quantitatively measured the PHEV charging behaviour of Mainstream consumers.

PHEVs have smaller batteries than BEVs: at a fixed recharging rate, the time to recharge a fully depleted battery on a PHEV with an AER of 50km is expected to be around a quarter of the time to recharge a fully depleted battery on a modern BEV with a claimed range of 150-

200km[2]. Despite having smaller individual charging demands, a greater willingness of Mainstream consumers to adopt PHEVs than BEVs (as suggested by Anable *et al.*, 2011) may imply that, collectively, PHEVs could make a much bigger contribution to overall EV charging demand than BEVs.

It follows that there is a clear need for empirical data on Mainstream consumer charging behaviours when using PHEVs.

Strength of motivation to recharge BEVs and PHEVs may differ. Users of BEVs are dependent on recharging their vehicles for mobility, since a BEV with a depleted battery cannot be used until recharged. Conversely, users of PHEVs are much less dependent on the SOC, since their vehicles can operate in ICE mode if the battery is fully depleted. Although PHEV users still have a motivation to recharge (i.e. lower energy cost), this is unlikely to be as strong as the mobility-related motivation for BEVs.

The optimum design for a study of this kind is an RCT in which participants are randomly allocated into an experimental group and given experience of either a BEV or a PHEV supplied by the researchers, as a substitute for an existing ICE vehicle in the household. This strategy would be unproblematic for PHEVs, as they have broadly similar utility to the ICE vehicles they would replace (particularly, range before needing to refuel). However, the utility of BEVs is objectively lower than that of ICEs because of their restricted range. As a consequence, BEVs are only objectively suitable as substitute vehicles for a sub-set of the Mainstream consumer segment; that is, those whose travel patterns are consistent with the restricted range offered by BEVs currently available in the market. The sub-set for whom BEVs are *subjectively* suitable (i.e. those Mainstream consumers who themselves perceive that BEVs would meet their needs) may be even smaller.

Accordingly, two distinct trials with different participant samples are required:

- a PHEV Charging Trial with a stratified sample of Mainstream consumers, and;
- a BEV Charging Trial with an opportunistic sample of Mainstream consumers, for whom BEVs are suitable for their travel needs (i.e. 'Compatible' mainstream consumers).

The BEV sample will be representative only of a more restricted sub-set of Mainstream consumers, and is therefore unlikely to be representative of the Mainstream consumer segment as a whole.

It should be noted that the difference between samples will confound attempts to make meaningful statistical between-groups comparisons of charging behaviour based on vehicle type. This is because any observed differences in charging behaviour could be causally attributed either to vehicle type or to the sample differences. Nevertheless, interpretation and discussion of the results between the PHEV Charging Trial and BEV Charging Trial will be made where possible, with appropriate caveats concerning the differences in method.

[2] EV range is a strong function of driving conditions. The range quoted by manufacturers typically refers to the range achievable in controlled tests using repeated NEDC cycles. Users typically report real-world ranges somewhat shorter than this. Measurements have shown that at extra-urban cruising speeds range can be less than half that claimed by manufacturers. Here, where the term "range" is used without specific qualification, it refers to range measured in repeated NEDC cycles.

The recommended design for the Consumer Charging Trials is to include two distinct elements, a PHEV Charging Trial and a BEV Charging Trial. These should be run as entirely separate RCTs in order to maintain high internal validity.

2.4.1.1 Other vehicles in the household

The extent to which participants in the study use (and therefore, charge) the trial vehicles may depend on the availability of other vehicles in the household. For maximum external validity, it is preferable to ensure that the total number of vehicles in the household does not change as a result of the trial.

This would involve substituting the trial BEVs and PHEVs for (one of) the participants' own vehicles, removing the latter for storage until completion of the trial. However, doing this adds substantial costs to the project, e.g. for secure parking for the removed vehicles, and staff time to transfer vehicles to/from secure parking. These costs must be met, either by increasing the budget allocated to the trial, or by reducing participant numbers. The latter course would compromise the validity of the trials, and so is not recommended.

The alternative approach would be to leave the participants' own vehicles with them, so that the trial vehicle is an addition to the household fleet. That course poses a potentially substantial threat to the external validity of the trial, as participants' vehicle use, and therefore EV charging behaviour, might be un-representative of 'real-world' vehicle use if those participants were to adopt an EV. This threat to validity would be particularly acute when there is one more driving licence holder in a household than the number of vehicles presently used by the household.

A pragmatic solution is therefore recommended for this study in which the vehicle is substituted in the following circumstances only:

- in households where there are more drivers than vehicles; or
- where (in the view of the Trial Participant) there is insufficient space to park an additional vehicle or a significant inconvenience or loss of utility would be experienced; or
- where the Trial Participant wishes their own vehicle to be removed.

If these criteria are not met, then the participant will be provided with the trial vehicle in addition to their own. In this circumstance, the risk of the participant not using the trial vehicle and engaging with the Managed Charging scheme will be mitigated by:

- Directly linking the trial incentives to charging, thereby encouraging use of the trial vehicle.
- Explicitly tasking participants with using the trial vehicle for their everyday travel needs, instead of their own vehicle.
- Making the requirements of the trial clear to participants upon recruitment, during the vehicle handover briefings, and in follow-up calls with participants during the trial period.
- Where there may be concerns of vehicle inactivity, vehicle use will be monitored periodically throughout the trial to ensure that participants are using the vehicles.

An escalation procedure will be developed to deal with situations where vehicle inactivity is identified.

- Consideration of physical or psychological barriers (e.g. steering wheel clamp).

Alternative design options related to the substitution of participants' vehicles are discussed in Section 6.

2.4.2 Seasonal variation

Energy demand from EV use is likely to be subject to some seasonal variation, and this may impact on charging behaviour. For example, the length of daylight hours could affect both the timing and number/length of trips undertaken during certain seasons. Adverse weather in winter may result in reduced private vehicle use. Likewise, the extended school holiday during the summer period may also impact on both the timing and number/length of trips undertaken. Further, battery efficiency is known to be lower in the colder temperatures of winter, and the energy load greater (due to the requirement for vehicle cabin heating), requiring more energy input to the battery for the same mileage capability (Zahabi *et al*., 2014).

Consideration for seasonal variation in charging behaviour must therefore be incorporated into the design of the trials. Ideally, the trials would be conducted over one complete 12-month period; but at a minimum, data from a 6-month 'half-cycle' from summer to winter (or vice versa) would be most useful so as to provide coverage of the broadest range in temperatures and daylight hours likely to occur over a full year (i.e. compared with a half-cycle covering spring to autumn, or vice versa).

2.4.3 Between-participants variation in behaviour

In behavioural research, individual differences between people (e.g. personality, physical state, life experience, and life situation) generally lead to wide variations in measured behaviour. Research designs must select an appropriate sample size to ensure that both the distribution of behaviours is adequately sampled and that the experiment is not over-powered.

Statistical power is defined as the chance of correctly identifying a difference between samples. When planning statistical comparisons, if there is sufficient information available, it is possible to compute a sample size that ensures an appropriate level of statistical power. In this situation, given the unique nature of this study, there were no previous data that could be used to compute an appropriate sample size using statistical power analysis. This is not unusual in transport research; however, it was possible to inform a sample size decision for these trials based on a few statistical assumptions and previous experience with designing empirical research studies of this kind.

These decisions have been based on a minimal practical significance level; that is, the minimum difference between groups that has practical significance. In this situation, it is suggested that if in one group, 50% of the individuals engage with the Managed Charging scheme, and in a second group only 20% of the individuals do so, then this difference would be of practical significance and so would provide useful inputs in the modelling framework.

Based on an experiment with a power of 80% (an accepted good practice figure in behavioural research), an accepted type I error[3] of 5%, and a meaningful practical difference between two groups of 50% to 20%, it is recommended that a minimum sample size of 40 per group is used.

2.4.4 Within-participants variation in behaviour

People do not exhibit exactly the same behaviour each time they encounter the same situation. Each person exhibits a natural variation from occasion to occasion. Research designs must therefore ensure sufficient repeats of the experimental situation to ensure that the distributions of within-participant behaviours are adequately sampled. Since charging behaviour is expected to be mainly a daily activity, the experiment must extend over multiple days to ensure enough repeats. In addition, since daily vehicle use behaviour is likely to differ between weekends and weekdays, charging behaviour may also differ substantially by day of the week.

Trial durations of four weeks, for example, would allow for measurement of eight repeats of charging behaviour on weekend days (i.e. two possible repeats per weekend). However, it may not be guaranteed that charging will take place on both the Saturday and the Sunday of every weekend. Further, it may take time for people to habituate to a new behaviour, and it may take many repeats before a stable distribution of behaviours has emerged. Therefore, trials below four weeks in duration may increase the likelihood of inadequate sampling of the within-participants distribution of weekend day charging behaviour; extended durations are recommended to maximise the chances of measuring a sufficient number of repeats. As outlined in Section 2.1.1, the decision must be traded off against limitations in budget and time, and the number of participants who can practicably be included in the trials over the entire duration of the project.

It is recommended that each participant's vehicle use and charging behaviours are measured for a minimum period of 8 weeks, to allow for habituation and sufficient measurement of multiple repeats of charging behaviours and vehicle use. Successive staggering of participants over a 6-month period would allow charging behaviour data to be captured for at least half of an annual cycle.

2.4.5 EV Managed Charging schemes

Measuring the EV charging behaviour of Mainstream consumers enables us to build an accurate picture of EV charging demand into the modelling framework. It is not enough, however, to enable the framework to be used to investigate how far EV charging demand can be optimally integrated within the wider energy system to provide systemic benefits[4].

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[3] In statistical hypothesis testing, a type I error is the incorrect rejection of a true null hypothesis (a "false positive"), while a type II error is incorrectly retaining a false null hypothesis (a "false negative").

[4] Systemic benefits can be expressed in terms of economic value, to be shared between parties in the value chain, and with the user. There may also be benefits in terms of CO_2 emissions reductions, etc. that are important for policy goals, for instance.

Supply-demand balance becomes an increasingly complex issue as electricity generation is decarbonised. Demand varies diurnally, weekly, seasonally, in response to changes in weather, and as a consequence of social factors. Supply from renewable sources also varies diurnally, seasonally, and in response to changes in weather. When supply from low-cost sources is low, additional supply capacity must be activated to meet demand as required. Such additional capacity may have to be maintained in order to meet peak demands but will often be under-utilised, so its costs are high. Thus supply-demand balance is reflected in a variable cost to supply, ranging from cheap when the balance is favourable to very expensive when it is unfavourable. It is generally the case that the carbon intensity of supply increases as it becomes necessary to bring additional capacity on stream.

One approach to addressing these issues is "demand management" – measures that time-shift demand from periods of unfavourable supply-demand balance, when supply cost and carbon intensity are high, to periods of favourable supply-demand balance, when supply cost and carbon intensity are lower. EV 'Managed Charging' schemes are proposed ways of managing the contribution of EV charging demand to the overall supply-demand balance[5].

To be able to model the systemic effects of EV Managed Charging schemes, there is a need for robust data relating to Mainstream consumers' EV charging behaviours under particular sets of conditions that represent the major types of possible EV Managed Charging schemes. Likewise, to be able to make valid causal inferences about the effect of engagement with various EV Managed Charging schemes on charging behaviour, the charging behaviour of Mainstream consumers using an EV Managed Charging scheme must be experimentally compared with the charging behaviours of Mainstream consumers who are not using an EV Managed Charging scheme.

Thus, the primary value of the Charging Trials can only be realised by comparing the charging behaviour of one or more *experimental* groups who have experienced Managed Charging schemes with that of a group of participants who have not experienced any Managed Charging scheme (i.e. the *control* group).

2.4.5.1 Supplier-Managed Charging schemes

The greatest potential for systemic optimisation is offered in principle by a Managed Charging scheme in which the 'Charging Supplier'[6] manages when the EV is charged, and thus can time-shift that energy demand to periods of favourable supply-demand balance, within constraints set by the user. In principle the user benefits from engagement with a Supplier-Managed Charging scheme by having their charging needs met at the lowest cost compatible with those needs, without the need to manage the charging themselves.

[5] Demand management may also be used to help manage constraints on the network, both at transmission and distribution level, as well as to provide services to the system operator (such as frequency response and reserve) that are required to manage short term fluctuations in supply and demand).

[6] Here, the term 'Charging Supplier' is used to describe a business entity that manages charging on behalf of the user, by controlling the timing of charging to time-shift energy demand to favourable periods of supply-demand balance and obtain the lowest costs for the user. It is assumed that the Charging Supplier buys electricity from a market in which prices vary according to the supply-demand balance, as discussed above.

To provide the Charging Supplier with flexibility in time-shifting EV charging demand, the user must ensure that their vehicle is plugged in (i.e. available to be charged) as often as possible, and for longer than the total time it will take to recharge it to the desired level. For example, suppose a BEV has a state of charge (SOC) of 20%, and that the user requires it to be fully charged by some stated departure time in the future, and that it will take eight hours to fully recharge it. If the user plugs it in eight hours before the stated departure time, the whole period between plugging in and the departure time will be required for charging, and this would therefore provide no opportunity for the Charging Supplier to time-shift the demand. If, however, the user plugs the vehicle in *twelve* hours before the stated departure time, then the Charging Supplier has some opportunity to time-shift the demand, has the potential to contribute to systemic optimisation, and can potentially deliver a lower cost of charging to the user.

Potentially, greater systemic benefits and greater user benefits (in terms of lower average cost of charging) can accrue if the Charging Supplier is able to add additional charge to the vehicle at times when the cost is particularly low, *in anticipation of future need* rather than in response to a specific user requirement. In other words, even if the user had requested a 70% SOC, it may be optimal for the system and for the user for the Charging Supplier to deliver 100% SOC if the cost of energy is particularly low at the time of charging. Hence, the Charging Supplier could take advantage of that lower rate (to the benefit of the user and the system) and charge the vehicle to a higher SOC, in anticipation of a future need for charge.

User behaviour to maximise benefits

It follows that, to maximise both user benefits (lower costs) and systemic benefits, users should be encouraged to adopt the following behaviours:

- Ensure that the EV is plugged in whenever not in use, when in a suitable charging location (in the trial, at home) and when a significant additional charge is possible (i.e not a high initial SOC), to enable the Charging Supplier to charge it whenever electricity can be obtained at a favourably low cost.
- Specify only the minimum SOC actually required, rather than routinely specifying 100% SOC (which might lead to the excess electricity being obtained at a higher than necessary price, because of the constraint that it needs to be obtained within a particular time window).

Users who follow this guidance will benefit from lower charging costs. Behavioural science indicates that users are more likely to adopt the most effective behaviours if they receive feedback on how effective their previous behaviours have been, in terms of the reward[7] gained (Fishbach & Finkelstein, 2012; Shafir, 2013). Therefore, the Charging Supplier should provide feedback on the actual cost of charging, so that the user can relate that cost of charging to their behaviour.

Consumer costs associated with a Supplier-Managed Charging scheme

Engagement with a Supplier-Managed Charging scheme also has some costs from a consumer's perspective. First, there is potential for some inconvenience associated with

[7] Reward here refers to the benefit gained as part of a rewards system. For example, an organisation may offer customers a benefit of rewards points to motivate lotyalty.

perceived loss of use of the EV while it is plugged in for a period longer than actually required to charge it. Second, there is a risk that, if the user unexpectedly requires the EV before the planned departure time, it may not be charged to a sufficient level (although this risk is arguably only slightly/marginally increased by the use of managed charging).

Engagement with a Supplier-Managed Charging scheme also places a requirement on the user to provide two pieces of information for each charging event. These are the minimum SOC required, and the planned departure time by which that SOC is required. The requirement to input information may also be associated with some degree of inconvenience. Since there are likely to be regularities in users' patterns of use, this can largely be addressed through a simple system of user-entered defaults. That is, the user would enter default values for required SOC and departure time when first making use of the system; the system would then use these values for all subsequent charging events unless the user overrides them.

Defining an experimental condition to study Supplier-Managed Charging

The essential attributes of a Supplier-Managed Charging scheme, from the user's perspective, are:

- The user specifies their goal for each charging event[8] (the required minimum SOC and the required departure time)
- The Charging Supplier manages the time of charging to obtain the required SOC, by the required time, at the lowest cost to the user
- The user determines the plug-in and plug-out times, and is encouraged to plug the vehicle in for as long as possible, in order to maximise user (and systemic) benefit, when in a suitable charging location and a significant additional charge is possible.
- If the Charging Supplier is able to capitalise on low cost energy available at the time of charging, it will charge the EV to a higher SOC than the user required, in anticipation of future use, and to minimise the cost of energy for that future use
- The user receives feedback on the cost of charging, and is rewarded (through a lower average cost of charging) for maximising the opportunity for the Charging Supplier to time-shift charging to periods of favourable demand
- The user does not have direct control of the risk that the vehicle will not be adequately charged if he/she chooses to use it before the planned departure time

[8] "Charging Event" defined as the continuous period between plug-in and plug-out, during which at least some charge is provided to the vehicle.

These attributes must all be present in an experimental condition for the experiment to have adequate external validity. However, it is NOT necessary for participants to experience these by virtue of engagement in an operational Managed Charging scheme; that is, with an operational supply side. It is only necessary for the above attributes to be present *in the participant experience*, and for them to be consistent with what the modelling analysis suggests is likely from a supply-side perspective. In other words, the trials must accurately emulate the participant experience so that it is representative of a real-world operational Managed Charging scheme.

Experimental representation of Supplier-Managed Charging

To achieve the above attributes, the user experience of a Supplier-Managed Charging scheme can be represented with the following elements:

1. **Cost Model of the variation in supply-side cost of electricity**

   A model to incorporate diurnal, weekly, seasonal, weather-dependent and other variations in both supply and demand. The model should provide cost data which is representative of a likely scenario from a chosen part of the study period, to feed into the Chargepoint Management System (see below). The Cost Model would be developed in the preparation phase of Stage 2, building on the analytical framework and results from Stage 1.

2. **Chargepoint Management System**

   A system to handle user requirement inputs via the User Interface (SOC and departure time), compare those requirements with the Cost Model, and control the timing of charging to minimise the cost of that charging and ensure delivery of the SOC by the stated departure time. Additionally the Chargepoint Management System should use data from the Cost Model to identify low cost charging opportunities (for example, by comparing prices in the charging period to anticipated future prices) to charge the EV to a SOC higher than requested by the user. Finally, the system should calculate the cost of charging for each charging event and output this to the User Interface.

3. **Research Database**

   A 'real-time' database to store the outputs from the Chargepoint Management System including plug-in time, plug-out time, required SOC, required Departure time, delivered SOC, time profile of charging, cost profile of charging, etc.

4. **User Interface Smartphone App**

   A user interface to a) enable the user to input required SOC, and required departure time, and b) feed information to the user, such as SOC, cost of charging for previous charging event, average cost of charging, etc.

   The interface should allow for user-supplied default values to be set, in order to minimise user effort and mitigate for the event of no user input. Users should be able to override the default values whenever their requirements are different.

5. **Home Chargepoint**

A domestic Mode 3 chargepoint that receives commands from the Chargepoint Management System to switch charging on and off, and feeds data on energy consumption and SOC to the Chargepoint Management System.

2.4.5.2 User-Managed Charging schemes

While Supplier-Managed charging schemes potentially offer the greatest systemic benefits and user cost savings, Stage 1 qualitative research with users of EVs suggested that a majority of those users were not comfortable with the risks associated with Supplier-Managed Charging (as discussed in Section 2.4.5.1). Instead, they tended to prefer to have full personal control[9] over when their vehicle was being charged. This finding suggests that Supplier-Managed Charging schemes may not have widespread appeal among Mainstream consumers (although see Section 2.4.6 for justification that both types of Managed Charging scheme need to be studied). It should be noted, however, that these findings are based on a small sample that had no direct experience of Supplier-Managed Charging; their views were therefore reflective of a brief presentation of the concept only.

Participants in the Stage 1 research were more positive towards the alternative of User-Managed Charging schemes[10], in which the user determines the time of charging, and cost of electricity varies diurnally in a banded tariff structure that represents, approximately, the average supply-side costs. Users in such a scheme can choose to maximise their benefit by charging at the cheaper times, whilst retaining full control of precisely when the charging occurs, so as to minimise (perceived) risk. Compared with Supplier-Managed Charging Schemes, these schemes more loosely couple the cost to the user with the cost of supply, so the expectation is that systemic and user benefits per consumer will be lower than with User-Managed Charging than Supplier-Managed Charging. However, if User-Managed Charging schemes have higher appeal to consumers, and succeed in shifting charging behaviour to times that are favourable from a systemic perspective, the aggregate systemic benefit may be higher.

In a User-Managed Charging scheme, the user would control the timing of charging directly. This could be done simply through plug-in and plug-out times, via a controller attached to the home chargepoint that enables the user to specify times when the vehicle is to be charged, or via a User Interface Smartphone App that connects with the home charging station. In the latter two cases, defaults for the timing of charging could also be established, to be used automatically for each charging event unless the user overrides them.

In a User-Managed Charging Scheme, the costs to the user should be reflective of the times of day when the EV is charged; the user benefits from choosing to charge at times of day when the cost is low, which is reflected in a 'tariff band structure'. Tariff bands will reflect supply-side costs. As the energy system develops over coming years, the present diurnal pattern of supply-demand balance is expected to change and is likely to become far more variable from day to day and also within a day, much more spiky and less predictable, and

[9] "Control" can refer to a range of different constructs in psychology. Here, and throughout this report, it is used not in relation to any specific theoretical construct, but rather to reflect the language used by participants themselves in the Stage 1 qualitative study.

[10] Often referred to as "Time of Use" (ToU) tariff schemes

consequently that the ability of a ToU tariff to reflect the real supply-demand balance is reduced. (The simplicity of the present Economy 7 type tariff for example, or even of multi-band tariffs, may not remain viable or effective reflections of real supply-demand balance or cost, and dynamic ToU tariffs may become necessary.

Defining an experimental condition to study User-Managed Charging

The essential attributes of a User-Managed Charging scheme, from the user's perspective, are:

- The user does not specify the goal of each charging event
- The user directly manages the time of charging
- The cost to the user is reflective of the times of day when the EV is charged, so the user benefits from choosing to charge at times of day when the cost is low – this is reflected in a 'tariff band structure'
- The user receives feedback on the cost of charging
- The user has control of the risk that the vehicle will not be adequately charged if the user chooses to use it before the planned departure time

These attributes must all be present in an experimental condition for the experiment to have adequate external validity. However, it is NOT necessary for participants to experience these by virtue of engagement in an operational User-Managed Charging scheme; that is, with an operational supply side. It is only necessary for the above attributes to be present *in the participant experience*, and for them to be consistent with what the modelling analysis suggests is likely from a supply-side perspective. In other words, the trials must accurately emulate the participant experience so that it is representative of a real-world operational User-Managed Charging scheme.

Experimental representation of User-Managed Charging scheme

To achieve the above attributes, the user experience of a User-Managed Charging scheme can be represented with the following elements:

1. **Banded Tariff Structure**

   The structure of the banded tariffs will be determined in the preparation phase of Stage 2, based on outputs from the Stage 1 initial modelling analyses.

2. **Chargepoint Management System**

   A system to handle user requirement inputs via the User Interface (charge start time) and control charging accordingly. The system should calculate the cost of charging for each charging event and output this to the User Interface, and output data to the Research Database.

3. **Research Database**

   A 'real-time' database to store the outputs from the Chargepoint Management System including plug-in time, plug-out time, required charge start time, delivered SOC, time profile of charging, cost profile of charging, etc.

4. **User Interface Smartphone App**

A user interface to a) enable the user to specify a sequence of charging on-off times, with defaults that can be overridden, and b) feed information to the user, such as the banded tariff structure, SOC, cost of charging for previous charging event, average cost of charging, etc.

The interface should allow for user-supplied default values to be set, in order to minimise user effort and mitigate for the event of no user input. Users should be able to override the default values whenever their requirements are different.

5. **Home Chargepoint**

   A domestic Mode 3 chargepoint that receives commands from the Chargepoint Management System to switch charging on and off, and feeds data on energy consumption and SOC to the Chargepoint Management System.

2.4.6 Mainstream consumer choice between Managed Charging schemes

The systemic benefit from Managed Charging schemes depends not just on the size of the effects on charging behaviour that they generate, but also on how many Mainstream consumers choose to engage with them.

The Stage 1 qualitative research found that, among its 60 participants, around two-thirds preferred a User-Managed Charging scheme, and around one-third preferred Supplier-Managed Charging. However, it is not possible to generalise findings from that qualitative research to the future Mainstream consumer population, because the participants were largely EV Innovators (and thus were likely to have had different motivations for engagement with Managed Charging schemes generally). In addition, participants in Stage 1 were given only limited information and *no* direct experience of engagement with a Managed Charging scheme, meaning they were psychologically distant from them. It therefore follows that data are needed on Mainstream consumer choice between Managed Charging schemes in order to maximise the validity of the modelling framework.

In theory it would be possible to include behavioural measures of choice between User-Managed Charging (UMC) and Supplier-Managed Charging (SMC) in the BEV and PHEV Charging Trials. For example, one option would be to provide participants in both experimental groups with the option to opt-out of engagement with User- or Supplier-Managed Charging for any particular charging event, or the option to opt-out of one Managed Charging scheme in favour of the other. However, this type of design would pose substantial threats to the validity of the charging behaviour measurements. For example, allowing participants to opt-out of either scheme would in essence create four experimental groups, not two:

a) SMC default: Participant accepts
b) SMC default: Participant rejects
c) UMC default: Participant accepts
d) UMC default: Participant rejects

Allowing participants to opt-out in this way could therefore reduce, to an unacceptably low level, the total number of charging behaviour repeats experienced by those participants who did opt-out. Likewise, enabling users to switch between Managed Charging schemes could reduce the effective size of the experimental groups to an unacceptably low level.

Accordingly, it would not be valid to measure choice through behavioural measures in the Stage 2 Consumer Charging Trials. A more robust way of measuring consumer choice is to use a 'choice experiment'. This methodology presents participants with a series of choices between options that enable exploration of the way that choice is influenced by a range of attributes. This allows robust study of consumer choice to be conducted without compromising the validity of other data collected during the course of the trial.

For this project therefore, consumer choice in relation to Managed Charging schemes will be measured using a choice experiment. In principle the choice experiment could be conducted independently from the Stage 2 trial, with separate participants. However, given that EV Managed Charging is a new, unfamiliar product category, consumers are generally psychologically distant from it. The psychological distance reduction achieved through these trials is ideal for providing a robust pool of participants to engage with a choice experiment of this kind. The choice experiment will therefore be administered to participants in the Consumer Charging Trials at the end of the trial period (i.e. after they have had direct experience with an EV and a Managed Charging scheme).

The Consumer Charging Trials will inform a new choice model based on a choice experiment carried out with Mainstream consumers whose psychological distance from PHEVs and BEVs (and associated Managed Charging schemes) has been reduced through direct experience of them.

2.5 Research questions

The CVEI project aims to model the potential integration of UK aggregated EV charging demand into the wider UK energy system to 2050. The validity of that modelling depends on having a clear picture of the charging behaviours of mainstream consumers who drive BEVs and PHEVs.

In other words, to update the modelling framework, empirical data are required regarding the actual charging behaviours of Mainstream consumers. The Consumer Charging Trials will therefore address a core research question:

What is the charging behaviour of Mainstream consumers?

To have real-world value, it is necessary to measure Mainstream consumers' EV charging behaviour under particular sets of conditions that are designed to facilitate system-level optimisation. The potential of Managed Charging schemes to deliver a system-level benefit depends on how far they *change* the charging behaviour of Mainstream consumers, compared with their charging behaviour if not engaged in such a scheme. It is also necessary to understand the importance of other external influences on EV charging behaviour and overall EV charging demand. This leads to the following supplementary research questions:

1. How does the charging behaviour of Mainstream consumers when participating in a Managed Charging scheme compare with their behaviour when they are not?

2. How does the charging behaviour of Mainstream consumers when participating in a Supplier-Managed Charging scheme compare with their behaviour when participating in a User-Managed Charging scheme?
3. What are the diurnal, weekly and seasonal time profiles of charging when participating (or not) in a given Managed Charging scheme?
4. What are the between-participant variabilities in Mainstream consumer charging behaviour when participating (or not) in a given Managed Charging scheme?
5. How does charging behaviour vary with time over the first eight weeks of using and charging an EV, whether participating in a Managed Charging scheme or not?
6. How do Mainstream consumers interact with specific features of User- and Supplier-Managed charging?
7. What preferences do Mainstream consumers have between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?
8. What factors influence preferences between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?

3 Proposed method

3.1 Experimental design

The purpose of the Consumer Charging Trials is to investigate consumer responses and attitudes to alternative Managed Charging schemes which aim to manage energy demand associated with charging electric vehicles. Two separate trials will be conducted:

- a PHEV Charging Trial to investigate the attitudes and responses of Mainstream consumers who drive a PHEV, and;
- a BEV Charging Trial to investigate the attitudes and responses of Mainstream consumers who drive a BEV.

Each trial will use a between-participants Randomised Controlled Trial (RCT) design, in which participants are randomly allocated to one of three conditions; these will be two experimental conditions representing alternative Managed Charging schemes and a control condition in which participants charge their vehicles in the absence of a specific Managed Charging scheme. Each trial will have 120 participants, with 40 allocated to each condition.

Trial vehicles (either a BEV or PHEV) will be provided to participants for use in place of the vehicle the participant normally drives. Participants' own vehicles will be retained by the participants for the duration of the trial, except for the following circumstances:

1. in households where there are more drivers than vehicles; or
2. where (in the view of the Trial Participant) there is insufficient space to park an additional vehicle or a significant inconvenience or loss of utility would be experienced; or
3. where the Trial Participant wishes their own vehicle to be removed.

In these cases, the trial vehicle will be provided to participants as a replacement for one of the household vehicles, and the participant's own vehicle will be stored by the research team for the duration of the trial. Replacing the vehicles in these circumstances will ensure that the trial does not alter the household's vehicle use dynamics and inadvertently bias the data collected during the trial.

Participants will be incentivised to use and charge the vehicle through reward points (see Section 3.5.2). Participants will be encouraged, in the participant briefing and participant information pack, to use the vehicle for their everyday travel needs.

Participants will be asked to complete a series of questionnaires at different time points:

- **Recruitment**: Screening questionnaire to select eligible participants
- **Time point 1**: Before selected participants are provided with the BEV/PHEV
- **Time point 2**: After they experience the BEV/PHEV

Data related to journeys, driving performance, battery SOC and fuel consumption will be collected from vehicle telematics (see Section 3.10).

Upon receipt of completed 'Time point 1' and 'Time point 2' questionnaires, participants will be given compensation for their participation in the trial (see Section 3.5.2).

An overview of the methodology for the two Consumer Charging Trials is illustrated below.

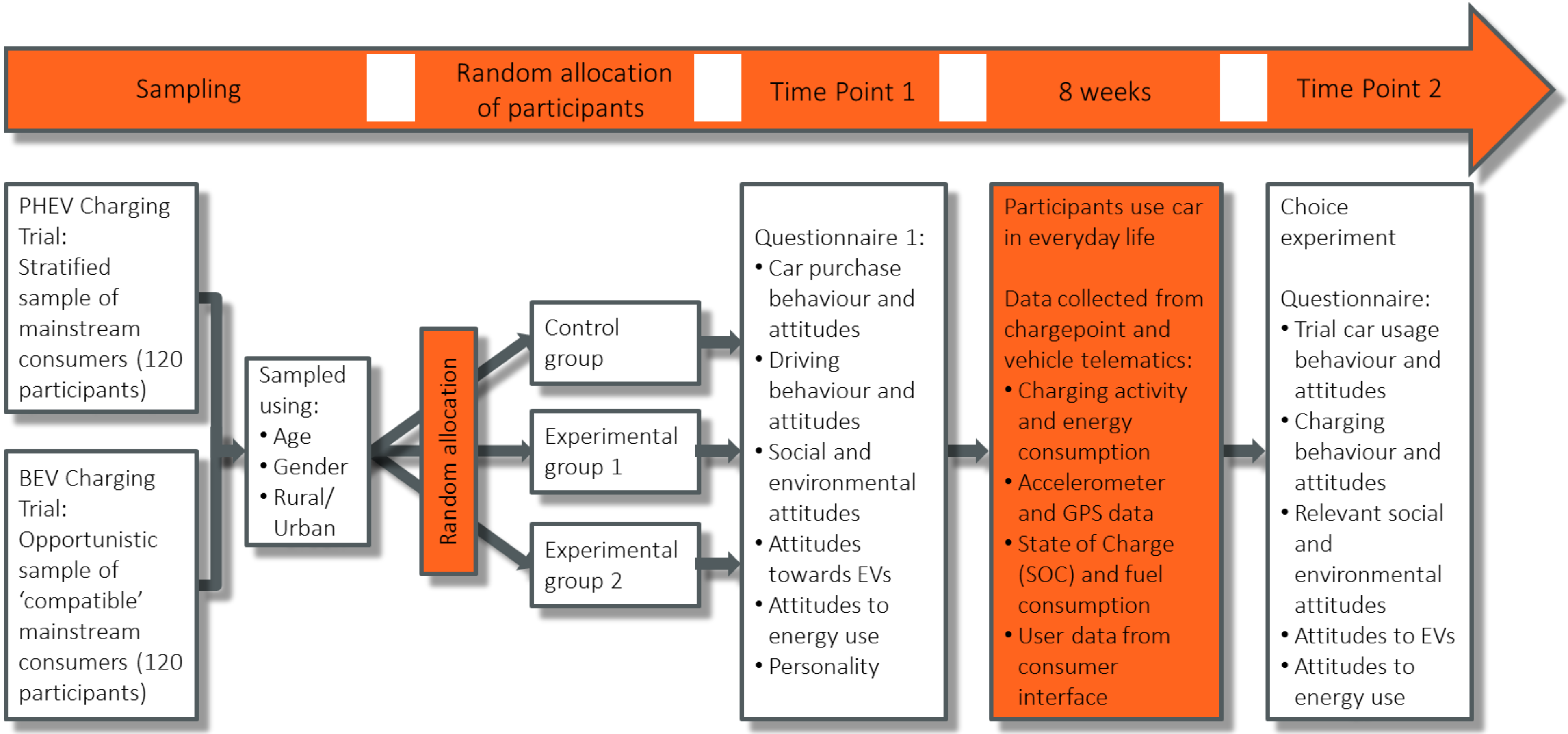

Figure 3: Overview of Consumer Charging Trials

As illustrated in Figure 3, the key differences between the two trials are the sample of consumers which the trials will recruit, and the vehicle type which that sample will experience. These differences are discussed further in the following sections.

3.2 Participants

3.2.1 PHEV Charging Trial

The PHEV Charging Trial will recruit 120 Mainstream consumers, defined as members of the driving population of Great Britain. To ensure that the sample is representative of this population, the 120 participants will be stratified according to driving licence, population and travel data from the National Travel Survey and the Office of National Statistics (ONS). The key metrics which have been used for this stratification process are age, gender and the resident area (i.e. rural or urban[11]).

Recruiting a stratified sample of 120 Mainstream consumers will ensure the sample is representative of the typical characteristics of drivers in Great Britain, avoiding the biases commonly associated with EV research which has traditionally recruited Innovators only.

The resulting target sample matrix is shown in Table 1.

Table 1: Target sample matrix for the PHEV Charging Trial[12]

Resident area	Age group[13]	Gender		Total
		Male	Female	
Rural	19-29	1	1	**2**
	30-49	4	4	**8**
	50+	7	6	**13**
Urban	19-29	9	7	**16**
	30-49	20	18	**38**
	50+	23	19	**42**
Total		**64**	**56**	**120**

3.2.2 BEV Charging Trial

Affordable C-segment BEVs currently available in the UK market claim an electric range of between 100 and 124 miles (see Table 2). With realistic everyday use, this stated range is likely to equate to an actual electric range of between 80 and 90 miles.

[11] The ONS defines urban areas as 'settlements of more than 10,000 people' and rural areas as 'smaller towns (less than 10,000 people), villages, hamlets or isolated dwellings (Defra Rural Statistics, May 2015).

[12] It has been suggested that consideration is given to increasing the proportion of younger participants in the sample. The impact on external validity of doing this will be explored at the start of Stage 2.

[13] 17-18 year olds will be excluded to mitigate known increased crash risk associated with young and novice drivers.

Table 2: Overview of BEVs currently available in the UK market

Segment	Make	Model	Base variant	Electric range (miles)
A	Citroen	C-Zero	47kW Auto	93
A	Mitsubishi	i-MiEV	Keiko 47kW Auto	93
A	Peugeot	iON	Electric 47kW Auto	93
A	Volkswagen	Up	e-Up! 60kW Auto	93
B	BMW	i3	Electric Car 127kW Auto	118
B	Kia	Soul	EV 81.4kW Auto	132
B	Renault	Zoe	Expression Nav 65kW Auto	149
C	Ford	Focus	Electric Car 107kW Auto	100
C	Mercedes-Benz	B-Class	Electric Drive B250 e Sport Auto	124
C	Nissan	Leaf	Visia 80kW Auto	124
C	Volkswagen	Golf	e-Golf 85kW Auto	118
F	Tesla	Model S	70 kWh Auto	275
M	Nissan	e-NV200 Evalia	80kW Tekna Rapid Auto 7-seat	106
M	Renault	Kango Maxi	Z.E LL 21 i-Maxi ZE 44kW Crew Auto	106

Due to this limited range, BEVs are only objectively suitable as substitute vehicles for a sub-set of the Mainstream consumer segment; that is, those whose travel patterns are consistent with the restricted range offered by BEVs currently available in the market. The sub-set for whom BEVs are *subjectively* suitable (i.e. those who themselves perceive that BEVs would meet their needs) may be even smaller.

For these reasons the travel needs of many individuals in the Mainstream consumer population will not be met by a currently available BEV. The BEV Charging Trial will therefore seek to recruit 120 Mainstream consumers whose vehicle needs are met by the current capabilities of BEVs available in today's market (this group will be called "Compatible mainstream consumers" - that is, Mainstream consumers for whom the vast majority of return journeys are shorter than 80 miles).

Recruitment of 120 Compatible mainstream consumers will require an opportunistic sampling approach. This technique will involve recruitment of interested individuals from the target population who meet the travel pattern (and other) eligibility criteria; but there may be limited opportunity to stratify the sample by other factors such as age, gender and location. As a result it will not be possible to ensure that this opportunity sample is fully representative of the Mainstream consumer segment as a whole. One particular issue which has potential to impact this trial is the possibility that Innovators who have yet to purchase an EV end up being recruited rather than 'Compatible mainstream consumers', as defined here. To mitigate this risk, it is proposed to exclude from the trial any consumer who is planning to purchase a plug-in, LPG or CNG vehicle in the next 3 years (see Section 3.3.1 for full details on the recruitment criteria).

The primary value of the BEV Charging Trial will be to investigate the charging behaviours of "Compatible mainstream consumers"; this will ensure that participants are able to use a BEV for their day-to-day travel, increasing external validity.

3.3 Recruitment

3.3.1 Recruitment criteria

A recruitment screening questionnaire will be administered to prospective participants in order to check their eligibility for the trial. The key eligibility criteria which participants must meet will be as follows:

- Full UK driving licence with fewer than 5 points, held for a minimum of two years[14]
- Currently owns and regularly drives an ICE car[15]. Where possible, preference will be given to recruits currently using a C-segment medium family hatchback, followed by those who self-report that a C-segment car will meet their functional needs
- Live within ~50 miles of TRL or Cenex
- Off-street parking available at home, with ability to accommodate installation of a Mode 3 chargepoint (subject to homeowner's approval)
- Must not have had a plug-in, LPG or CNG vehicle in the last 5 years
- Must not be planning to purchase a plug-in, LPG or CNG vehicle in the next 3 years
- Must not be a current customer of Economy 7 or pre-pay tariff
- Must not have or plan to have solar panels installed in home for duration of trial

In addition to these, in order to be eligible for the BEV Charging Trial participants daily travel patterns must be compatible with the capabilities of a BEV (see Section 3.2.2).

The screening questionnaire will also be used to obtain information relevant to the stratified sampling approach, and other key demographics which will be used to understand more detailed characteristics of the final participant sample:

- Age

[14] Terms subject to final agreement and acceptance by AVIVA insurance

[15] Ownership to include all forms (e.g. outright, lease, hire-purchase, personal contract purchase, user-chooser company car)

- Gender
- Rurality (urban or rural) (obtained via home postcode)
- Annual mileage
- Number of cars in household
- Number of drivers in the household
- Current domestic energy supplier and tariff

Use of the recruitment screening questionnaire will ensure that:

- **The final sample of participants matches the Mainstream consumer and Compatible mainstream consumer populations**
- **The sample is not biased by potential confounding factors identified during Stage 1 (such as the use of solar panels, Economy 7 energy tariffs, pre-pay tariffs, or previous recent experience/future intentions with ULEVs)**

3.3.2 Recruitment strategy

Recruitment adverts will be used to promote the study in the target geographical locations (i.e. Wokingham, Loughborough and surrounding areas). The adverts will provide a URL to direct interested individuals to an online screening survey.

Adverts will be distributed via several media:

- **TRL's participant database**:

  A database containing over 2,000 members of the public, local to TRL, who have registered to take part in research.

- **Social networking**:

  Use of LinkedIn, Facebook and Twitter to target adverts by location, age and gender.

- **Company websites**:

  Large businesses local to TRL and Cenex will be asked to disseminate details of the study amongst their staff.

- **Local newspapers**:

  Publication of adverts in print and online newspapers.

- **Local noticeboards and forums**:

  Publication of adverts in supermarkets, community centres, local online forums, etc.

- **Word of mouth**:

  Participants will be asked to inform friends and family of the trial. Participants will be limited to one per household, but otherwise, friends and family of current or previous participants will be permitted to take part (assuming they fall within the recruitment criteria listed in Section 3.3.1).

This varied approach has been developed by TRL over many years of experience in recruiting large samples of research participants. Use of a variety of methods will maximise the opportunity to target and secure the required participant sample for this trial, whilst minimising self-selection bias as far as possible.

3.4 Vehicles

A market analysis of BEVs and PHEVs currently available in the UK was performed to identify possible vehicles for the two trials. Since B- and C-segment vehicles account for approximately 35% and 25% of the UK vehicle fleet, respectively (Society of Motor Manufacturers and Traders [SMMT], 2015), a shortlist was developed using B and C-segment vehicles only (see Table 3)[16].

Table 3: B- and C-segment BEVs and PHEVs in the UK market (April 2016)

Make	Model	Base variant	Segment	Electric range (miles)	List price (£)
Plug-in Hybrid Electric Vehicles (PHEVs)					
Audi	A3	Sportback e-tron 1.4 TFSI 150PS S Tronic	C	31	35,690
Volkswagen	Golf	1.4 TSI GTE DSG	C	31	33,995
Battery Electric Vehicles (BEVs)					
BMW	i3	127kW Auto	B	118	30,980
Ford	Focus	107kW Auto	C	100	31,145
Kia	Soul	EV 81.4kW Auto	B	132	29,995
Mercedes-Benz	B-Class	Electric Drive B250 eSport Auto	C	124	32,275
Nissan	Leaf	Visia 80kW Auto	C	124	25,790
Renault	Zoe	Expression Nav 65kW Auto	B	149	18,445
Volkswagen	Golf	e-Golf 85kW Auto	C	118	31,650

This market analysis identified 7 models of BEV and 2 models of PHEV (with an official stated electric range of at least 50km) which are currently available in the UK and are classified as either B- or C-segment vehicles. The VW Golf GTE is one of the only C-segment PHEVs with an official stated electric range greater than 30 miles. The only other C-segment PHEV is the Audi A3 Sportback, which is a premium version of the VW Golf GTE.

[16] PHEVs were limited to those with at least 50km of electric range.

The Golf GTE therefore represents the optimal choice of PHEV.

In order to enable a comparable vehicle experience between the PHEV Charging Trial and BEV Charging Trial, the BEV must also be C-segment.

The VW Golf is the only vehicle to offer comparable models of BEV and gasoline PHEV. Accordingly, this vehicle represents the most appropriate vehicle selection.

Use of the BEV equivalent to the PHEV Golf GTE (i.e. the e-Golf) is the optimal choice for the BEV Charging Trial since it will allow identical data collection methodologies to be employed between the two trials. This will represent a significant cost and time saving compared with using either of the other non-premium C-segment BEVs (Ford Focus or Nissan Leaf).

The number and type of vehicles required for the two trials is shown in Table 4.

Table 4: Number and type of vehicles required for the two charging trials.

Trial	Vehicle type	Number required
BEV Charging Trial	VW e-Golf	30
PHEV Charging Trial	VW Golf GTE	30
	Total	**60**

OEM-provided statistics regarding the range and charging specifications of the VW e-Golf and VW Golf GTE are summarised in below:

Table 5: OEM-statistics on BEV and PHEV range and charging specifications

Range / charging specification	Golf GTE	e-Golf
Maximum range (miles)	31	118
Expected range (miles)	25	90
Charge time from 0-100% (AC) 2.3kW (hours)	3.75	13
Charge time from 0-100% (AC) 3.6kW (hours)	2.25	8
Charge time from 0-80% (DC) (hours)	n/a	0.5

This pool of vehicles will allow the total target sample of 240 participants (120 per trial) to be achieved within approximately 12 months.

3.5 Experimental conditions

Both the PHEV Charging Trial and the BEV Charging Trial will employ identical experimental conditions. The detail provided in this section therefore applies to both trials.

Trial participants will be randomly allocated to one of three groups; the group into which participants are allocated will determine the Managed Charging schemes (experimental conditions) which they will experience during the trial (see Table 6):

Table 6: Managed Charging schemes (Experimental conditions)

Group	Managed Charging schemes (Experimental conditions)	
1	**Control group: Consumer charges as they wish**	Participants will be free to charge when they want, with no financial or other incentives for charging in a particular way. This will establish a baseline for energy use when there are no constraints placed on the consumer, so that comparisons can be made with each of the experimental groups.
2	**Experimental group 1: User-Managed Charging**	Participants will be encouraged to actively manage their charging, through the provision of financial incentives to charge at particular times of day. This will be used to understand energy use when consumers are encouraged to engage with a User-Managed Charging scheme.
3	**Experimental group 2: Supplier-Managed Charging**	Participants will be encouraged to delegate management of their charging to the (simulated) energy supplier. Participants will be provided with financial incentives for relinquishing control[17] of when their vehicle is charged. This will be used to understand energy use when consumers are encouraged to engage with a Supplier-Managed Charging scheme.

3.5.1 Simulation of energy prices and potential cost savings

For experimental group 1 (User-Managed Charging scheme), the structure of the banded tariffs to be simulated in the trials will be determined in the preparation phase of Stage 2, based on outputs from the Stage 1 initial modelling analyses.

Likewise, for experimental group 2 (Supplier-Managed Charging scheme), the structure of the reward scheme to be simulated in the trials will also be determined in the preparation phase of Stage 2. This preparation work will also include development of a Cost Model to determine a representative seasonal and stochastic variation in supply-side cost of electricity, which can then be simulated in the trials through the implementation of appropriate levels of reward for given charging behaviours.

[17] As discussed earlier, "control" here, and throughout this document, is used not in relation to any specific theoretical construct, but rather to reflect the language used by participants in the Stage 1 qualitative study.

The Cost Model will incorporate diurnal, weekly, seasonal, and weather-dependent variations in both supply and demand, and variations in demand due to social factors. It is anticipated that the full range of variation of actual costs of supply would not be passed onto the user, but would be instead smoothed for the purposes of the experimental condition. Thus, the Cost Model should reflect the smoothed costs – those that will actually be passed onto participants in experimental group 2.

3.5.2 Trial incentives and charging processes

As part of Stage 1, a literature review was conducted by the Behavioural Insights Team (BIT) to understand the validity of using different forms of incentives in behavioural research. The key findings from this literature review have been used to inform the design of the trial incentives.

It is first important to distinguish between two types of incentive:

1. an incentive to participate in a research trial, and;
2. an incentive designed to influence a particular behaviour during a research trial.

The former of these will be referred to as 'compensation' (for participating), and the latter as an 'incentive' (to encourage engagement with particular Managed Charging schemes).

Fundamentally, it is important to ensure that compensation and incentives are psychologically separated so that one does not distort the effect of the other. This will be achieved via two approaches:

- Taken together, the compensation and incentives will be equivalent to a total offering of £250, but will take two distinct forms:
    - Compensation will be provided in the form of Amazon vouchers, so as to remove the likelihood that the value of the compensation will be psychologically offset against expenditure on electricity bills during the trial.
    - Incentives will be provided in the form of a points-based reward system, where desired charging behaviours are rewarded with points. Points will be accumulated and redeemable against a cash lump-sum at the end of the trial (the monetary value of points will be determined during the preparation phase of Stage 2; values will be mapped against realistic energy savings achievable through such Managed Charging schemes).
- The compensation and the incentives will be provided at different points in time:
    - Compensation will be provided both at the start of the trial, before participants collect the trial vehicle (once 'Time point 1' questionnaires have been completed), and at the end of the trial (once the final 'Time point 2' questionnaires have been completed).
    - Participants will be provided with the status of their points in real-time throughout the trial, and alerted when actions result in points. Total accumulated points will be converted to cash at the end of the trial (once the final 'Time point 2' questionnaires have been completed). The specific ways

in which participants will engage with the tariff conditions in order to receive reward points are described in the following sections.

In addition to the guaranteed compensation and the incentives, participants who complete the trial (i.e. those who complete the Time point 2 questionnaires) will be entered into a prize draw for a chance to win £2,500.

3.5.2.1 *Control group: Charge as you wish*

Participants in the control group will be free to charge their vehicle as they wish. There will be no incentives provided for charging in a particular way. Instead, participants will be incentivised to charge their vehicle at least twice per week, and for every week in which their vehicle is charged at least twice (for more than 1 hour per charge event) they will be credited with points. Participants will be able to accumulate points over the course of the 8-week period.

For participants in the control group, the assumed day-to-day charging process is as follows:

1. User plugs-in
2. User plugs-out when they wish
3. Points credited to user account on weekly basis

In order to ensure that the experience of using and charging the vehicle during the trial is representative of normal EV ownership, participants in the control group will be free to utilise the VW Car-Net mobile phone application[18], or other third-party applications, if they wish to do so. Items will be included in the Time point 2 questionnaires to ask participants about which apps they used, if any, and what their experience was like.

3.5.2.2 *Experimental group 1: User-Managed Charging scheme*

Participants in experimental group 1 will be encouraged to manage their vehicle charging themselves.

Participants will be incentivised to charge the vehicle during particular times of the day via a simulated four phase User-Managed Charging tariff. The structure of this tariff and level of reward (number of points) available to consumers will be informed by analysis performed in WP1a, and finalised during the preparation phase in Stage 2 to ensure that the experimental condition provides high internal and external validity.

At the beginning of the trial, participants will be informed of the structure of the tariff and how the level of reward available is related to the times at which the vehicle is charged. This will ensure that participants are provided with sufficient information upon which to base their charging decisions. Users will be able to select a default time when the vehicle should begin charging (e.g. 22:00). Upon plug-in, the vehicle will begin charging at this default time, unless the user chooses to override the default and specify a new charge start time, or chooses to start the vehicle charge immediately.

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[18] Details about this application can be found here: http://www.volkswagen.co.uk/technology/car-net/e-remote

Therefore, for participants in experimental group 1, when charging at home the day-to-day process will be as follows:

1. User plugs-in at home charge point
2. User reminded of default charge start time via smartphone notification
3. User presented with three options via the smartphone application:
    a. Accept default charge start time (system will accept default automatically in the event of no user input)
        i. System calculates required time to fully charge and presents to user
        ii. System reminds user of level of reward available
        iii. Vehicle begins charging at default time
    b. Adjust charge start time
        i. User chooses new charge start time
        ii. System calculates required time to fully charge and presents to user
        iii. System reminds user of level of reward available
        iv. Vehicle begins charging at time specified
    c. Begin charge immediately
        i. System calculates required time to fully charge and presents to user
        ii. System reminds user of level of reward available
        iii. Vehicle begins charging immediately
4. User plugs-out when vehicle needed
5. Reward credited to user account

This charging process is illustrated in Figure 4 below.

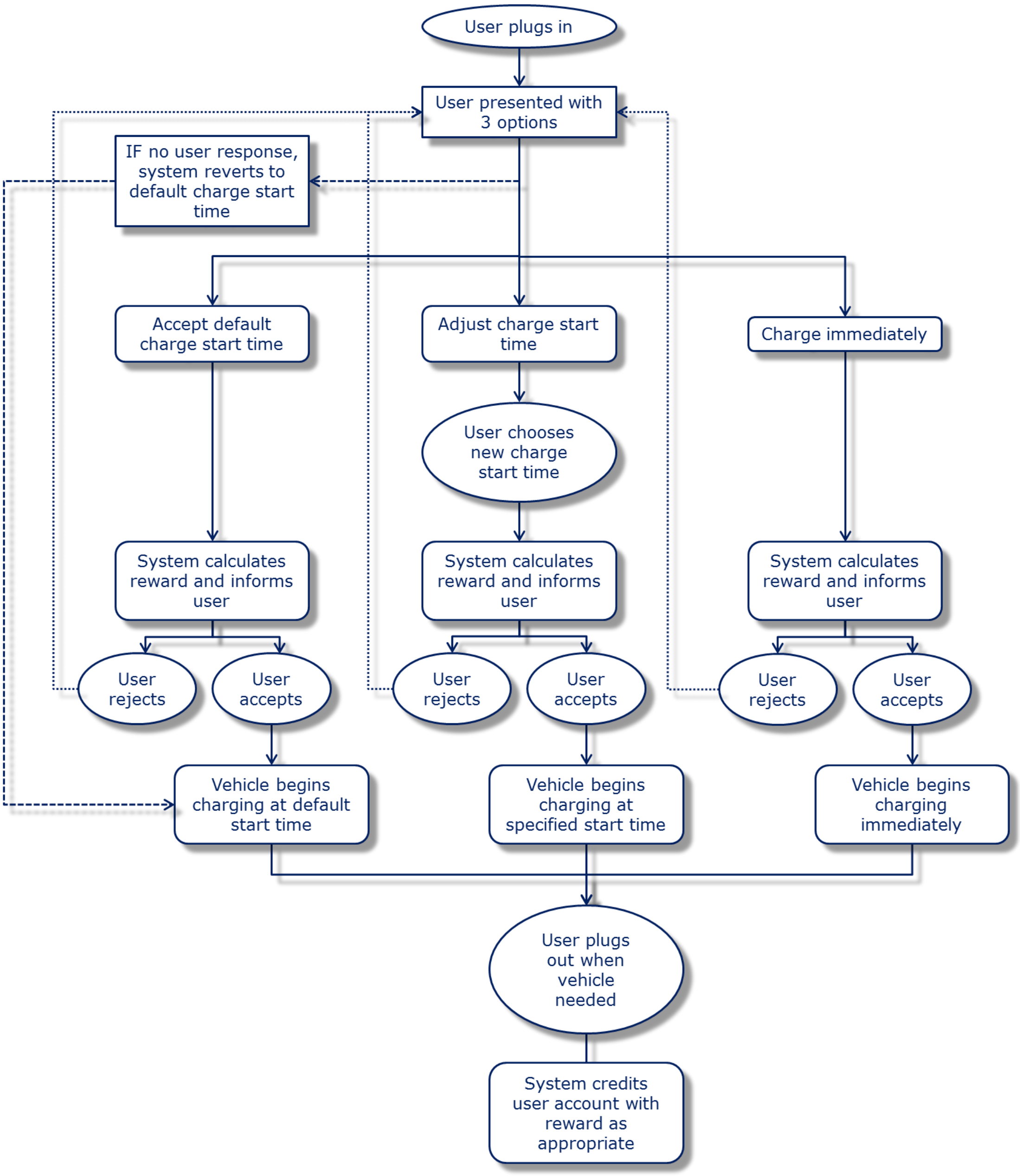

Figure 4: Day-to-day charging process for participants in experimental group 1

To help illustrate the concept of this experimental condition, an example User-Managed Charging tariff structure is shown in Table 7.

Table 7: Example User-Managed Charging scheme reward structure

Time period	Band	Example reward points per hour of charging
06:00-09:00	High	0
09:00-18:00	Standard	4
18:00-22:00	High	0
22:00-06:00	Low	10

In this example, the number of points consumers receive would be dependent on the duration and timing of charging. For example, charging for 4 hours between 2200 and 0600 would be awarded 10 points per hour, 40 points in total. Likewise, charging for 4 hours between 1600 and 2000 would be awarded 4 points per hour from 1600-1800, and 0 points per hour from 1800-2000, totalling 8 points. Charging time would be rounded to the nearest half-hour, and points would be awarded accordingly. For example, 4 hours and 20 mins of charging between 22:00 and 02:20 would be rounded to 4.5 hours and awarded 45 points.

Rewards could be structured as follows, for example:

- 40 points equivalent to £1
- Minimum of one hour of charging required to be eligible for rewards
- Maximum 80 points per charge event (i.e. hourly points will not be awarded after the first 8 hours of a single charging event)
- Maximum 500 points per 7-day period
- Maximum 4000 points over entire 8-week trial period (e.g. equating to £100)

As discussed above, the specific structure of this tariff and the level of reward available to consumers will be finalised during the preparation phase in Stage 2; this will ensure that the reward system is representative of the likely 'real-world' implementation of User-Managed Charging schemes in the future.

The specific structure of User-Managed Charging scheme reward system will be finalised during the preparation phase in Stage 2; this will ensure that the reward system is representative of the likely 'real-world' implementation of User-Managed Charging schemes in the future.

3.5.2.3 Experimental group 2: Supplier-Managed Charging scheme

Participants in experimental group 2 will be encouraged to delegate management of their vehicle charging to the supplier. Participants will be incentivised to plug the vehicle in for longer than the required charging time, thus allowing the supplier to manage when charging takes place.

As with experimental group 1, the structure of the reward system will be informed by analysis performed in WP1a, and finalised during the preparation phase in Stage 2 to ensure that the experimental condition provides high internal and external validity.

At the beginning of the trial, users will be informed about the level of reward available when delegating charging to the supplier. Users will be able to specify defaults in the smartphone app; they will be asked to specify their desired default SOC and the time they usually need the charge completed. Upon plug-in these defaults will be selected unless the user chooses to override the default and specify a new SOC and charge finish time, or requests that the vehicle begins charging immediately.

For participants in experimental group 2, when charging at home, the day-to-day charging process will therefore be as follows:

1. User plugs-in
2. User reminded of default SOC and charge finish time via smartphone notification
3. User presented with three options via smartphone app:
    a. Accept default SOC and charge finish time (system will accept defaults automatically in the event of no user input)
        i. System calculates Managed Charging Availability Ratio (MCAR)[19]
            1. If MCAR < 1, user informed that no reward available
            2. If MCAR > 1, user informed of level of reward available
        ii. Managed charging initiates (unless user overrides)
    b. Adjust SOC and charge finish time
        i. User chooses desired SOC and time for charge to be complete
        ii. System calculates MCAR
            1. If MCAR < 1, user informed that no reward available
            2. If MCAR > 1, user informed of level of reward available
        iii. User confirms choice
        iv. Managed charging initiates
    c. Begin charge immediately (override)
        i. System informs user that no reward available
        ii. Vehicle begins charging immediately
4. User plugs-out when vehicle needed
5. Reward credited to user account

This charging process is illustrated in Figure 5 below.

[19] MCAR is ratio of time required for charging the battery to its prescribed level versus the time available.

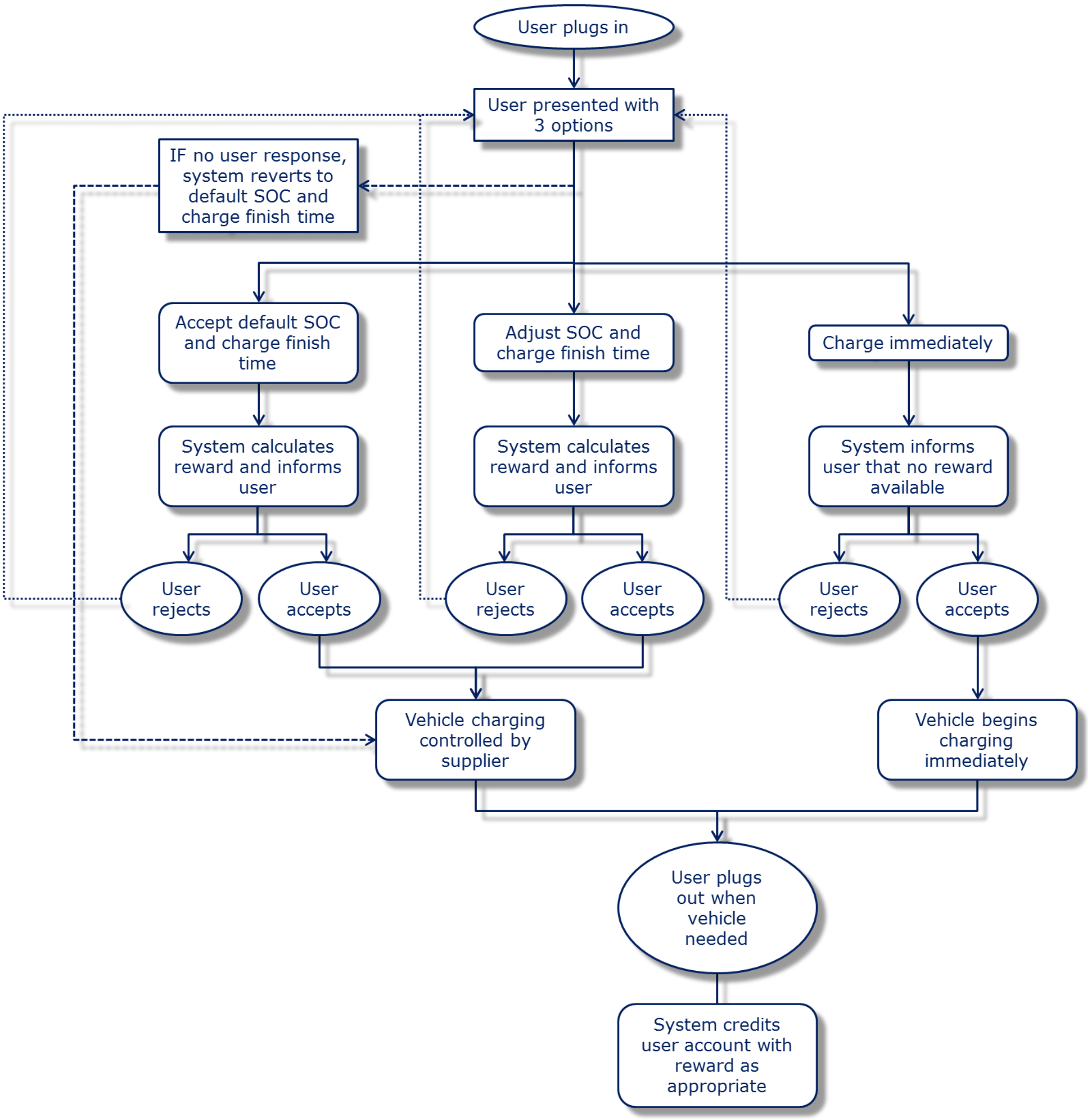

Figure 5: Day-to-day charging process for participants in experimental group 2

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The specific structure of Supplier-Managed Charging scheme reward system will be finalised during the preparation phase in Stage 2; this will ensure that the reward system is representative of the likely 'real-world' implementation of Supplier-Managed Charging schemes in the future.

3.6 Procedure

3.6.1 *Piloting*

The aim of piloting vehicle data collection, questionnaires and the trial procedure is to identify issues and mitigate potential confounds during data collection, ensuring maximum internal validity during the trial. The piloting process will be as follows:

- All questionnaires and the choice experiment will be piloted internally at TRL to ensure that the wording of questions is understandable for participants, that the questionnaires can be completed in a reasonable timeframe, and that the delivery methods are functional.
- The vehicle telematics data collection system (and post-processing procedure) will be fully tested to ensure that meaningful and valid data are obtained from the vehicles.
- The Chargepoint Management System (CPMS) – see Section 3.8 – will be fully tested to ensure that the user interface, data collection and chargepoint are functioning correctly.
- The full trial procedure (including questionnaires and telematics) will be piloted with naïve participants. The pilots will recruit up to three participants and will provide an opportunity to fully test all data collection tools and trial procedures.

This piloting process will ensure the methodology is fit-for-purpose before starting data collection for the full trials.

3.6.2 *Day-to-day running of the trials*

Trials will be run from two separate locations in the UK:

- TRL headquarters (Crowthorne House) in Wokingham, Berkshire
- Cenex headquarters in Loughborough, Leicestershire

The use of two locations will allow recruitment of participants from a wider geographical area than if only one location was used; this will increase the robustness of the participant samples.

The trial procedure will be identical for both the PHEV Charging Trial and the BEV Charging Trial. An overview of this procedure is provided below:

Recruitment

1. TRL will identify potential participants through use of recruitment databases and advertising methods. Participants will be recruited from within a 50-mile radius of either TRL or Cenex headquarters.
2. TRL will screen potential participants, using an online screening questionnaire to determine suitability for the trial.
3. TRL will invite suitable participants to take part in the trial.

4. TRL will provide participants who agree to take part with an online trial information pack and consent form so that informed consent can be obtained.
5. TRL will assign participants with a unique reference number.

Chargepoint installation

6. TRL will forward participants' contact details to the Chargepoint Sub-contractor. The sub-contractor will contact the participants to arrange installation of the chargepoint at participants' homes (including any necessary site surveys).
7. The Chargepoint Sub-contractor will install the chargepoint in the participants' homes.

Time point 1 questionnaires

8. TRL will ask participants to complete the 'Time point 1' online questionnaires, quoting their unique reference number so that responses can be identified.
9. TRL will compensate participants for completion of the 'Time point 1' questionnaires (see Section 3.5.2).
10. TRL will randomly assign participants to one of three groups (control group, experimental group 1, or experimental group 2). Participants will not be told which group they are in.
11. TRL will assign each participant with a dedicated Trial Manager (at either TRL or Cenex as appropriate) to arrange the collection and return of vehicles.

Vehicle collection

12. The Trial Manager will arrange the date and time for collection and return of the vehicle from the trial headquarters (TRL or Cenex).
13. Participants will collect the vehicle from trial headquarters at the date and time specified. The Trial Manager will take the participant through the vehicle handover process.
14. The Trial Manager will log the date and time of collection, the Participant ID and the Vehicle ID.
15. Participants will use the vehicle during their normal day-to-day activities for a period of 8 weeks.
16. The Trial Manager will follow-up with a phone call to the participant after 3 days and after 10 days to answer any further questions, check that the vehicle and chargepoint systems are functioning correctly and that they have been using the vehicle.

Vehicle return

17. Participants will return the vehicle to trial headquarters at the end of the 8-week period.
18. The Trial Manager will log the date and time of return, the Participant ID and the Vehicle ID.

19. The Trial Manager will complete a vehicle 'walk-around' to record the condition of the vehicle.

Time point 2 questionnaires and trial end

20. The Trial Manager will ask participants to complete the 'Time point 2' online questionnaires (approximately one day after return of the vehicle).

21. TRL will compensate participants for their involvement in the trial upon completion of the final questionnaires.

22. Where requested by participants, the Chargepoint Sub-contractor will remove the chargepoints from participants' homes.

This trial procedure will be standardised to minimise any potential bias resulting from differences in vehicle handovers between the two locations (TRL and Cenex).

All staff will receive identical training on the trial procedure to ensure that it is fully understood before the trial commences.

3.6.3 Research team training

TRL will run a training workshop with TRL and Cenex staff prior to the trials commencing to ensure that all staff involved in the trial procedure are fully briefed. This will include specific training on the vehicles from VW representatives.

At the start of the trials, the TRL Trial Manager will attend the first few trial days at Cenex to ensure consistency across the two trial locations.

3.6.4 Vehicle handover process

The vehicle handover process will include a 'walk-around' of the vehicle to check for scratches and dents, an explanation of how to use key instruments (e.g. lights, climate control, etc.), a demonstration of charging (PHEV and BEV only), a briefing on the materials in the vehicle information pack, and a short familiarisation drive with the Trial Manager. Specific tasks will include:

- Ensuring the interior and exterior of vehicles are clean and tidy before participant collection (a professional valet service will be utilised to ensure all vehicles are fit for purpose before given to participants).
- Ensuring BEV and PHEV vehicles have a minimum of 80% charge. It is desirable for all BEVs and PHEVs to have 100% change at participant collection but this may not be possible in some circumstances depending on the time available and level of charge on previous participant return.
- Performing routine safety and maintenance checks on the vehicles to ensure the vehicles are safe and fit for purpose, i.e. F-L-O-W-E-R:
    - **Fuel**: Check fuel levels.
    - **Lights**: Clean and check all exterior lights are working.
    - **Oil**: Check oil and other fluid levels (as appropriate).

- **Water**: Check coolant and windscreen washer levels.
- **Electrics**: Check for highlighted warning signs on vehicle ignition.
- **Rubber**: Check tyre pressure and tyre condition.

3.7 Chargepoints

3.7.1 3.6 vs. 7.2 kW charging

For the purposes of these trials, a dedicated Mode 3 chargepoint will be installed at each participant's home. Domestic chargepoints currently available in the EVSE market are typically rated for 3.6kW or 7.2kW power transfer. It is predicted that 7.2kW installations will become more common in UK homes over the next few decades. But, at present, many households in the UK, particularly those older than 20 years, will not have the capacity to accommodate 7.2kW charging since they are likely fused for a maximum current draw of 60A. A 7.2kW chargepoint brings a current draw of approximately 30A on its own; therefore the maximum of 60A will likely be exceeded if a 7.2kW chargepoint is used in combination with other electrical appliances in the household.

For this trial it was decided that a 3.6kW chargepoint would be the most appropriate option. Two main factors drove this selection. Firstly, (for reasons outlined above) the domestic wiring circuits of most UK households should be able to cope with this level of charging without any overall strain being put on household power consumption, or any increase in safety risk. This means a broader pool of participants will be available to take part in the study, even if they live in older houses or houses without a high capacity wiring system; thus maximising the ability to recruit a representative sample of Mainstream consumers. Using a 7.2kW chargepoint would either have ruled out a number of potential participants, or would have incurred time and cost penalties associated with upgrading domestic wiring.

The second main determining factor in the selection of a 3.6kW chargepoint over a 7.2kW one is that the UK market PHEV VW Golf GTE and BEV VW e-Golf are currently only capable of receiving charge at a maximum rate of 3.6kW. Therefore, a more powerful chargepoint would provide no additional benefit to participants during the course of the study, even if their domestic wiring was sufficient or appropriately upgraded to handle 7.2 kW.

3.7.2 Required chargepoint specification

A minimum required specification for the chargepoints has been developed by TRL, EV Connect, Cenex and EDF (Table 7). Fundamental aspects of this specification included:

- The ability of the chargepoint equipment to communicate with the CPMS
- Compatibility between the chargepoints and the VW e-Golf and VW Golf GTE
- Compliance with relevant safety standards (e.g. IET's Code of Practice on Electric Vehicle Charging Equipment Installation[20]).

[20] Code of Practice for Electric Vehicle Charging Equipment Installation (2nd Edition): http://www.theiet.org/resources/standards/ev-cop.cfm

Table 8: Preferred chargepoint specification

Mode	Mode 3 (IEC 61851)
Connector	Tethered IEC 62196 Type 2 (aka. Mennekes)
AC Voltage	230Vac +10% / -6%
Nominal input current	16A
Nominal input power	3.6kW
Required power supply capacity	3.6kVA
Frequency	50Hz
Maximum output power	3.6kW
Maximum output current	16A
AC output voltage	230Vac 1P + N
Cable length (connector type)	4m or longer (tethered)
Connector holster	Integral
Enclosure rating	NEMA 3R / IP44 or better
Circuit protection	MCB + RCD or RCBO
Metering	Class 1 kWh meter
Installation mode	3+ point wall mount
Operating temperature	-10 to +45°C
Operating humidity	95% RH non-condensing
Status lights	Three colour LED: ready, charging, fault
Cellular network comms.	Wi-Fi / GSM (or better)
EVSE application comms.	Open Charge Point Protocol (OCPP) v1.5

3.7.3 Chargepoint suppliers

A Request for Quotation was distributed to 25 charge point manufacturers and suppliers identified through a market scoping exercise. This provided details of the technical and safety specifications necessary to meet the requirements of this trial, including the number of units needed, installation work, technical support and possible removal requirements on completion of the trial.

The preferred supplier will be confirmed during the preparation phase of Stage 2, once contracts for Stage 2 of the project have been put in place.

3.7.4 Public charging

To encourage participant use of the trial vehicles and provide a representative experience of EV ownership, participants will be given access to a public charging scheme in the relevant trial areas (TRL or Cenex).

The schemes that are in use in these areas are:

- **Chargemaster Polar Plus:** a membership-based scheme with a flat monthly charge, giving access to over 4000 chargepoints across the country. The majority of these chargepoints are free to use; some charge about 9p/kWh.
- **Chargemaster Polar Instant:** a Pay-As-You-Go system, managed and operated through a smartphone app. Users are required to register and load their account with a minimum of £20 credit. They can then access Polar network chargepoints for a fee of £1.20 per use, plus any electricity costs.
- **Charge Your Car:** a Pay-As-You-Go network accessible either through a £20 swipe card or a smartphone app (for free), providing access to over 2000 chargepoints, as well as a number of regional networks. These include a mixture of free-to-use and priced chargepoints.
- **Ecotricity Electric Highway:** free-to-use chargepoints managed by Ecotricity along the motorway network, mainly at motorway service areas. Access requires a swipe card which is provided free upon registration.

Both the Chargemaster options, and Charge Your Car option, offer coverage in the two geographical areas where the trials will be run. The Ecotricity network offers easy to locate charging options if participants choose to travel longer distances or regularly use the motorway network.

The schemes that will be provided to participants during the trial will be determined at the start of Stage 2 based on an assessment of geographical coverage, administrative impact on the trial and support offered by scheme providers.

3.7.5 Access to VW, or other, apps

During the preparation phase of Stage 2, the VW Car-Net mobile phone application, and other third-party vehicle/charging applications, will be reviewed. It might be argued that participants in the control group of the Consumer Charging Trials should be free to utilise these types of applications, if they wish to do so, since that would be most representative of the ‘normal’ charging experience in the real-world. However, it will be important to ascertain whether or not use of these third-party applications is likely to introduce confounds into the trial design, for example, if the user experience with third-party apps differs greatly from the experience offered by the bespoke User Interface designed for the purposes of this trial (Section 3.9).

If the VW, or third-party, applications are found to conflict with the objectives of the dedicated User Interface developed for this trial, or if they are found to introduce potential confounds into the trial, then participants will not be allowed to use them. In this instance, one possible mitigating step could be to block access to the VW Car-Net app through assistance from the OEM.

3.8 Chargepoint Management System (CPMS)

This section details the requirements for the Chargepoint Management System (CPMS) which will manage the presentation of the Managed Charging schemes to participants, feed information to and process information from the User Interface (smartphone app), collect data from the vehicles and chargepoints, and process the data into a usable format, saving it into the Research Database (Section 3.10).

3.8.1 System overview

The system will encompass the vehicles, the drivers who operate the vehicles, the chargepoints which charge the electric vehicles, and the cloud-based Chargepoint Management System (CPMS) which will:

i. control and manage the interactions between these constituents, and;

ii. collect and process the information generation during the trial.

The CPMS will act as intermediary between all of the components and will log all interactions.

- The vehicle will communicate location, status and other relevant information to the CPMS.
- Vehicle information will be processed and served to the driver from the CPMS through a mobile application on their smartphone enabling the driver to make decisions about charging their vehicle.
- Decisions from the driver will be processed by the CPMS which controls the chargepoint.
- Regularly updated status from the vehicle will be received by the CPMS and used to drive chargepoint behaviour.
- Charge session status is used to inform the driver of charging progress.

An overview of the CPMS is shown in Figure 6.

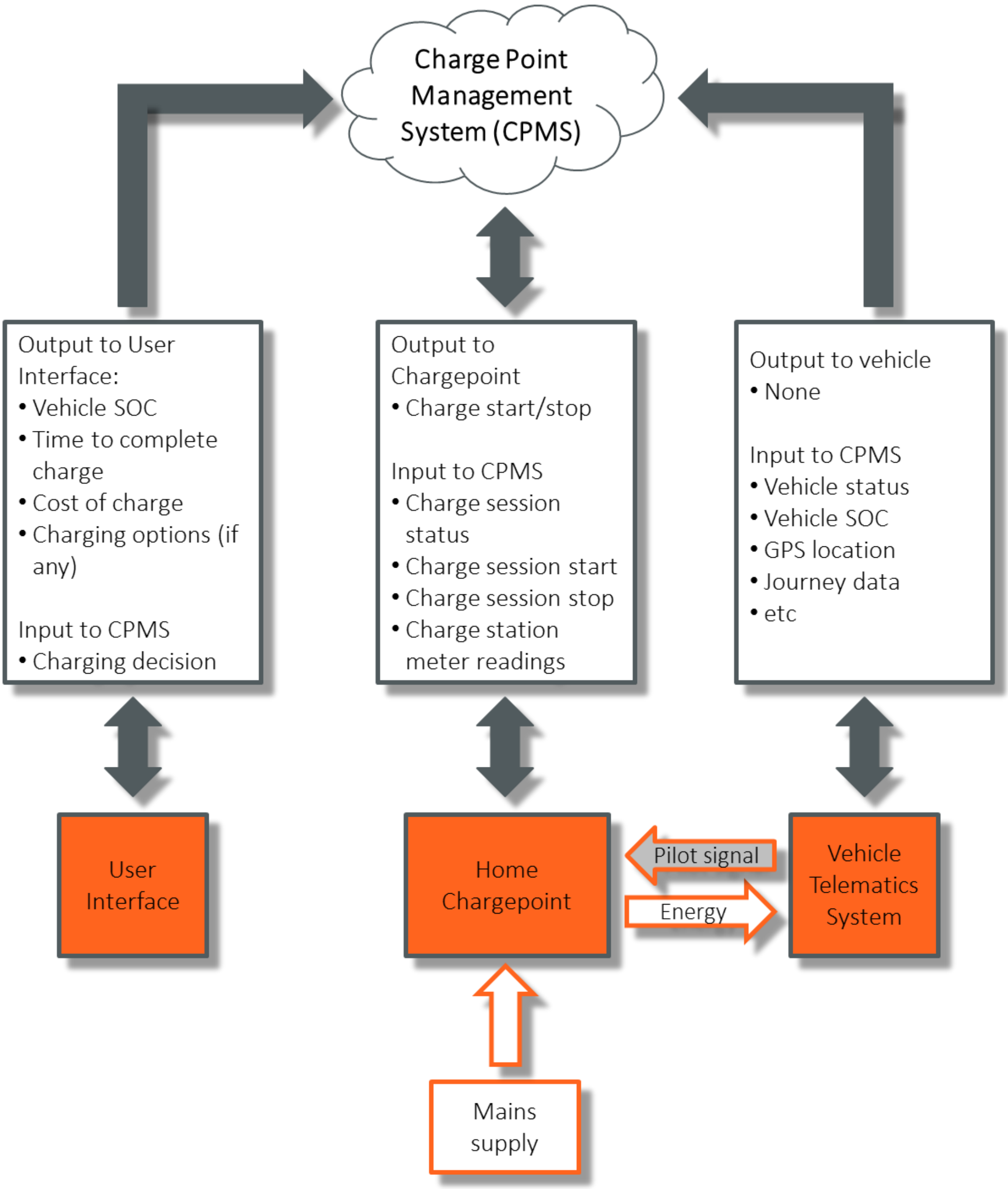

Figure 6: Overview of Chargepoint Management System (CPMS)

3.8.2 Control group

The CPMS will collect information about the location of the vehicle at plug-in to confirm that the vehicle is charging at home. If it is, then it will start the charge session. If not, then the CPMS will record the fact that a charge session is taking place at a location other than home.

The CPMS will also collect vehicle data at plug-in, plug-out and at regular intervals throughout the charge cycle (see Section 3.1).

When the charge session is complete and the vehicle stops charging, the CPMS will notify the driver that the vehicle is fully charged.

If the vehicle is unplugged from the chargepoint before the charge session is complete, the CPMS will record the SOC and various other parameters at plug-out.

3.8.3 *Experimental group 1: Simulation of SToU tariff*

The CPMS will monitor the location of plug-in events to confirm whether or not the vehicle is being plugged in at home. When charging at home, the CPMS will control the actual start of the charge session, dependent on the user inputs via the User Interface (smartphone app). If not at home, then the CPMS will record the fact that a charge session is taking place at a location other than home.

The user may choose to accept the default charge start time, choose a new charge start time, or start charging immediately. In the event of no input from the user, the previously set-up defaults will be selected automatically by the system.

During charging the CPMS will continuously monitor the charge session and the vehicle parameters, and will provide the driver with updated status via the User Interface.

If the vehicle is unplugged from the chargepoint before the charge session is complete, the CPMS will record the SOC and various other parameters at plug-out.

When the charge session is complete and the vehicle stops charging, the CPMS will notify the driver that the vehicle is fully charged. The CPMS will also inform the user about the level of reward received via the User Interface.

3.8.4 *Experimental group 2: Simulation of supplier managed charging*

The CPMS will monitor the location of plug-in events to confirm whether or not the vehicle is being plugged in at home. When charging at home, the CPMS will control the actual start of the charge session, dependent on the user inputs via the User Interface (smartphone app). If not at home, then the CPMS will record the fact that a charge session is taking place at a location other than home.

The user may choose to accept the system defaults, specify a different SOC and required charge finish time, or start charging immediately. In the event of no input from the user, the previously set-up defaults will be selected automatically by the system.

The CPMS will use the Cost Model to time-shift the charging to periods of low cost, as far as is possible, in order to ascertain cost savings for the user. In addition, where periods of particularly low cost energy are available (as indicated by the Cost Model), the CPMS will deliver a level of charge over and above that requested by the user in anticipation of future need, as far as is possible in the time frame allocated by the user.

During charging the CPMS will continuously monitor the charge session and the vehicle parameters and will provide the driver with updated status via the User Interface.

If the vehicle is unplugged from the chargepoint before the charge session is complete, the CPMS will record the SOC and various other parameters at plug-out.

When the charge session is complete and the vehicle stops charging, the CPMS will notify the driver that the vehicle is fully charged. The CPMS will also inform the user about the level of reward received via the User Interface.

3.8.5 Vehicle interface

Vehicle telematics data will be collected either directly from the vehicle through the OEM's telematics system (which communicates with the automotive manufacturer's network system) or through a third-party 'dongle' that is attached to the vehicle's OBD port.

If the data are collected from the automotive manufacturer's network system, then no additional hardware will be required. The following requirements shall be met:

- Data must be downloadable on a regular basis (to be defined during the preparation phase of Stage 2)
- Data must be collected and transmitted even when the vehicle ignition is off and the vehicle is charging
- Data transmitted to the vehicle manufacturer's network must be accessible via a well-defined API which allows periodic polling of data from the CPMS.

If an OBD dongle is used, the device shall have the following capabilities:

- Conforming to published OBD-II (USA) or EOBD (European) standards
- Conforming to SAE J1962 (specification for type A and/or type B connector), SAE J1850 (serial communication protocol), J1978 (minimum operating standards), or their ISO equivalent standards
- Powered from the vehicle system with minimal electrical draw
- On-board battery backup
- Capable of functioning even when the vehicle ignition is off
- Capable of collecting all of the data outlined in Section 3.10
- Capable of communication to a data collection system in real time through a cellular connection
- Small enough to fit within the vehicle without obstructing driver interaction or vehicle operation
- Connected to a network system which is accessible by the CPMS via a well-defined API which allows periodic polling of vehicle data.

Appendix A provides the specification of the data exchange / API.

3.9 User Interface: smartphone app

Participants will interact with the system through an application installed on their mobile phone. This application will provide the driver with both their current vehicle status as well as their choices when it comes time to charge their vehicle.

The User Interface smartphone app shall be developed to run on both Android and Apple (iOS) smartphone devices. The app will not require the user to install any additional hardware or software (beyond the app itself) on their phone. The app will be made available through private channels and so will not be made available to the general public through the app stores.

The mobile app shall be easy to use and shall conform to industry standard app designs.

The mobile app shall provide a facility to enable drivers to register with the program including capabilities to enter:

- Username
- Password
- Email address (to enable notifications via email)
- Phone number (to enable notifications via SMS)
- Address
- Participant ID
- Vehicle ID
- Vehicle type
- Home chargepoint ID

Once registered, the user will receive an email containing their participant ID and confirming the information entered at registration. The driver will then be prompted to re-login to their account to complete registration.

The User Interface shall include 'tabs' for Vehicle Status, Charging Selection and User Profile. These are described below.

3.9.1 'Vehicle Status' tab

The 'Vehicle Status' tab shall display near real time data on the state of the vehicle including:

- Vehicle status (see list below)
- Vehicle SOC (measured in percentage from 0% - 100%)
- Vehicle location GPS coordinates
- Energy provided to the vehicle (during charging)

Vehicle status options shall include:

- In transit
- Idle/Off
- Charging
- Charge scheduled to begin at (e.g.) 8:00PM
- Managed charging enabled

- Charge finished
- Vehicle unplugged
- Chargepoint offline

The app shall update the status displayed every 5 minutes.

3.9.2 'Charging Selection' tab

The 'Charging Selection' tab shall present the driver with the options for charging (applicable to the experimental groups only). The charging processes are described in Section 3.5.1.

Options shall be selected by pressing a button within the app. The button shall change colour or otherwise highlight itself to communicate that an option has been selected.

Once a selection is made, a message shall be displayed indicating the choice that was made by the participant. This decision will be transmitted to the CPMS for action. The mobile app will then move to automatically display the Vehicle Status tab.

3.9.3 'Profile' tab

The 'Profile' tab shall display the driver's information including:

- Username
- Email address
- Mobile phone number
- Home address / charging location
- Participant ID
- Vehicle ID / license plate number
- Vehicle type
- Notification preferences (email, SMS, both, neither)
- Charging defaults (experimental group 1 and 2 only)

The Profile tab will also provide a workflow for changing the account password.

3.9.4 Indicative screenshots for mobile app

Indicative screenshots showing how the user app could look are shown in the figures below. These should be considered illustrative only; the actual design and development of the app will take place during the preparation phase of Stage 2.

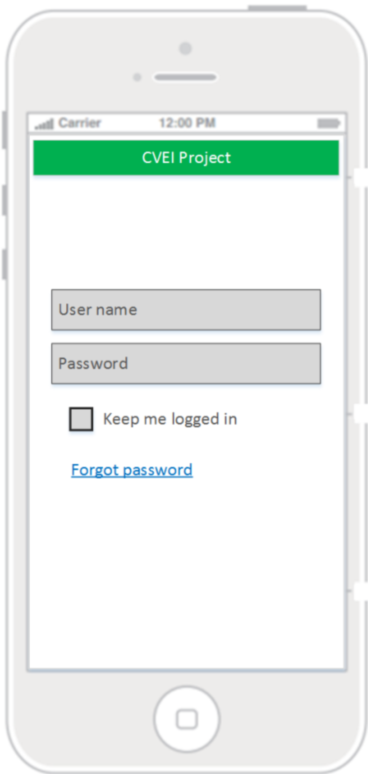

Figure 7: Indicative illustration of mobile app login screen

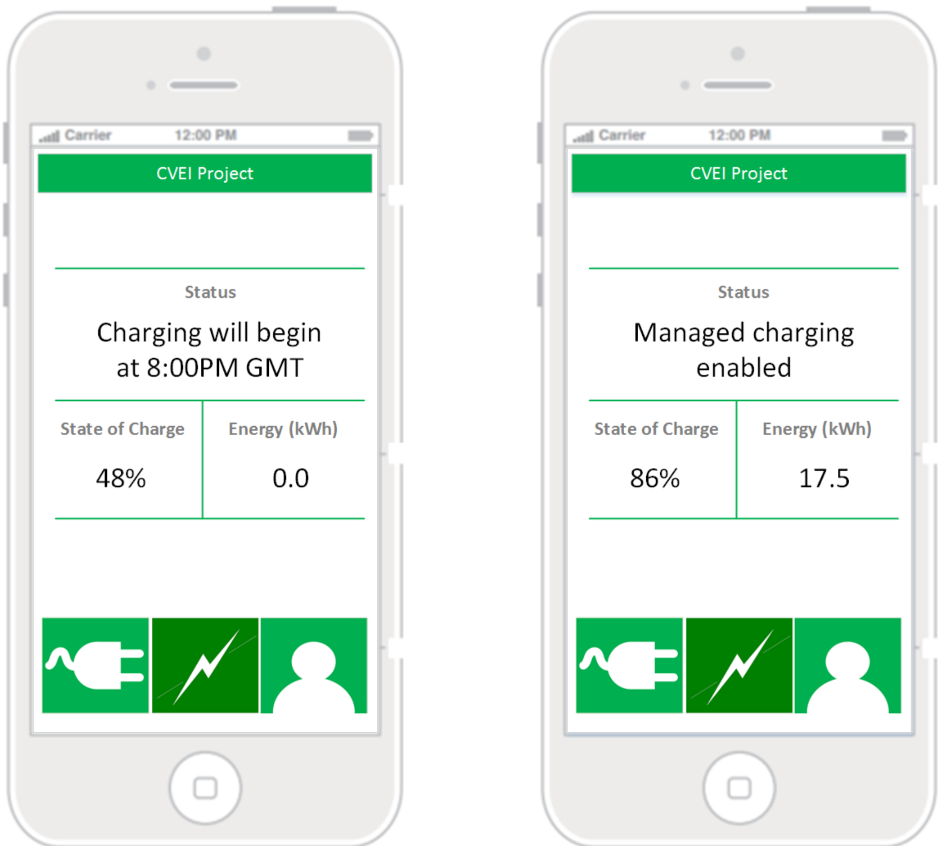

Figure 8: Indicative illustration of experimental group charging status tabs

3.10 Research Database

The Research Database shall consist of a 'real-time' database to store the outputs from the CPMS, User Interface and vehicle telematics system; including, plug-in time, plug-out time, required SOC, required Departure time, delivered SOC, time profile of charging, cost profile of charging, etc. These data shall also be linked in the Research Database to data from the participant questionnaires (Section 3.10.3) and the choice experiment (Section 3.10.4). The various data sources are described in more detail in the following sections.

3.10.1 Vehicle and chargepoint data

A vehicle telematics system will be used to collect vehicle data from the CAN bus via the OBD port. It is proposed that the following core data are collected:

Table 9: Core telematics dataset

Field	Description
Journey start date & time	Date and time of start of journey (i.e. ignition on)
Journey end date & time	Date and time of end of journey (i.e. ignition off)
Max speed (mph)	Maximum speed reached during journey
Mileage	Odometer reading at start of journey (i.e. ignition on) and end of journey (i.e. ignition off)
Journey distance (miles)	Total journey distance
SOC	Battery SOC at plug-in and plug-out, and at journey start and journey end.
Energy consumed during journey (kWh)	Amount of energy used by vehicle during journey
Journey start liquid fuel level (%, or litres)	Liquid fuel level (petrol / diesel) at start of journey (i.e. ignition on) - PHEV and ICE only
Journey end liquid fuel level (% or litres)	Liquid fuel level (petrol / diesel) at end of journey (i.e. ignition off) - PHEV and ICE only
GPS coordinates	Lat / Long, OSGR or .shp or .tab file
Plug-in / plug-out date & time	Date and time of plug-in and plug-out
Charge start / finish date & time	Date and time charging begins and ends
Energy provided during charge (kWh)	Amount of energy provided to vehicle during charge
Chargepoint GPS coordinates	Location of plug-in/plug-out (GPS coordinates)
Charge start liquid fuel level (%, or litres)	Liquid fuel level (petrol) at start of charge - PHEV only

Analysis of these data will enable:

- **Understanding of vehicle usage patterns**
- **Comparison of vehicle usage and driving behaviour between vehicle types**
- **Understanding of Mainstream consumer charging profiles and plug-in behaviour**
- **Comparison of charging behaviour between the two vehicle types**

Subject to availability from the CAN bus, the following additional data will also be collected:

Table 10: Secondary telematics dataset

Field	Description
Road class	E.g. M, A(M), A, lower class. To provide details on the characteristics of journeys made by participants.
Road number / name	Road number or street name. To provide details on the characteristics of journeys made by participants.
Driving mode (PHEV only)	Vehicle driving mode currently active (e.g. all electric mode / hybrid mode / etc). To inform battery state of health modelling (ElementEnergy)
Battery pack temperature	To inform battery state of health modelling (ElementEnergy)
Ambient temperature	To inform battery state of health modelling (ElementEnergy)
Time spent stationary (s)	To inform battery state of health modelling (ElementEnergy)

A third dataset will also be sought for the purposes of additional analysis performed by Shell. This analysis (reported in Deliverable 1.2b, separate to the main report on the findings of the Consumer Charging Trials) will investigate the potential impact of PHEVs on the ability of liquid fuels to act as a buffer in the energy supply system.

The details of the dataset required for this analysis are shown in Table 11 below. It is desired to obtain these data at a sampling frequency equivalent to one or more of the following:

- Once every ¼ mile during each journey, OR;
- Once per 1% reduction in battery SOC, OR;
- Once per 0.1% reduction in liquid fuel level.

Table 11: PHEV liquid fuel dataset (for Shell analysis)

Field	Description
Date and time stamp	Date and time of data reading
Speed (mph)	Current speed vehicle is travelling
Mileage	Current mileage of vehicle
Distance travelled in journey	Distance travelled in journey so far
Battery SOC	Current battery state of charge (SOC)
Current liquid fuel level (%, or litres)	Current liquid fuel level (%, or litres)
Total energy consumed (kWh)	Energy consumed so far in journey (kWh)
Energy consumed for tractive effort (kWh)	Energy consumed for tractive effort so far in journey (kWh), discounting that used by auxiliaries such as air conditioning.
GPS coordinates	Current GPS location of vehicle
All-electric mode active? Y/N	Indication of status of all-electric driving mode
Petrol-only mode active? Y/N	Indication of status of petrol-only driving mode
Cruise control active? Y/N	Indication of status of cruise control driving mode

The availability of all vehicle data, and the sampling frequency at which it will be extracted from the telematics system, will be confirmed at the beginning of Stage 2 trials once the vehicle telematics system has been fully tested.

3.10.2 App data

In addition to the telematics and chargepoint data described in Section 3.10.1, data from the User Interface (smartphone app) will be collected in order to understand how users interacted with the system. These data are summarised in Table 12.

Table 12: Data to be collected from the User Interface smartphone application

Field	Description
User defaults	Defaults set by participants (experimental groups only)
Required plug-out time	User-requested plug-out time (Experimental group 2 only)
Required SOC at plug-in	User-requested SOC at plug-in (Experimental group 2 only)
MCAR provided	Amount of MCAR provided to supplier (Experimental group 2 only)
Reward provided	Reward provided to participant

3.10.3 Questionnaires

Information on participant demographics, vehicle ownership, personality, and attitudes will be collected from questionnaires. Four sets of questionnaires will be administered at five distinct time points during the trial (see Table 13**)**.

The purpose of these questionnaires is as follows:

- **Recruitment questionnaires:**
  - To determine the eligibility of prospective participants to take part in the trial (see recruitment screening, Section 3.3).
  - Questionnaires will include a number of items relating to the demographics of participants, including age, gender, postcode, education, marital status and income, as well as questions related to vehicle use, parking availability and travel patterns.
- **Segmentation and personality questionnaires:**
  - To understand the characteristics of the sample population, including how they fit into consumer segments investigated in previous research (e.g. Lloyd *et al.*, 2014).
  - This will include the Multi-Dimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari, Mikulincer, & Gillath, 2004), questions on personality (such as the IPIP-NEO personality inventory), and a set of questions on previous vehicle ownership, personal travel and attitudes to new technology.
- **Attitudinal questionnaires:**
  - To understand participants' attitudes towards electric vehicles, internal combustion engine vehicles, their likely uptake of electric vehicles in the future, and how these attitudes change following direct experience with the vehicles in this trial.
  - This questionnaire set will include items related to attitudes towards driving and the environment (e.g. using the 20-item Attitudes to Driving and the

Environment Inventory), instrumental, symbolic and affective attitudes to electric vehicles, attitudes towards associated behaviours such as recharging and likelihood to choose to have an electric car in future.

- **Evaluation of vehicle performance:**
    - To understand participants' ratings of the performance of each vehicle experienced during the trial.
    - This questionnaire set will include items related to acceleration, responsiveness, smoothness, noise, comfort, safety, enjoyment and overall performance (Category-Ratio scales developed by Borg, 1998).

Table 13: Administration of participant questionnaires

Questionnaire set	Recruitment screening	Time point 1 (before vehicles received)	Time point 2 (after vehicles returned)
Recruitment questionnaires: - Participant demographics, vehicle use and parking availability at home	✓		
Segmentation questionnaires: - MDSI, vehicle ownership and use, personal travel and attitudes to new technology		✓	
Attitudinal questionnaires: - Attitudes towards EVs, ICE vehicles and likelihood to purchase EVs		✓	✓
Vehicle performance: - Borg Category-ratio scales (acceleration, responsiveness, comfort, noise).			✓

3.10.4 Choice experiment

There are two main research questions of interest for the Charging Trials:

1. What are impacts of different ToU tariff and managed charging configurations on a consumer's likelihood to participate in these arrangements?
2. What are the impacts of different ToU tariff and managed charging configurations on the likelihood of car buyers choosing a PHEV / BEV over other powertrains?

Question 1 will be addressed through a choice experiment, where the 'choice' will be between a variety of Managed Charging scheme configurations, described by attributes such as the proportions of peak versus off peak period, the degree of control over charging, the ability to override, effect on energy cost/rebates and the interaction method (e.g. automatic, daily interaction with an app etc.). The choice experiment will allow a much wider range of charging 'offers' to be tested than will be possible in the two experimental conditions themselves.

Question 2 will either be answered by choice questions on vehicle purchasing within the trials, or with separate questions directly asking the impact of different tariff/charging offers on willingness to purchase. The choice of approach will depend on the content of the wider questionnaire and the complexity of the choice experiment; a final decision will be made during the Stage 2 design phase.

The key outputs from the choice experiment will be a set of choice coefficients that allow calculation of the number of participants selecting a given Managed Charging scheme. The impact of demographic and attitudinal factors will be used to map the results to the existing consumer segments.

3.11 Data management

All data storage and handling will be performed in accordance with the International Standard for Information Security Management System (ISO 27001:2013). Full details about TRL's data privacy management policies and procedures are provided in Part 1 (Overview of Stage 2).

An overview of the key types of data which will be collected, along with the roles and responsibilities for cleaning, processing and analysis, is provided in Figure 9.

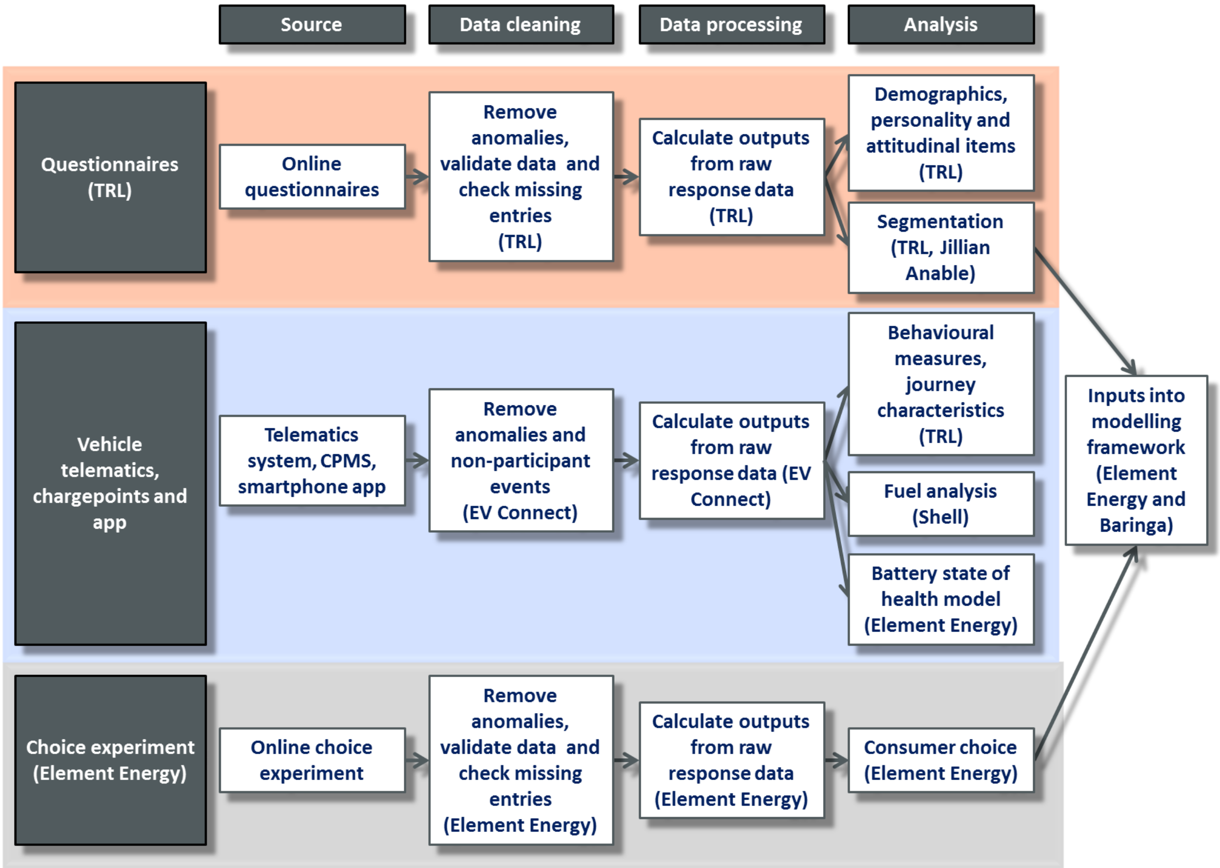

Figure 9: Overview of data management roles and responsibilities

On completion of the first recruitment survey, all participants will be assigned a Participant ID. All subsequent data collected will be linked to the Participant ID, rather than a participant's name or other personal details, in order to anonymise data. Where possible, all questionnaires will be administered to participants electronically via an online survey tool (such as 'SmartSurvey' or 'Survey Monkey'). Questionnaire data will be saved on the secure server of the survey tool, before being transferred onto secure TRL servers for cleaning, processing and analysing.

Vehicle telematics data, chargepoint data and data from the User Interface will be remotely accessed by EV Connect via vehicle data loggers connected to the OBD link and saved on secure TRL SQL servers. Vehicle telematics data will be linked to a Participant ID, not the name or other personal details of a participant. EV Connect will provide a cleaned and processed dataset, linked to participants' unique reference numbers, to TRL for subsequent analysis. Data cleaning and processing will ensure:

- Data are fully anonymised, with names and/or other types of personally identifiable information converted to unidentifiable user ID numbers.
- Data are filtered to remove non-participant events. These will be identified by:
  - Removing trips which are less than 0.1 miles in distance.
    - Examples of such could include events during which the driver turns on the vehicle, and then quickly turns off the vehicle to go and retrieve some forgotten item at home or office. This would also

include periods when the research team operate the vehicles in between participant handover days at TRL or Cenex headquarters.

- Removing anomalous charge events.
  - Examples of such would include charge events which last for less than 2 minutes and which could be indicative of:
    - A loss of power to the chargepoint.
    - A chargepoint fault which caused the station to perform a hard reset and ended the charge session.
    - An erroneous plug-in event by the driver when the driver needs to take the vehicle out again immediately.

The choice experiment will be hosted and administered by a third-party online survey tool (to be confirmed during the preparation phase of Stage 2). EE will clean and process the raw data before undertaking the required consumer choice analyses.

Outputs from the segmentation analysis and consumer choice analysis will be fed into the modelling framework by Baringa and EE.

4 Analysis and reporting

4.1 Introduction

A number of statistical techniques will be used to analyse the data collected in the two Charging Trials. An overview of these techniques is provided below.

4.2 Factor analysis

The questionnaire data will contain responses to numerous attitudinal items which aim to measure participants' attitudes and changes in attitudes towards EVs following their experience in the trial. Factor analysis, a powerful 'data reduction' technique, will be used to combine information from this large set of similar variables into a smaller set of factors.

This technique will be used to identify common factors within the multi-item attitudinal scales to allow comparison between attitudes before and after the trial experience.

4.3 Statistical comparisons

Comparison of the questionnaire factors will be conducted using a variety of statistical methods. The comparisons will enable identification of differences in attitudes before and after the trial experience.

Similar methods will also be used to analyse the vehicle telematics and charging data to determine if there are differences in vehicle use or charging behaviour between the three charging conditions over time.

These repeated-measures techniques will include (but may not be limited to):

- Analysis of Variance (ANOVA) or Generalised Estimating Equations (GEE)
- Paired t-tests or Wilcoxon matched-pairs tests
- Cochran's Q or the McNemar dichotomous variables test

Experienced statisticians will select the most appropriate statistical techniques for analysis of the various datasets collected during this trial. The techniques selected will depend on the characteristics of the data obtained. For example, parametric statistical tests rely on underlying assumptions about the distribution of the data; tests will be performed to check these assumptions before any analysis is carried out.

4.4 Reporting

Full details of the methodology, analysis, results and conclusions from the Consumer Charging Trials will be documented in a single written Consumer Charging Trials report (Deliverable 1.2a).

Full results of Shell's analysis (which will be documented in Deliverable D1.2b) will provide an understanding of utility factors (UF, the fraction of mileage covered under electric power) which will allow estimation of the impact of the unavailability of electricity (due, for instance, to variability in the provision of renewable power) on the PHEV component of a future, de-carbonised, light-duty road transport fleet in the UK.

In addition to the final written reports, a PowerPoint presentation will be produced in order to provide the ETI Review Panel with an overview of the key results and conclusions from the two trials. This presentation will be delivered before the delivery of the written reports to allow for comments from the Review Panel to be incorporated into the written deliverable.

Subject to approval and sign-off of the final Consumer Charging Trials Report from the ETI, a separate paper(s) will be written for submission to a peer-reviewed academic journal(s) (e.g. Renewable and Sustainable Energy, Transportation Research Part D: Transport and Environment, Energy Policy or International Journal of Electric and Hybrid Vehicles).

The reporting process will form part of a dissemination strategy to ensure that the knowledge gained from this trial is appropriately published into the wider academic community. Full details of the dissemination strategy are provided in Part 5 of this deliverable.

Deliverable 1.2a will document clear and concise evidence-based conclusions to the research questions, providing valuable inputs to the modelling framework on Mainstream consumer responses and attitudes to alternative propositions which aim to manage energy demand associated with charging PHEVs and BEVs.

Deliverable 1.2b will provide an eveidence-based understanding of utility factors (UF, the fraction of mileage covered under electric power) which will allow estimation of the impact of the unavailability of electricity on the PHEV component of a future, de-carbonised, light-duty road transport fleet in the UK.

5 Timeline

An indicative timeline for the Consumer Charging Trials is shown in Figure 10 below. From project inception, a minimum of 18 months is required to allow sufficient time to prepare for and pilot the trial, recruit participants, collect, clean and analyse data, and report and disseminate the findings.

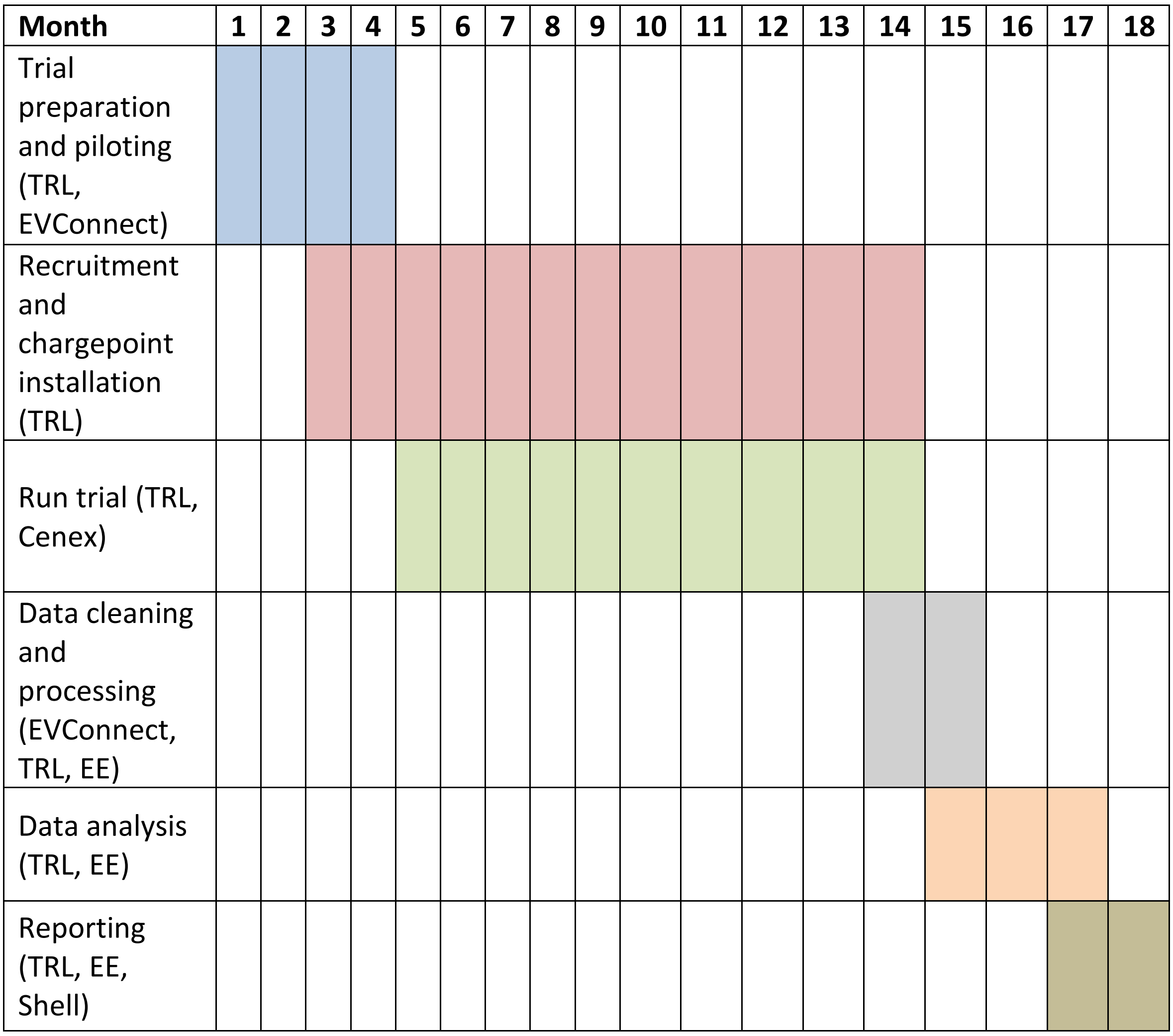

Figure 10. Indicative timeline for Consumer Charging Trials

6 Alternative options to trial design

6.1 Principles used to determine our recommended option

The methodology proposed for the Stage 2 Trials has been designed with consideration for the rationale and lessons learned discussed in Section 2:

- The trials will utilise an RCT design to maximise internal validity.
- The trials will recruit a sample of Mainstream consumers, to ensure the predictions of the modelling framework are based on robust data and not reliant on assumptions about EV Innovators.
- The trials will provide participants with direct experience of using either a BEV or a PHEV, to ensure adequate data are generated on both vehicle types.
- The trials will provide participants with experience of engaging with either a managed charging scheme, a ToU scheme, or a control scheme.
- The trials will be run for a period of 8 weeks to ensure the participants' psychological distance is sufficiently reduced and that the behaviours are representative of the real-world.

This methodology represents our recommended approach and has been developed on the basis of the following principles:

1. It prioritises statistical power and internal validity (since research with low internal validity cannot generate meaningful answers to research questions)
2. It prioritises external validity where doing so does not unduly compromise internal validity
3. It does not require additional budget

The trial design outlined in this document therefore represents the most scientifically robust solution for investigating Mainstream consumer charging behaviours and attitudes towards alternative Managed Charging schemes, which is achievable within the budget of the project.

6.2 Alternative options

There are two possible alternatives to the recommended trial design for both the PHEV Charging Trial and BEV Charging Trial which ETI might wish to consider. These options relate to:

- The substitution of participants' vehicles, and;
- The use of alternative EVs to investigate a higher charging rate (i.e. 6.6kW).

An overview of these alternative options is provided in Table 14.

Table 14: Alternative trial design options.

Design	Details
Recommended design (as detailed in this document)	• Trial vehicle provided as additional vehicle to household, except for households where the number of drivers exceeds the number of vehicles, or households where there is insufficient off-street parking. In these cases, the trial vehicle would be offered as a replacement for the participant's own vehicle. • VW Golf GTE used for PHEV Charging Trial. • VW e-Golf used for BEV Charging Trial. • 3.6kW chargepoints installed in participants' homes for both trials.
Alternative design 1: Substitution of vehicles	• Trial vehicle replaces participants' own vehicles, for all cases.
Alternative design 2: 7.2kW charging	• VW Golf GTE used for PHEV Charging Trial. • Nissan Leaf used for BEV Charging Trial (half participants with 3.3kW on-board charger, half with 6.6kW on-board charger) • 3.6kW chargepoints installed in participants' homes for PHEV Charging Trial. • 7.2kW chargepoints installed in half of participants' homes for BEV Charging Trial.

Selection of these alternative designs would result in one of two consequences:

1. An increase in cost;
    - This would:
        i. Retain participant numbers and statistical power
        ii. **Require additional budget from ETI**

OR

2. A reduction in the number of participants (to offset the increase in cost);
    - This would:
        i. **Reduce participant numbers and statistical power**
        ii. Not require additional budget from ETI

Full details regarding the impact of these options on cost and participant numbers are provided in Deliverable 1.4 (Part 6 – Commercial Submission).

The following section further outlines the pros and cons associated with the two alternative options.

6.2.1 Alternative design 1: Replacing all vehicles

This option would involve replacing participants' own vehicles with the trial vehicle for all participants. Participants' own vehicles would be stored at TRL or Cenex (or nearby parking locations) for the duration of the trial.

Table 15: Pros and cons associated with replacing all participants' vehicles.

Pros	Cons
Validity • Total number of vehicles in household would remain the same. This would provide a representative experience of current vehicle use involving replacement of a vehicle with an EV. • For 1-car households, risk of loss of data due to use of own vehicle is eliminated. • For 2-car households, risk of loss of data due to use of own vehicle is reduced, but not eliminated. **Practicality and cost** • None - logistically difficult and costly to store participants' vehicles.	**Validity** • Recruitment will be limited to only those individuals who are willing to part with their own vehicle for a period of 8 weeks. This could bias the sample of potential participants which the trial is able to recruit. **Practicality and cost** • Removal of participants' vehicles for 8 weeks likely to be a major barrier to participant involvement and lead to increased risk and costs for recruitment and meeting desired sample. • Increased risk and cost to project associated with storing (and maintaining) participants' vehicles for the duration of the trial. • Complex and expensive insurance requirements if TRL and Cenex staff are required to drive participants' vehicles to storage facility. • Increased staff costs, fuel costs and contingency for damage or lost time, depending on storage solution.

6.2.2 Alternative design 2: 3.3kW vs. 6.6kW BEV charging

As discussed in Section 3.7.1, the recommended trial design involves installation of 3.6kW chargepoints in participants' homes. This type of Mode 3 chargepoint was chosen because:

1. It is likely that most households in the UK have a 60A maximum current draw; this means many potential participants' homes would not be compatible for 7.2kW chargers which would likely push the household current draw above 60A. Use of 3.6kW chargepoints allows a broader pool of participants to be able to take part in the study, maximising external validity.

2. The UK market Golf GTE (PHEV) and e-Golf (BEV) can only accept a maximum charge rate of 3.6kW. Therefore, a more powerful chargepoint would provide no additional benefit to participants during the course of the study, even if their domestic wiring was sufficient or appropriately upgraded to handle 7.2 kW.

Higher power transfer (associated with 7.2kW charging) implies higher demand for a shorter time and clearly has a significant impact on charging profile, and there is a view that 7.2kW installations will become more common with time in the decades up to 2050. The move towards 7.2kW power transfer clearly has benefits in reducing charging times for BEVs, but its merits for charging PHEVs are potentially more limited, given their smaller battery capacities and consequent shorter charging times. There is inadequate knowledge at present as to whether Mainstream consumer PHEV users would consider the extra costs worthwhile.

There may however be merit in gathering data on charging behaviour with BEVS (with their higher potential total charging demand) when using both 'standard' (~3.6kW) and 'high' (~7.2kW) output chargers, in order to provide additional inputs to the modelling framework.

This alternative design would therefore alter the approach for the BEV Charging Trial to examine charging behaviours with two different rates of charging. Currently, the Nissan Leaf BEV represents the most suitable vehicle for this type of investigation, since it offers two otherwise identical models with different charging rates:

- Nissan Leaf with 30kWh battery and 3.3kW on-board charger
- Nissan Leaf with 30kWh battery and 6.6kW on-board charger

Whilst the higher of these two charging rates falls slightly short of the 7.2KW maximum offered by some Mode 3 domestic chargepoints, comparisons between the attitudes and behaviours of Mainstream consumers using each of these types of Nissan Leaf would provide useful inputs to the modelling framework.

Since the use of two types of BEV introduces a difference in maximum charging rate, this option would create an additional variable to be tested compared with the recommended study design outlined in this document. As a result, the BEV Charging Trial design would involve 6 experimental groups (instead of 3), as shown in Table 16 below:

Table 16: Experimental design required for Bev Charging Trial in order to investigate differences between 3.3kW and 6.6kW charging behaviours.

Model	Maximum charging rate	Experimental groups		
		Control group	Experimental group 1	Experimental group 2
Nissan Leaf with 30kWh battery and 3.3kWh on-board charger	3.3 kW	1	2	3
Nissan Leaf with 30kWh battery and 6.6kWh on-board charger	6.6 kW	4	5	6

The pros and cons associated with this alternative design are listed in Table 17.

Table 17: Pros and cons associated with using Nissan Leafs to examine the difference in charging behaviour between 3.3kW and 6.6kW chargers.

Pros	Cons
Validity • Would provide valuable data on both 3.3kW and 6.6kW BEV charging, as inputs to the modelling framework. **Practicality and cost** • None – this option will increase costs and timescales.	**Validity** • Characteristics of sample unknown: reliant on people with homes capable of handling 6.6kW charging. This is likely to be limited to new homes. • The slower rate of charging provided by 3.6kW chargepoints means that some charge events will fail to fully replenish an empty battery. This is likely to be representative of future charging, since battery capacities are likely to increase, before further increases in the maximum charging rate delivered by domestic charging units. In other words, the relationship between battery size and charging rate in the future may be better represented today through investigation of 3.6kW charging. **Practicality and cost** • Increased costs and timescales associated with leasing different vehicle types and developing additional CPMS and telematics system.

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Appendix A Chargepoint Management System (CPMS) system architecture

A.1 General requirements

The system shall include the vehicle (with an integrated telematics system), the chargepoint, a charge point management system (CPMS), a mobile app for drivers and a web portal for the project team.

The CPMS shall be hosted in a secure manner with all communications to and from the CPMS handled through a firewall which limits access to only those on the project team.

The CPMS components shall be sized and configured with redundancy and failover in mind and designed to achieve a minimum of 99% uptime. [Note: Redundant servers for each function ensure that should one server of a redundant pair fail, there is always a second server that is carrying the full load of the system until such time as the failed server is returned to service. As failures are rare, it is highly unlikely that both servers of redundant pair will ever fail at the same time, and thus targeted uptimes will be achieved.]

A.2 System Architecture

The main components of the system are the vehicle, the vehicle interface device (OBD dongle), the chargepoint, a driver-focused mobile application and the CPMS itself.

Due to the very large volume of messages to and from the chargepoint, from the vehicle Telematics system and to and from the mobile app and administrator portal, a message queue driven architecture will be the preferred topology for the overall system architecture.

Under this type of architecture, all system activities are performed as a result of an incoming message to the central queue service. Inputs will include vehicle status, chargepoint status, user/driver instructions and preferences and requests from administrators. Outputs will include messages to the chargepoints, notifications to drivers, and reports to administrators.

In order to make this architecture work, the system will include a central Simple Queue Service (SQS) server which will be fed by (i) a vehicle data collection server which will poll data from the vehicle or vehicle manufacturer's Telematics server; (ii) the driver who will issue directions through the mobile app; (iii) the chargepoint which will send system health, system status and metrology data, and (iv) administrators who will track data via a web portal.

The servers which act as these collectors are shown in the figure below. They are the:

- Vehicle data collector
- Charge Station Manager (CSM)
- Mobile manager
- Web server

The SQS feeds data into an asynchronous message server which performs all of the system logic and then returns actions to the CSM, mobile manager and web server for disposition to their respective clients.

The overall system architecture is shown schematically in the figure below.

To ensure up-time, the system will have load-balanced pairs of each server where each server in the pair is capable of handling the full load of the system should it partner fail during service. All of the system data will be stored in redundant databases and regularly archived to ensure that all data is safe for the duration of the project.

To ensure data security, the entire system will be housed behind an industrial grade firewall, and all communications which include personally identifiable information will be secured using industry standard encryption technologies.

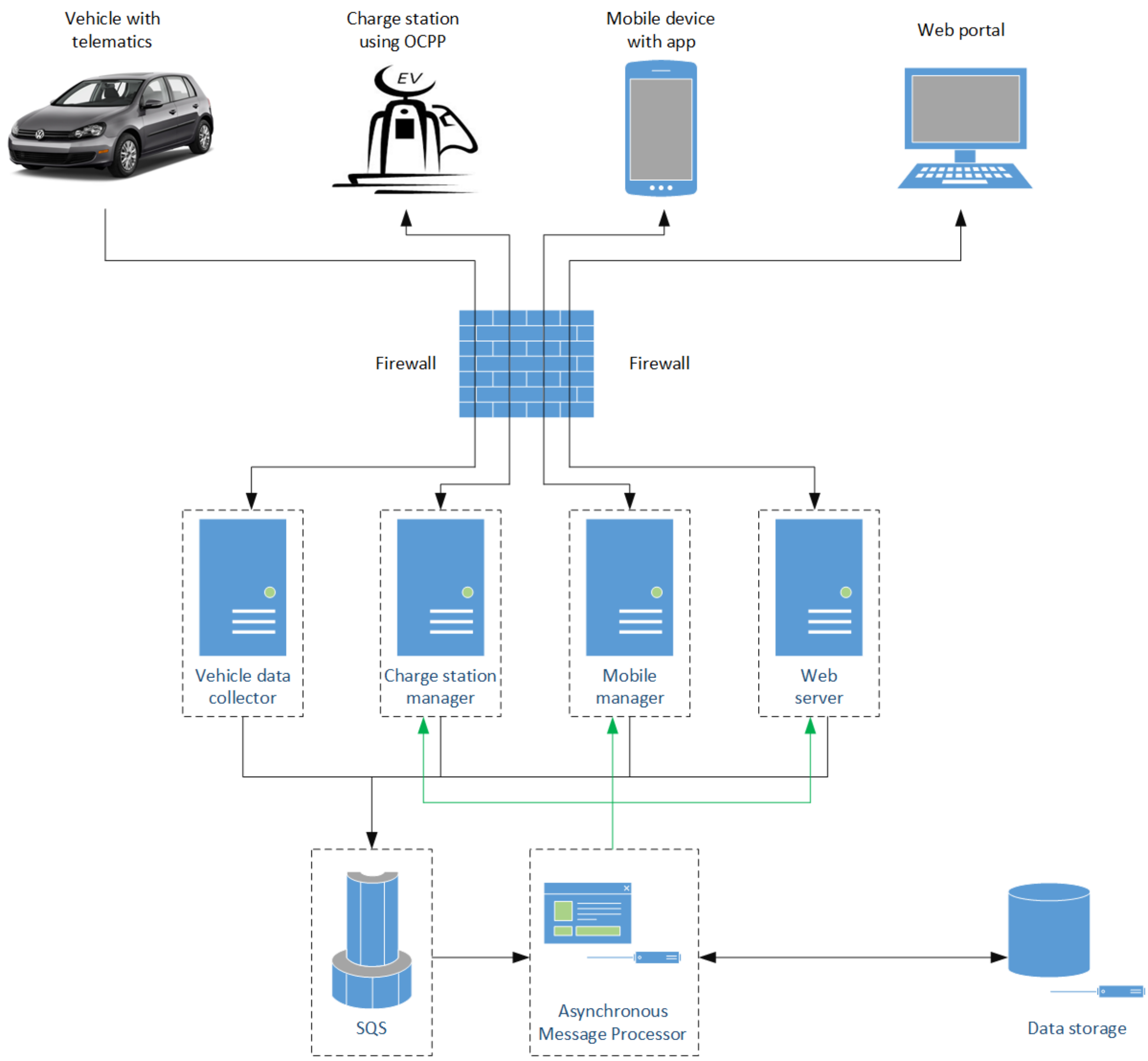

Figure 11: Overview of CPMS System Architecture

A.2.1 Chargepoint integration

The chargepoint will be integrated to the CPMS through the Charge Station Manager (CSM). This server provides all of the logic to manage the chargepoint, including starting and stopping charge sessions, processing heartbeats and meter readings and other remote management functions.

The chargepoint will speak to and with the CSM using Open Charge Point Protocol (OCPP) version 1.5. This is a well-defined and widely accepted open standard protocol for chargepoint to network communication and is supported by several charge manufacturers that support the chargepoint requirements provided earlier in this section.

Communications between the CSM and the chargepoint will be bi-directional as the network sends start and stop charge commands to the station and receives notifications and meter readings back from the station.

A.2.2 Vehicle integration

Vehicle integration can be handled in one of two ways. The first option is to integrate directly to the automotive manufacturer's telematics system via a cloud-to-cloud integration with their server. This is the preferred method, and the project team is working with the chosen vehicle OEM on data requirements at this time. The interface specification is documented in Appendix B.

The second option is to insert a third party OBD device into the vehicle which is capable of communicating data to the third party's cloud-based platform and then develop a cloud-to-cloud integration with that system. This approach will also employ a similar interface specification.

Communication with the vehicle is uni-directional, flowing from the vehicle to the telematics network provider. No communication is sent from the telematics system back to the vehicle.

The communication protocol between the CPMS and the Telematics provider will be bidirectional with the CPMS (through the Vehicle Data Collector or VDC) regularly polling the telematics system for vehicle status and usage data.

Vehicle telematics data will be collected either directly from the vehicle through the OEM's telematics system (which communicates with the automotive manufacturer's network system) or through a third-party 'dongle' that is attached to the vehicle's OBD port.

If the data is collected from the automotive manufacturer's network system, then no additional hardware will be required. The following requirements shall be met:

- Data must be downloadable on a regular basis (to be defined during the preparation phase of Stage 2)
- Data must be collected and transmitted even when the vehicle ignition is off and the vehicle is charging
- Data transmitted to the vehicle manufacturer's network must be accessible via a well-defined API which allows periodic polling of data from the CPMS.

If an OBD dongle is used, the device shall have the following capabilities:

- Conforming to published OBD-II (USA) or EOBD (European) standards

- Conforming to SAE J1962 (specification for type A and/or type B connector), SAE J1850 (serial communication protocol), J1978 (minimum operating standards), or their ISO equivalent standards
- Powered from the vehicle system with minimal electrical draw
- On-board battery backup
- Capable of functioning even when the vehicle ignition is off
- Capable of collecting all of the data outlined in Section 3.10
- Capable of communication to a data collection system in real time through a cellular connection
- Small enough to fit within the vehicle without obstructing driver interaction or vehicle operation
- Connected to a network system which is accessible by the CPMS via a well-defined API which allows periodic polling of vehicle data.

Appendix B Vehicle telematics interface specification

B.1 Purpose

This Appendix describes the preferred form of the web service for integration of the vehicle telematics system and the EV Connect Charge Cloud platform.

B.2 Events

A set of five messages is envisioned. These include the following:

- Plug in
- Plug out
- Ignition on
- Ignition off
- Vehicle status

EV Connect shall provide the following endpoints for telemetry consumption via http POST:

- telemetry.evconnect.com/vw_uk/event/plug_in
- telemetry.evconnect.com/vw_uk/event/plug_out
- telemetry.evconnect.com/vw_uk/event/ignition_on
- telemetry.evconnect.com/vw_uk/event/ignition_off
- telemetry.evconnect.com/vw_uk/event/vehicle_status

The payload for each recorded event shall be sent as JSON in the request body as described in the sections below.

The frequency of messages will be as follows:

- Plug in: Once at time of event
- Plug out: Once at time of event
- Ignition on: Once at time of event
- Ignition off: Once at time of event
- Vehicle status: Every 5 minutes while vehicle is in operation or charging

B.3 Payloads

B.3.1 Plug in

{

"vehicleId":"< String id>",

"vehicleStatus":"< CHARGING, IDLE, UNKNOWN >”,

"stateOfCharge":"< integer representation of a percentage >",
"liquidFuelLevel":"< integer representation of a percentage >",
"odometerReading":"< integer representation of distance >",
"vehicleRange":"< integer representation of distance >",
"distanceUnitOfMeasure":"< KILOMETERS or MILES >",
"timeStamp":"< ISO 8601 Combined Date Time >”,
"location":"< ISO 6709 String Representation of Latitude and Longitude >",
}

B.3.2 Plug out

{
"vehicleId":"< String >",
"stateOfCharge":"< integer representation of a percentage >",
"liquidFuelLevel":"< integer representation of a percentage >",
"vehicleRange":"< integer representation of distance >",
"odometerReading":"< integer representation of distance >",
"distanceUnitOfMeasure":"< KILOMETERS or MILES >",
"timeStamp":"< ISO 8601 Combined Date Time >”,
"location":"< ISO 6709 String Representation of Latitude and Longitude >",
}

B.3.3 Ignition On:

{
"vehicleId":"< String >",
"stateOfCharge":"< integer representation of a percentage >",
"liquidFuelLevel":"< integer representation of a percentage >",
"vehicleRange":"< integer representation of distance >",
"odometerReading":"< integer representation of distance >"
"distanceUnitOfMeasure":"< KILOMETERS or MILES >",
"timeStamp":"< ISO 8601 Combined Date Time >”,
"location":"< ISO 6709 String Representation of Latitude and Longitude >",
}

B.3.4 Ignition Off:

```
{
    "vehicleId":"< String >",
    "stateOfCharge":"< integer representation of a percentage >",
    "liquidFuelLevel":"< integer representation of a percentage >",
    "vehicleRange":"< integer representation of distance >",
    "odometerReading":"< integer representation of distance > ",
    "distanceUnitOfMeasure":"< KILOMETERS or MILES >",
    "timeStamp":"< ISO 8601 Combined Date Time >”,
    "location":"< ISO 6709 String Representation of Latitude and Longitude> ",
    “averageSpeed”:”<integer representation of speed, consistent with distance unit of measure, since Ignition On>”,
    “energyConsumed”:”<integer representation of KwH consumed since Ignition On> ”,
    “driverBehaviour”:”<String or integer representation of driving style>”,
}
```


B.3.5 Vehicle Status:


```
{
    "vehicleId":"< String >",
    "stateOfCharge":"< integer representation of a percentage >",
    "liquidFuelLevel":"< integer representation of a percentage >",
    "distanceUnitOfMeasure":"< KILOMETERS or MILES >",
    "vehicleRange":"< integer representation of distance >",
    "timeStamp":"< ISO 8601 Combined Date Time >,
    "location":"< ISO 6709 String Representation of Latitude and Longitude> ",
    "odometerReading":"< integer representation of distance > ",
}
```

D1.4 Stage 2 Trial Design, Methodology and Business Case

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN

ISBN

PROJECT REPORT

D1.4 Stage 2 Trial Design, Methodology and Business Case

Part 4 - Fleet Study

J. Chappell, V. Chesterton, R. Jenkins, A. Tailor & N. Kinnear

Report details

Report prepared for:	ETI
Project/customer reference:	TR1006 Consumers, Vehicles and Energy Integration (CVEI) project
Copyright:	© Energy Technologies Institute
Report date:	March 2017
Report status/version:	4.0

Quality approval:

H. Al-Katib (Project Manager)		S. Skippon (Technical Reviewer)	

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	October 16	First Draft	JC	SS
2.0	December 16	Second version	HAK	SS
3.0	February 17	Third version	HAK	SS
4.0	March 17	Final version	HAK	SS

Document last saved on:	13/03/2017 14:49
Document last saved by:	Al-Katib, Hannah

Contents

Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics
ESME	Energy System Modelling Environment
ESOS	Energy Savings Opportunity Scheme

EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
ISO	International Organization for Standardization
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
ONS	Office for National Statistics

OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
UMC	User Managed Charging
VAT	Value Added Tax
VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services
WP	Work Package

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)

Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how you see yourself and how one perceives others see them.
Social norms	Similar to injunctive norms but mores specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.
Symbolic meaning/ attitudes	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

1 Introduction

Fleets buy around half of the new Light Duty (LD) vehicles sold in the UK and those vehicles are disposed of into consumer used-vehicle markets after fleet use. Thus potentially they could have a substantial influence on the uptake of Electric Vehicles (EVs).

Fleets operate around 10% of the UK light duty vehicle parc, accounting for around 17% of total LD Vehicle Kilometres Travelled (VKT), and a similar percentage of energy demand. Thus although total LD VKT and energy demand is dominated by private consumers, fleet energy demand represents a significant share. The **fraction** of that energy demand that could potentially switch from liquid hydrocarbon fuels to electricity and/or hydrogen depends on the uptake decisions fleets make; i.e. on what fraction of their vehicles (representing what fraction of VKT) fleets might choose to replace with EVs.

However, little is known about the attitudes of organisations that operate LD fleets either to EV adoption or to EV use; compared with consumer buyers, there has been very little published research.

The main reason for this dearth of useful research literature is that research with fleets is problematic. Fleets are known to use vehicles for a wide variety of purposes, from business operations such as local goods delivery or transporting service staff to work sites, to staff remuneration/rewards in the form of company cars. There is limited quantitative understanding of the structure of the light duty fleet sector, so statistically valid sampling is difficult. In addition, responsibility and decision making regarding fleets in organisations can be shared between staff in different roles and at different levels (see below), so identifying appropriate contacts can be challenging. It can be difficult to access the time of the appropriate people when they work in busy commercial settings. Finally, organisations are naturally reluctant to engage in research activities such as field trials where they perceive there might be some associated risk to their operations, while the link between employer-supplied van and car use and personal Benefit in Kind (BiK) taxation introduces an additional level of sensitivity.

Accordingly there are substantial gaps in our knowledge. Modelling of both uptake and energy use is necessarily based on a series of assumptions rather than grounded in real-world data. The risk in such an approach is, of course, that the validity of those assumptions is not known.

This proposal outlines an approach to closing the key knowledge gaps by seeking to discover organisations' own perspectives on what factors are important in their fleet decision making, using a case study methodology that addresses as far as possible many of the research challenges outlined above. The case study methodology focusses on in-depth, particular study of individual organisations that fall into categories in whose fleets EV uptake would potentially have the most impact of the UK energy system. This focus on depth aims to maximise the opportunity to fully understand participating organisations' own perspectives. Because of the small number of case studies carried out, research findings cannot be considered statistically representative. Generalisation from the findings of particular case studies is not, therefore, based on the assumption that they accurately represent the perspectives of the UK wider population of fleets, but is rather based on theoretical extrapolation, and thus has a provisional nature. Like all qualitative research outputs, the findings can be considered as *hypotheses* about what may be the perspectives of the wider population, subject to further exploration and/or testing.

Insights from the research will therefore be used to inform interpretation of Stage 2 modelling outputs, and where appropriate to inform sensitivity analyses that explore the effects of varying the modelling assumptions in ways suggested by the organisational perspectives identified in the field research.

1.1 Three potential sources of value

It is of course not possible to estimate in advance the value that will be generated in any particular exploratory research project: its value depends on what is found. Nevertheless it is possible here to outline the three potential routes to value that the proposed study offers.

Outputs of case study research, like all qualitative approaches, should be treated as hypotheses to be further evaluated, not as firm conclusions. They provide richness and depth of understanding of participants' perspectives, but no quantitative information on how widespread those perspectives are in the population. Hypotheses generated can be tested in two ways:

- Experimentally – e.g. through Randomised Controlled Trials
- In modelling – e.g. Sensitivity analyses to explore their potential impacts

There is no opportunity for experimental testing in the CVEI project, but there is substantial opportunity to explore the potential impacts of factors identified in the Case Studies on the outputs of the modelling framework. Accordingly, Stage 2 Case Study findings will be used to inform sensitivity analyses in WP7 (modelling) and discussion/interpretation of modelling outputs. Specifically:

- Knowledge Gap 1 specific information on EV uptake decision processes may inform sensitivity analyses (using alternative assumed values and/or additional variables in ECCo) that explore the impacts of the decision making factors that the case studies suggest are important.
- Knowledge Gap 2 specific information on charging profiles for target fleet categories may enable more appropriate base case charging profiles and/or sensitivity analyses in the analytical framework
- For both knowledge gaps the deeper insight will enhance interpretation and discussion of the final CVEI modelling outputs - for instance, limits of validity – and will enable a better informed view of their strengths and limitations.

2 Research focus: Fleets where EV uptake would have most potential impact on energy system

The Analytical Framework models the potential for EV uptake in different categories of fleets to impact on the wider energy system, drawing on ECCo and Route Monkey's fleet energy management model (D1.3 Appendix B).

Figure 1 shows a high-level segmentation of light duty vehicle sales. Privately chosen cars (which includes both Private Consumers and User-Chooser fleets) account for 67% of new LD car sales; the balance of sales are to Centralised-Chooser fleets. Around a third of these are van sales, the rest cars.

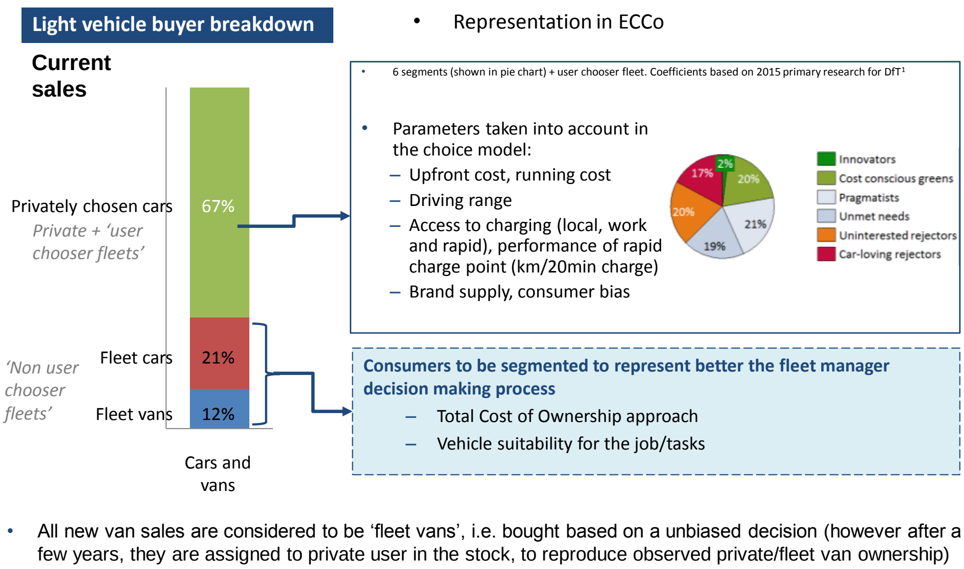

Fig. 1. High level segmentation of UK light duty new vehicle sales.

Additional analysis was conducted for D1.3 to provide a finer-grained segmentation of vehicle acquisition by Centralised-Chooser fleets. Eighteen a priori segments were defined based on the typology developed in Stage 1 Work Package 2 (segments defined in terms of: vehicle types (i.e. vans only or mixed), public or private, fleet size (> or <20 vehicles), daily mileage (> or <150km), is transport core to the business, based overnight at depot or not). Data on vehicle utilisation by the 341 fleets included in the Route Monkey database (12,336 cars and vans) was analysed using Route Monkey's fleet energy management model and aggregated per segment.

The Route Monkey database is known to be a biased sample of the population of Centralised-Chooser fleets (biased towards larger fleets) so the frequency of the derived fleet segments were been adjusted to correct for this bias. A sample representativeness analysis was conducted to adjust the fleet segment shares used in ECCo; based on a DfT Survey of Company Owned Vans and previous fleet segment analyses carried out by Element Energy for Dft and private clients.

The analysis provided duty cycle suitability curves (percentage of fleet vehicles that could be replaced by a Battery Electric Vehicle (BEV) for a given BEV electric range). Four profiles emerged, as shown in Fig. 2.

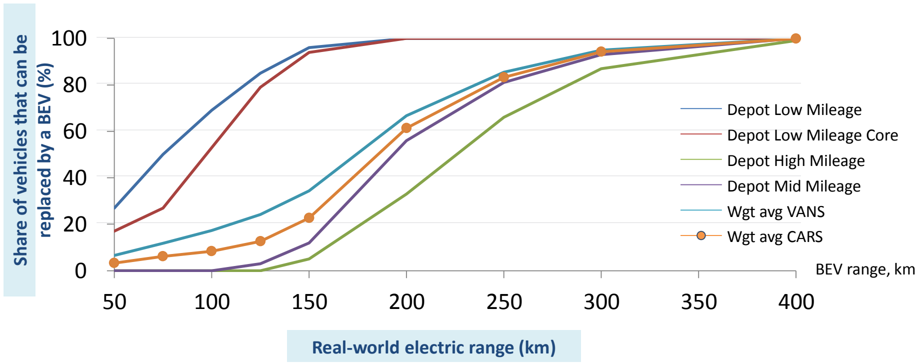

Fig. 2. Duty cycle suitability curves

Lower mileage fleets showed a greater ability to use a BEV due to their lower range demands. The “Low Mileage” fleets were defined as having an average daily mileage of less than 150 km.

There were no advantages to providing rapid charging at depot or public charging access, as the window of charging at depot is suitable for slow charging and the daily duty cycle doesn’t allow the flexibility to recharge during the day.

However a ‘high case’ was derived for sensitivity purposes (not shown here), where time slots were made flexible, so that access to rapid public charging was enabled, thus increasing the share of vehicles that could be BEVs.

Centralised-chooser fleets can be grouped according to their suitability curves and overnight base location (user’s home or depot), as shown in Fig. 3.

The vast majority of Centralised-chooser fleet cars are not based at a depot, but at users’ homes.

For van fleets, RouteMonkey data does not include Construction and Heavy Industry fleets. Previous EE analysis of the “Survey of Company Owned Vans”, showed that these two fleets account for 49% of vans. These were “added in” and attributed a low suitability curve. With that addition, overall 69% of vans are assumed to not spend the night at a depot (compared with at least 63% of vans in residential areas according to DfT data).

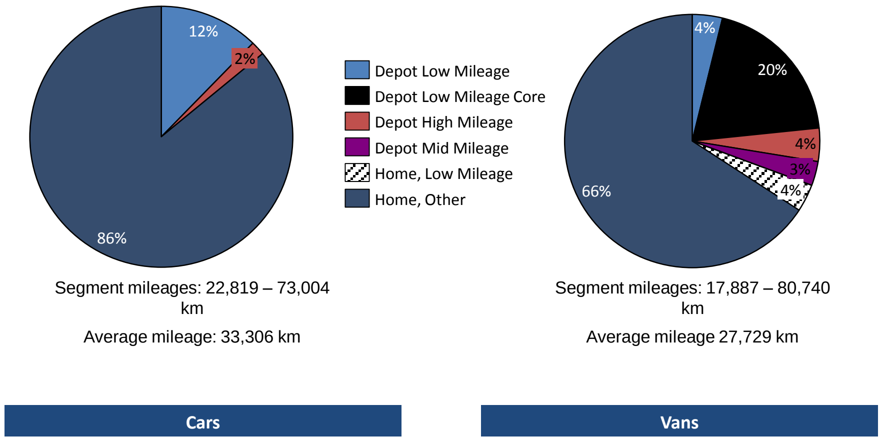

Fig. 3. Centralised-chooser fleets grouped according to suitability curve and overnight base location.

2.1.1 Vehicle sales and energy system impacts of car and van user segments

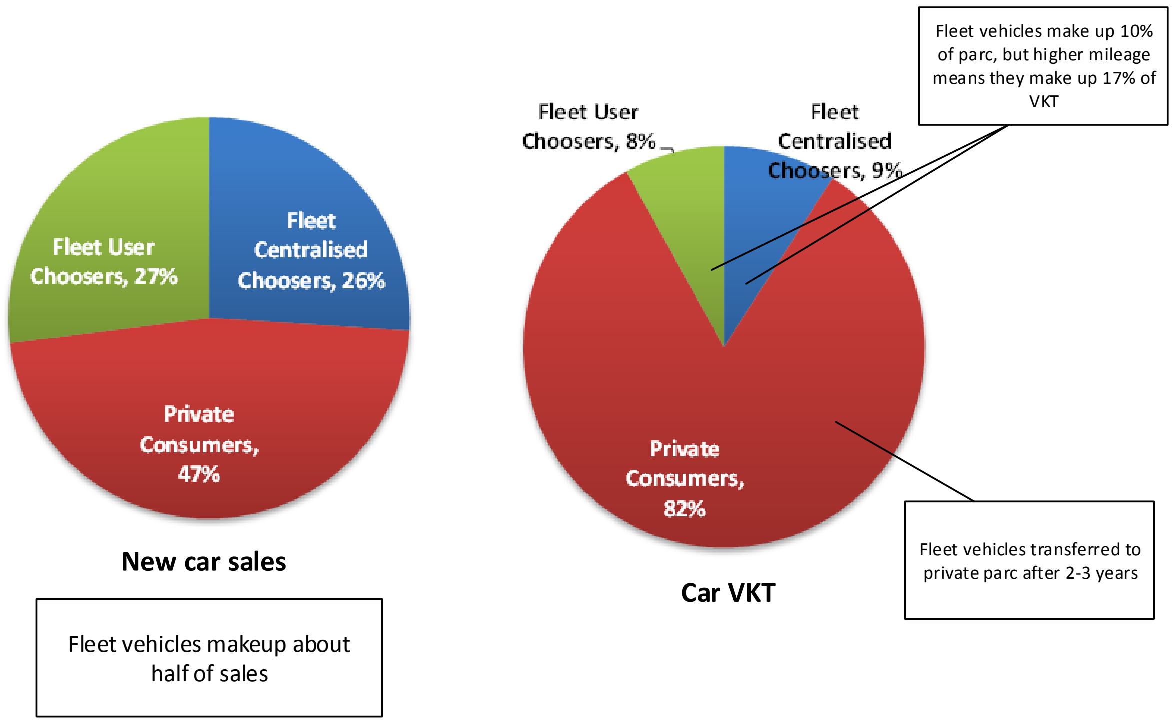

Fig. 4. New car sales and VKT by user segment.

Fig. 4 shows the relative impacts of each car user segment in terms of new car sales and VKT. Fleets make just over half of all new car purchases. Because these vehicles are disposed of into the private consumer parc after several years, fleet cars only make up around 10% of the total car parc. However, their higher mileage means they account for 17% of the total car VKT, and a similar proportion of overall energy utilisation. Around half of this is attributable to User-chooser fleets (whose vehicles are based overnight at users' homes).

Analysis of sales data revealed that among User-Chooser fleets, 26% paid Benefit in Kind (BiK) tax; of the 74% that did not, half were motability vehicles and the rest rental vehicles. Assuming mileages of BiK and non-BiK vehicles are similar, these percentages also represent the relative shares of VKT.

Among Centralised-chooser fleets, home-based vehicles make up ~80% of new car sales, VKT, and energy use (Fig. 5).

Considering both User-chooser and Centralised-chooser fleets, the analysis shows that the large majority of VKT and energy use is contributed by vehicles based overnight at users' homes, rather than those based in company depots.

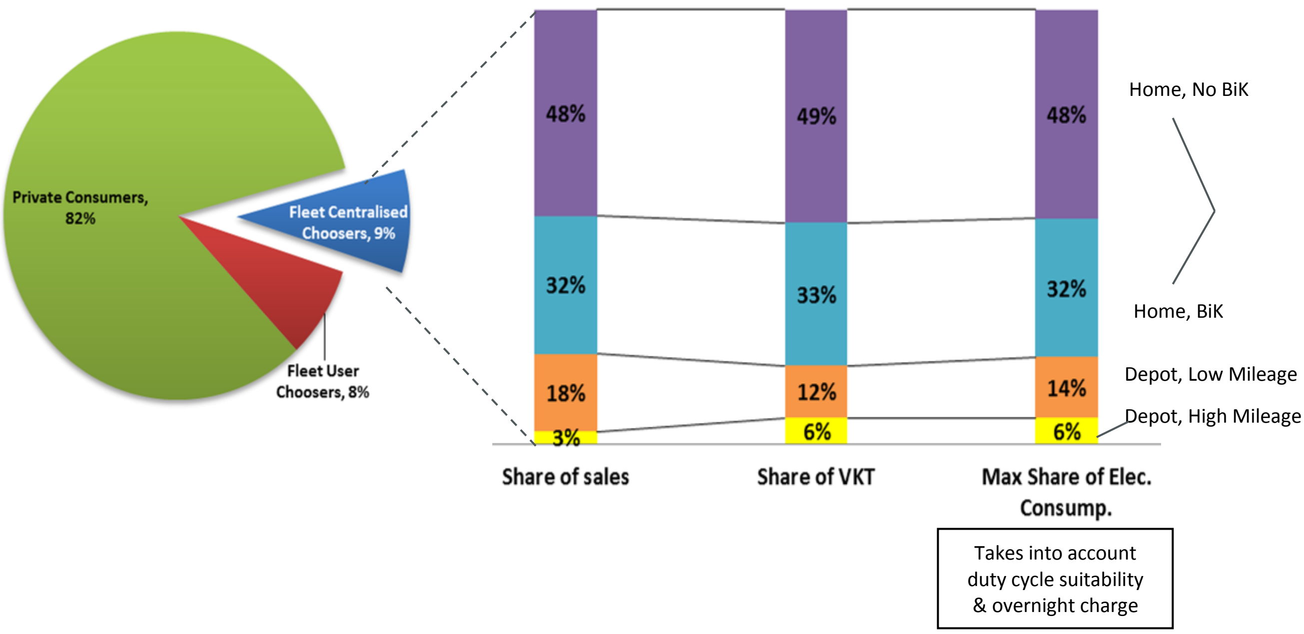

Fig. 5. Centralised-chooser fleets: new car sales, VKT and energy use by segment.

A similar picture emerges for vans. ECCo assumes that all new van sales are into Centralised-chooser fleets; but since these are disposed of into private use after 4 years, the share of overall VKT for Centralised chooser fleets is only 43% (the balance being from vans owned privately)[1].

Fig. 6 disaggregates Centralised-chooser van fleet VKT and shows that Home-based fleet vans make up the majority of fleet sales, VKT and the maximum possible electricity consumption.

CONCLUSION: the categories of fleets in which substantial uptake of BEVs could have the most potential impact on the energy system are:

- **User-chooser car fleets**

[1] Vans operated in fleets of one (i.e. by individual tradespeople) are included in the Centralised Chooser segment. Once vans are disposed of by fleets they are assumed to be used privately, i.e. not for business.

* **Centralised-chooser car and van fleets where vehicles are home-based**

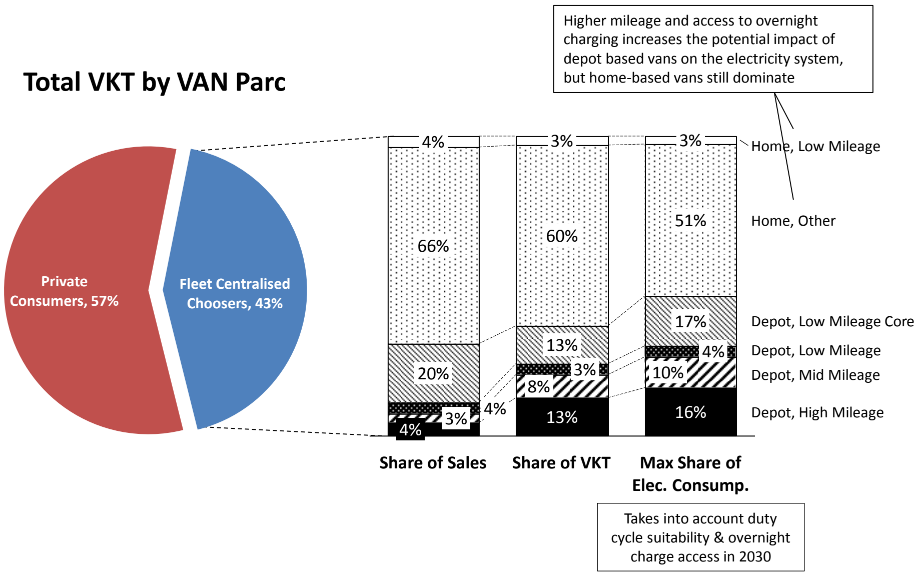

Fig. 6. Share of van sales, VKT and maximum share of electricity consumption from Centralised-chooser fleets, by segment

Car sharing fleets do not figure in this analysis as their shares of new vehicle purchases and VKT are as yet tiny in comparison with those of other segments discussed above. However it is appropriate to include them in the focus for Stage 2 research because (a) narratives that assume a move towards "mobility as a service" (asset sharing) afford them a much higher fraction of both sales and VKT in the future, and (b) any increase in their VKT is likely to come at the expense of VKT by private consumers.

3 Knowledge Gap 1: Potential for EV uptake in fleets

3.1 Vehicle selection: organisational decision making processes

Decision making in organisations can be considered to take place at three levels:

* Strategic: decisions made by senior corporate executives to implement aspects of corporate strategy.
    * In the context of potential EV uptake, these might include, for instance, corporate social responsibility, brand positioning, financial, or staff reward/remuneration strategies. These decisions may be influenced by information flow from operational level (for instance, on costs and operational suitability of EVs).
* Operational: decisions made at operational level, to maximise cost-effectiveness of business operations.
    * In the context of EV uptake, these are specific choices of vehicles, made at "fleet manager" level, to maximise cost-effectiveness of vehicle-dependent aspects of business operations. These choices may be influenced and/or

constrained by strategic-level decisions that determine an overarching framework

- Personal: decisions made by individual employees, where they have capacity to exercise individual choice.
    - In the context of EV uptake, these are specific choices of vehicles to support personal, instrumental and symbolic motivations. Those choices may be constrained by operational-level decisions that restrict the range of available choice options in line with the organisation's operational and/or strategic-level goals.

3.2 Modelling of vehicle choice processes in ECCo

3.2.1 Four chooser categories, two choice processes

The Electric Car Consumer (ECCo) model, developed for the ETI and in use by its members and the DfT, forecasts future alternative fuel vehicle demand by bringing together an understanding of purchase behaviour, the vehicle cost and performance offer, and the policy context. In ECCo, vehicle choosers are categorised into four user categories, three of which represent categories of fleet choosers:

1. Private Consumers

Vehicles are owned privately and choice lies entirely with the driver. The purchase decision is modelled in ECCo based on a weighted sum of six attributes: Purchase cost, Operating cost, Driving range, Access to charging infrastructure (local, workplace, & rapid), Performance of rapid charging, and Availability of preferred model/make. Six consumer segments ("Innovators", "Cost conscious greens", "Pragmatists", "Unmet Needs", "Uninterested rejectors", and "Car-loving rejectors" are modelled, each giving different weights to the different attributes (this segmentation, and the attribute weights, are based on empirical data from a 2015 choice experiment carried out for the Department for Transport with UK consumers (see D1.3 Appendix B)).

2. User-Chooser Fleets

Vehicles are registered to a company but chosen by individual employee users who are offered a mix of cash allowances, company cars or employee car ownership arrangements. Vehicle choice is modelled in ECCo on the same basis as Private Consumer choice – i.e. as essentially free. Fleet user-choosers value a vehicle through the same range of attributes as Private Consumers; though with different weights, specific to the User-Chooser fleet segment.

3. Centralised-Chooser Fleets ("Non-User Choosers")

Vehicle choice decisions are modelled as being made centrally by a "Fleet Manager" rather than by individuals. ECCo assumes that Fleet Managers' choices are "rational", i.e. made to maximise utility based on operational cost-effectiveness, and based first on operational suitability of vehicles (vehicles must meet duty cycle requirements) and then on total cost of ownership. Thus vehicle choices by Centralised-Chooser fleets and User-Chooser fleets are modelled using different processes and there is a recognition that this may result in substantially different choices. The separate treatment of these groups was a significant improvement to ECCo, developed in Stage 1 that expected to improve the validity of ECCo.

Analysis of Route Monkey data was used to disaggregate the Centralised-Chooser segment by duty cycle requirements. Further analysis of tax receipts was used to differentiate what proportion of centrally-chosen vehicles are liable to pay BiK tax and are therefore likely to be home-based.

4. Fleet Car Sharing

Vehicles are owned by companies that provide access to user-driven transport as a service, involving a degree of asset-sharing (e.g. car clubs and private hire cars). Vehicle choices are modelled in ECCo in the same way as those of other Centralised-Chooser Fleets, though with different assumptions about vehicle duty cycles. However, vehicle **use** by Car Sharing Fleets is assumed to satisfy a portion of the VKT demand of Private Consumers, effectively replacing a fraction of Private Consumer VKT with a more efficiently utilised fleet.

Such assumptions have largely been based on the "rational choice" perspective that dominates econometric modelling: that organisations make choices that maximise their net utility, based on cost-benefit considerations. Although it is now understood that this perspective sometimes fails to represent individual consumer choices adequately (because it over-emphasises instrumental (functional) motivations over symbolic motivations), the assumption is made that symbolic motivations play a less significant role in organisational decision making, so that a rational choice perspective is appropriate.

3.2.2 Potential limitations of the current approach

There are two key potential limitations of the approach outlined above, both of which arise because of the knowledge gap identified in Section 1.

1. Neither Strategic level factors, nor interactions between decisions at Strategic, Operational, and Personal levels are modelled, for either choice process.

Evidence was found in Stage 1 research with Operational-level decision makers (Fleet Managers) in depot-based centralised-chooser fleets that their decisions were indeed influenced by Strategic-level concerns (see Section 2); so a hypothesis might be formulated that this can be generalised to Centralised-Chooser fleets in general. If so, then insight into the extent to which that influence affects the choices made could usefully inform sensitivity analyses that explore the potential impacts of other choice variables that relate to Strategic-level factors, and/or interactions between Strategic- and Operational-level factors.

In car-sharing fleets, marketing strategy requires that vehicles are chosen that have consumer appeal – so while decisions are made centrally, they are likely to be influenced by consumer preference. Thus vehicle choice in car-sharing fleets in principle may share some of the properties of both choice mechanisms outlined above. Again, insight into this could usefully inform sensitivity analyses that explore its potential impacts.

2. Operational-level modelling in terms of suitability of vehicles for duty cycle plus total cost of ownership is known to over-predict current EV acquisition rates.

This over-prediction is corrected for in ECCo using a "familiarity penalty", a factor that reduces uptake based on an assumption that choosers in the early market have a bias against choosing EVs because of their relative unfamiliarity. This effect of this factor is assumed to decrease as the penetration of EVs in the LD vehicle parc (and therefore their familiarity) increases. However, there may be other factors influencing operational-level decision making, beyond operational suitability, total cost of ownership, and the strategic-level influences discussed above, that influence those decisions in ways that are not well represented by the familiarity penalty. Such factors might be explicitly known to fleet managers, though not by modellers. Explicit evaluations of the operational risk of choice options would be one example. The Stage 1 research with Fleet Managers in Centralised-Chooser depot-based fleets suggests others: it identified the indirect influence of positive feedback from drivers, and the anticipated higher administrative burden of operating with EVs (including scheduling of charging, and more complex route scheduling) as having a bearing on some Operational-level vehicle choices. Alternatively they might reflect implicit influences that are outside the immediate awareness of Operational-level decision makers, but indirectly influence their choices (for instance, implicit social signalling within the organisation, by those decision-makers).

Insights into such factors as they relate to Centralised-chooser fleets with home-based vehicles, and to Car-sharing fleets, could usefully inform sensitivity analyses to explore their potential impacts.

3.3 Research Questions

To reduce Knowledge Gap 1, the Case Studies will address the following key research questions:

User-chooser fleets:

1. How is the range of choice options available for personal-level choices by User-Choosers influenced by operational and strategic level decision making?
2. How are those operational and strategic level decisions reached?

Centralised-Chooser fleets with home-based vehicles:

3. How do strategic-level factors influence uptake decisions (and in what ways), and how do these interact with operational-level decision making?
4. What operational-level factors contribute to Fleets' evaluation of operational suitability and TCO, and thus influence decision making (and in what ways)?
5. What other operational-level factors (beyond operational suitability and TCO) influence decision making (and in what ways)?

Car-sharing fleets:

6. How do Strategic-level factors influence uptake decisions (in what ways) and how do these interact with Operational-level decision making?
7. How do Consumer preferences influence Strategic-level and Operational-level decision making?

4 Knowledge Gap 2: Charging profiles

There is also very little research evidence to draw on regarding the charging profiles of EVs in User-Chooser fleets, Centralised-Chooser fleets with home-based vehicles, or Car-Sharing fleets. Modelling is necessarily based on plausible assumptions rather than grounded in empirical data.

A starting assumption for modelling the charging profiles of home-based EVs, whether in User-Chooser or Centralised-Chooser fleets, is that they are similar to the charging profiles of private consumers. That is, charging is mainly carried out at home, in the evening and overnight.

However, given the dearth of research evidence, that assumption is potentially subject to challenge. For instance, it is known that the average VKT by fleet-operated vehicles is higher than the average VKT by private consumers, so on average, daily charging demand from home-based vehicles in both User-Chooser and Centralised-Chooser fleet categories may be higher than that of private consumers. This will also alter demand-time profiles, by extending the duration of charging periods. Consequently it will limit flexibility of charging times, and therefore suitability for Managed Charging.

There may be other reasons why the charging profiles of real-world User-Chooser fleets and Centralised-Chooser fleets with home-based vehicles may differ from those predicted under this starting assumption. To the extent that organisations provide workplace charging, and duty cycles place vehicles at the workplace for substantial intervals, then a shift towards daytime charging is plausible. Fleet EV users may also have different patterns of access to public charging during daytime than private consumers, e.g. where fleets, for operational reasons, negotiate access to charge point networks.

Car-sharing fleet vehicles are not based at users' homes, but rather are based at distributed locations: near to members' residences, at transport hubs, and near key destination locations in city centres. As suggested in the preceding section, car sharing fleet uptake of EVs is likely to depend on their ability to provide charging points at these locations.

Car-sharing vehicles are typically in use daytime & evening, so their main window of opportunity for charging at their distributed base locations is overnight (late evening to early morning). However, car sharing business models depend on vehicles having high utilisation rates while offering members reasonably high availability. To achieve both of these with an EV requires that it have sufficient charge to meet user needs throughout the day and evening, suggesting that car sharing fleet EVs would need to be recharged whenever returned to a base location. In addition, users on longer hires may seek to recharge vehicles at public chargers during their hire periods.

Thus a number of research questions need to be addressed.

4.1 Research questions

User-Chooser and Centralised-Chooser fleets:

1. What is the form of home-based charging profiles? What is daily charging demand? What are charging durations? How valid are the assumptions that charging will mainly occur at home during evening and overnight?
2. How far would organisations provide workplace charging, and to what extent would they make it attractive for users?
3. How far would users have different patterns of access to public charging during daytime than private Consumers?
4. How would users pay for electricity used by the vehicle (at home, or at public chargers)? How would they be reimbursed for electricity used for business purposes?

Car sharing fleets:

5. How readily can chargers be provided at the appropriate distributed locations?
6. What is the pattern of vehicle availability for charging? (specifically, what fraction of daytime and evening)?
7. What fraction of charging would be carried out by users at public charge points, rather than between users at base locations?
8. How would Car-Sharing Fleets ensure that members leave vehicles connected to chargers at the end of trips?

Insights generated in relation to these questions will inform potential sensitivity analyses that explore the impacts of factors identified in the Case Studies.

5 Stage 1 research

Stage 1 field research focussed on Centralised-chooser, depot-based fleets, using a semi-structured interview approach at Operational level (with Fleet Managers). This focus was chosen because Centralised-chooser fleets are modelled in ECCo using a choice process that seems plausible but to date lacks empirical support. Depot-based rather than home-based fleets were selected to facilitate discussion of Managed Charging options.

Participating fleets were recruited largely from the Route Monkey database, supplemented by fleets recruited by Cenex. Most participating fleets either had EVs already, or were considering them; they could thus be considered as EV Innovators. The research addressed research questions around attitudes to EVs, experience with EVs, charging behaviour, and initial responses to User-managed and Supplier-managed Charging options. As a stimulus to discussion, Route Monkey analysed vehicle utilisation and the potential to replace ICE vehicles with BEVs either on a like-for-like basis or more optimally by adjusting scheduling to maximise opportunities for EV use; a summary of the analysis was provided to participants in advance, and discussed during the interview.

Key research findings relevant to EV uptake were:

- Strategic-level considerations, particularly around positioning of the organisation as seeking to minimise its carbon footprint, were evident in many participating fleets' accounts of the factors involved in vehicle selection.
- Several other factors were identified in addition to suitability for duty cycle and total cost of ownership as being relevant to vehicle purchase decisions.

The research served as a methodological pilot study, testing the usefulness of individual semi-structured interview research, and the use of the Route Monkey fleet energy management optimisation tool as a means to stimulate discussion of Managed Charging options. In fact neither proved particularly successful. The short duration, long list of research topics to address, and limited time for the development of relational depth meant that there was insufficient time in a 1-hour slot to address any of the research questions in depth. Nor was there sufficient time to discuss and explain the Route Monkey analysis summary.

6 Methodology

Given that the existing evidence base is so sparse, there is a need to explore fleets' own perspectives on what factors are important in their decisions about EV uptake: these are not known in advance. Research methods that draw on researchers' own knowledge, experience or personal understanding are therefore inappropriate, because they run a high risk of the "Procrustean" error – that is to say, forcing information to fit prior theory, irrespective of its validity. Theory should emerge from and be grounded in the information and data gleaned. For this reason quantitative research methods such as surveys are not suitable; nor are highly structured interview methods.

Rather, to address the research questions discussed above an exploratory, qualitative methodology is required that reflects rather than constrains participants' own ways of construing the issues. Qualitative methods do not generate statistically representative data, but rather hypotheses whose potential impacts can be explored in modelling.

6.1 Common qualitative research methods in transport and organisational research

Two qualitative research methods dominate the literature in both transport research and organisational research: the semi-structured individual interview, and the discussion group ("focus" group). For the reasons set out below, neither is sufficient on its own.

6.1.1 Semi-structured interviews

The semi-structured interview method is the most widely used qualitative research method in both the transport and organisational research fields.

In organisational research, participants are typically individuals in similar roles in different organisations. A sufficient number of interviews is required to achieve "saturation" – a point where adding extra participants does not add further themes in the analysis. If the population being studied is relatively homogeneous in terms of its ways of construing the topics of research interest, then as few as ten interviews may suffice to achieve saturation. Often, the population will be heterogeneous in its ways of construing, so a larger number of interviews may be required. Experience suggests that, across a wide range of domains including transport and organisational research, around 30 interviews will often be sufficient.

In a semi-structured interview, the participant has the opportunity to discuss the research topics from his/her own perspective, in his/her own words. The interview does not take the form of a survey or questionnaire, with the participant being asked to select from a range of researcher-supplied answer options. Instead the researcher asks open questions that invite the participant to talk about their experiences, understandings, feelings and views about the topic. The researcher draws on a discussion or topic guide to provide overall direction and focus, so that the topics of research interest are covered; but it is not necessary to follow the specific order of questions, ask every question, or to use the exact wording for a question as suggested in the guide. Rather, the researcher seeks from the start to develop a comfortable, relaxed rapport with the participant so that he/she feels confident to talk as openly as possible. In a semi-structured interview the researcher is seeking to build a rich picture of the way that the participant relates to the topics – how the participant experiences them, is affected by them, thinks and feels about them, and what influences his/her responses to them.

In organisational research interviews are typically limited to an hour or less in duration, as it can become more difficult to recruit organisational participants if the research imposes any bigger loss of working time. However, this relatively short duration limits the value of the method when the range of topics to be explored is wide, when topics need to be explored in depth, or when rapport between researcher and participant is expected to be critical (for instance where research topics may be commercially or personally sensitive) because even with a skilled researcher it may take some time to develop.

Telephone interviews are the norm, as these can be conducted efficiently at lower cost, and participants are generally comfortable engaging in extended discourse by telephone. However, face to face interviewing is preferred when rapport between researcher and participant is expected to be critical.

In scientific qualitative research (in contrast to marketing research) semi-structured interviews are audio recorded, and transcribed. The set of transcripts is then analysed, line by line and transcript by transcript, to identify and describe common themes.

This method was used for the qualitative research with Fleet Managers of depot-based Centralised-Chooser fleets in Stage 1. Experience in that study suggested that the limited duration of individual interviews was insufficient to enable in-depth exploration of the wide range of topics involved in exploring EV uptake and use. In addition, short-duration telephone interviews provided limited opportunity for researcher-participant rapport to develop.

6.1.2 Discussion groups

Discussion or “focus” groups (rather than individual interviews) are also common in both transport and organisational research, mainly for reasons of speed and cost.

In organisational research, participants may either be individuals in similar roles in different organisations, or individuals in different roles within same organisation, depending on the research questions being addressed. Discussion groups are typically of two hours’ duration, and to be effective, must be carried out face-to-face. In scientific research, discussion groups are either audio or video recorded (the latter making transcription of multiple voices easier, and enabling observation of social processes enacted through non-verbal means).

However, there are often substantial issues of social influence in groups that can lead to distortions in the information gathered; individual semi-structured interviews are often to be preferred when possible. Some exceptions include research where social influence processes are themselves of research interest, and workshop-style sessions where the aim is to make use of social processes to help with, say, ideas generation or concept development.

6.2 Case studies

Where research involves the exploration of complex organisational phenomena, particularly those which have an inter-personal dimension, or those which involve multiple organisational goals that may complement each other, compete, or conflict, then neither semi-structured interviews nor discussion groups provide sufficient engagement time, breadth, or depth of exploration. As seen, EV uptake by fleets may involve complex interactions between the decision-making of staff at Strategic, Operational, and Personal levels. The perspectives of staff in a variety of roles that reflect these levels therefore need to be listened to and interactions understood. This requires a more complex approach. For the Stage 2 Fleets research, a Case Study approach is therefore proposed.

Case studies are detailed studies of individual cases, aimed at exploring their particularities and complexities in depth (Yin, 2009). Individual case studies are tailored to the individual circumstances of their subject cases, so the specific methods adopted from case to case may differ. However, in organisational research they generally share certain characteristics. Case studies typically take place over an extended time interval, providing multiple opportunities to engage and re-engage with the organisation and its staff. In addition, they typically involve engagement with staff in a variety of roles.

Case studies also enable the development of greater relational depth between researchers and participants. Relational depth refers to the development of a relationship of familiarity and trust between participants and researchers, in which participants are facilitated to disclose more sensitive information, and to access motivations that are at the edge of, or outside awareness. Case study approaches provide the opportunity for relational depth to develop.

To achieve relational depth, researchers need to be able to engage in meaningful contact with all participants. In relation to fleets, this means researchers need experience of engaging appropriately with senior executives as well as with operational level staff such as fleet managers. Researchers also need to be able to engage with, understand, and reflect their understanding of participants' own frames of reference and ways of construing their situations (NOT attempting to fit/interpret participants' contributions using their own frames of reference); they need to be non-judgemental, and convey that to participants; and they need to be genuine, authentic, open, and trustworthy (NOT acting as if concealing something, such as why a particular question is being asked). Working at relational depth requires specific training.

TRL has experience of applying the case study approach to a research programme for Transport for London which aimed to understand why construction vehicles are overrepresented in cyclist fatalities in London (Helman, Delmonte & Stannard, 2013). Researchers identified specific construction sites and engaged in qualitative discussions with a 'network' of key stakeholders (such as clients, principal contractors, subcontractors, drivers). This level of engagement enabled us to build a detailed picture of perceived relative risk to cyclists represented by construction vehicles as well as examining which features of contractual arrangements, working practices, driver behaviour and vehicle design could contribute to fatal collisions between construction vehicles and cyclists in London.

Case study methodology has so far been more fully developed and applied in other technology innovation domains than in transport research. For example, one American case study investigated technology implementation and integration in rural schools (Cullen, Brush, Frey, Hinshaw, & Warren, 2006). Here, researchers adopted a case study approach to examine a school in-depth to gain an insight into several key issues. The approach adopted by researchers involved:

- contacting a relevant individual at a school of interest;
- conducting an initial interview with the individual;
- asking the interviewee to supply a list of teachers and administrators who could provide further insight into technology implementation in the school;
- conducting face-to-face interviews with these additional participants, and

- observing teacher and student behaviour in a classroom setting.

This example illustrates how, in organisational Case Studies, initial engagements with members of staff can be used to identify other staff for further engagements; and how multiple specific methods (in this case, both interviews and observation) can be used within a single study. Generalisation from any particular case studied is based on theoretical extrapolation, not statistical representativeness; the outputs can be treated as hypotheses about how a wider population that shares theoretically salient attributes will respond.

In conclusion, the more common qualitative research methods are insufficient on their own for our purposes. A flexible case study approach offers the maximum opportunity to answer the research questions needed to address Knowledge Gaps 1 and 2.

7 Research design

The proposed research will consist of five in-depth case studies, addressing the research questions set out above in relation to Knowledge Gaps 1 and 2, as follows:

- 2 x case studies of user-chooser fleets
- 2 x case studies of centralised-chooser fleets where vehicles are based at users' homes (one of which operates predominantly cars, the other also operates a substantial fraction of vans)
- 1 x case study of a Car sharing fleet (Zipcar have expressed interest)

Each case study will be an in-depth study of one organisation. Specific methods used for each case study must be negotiated and agreed with the participating organisation.

8 Recruitment of participating fleets

8.1 Recruitment criteria

Participating fleets will be recruited against the following criteria:

- The fleet size will be greater than 100 vehicles. This will ensure that the organisation is of a sufficient scale to exhibit the decision-making complexity outlined above, and also provide a variety of usage profiles and scenarios within each case study.
- Organisations will be potential "Early Adopters" (as defined in Rogers' (2003) Diffusion model) of EVs, but not "Innovators" – so willing to consider EVs in near future, but not currently using them (or only trying out a few).
- Organisations will have a track record of successful early adoption of other technological innovations.
- Organisations will be successful businesses (measured in both profit & growth), as this is a demonstration that their strategic thinking is effective.

8.2 Recruitment channels

To maximise the chances of recruiting against the criteria above, initial engagement with potential participating fleets will be made via a variety of channels:

- Engagement via relevant project partners who have established relationships with fleet contacts (e.g. Route Monkey and Cenex).
- Established relationships with key industry facilitators (such as the Freight Transport Association, ACFO, Transport Engineer and Fleet news) who are well-placed to engage with our target participants.
- Advertisement of the research on the TRL website, Twitter, LinkedIn accounts and other social media channels.
- TRL runs the ECO Stars Fleet Recognition scheme which operates in fleets in over 20 different local authority areas across the UK. This team have established ongoing relationships with the fleet managers associated with this scheme.
- Engage with fleets for which Energy Savings Opportunity Scheme (ESOS) audits have been completed.
- Appropriate contacts from TRL's database.

Once initial contact is made, a strategic engagement plan will be developed for each participating fleet, along with bespoke incentives for participation. A key element of the strategic engagement plan will be early contact with strategic-level decision makers within the organisation, as their engagement in the research, and support for the organisation's involvement, will be a critical success factor.

8.3 Potential incentives for participation

Different organisations may be motivated to take part in this research by different incentives, so a range of incentives have been designed based on previous successes in engaging with fleets to encourage participation in this research.

Potential incentives and the rationale for their selection include:

- The option to take part in an EV demonstration event – these events could be held at either TRL or Cenex and would give fleet managers the opportunity to experience driving the different types of EVs, learning about how to charge them and receiving a briefing about their capabilities.
- Charitable donation – this is a well-established incentive and historically has worked well at encouraging fleets to participate in research. In Stage 1, individual fleet manager participants were offered a £50 donation to one of three charities in exchange for participation in telephone interviews. It is proposed incentives of £50 per participant for Stage 2 (i.e. up to £250 to a charity of choice where multiple staff in different organisational roles are involved enabling the organisation to get favourable PR through publicising their corporate citizenship).
- Positive public relations about being associated with the project – one of the findings from the Stage 1 research was that some fleets operate EVs in order to signal corporate social responsibility and/or for reasons of brand positioning. Therefore participation in novel research such as this could be used in marketing and promotional activities for participating organisations.
- Enhanced knowledge and understanding of the current status of the EV market – this would be provided on a consultancy basis with relevant experts from across the project partners. This would enable decision makers at Strategic and Operational

levels to have a better understanding on which to base any future decision-making about incorporating EVs into their fleets.

9 Case study format

The specific methods used in each Case Study will be negotiated with each participating fleet. Given the focus on the particular that is in the nature of Case Study research, there is no disadvantage to variation between Case Studies in the methods employed, provided that they enable adequate exploration of the research questions. Indeed some methods (such as interviews at Personal level) are only relevant for some categories of fleets (in this case, User-Choosers). Nevertheless, each of the Case Studies will draw on the following repertoire of methods where appropriate and where it can be negotiated.

- Initial desk research will be conducted prior to engagement with the targeted organisation to identify and contextualise general sector trends and strategic issues
- This will be followed by individual semi-structured face to face interviews with multiple staff from the case study organisation with diverse roles relevant to the research. These will be at the strategic, operational, and where appropriate, personal levels. They will also cover a variety of departments or sectors of the organisation such as procurement, finance and personnel.
- Multiple interviews will be held with key individuals to build relational depth and cover complex topics in sufficient depth.
- Each of the case study organisations will be studied over several months' time interval to provide more than a 'snap shot' of opinions and evidence.
    - Where it is available, analysis of organisational data on VKT, fleet costs, and other relevant metrics will be made. It is important to note that in our experience these are not always available in granulated detail, and may be as general as annual mileage per vehicle.
    - Where possible, observation will be made of the decision making processes in action to give insight into relational dynamics within the fleets' organisations.
    - Where appropriate, observations will be made of business activities such as accompanied drives (example of duty cycles) and patterns of workplace car park occupancy to gain first-hand experience of the utilisation of fleet vehicles and the potential opportunities for away-from-home charging.

10 Analysis

Thematic analysis will be used to integrate findings across the elements of each Case Study. Discrete sets of themes will be identified in relation to each research question.

In thematic analysis, the content of each item of data is considered in turn, and allocated a category. For the very first item, the category will be a proposed generalisation of the specific content. Subsequent items are reviewed for similarity with existing categories; if insufficiently similar, a new category will be created. The meanings of categories are not fixed at the start of the analysis, but are allowed to emerge and evolve as the analysis proceeds, led by the meanings in the data.

Initial analyses can give rise to a large number of initial categories. Subsequent analyses consider how far these categories can meaningfully be grouped into a smaller number of “themes” that are internally homogeneous (all constructs allocated to a particular theme are closer in meaning to each other than they are to any constructs allocated to different themes) and externally heterogeneous (all constructs allocated to different themes are more different in meaning than any of the constructs within a particular theme). Themes represent the diversity of ways of responding to the topic that have emerged in the research, at a level of generalisation where they could be thought of as understood in common by participants.

The analysis will be approached inductively (Braun & Clarke, 2006), i.e. the structure of themes allowed to emerge from the data itself. It will be conducted at a semantic level (Braun & Clarke, 2006), from the explicit meanings contained in the data, without attempting to draw inferences about underlying meanings, and from an essentialist/realist epistemological stance - assuming that the language used by participants reflected their experience and personal constructions in a straightforward way.

To ensure reliability of categorisation, the procedure will be carried out independently by two researchers. Their provisional categorisation schemes will be compared and negotiated until a common scheme is arrived at. The main issue for negotiation is the saliency of similarities and differences between constructs with respect to the research topic. Thematic ambiguities will be resolved by giving priority in interpretation to nouns, noun phrases and verbs over adjectives or adverbs. Each analyst will then independently re-allocate constructs to the common set of themes.

11 Reporting

Full details of the methodology, analysis, and findings from this research study will be documented in a Report (Deliverable D2).

In addition to the final written report, a PowerPoint presentation will be produced in order to provide the ETI Review Panel with an overview of the key results and conclusions from the Case Study Research. This presentation will be delivered before the Report to allow for comments from the Review Panel to be incorporated into the written deliverable.

Subject to approval and sign-off of the Fleet Research Study report from the ETI, separate content will be written for submission to a peer-reviewed academic journal(s) (e.g. Renewable and Sustainable Energy, Transportation Research Part A: Policy and Practice, Transportation Research Part D: Transport and Environment, Energy Policy, or International Journal of Electric and Hybrid Vehicles).

The reporting process will form part of a dissemination strategy to ensure that the knowledge gained from this trial is appropriately published into the wider academic community. Full details of the dissemination strategy are provided in Part 1 of this deliverable.

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TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN

ISBN

PROJECT REPORT

D1.4 Stage 2 Trial Design, Methodology and Business Case

Part 5 - Analytical Tools

Greenleaf, J., Cluzel, C., Bird, N., Rix, O. and Stewart, A.

Report details

Report prepared for:	ETI
Project/customer reference:	TR1006 Consumers, Vehicles and Energy Integration (CVEI)
Copyright:	© Energy Technologies Institute
Report date:	March 2017
Report status/version:	4.0

Quality approval:			
H. Al-Katib (Project Manager)		S. Skippon (Technical Reviewer)	

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer
1.0	10/06/16	Draft delivered to client	James Greenleaf (Baringa), Celine Cluzel (Element Energy), Natalie Bird (Baringa), Oliver Rix (Baringa), Alex Stewart (Element Energy)	Stephen Skippon (TRL)
2.0	14/12/16	Second version including client comments	James Greenleaf (Baringa), Hannah Al-Katib (TRL)	Stephen Skippon (TRL)
3.0	14/12/16	Third version	Hannah Al-Katib (TRL)	Stephen Skippon (TRL)
4.0	13/03/17	Final version	Hannah Al-Katib (TRL)	Stephen Skippon (TRL)
Document last saved on:	13/03/2017 14:43			
Document last saved by:	Hannah Al-Katib			

Table of Contents

Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics
ESME	Energy System Modelling Environment
ESOS	Energy Savings Opportunity Scheme

EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
ISO	International Organization for Standardization
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer

ONS	Office for National Statistics
OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
UMC	User Managed Charging
VAT	Value Added Tax
VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services
WP	Work Package

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)

Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how you see yourself and how one perceives others see them.
Social norms	Similar to injunctive norms but mores specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.
Symbolic meaning/ attitudes	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

1 Introduction

1.1 This report

This report is part of Deliverable 1.4: Stage 2 Trial Design, Methodology and Business Case. There are six parts to this deliverable:

- Part 1: Overview of Stage 2
- Part 2: Consumer Uptake Trial
- Part 3: Consumer Charging Trials
- Part 4: Fleet Study
- Part 5: Analytical Tools (this document)
- Part 6: Commercial Submission

This report covers Part 5, the Analytical Tools and supporting analysis (Work Package 7). The proposal reflects collaborative development involving TRL, Baringa, Element Energy and the ETI.

The other parts of Deliverable D1.4 are provided in separate documents. Part 1 includes an overview of the CVEI project as a whole.

1.1.1 Scope

The contents of this report provide details of the following:

- Provision of supporting data inputs for the Consumer Charging Trials in Section 2
- Analysis of trial outputs and update of the Analytical Tools in Section 3
- Development of the Demand Management Aggregator framework in Section 5
- Update of the Stage 1 analysis in Section 6
- Other supporting activities in Stage 2 in Section 7

2 Task 7.1: Data inputs for Consumer Charging Trials

The aim of the Consumer Charging Trials is to enable study of the consumer response to User-Managed and Supplier-Managed Charging tariffs. The Stage 1 modelling will help to provide key inputs to the trial, in particular informing the retail electricity prices for all tariffs, and the potential cost savings that a consumer may obtain under an actively Supplier-Managed Charging regime. The trials will measure consumer charging behaviour in response to a particular set of User-Managed or Supplier-Managed tariff conditions, determined by the outputs of Task 3.1.

The inputs will be for a representative future year (e.g. 2030 or 2035) and will include an element of variation within year and day (e.g. seasonal prices and weekday / weekend) reflective of underlying electricity system costs. However, providing excessive variation in the input data will make it harder to understand consumer behaviour and therefore the input data cannot be used to represent a range of other years simultaneously.

Additional variation in tariff structures will be explored by choice experiments at the end of the trial in WP1. For example, this could allow testing of respondents' choices between user-managed and supplier-managed charging options under different price levels, ability to override, or the choice between standard and time of use tariffs based on different peak/off-peak prices. The results from these choice experiments and the consumer charging trial itself will be used to provide revised input data for the modelling tools to reflect better likely consumer behaviour over the pathway to 2050 under changing system conditions.

2.1 Retail electricity prices

Prices will be provided on an hourly basis for the representative year. We will combine Baringa's detailed PLEXOS electricity system modelling from our in-house GB Market Report[1] with components of the higher level modelling in Stage 1 (e.g. demand profiles, commodity prices and electricity capacity mix from a selected Narrative) and adapt our existing PLEXOS model to produce a set of hourly wholesale prices.

- To provide a User-Managed tariff for the relevant consumer group, we will convert the hourly price series into several blocks, which have the same price per individual block.
- The expectation is that tariffs will be reflective of the generation costs and will include variation within each day (3-5 periods to be finalised), across each week (weekday/weekend variation) and across seasons.
- For the consumer group in the Supplier-Managed Charging condition, we will average the hourly price series in a manner that is appropriate according to the final trial design, e.g. they will not be provided with a diurnal price signal but be offered flat tariffs for their electricity usage so that their observed response is only

[1] Used primarily for private developers, lenders and investors, but also for public organisations e.g. see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/441809/Baringa_DECC_CfD_Negative_Pricing_Report.pdf

considered a function of the Supplier-Managed Charging tariff rather than both this and a User-Managed price differential.

The wholesale prices will be translated to retail electricity prices by adding the other components in the stack (TNUoS/DUoS charges[2], VAT, cost to serve etc.) using the evolution observed in the Stage 1 modelling for the selected Narrative to make them representative of the future 2030/35 period. For those charges that are typically shaped within the day, week or year (such as DUoS), we will draw on our internal modelling tools in order to apply sensible shape to the components (under the simplifying assumption that the charging structures will remain broadly unchanged over the medium term).

Output: An ex-ante price series for each hour of the 2-month trial period, shaped appropriately for the different trial groups.

2.2 Supplier-Managed Charging incentives

Under the Supplier-Managed tariff the user will plug-in and specify the desired minimum State of Charge (SOC) and departure time. We define a Managed Charging Availability Ratio (MCAR) as the ratio between the length of the time window available for charging to the length of time required to charge the vehicle to the desired SOC. Where the offered and delivered MCAR is >1 (i.e. they do not plug-out ahead of this window) the user is effectively providing the DM aggregator with a degree of flexibility over the precise charging profile.

The DM aggregator is also able to provide additional charge, in anticipation of future need, during any period when the vehicle is plugged in and costs to the user are 'low'. To take advantage of this route to cost saving the user must both maximise MCAR by making the vehicle available for charging whenever parked at home, and avoid over-stating desired SOC (a user who specifies maximum SOC constrains the supplier to fully charge the vehicle before the departure time even if prices are high; whereas if the user specifies a lower required SOC, the supplier can top charge up beyond this level if prices are low, but not otherwise, thus yielding a net saving).

For the purposes of the trial, simple logic would need to be defined to represent this anticipatory charging. For example, charging between the required SOC and 100% would take place to the extent that the average £/kWh (based on the wholesale price shape) is ≤ that when charging to the required SOC only. We would also need to consider whether the metric is based on assumed perfect foresight of the provided price series or e.g. a previous period, to reflect the challenges the DM aggregator faces when trying to trade their position more frequently and closer to Gate Closure.

It is assumed that the under this tariff the DM aggregator uses this flexibility *to maximise the cost-savings to the consumer,* compared to a situation where no flexibility was provided and the underlying costs of electricity are passed through in as cost-reflective manner as

[2] Transmission Network Use of System (TNUoS) charges and Distribution Use of System (DUoS) charges

possible[3]. The level of cost savings may vary by time of day, day of week or season depending on the underlying conditions on the system. In addition, cost savings would need to account for the operating and risk management costs associated with the DM aggregator's commercial model.

The Supplier Managed Charging trial aims to understand what level of cost-saving is required by the consumer to motivate them to provide maximum MCAR (i.e. leaving the vehicle plugged in and available to charge whenever physically at the charging point) and avoid over-stating desired SOC. The challenge for the DM aggregator (as discussed further in section 5) is the potential mismatch between the costs they face and the revenues they can generate based on a given consumer response.

In practice, it is not certain that the DM aggregator will automatically be able to pass through all of its underlying costs (plus a margin) to the consumers, due to:

- Competitive retail market pressures if the DM aggregator is also effectively a supplier of electricity, with consumers free to switch to alternative suppliers
- A mismatch between the provision of flexibility by the consumer compared to what the DM aggregator needs to maximise its revenues. For example, this affects the ability of DM (or other DSR) aggregators to participate in capacity markets or triad avoidance where the precise timing of the requirement is unknown and where there may be also be a penalty (in the case of the capacity market) for non-provision of the service.

For the purposes of the trial input data it is not necessary to simulate these complicated dynamics. What matters is that the scale of potential savings on offer from the consumer's perspective is sensible in relation to those that the DM aggregator may be able to provide. The potential consumer cost-savings can be split into two main categories:

- **Management of wholesale prices:** here the underlying wholesale (spot) price shape from section 2.1 will be used. Where the consumer provides an MCAR >1 it is assumed that the DM aggregator undertakes their charging in the cheapest hours across the period and the consumer sees the saving relative to having charged in the periods if they had provided no flexibility from plug-in. In addition, the use of anticipatory charging will be focused around the costs associated with the wholesale price shape.
- **Additional consumer cost savings from providing other system level benefits:** these comprise a potential mix of e.g. post-gate closure energy balancing, other ancillary services or capacity payments. These are potentially accessible to the DM aggregator in future and represent benefits to consumers beyond those from managing wholesale price variation, but for which there is a

[3] This implies that a significant portion of the volume and price risk along the electricity value chain sits with the end-consumer by default under this tariff, unless they are proactively providing flexibility to the aggregator/supplier. By contrast, current flat rate tariffs mean that the supplier assumes much of this risk.

potentially greater mismatch between the costs to engage consumers and the revenue streams themselves. As a result they are treated as an 'additional cost saving/discount' on top of the management of wholesale prices, which takes priority. The stage 1 analysis helps to provide an appropriate range on the potential value of these types of savings. Consideration would also need to be given to situations where the use of anticipatory charging significantly reduces (or even eliminates) the potential flexibility in charging, as this would limit the ability of the DM aggregator to provide additional system benefits.

We will define the logic and data such that for a given time period it is possible to estimate the potential cost savings that a consumer would be given if the vehicle were available for charging (given assumptions about required SOC and departure time). Whilst the ladder of savings will not be linked dynamically to what is occurring on the supply side, the savings available will need to reflect some sensible variation of 'stress' on the system (by time of day, day of week and season) as the revenue streams available to the DM aggregator, or ability to manage wholesale price variation, will vary in this manner. For example, it is generally more valuable to provide greater charging flexibility during winter evening peaks when the margin on the system is already tight.

The range of potential cost-savings (including those arising from "anticipatory" charging) on offer must reflect the wholesale price savings and the scale of potential additional system savings seen from the Stage 1 modelling (both now and in future years). Simple analysis will be conducted at the start of Stage 2 to establish what this sensible range of savings per user per period is.

As the consumer response is not known in advance of the trial itself the analysis will need to estimate a low / high range of typical MCARs offered and contrast this with a series of MCAR savings such that at the top end of the range (large MCARs offered and high consumer cost savings) the total DM aggregator payments (when extrapolated to the total number of likely PIV owners from the Stage 1 analysis) do not significantly exceed the system value of the additional flexibility provided (separate to the wholesale price savings).

The exact approach and outputs will be determined in discussion with TRL and ETI, and will depend on the final detailed trial design. Further learning from the development of a DM aggregator framework will be incorporated where relevant (see Section 5).

Output: Ex-ante sets of potential cost-savings for consumers given the level of MCAR offered (e.g. values per characteristic day and within day for increasing levels of MCAR).

3 Task 7.2 Analytical Framework Update

Data from the various components of the Stage 2 trial will be used to improve the input assumptions from the Stage 1 analysis. In some cases, enhancements may be built into the tools to allow us to better accommodate the insights provided by the tool. The main areas of trial output data which can be used to inform the update of the analytical tools are described in the sections below and cover:

- Consumer Uptake Trial outputs
- Consumer Charging Trials outputs
- Updated State of Health model
- Fleet analysis

It is assumed that the raw data from the trial components will already have been consolidated, cleaned and have some basic Quality Assurance undertaken on it as part of WP 5, before this data is provided in a suitable electronic format (e.g. SQL database or Excel) for use in WP7.

3.1 Consumer Charging Trials output analysis

3.1.1 Proportion of charging at each location

The proportion of charging at different locations (home, work, public, rapid) is derived in ECCo, using the trip distribution data from NTS (grouped by destination type) with assumed probabilities around where people charge and how likely they are to charge at the end of a trip.

Further constraints are also applied, such as maximising charging at non-home locations if the retail prices are on average cheaper than at home, and vice versa. The trial data will be used to update these parameters if possible, although the data will be limited as the focus of the trial is on home charging. Exact data on public and workplace charging is unlikely to be available, although inferences can be made as participants will be asked whether they have access to charging at work and it will be possible to identify the regular use of a charging point during normal work hours.

However, it is expected that the trial will confirm that the vast majority of charging is currently carried out at home, thus the value of updating the representation of home charging behaviour is significantly greater than public and work place charging. The trial data will provide average demand profiles for home charging, at the very least, and work and public charging provided charging events at work can be reasonably distinguished in the non-home charging data. Overall electricity demand profiles at each location type are required to calibrate the charging logic within ECCo, and the calculated proportion of charging across location is used in the MCPT to evaluate the perceived access to charging at different locations.

Output:

- Updated typical plug-in start time and duration per charging event at home (and non-home location if data is available), per powertrain type
- Potentially enhanced ECCo logic

3.1.2 Charging Profiles for flat and User-Managed Charging tariffs at home

The charging start time profiles in Stage 1 were defined exogenously and we will update these profiles using the results of the trial data for the flat tariffs (the control groups), User-Managed and Supplier-Managed tariffs. Whilst in Stage 1 the start time profiles were different for weekdays and weekends, if the trial data suggests it is material, we would look to define profiles that also differ by the time of year (summer, winter). As such, characteristic days will be grouped together for analysis.

However, in the latter two tariff cases the direct results will only be reflective of the 2030/35 conditions that the consumers saw as part of the trial (as varying the tariff structure during participation introduces an extra variable and would decrease the number of repeat measures per participant, per condition, degrading statistical power).

For the updated Analytical Tools the trial results would insofar as is possible be parameterised as more-dynamic functions so that the consumer profiles change endogenously as other system conditions change (across both the pathway from 2015-2050 and across different Narratives/sensitivities).

For example, the retail electricity prices are dynamic in the modelling framework and one option might be to parameterise charging start time as a function of 'relative' price differentials between the different tariff periods (e.g. the ratio of the price of each block to the overnight price). This functionality could be implemented in the CPAT tool such that charging start times are shifted dynamically within defined flexible bands (that reflect observed journey requirements) as a function of the retail prices which CPAT also calculates, both sets of data are passed to ECCo. It may also be possible to describe the consumer response as a function of parameters other than within-day price shape, such as: whether they are a PHEV or BEV consumer.

Based on the User-Managed tariff data available we would look to undertake regression analysis on the direct charging trial results (e.g. charging start times versus prices differences between the bands provided).

As the trial is focused on the home location, there is unlikely to be sufficient data to derive the same relationship for non-home locations. However, we will consider to what extent any relationship between load shifting and price ratios at the home location may be applicable for non-home locations (primarily at work rather than public or rapid locations).

Output:

- Initial charging start time profiles by characteristic day, per user group, per year, at the different locations for User-Managed and flat tariffs.
- Where possible for User-Managed Narratives, derived relationships between the prices in different periods in the day and load shifting
- Potentially enhanced CPAT tool logic

3.1.3 Charging Profiles for Supplier-Managed Charging

The results of the trial will help to provide an understanding of the extent of the maximum MCAR offered in different time periods for a given level of cost-saving (including anticipatory charging) offered to mainstream consumers.

- In a similar manner to using the User-Managed trial results we aim as far as is possible to derive relationships between the required SOC, maximum MCAR and the level of cost-saving required by consumers to provide this (with or without the anticipatory charging). Provided the data allows, we will consider how this relationship varies with e.g. the time of day/ week or type of consumer (BEV/ PHEV).
    - One complication with the analysis of the Supplier-Managed trial results is that the cost-savings are seen ex-post by the consumer. The consumer will gradually adapt their behaviour over time such that behaviour in the current period reflects savings seen in previous periods (based on feedback metrics such as cost per kWh of the last charge and the average paid to-date). Any analysis will need to account for this lag effect
- Additional logic will be required within the modelling framework (likely within both the CPAT and ECCo tools) to accommodate the insights from the Supplier-Managed trial
    - Changes to accommodate input data e.g. specifying different levels of savings by timeperiod, or adding parameters to represent the proportion of time the consumer unplugs early and so limits flexibility for the system and does not receive a cost-saving. Both of these would flow through into the DM aggregator cashflows
    - The maximum level of MCAR offered could be calculated as a function of the cost-saving offered as estimated from the trial data (but it is not assumed that both the saving and response will vary endogenously within the tools)
    - For Narratives with Supplier-Managed charging the data from the trial no longer represents the actual proportion of people starting to charge at a given time of day, but the typical MCAR provided by a proportion of people who *plug-in* at a certain time of day. As the actual length of time to charge the PiVs in the modelling tool is dynamic (e.g. as the efficiency and battery size of PiVs purchased changes) the updates to the logic will need to work out the charging demand profile based on:
        - The actual hours required to charge the vehicle for an MCAR of 1

   - The total hours available for charging given the understanding of the likely maximum MCAR
   - Minimising costs to the consumer by charging in the cheapest periods (accounting for the potential for anticipatory charging on behalf of the consumer above the required SOC).

- In ECCo we will also explore the potential for a new module which makes the choice of tariff/charging scheme an endogenous part of the model calculation rather than a user input as it is currently, based on results from the choice experiment. This will allow a series of ca.3 'offers' provided from another part of the analytical framework to be converted into the proportion of BEV/PHEV drivers participating, and hence a more robust set of charging patterns which can be fed into the network impact modelling (MEDT) tool and commercial/business model (CPAT) tool. For this choice in ECCo to be manageable, we suggest that a shortlist of 'preferred' charging/tariff configurations is implemented in the analytical framework, based on a larger number of configurations tested in the choice experiment.

Changes to the existing Stage 1 tool logic will also be informed by the proposed development of the more detailed DM aggregator framework (see Section 5).

Output:

- Relationship between consumer cost-saving savings and effective MCAR offered / required SOC specified, varying across days and potentially by weekday/ weekend and peak/ summer/ winter.
- Potentially enhanced ECCo and CPAT tool logic

3.2 Update of ECCo uptake calculations

The results from the uptake choice experiment (WP5) will be used to update the choice coefficients currently derived from a survey of 2,000 car buyers conducted by Element Energy in 2015 for DfT. The new results will need to be combined with the existing customer segmentation model, which is a critical part of representing the transition from early adopters in the model. Depending on the final trial sample, the choice experiment results may replace only a subset of the existing customers (e.g. as innovators/early adopters will be excluded from the trial).

Amending the private buyers' choice coefficients and fleet related parameters will require a re-calibration of the model, which will be conducted over sales observed over 2010-2015. Impact of these changes will be documented in the final report.

Output:

- Updated ECCo model (in terms of uptake calculations)

4 Task 7.3 - State of Health Model Update

The purpose of this task is to estimate the impact of managed charging on the EV battery lifetime to inform DM pricing strategies based on the real world data obtained during the trial. The State of Health (SOH) model developed in Stage 1 will be used for the analysis. The SOH model requires high-level inputs, such as the average State of Charge and the average battery pack temperature during the trial. Therefore, an integral part of the analysis will be the derivations of 'usage profiles' based on the collected data. These will then be used as inputs for the SOH model. The analysis will aim to identify scenarios where the battery degradation cost is minimised and to outline the key factors.

4.1.1 Required inputs

The SOH model uses averaged values for all inputs and therefore data for individual journeys and charging events is not strictly necessary. However, the data disaggregated by individual charging and discharging events may help to inform counterfactual traveling or charging scenarios if required for the analysis. Table 1 summarises the data required for the analysis.

Table 1: Data required from Consumer Charging Trial for Task 7.2

Input category	Parameters	Details
Electrical energy consumption during driving	• SOC at the start and the end of the journey (%) • total energy consumption during the journey (kWh) • liquid fuel level at the end of the journey (litres)	This data would need to be provided separately for driving in 'charge-depletion' and in 'charge-sustain' modes.
Driving profiles	• C-rate during driving • distance travelled (km) • time spent with the engine idle and running separately (seconds)	This data should be provided for city and highway driving.
Battery parameters	• Battery pack temperature at the start and at the end of each journey (°C) • Battery pack temperature at the start and at the end of each charging event (°C)	Additionally, high resolution battery and ambient temperature measurements (e.g. half hourly) would be beneficial.
Charging data	• Timestamps for the start and the end of all charging events (hh:mm:ss) • SOC at the start and at the end of each charging event (%)	Alternatively, high resolution data (e.g. half hourly) on the SOC could provided

In addition to constantly measured data, information on the Depth of Discharge windows available in charge depleting and charge sustain modes will need to be provided.

The information listed above details the ideal data which are required in order to perform the analysis set out in the scope of Task 7.2. Extraction of these data is reliant on the capabilities of the telematics system; the availability of all vehicle data, and the sampling frequency at which it will be extracted from the telematics system, will be confirmed at the beginning of Stage 2 trials once the vehicle telematics system has been fully tested.

Outputs:

- A chapter in the DM aggregator analysis report (D7.3) on findings from analysis of impact of Managed Charging including the extent to which battery degradation costs should be accounted for in the consumer offer/DM payment
- Updated Excel SOH model to include a set of inputs derived from the WP5 data analysis, and updated model manual (if relevant)

5 Task 7.5 - Demand Management aggregator framework

The Stage 1 analysis explored a high-level picture of the potential revenues and costs that a DM aggregator applying a Supplier-Managed Charging tariff might see, focusing primarily on the potential system-level benefits from this. In reality the incoming and outgoing cashflows will be more complex.

The aim of this task is to provide a more detailed understanding of the decision structure and potential commercial implications for a DM aggregator. A variety of revenue streams (wholesale market, ancillary services, etc) with different requirements and risk profiles are available to aggregators, which would be modelled by a (simplified) simulation of electricity markets. The cost and risks associated with engaging consumers in Supplier-Managed Charging are also uncertain, but will be informed by the Stage 2 trial, and this analysis will help to understand better the potential strategies available to the DM aggregator given uncertainty over both their costs and revenue streams as illustrated in Figure 1.

The early development of the more detailed DM aggregator framework will also help inform how the consumer costs for the Supplier-Managed Charging tariff are structured for Task 7.1. This will be combined with the higher-level Stage 1 analysis of the potential system value to the system from Supplier-Managed Charging, to bound the potential scale of cost savings that a consumer may see as part of the trial relative to a world without this.

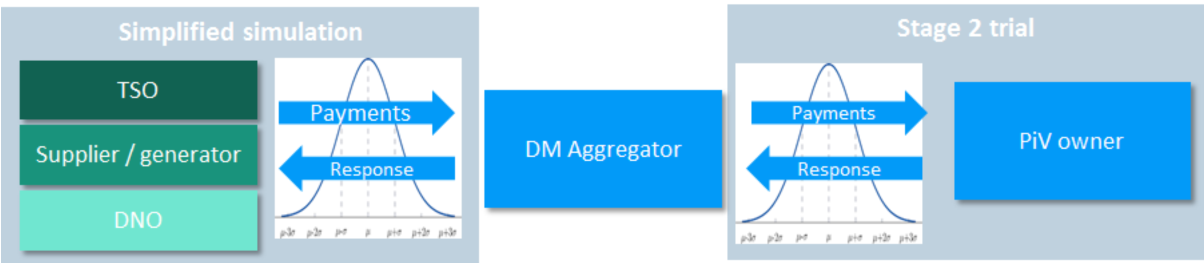

Figure 1: Illustration of revenue and cost uncertainty for DM aggregator

It is anticipated that the task would explore the following questions:

- What trading strategy would be employed by the DM aggregator in managing its position in regard to the consumer charging load?
- To what extent does the provision of anticipatory charging on behalf of the consumer under a supplier managed charging tariff alter this strategy?
- What is the likely combination of additional services that the DM aggregator could access which helps to maximise revenue and minimise risk given uncertainty across both of these, and how is this likely to change in the future (e.g. reserve provision, supplier hedging/imbalance costs, etc)?
- Are there alternative contracting strategies that offer higher risk / higher reward and conversely lower risk but more stable revenue streams given the scale of PiV consumer response?
- Are there implications for where the DM aggregator sits (supplier, 3rd party, DNO) that significantly impact the risks / rewards for the aggregator or lead to implications

for the way PiV DM would maximise benefits at system level (e.g. conflicts with DNO CLASS[4] provision)?

In addition to the trial analysis of consumer behaviour under a Supplier-Managed Charging tariff, the analysis would consider any potential implications from the updated SOH model in Task 7.3. For example, if access to a particular revenue stream involves cycling of the battery that leads to more rapid degradation what might this mean for additional compensation that the DM aggregator would need to provide the consumer.

Figure 2 provides a summary of the types of revenue streams that a DM aggregator may look to access in terms of their service characteristics and service demand drivers, given the *current* structure of the electricity market.

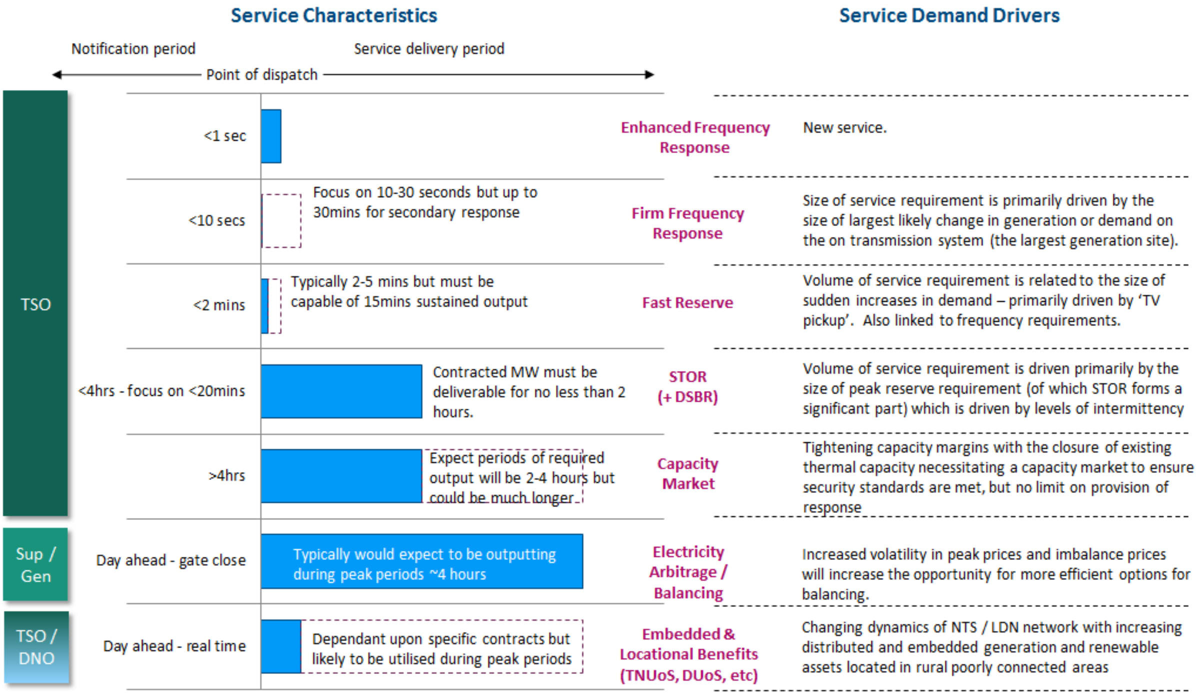

Figure 2: Illustration of revenue and cost uncertainty for DM aggregator

Not all revenue streams are compatible with each other, and there are a number of mutual exclusivities (i.e. services that cannot be provided simultaneously) that must be considered when the DM aggregator is deciding on an operating regime. Two key mutual exclusivity "rules" are:

- An asset cannot contract for multiple services with the same counter-party (i.e. different Balancing Services with National Grid).
- Balancing Services with availability payments preclude an asset from dispatching for any other services/revenues during their contracted periods.

In addition, some services may be more challenging for DM to provide compared to the competing alternatives such as flexible thermal plant; for example there is currently no limit on the provision of response when an event is triggered within the capacity market, but PiV

[4] Customer Load Active System Services

consumers will have a finite time limit before they require their vehicle to be charged to a minimum level.

It is *not* proposed to create a detailed representation of the current electricity market arrangements, as these may change significantly in the future. It is instead proposed to create a simpler representation of the key groups of service requirements the DM aggregator could take part in, covering:

- Capacity
- Energy balancing and wholesale arbitrage
- Very short term (e.g. <30 min) ancillary services

This would represent a future system structure which aligns with the Stage 2 trial (e.g. 2030/35) and whose core components (such as the underlying electricity system mix) are informed by the Stage 1 analysis.

The key inputs to the analysis of the system requirements would be distributions and correlation factors for the volumes and prices associated with each service group that are then consistent with each other (e.g. modelling the system across a given characteristic day) and the wider electricity system for a given spot year. Importantly the distributions would need to reflect uncertainty over the scale and timing of the potential revenues available to the DM aggregator. The analysis to inform the system data would be based around our existing suite of in-house Baringa models including our:

- Wholesale electricity PLEXOS market modelling capability[5], which is already being used for Task 7.1
- GB electricity Balancing Mechanism simulation tool[6]
- Capacity Market simulation tool
- Ancillary Services stack tools

In a similar manner the Supplier-Managed Charging consumer behaviour results from the Stage 2 trial would be parameterised into distributions of MCARs available at different times of day given different consumer cost savings, reflecting the uncertainty in consumer behaviour (both in the MCAR offered and the extent to which they unplug early).

It is envisaged that the overarching model for the DM aggregator is then based around a probabilistic monte carlo simulation which reflects:

- Simulated uncertainty around the level of consumer response under a Supplier-Managed Charging tariff on the one hand

[5] Used primarily for private developers and investors, but also for public organisations e.g. see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/441809/Baringa_DECC_CfD_Negative_Pricing_Report.pdf

[6] As developed for Ofgem's Electricity Balancing Significant Code Review e.g. see https://www.ofgem.gov.uk/ofgem-publications/87788/electricitybalancingsignificantcodereview-furtheranalysistosupportofgemsupdatedimpactassessment.pdf

- Simulated uncertainty around the scale and pricing of system service requirements which impacts the competitiveness and volume of flexibility that the DM aggregator can reasonable provide

The DM aggregator sits in the middle of these two sets of simulated outcomes and its potential cashflow across the year is calculated for each iteration within the simulation. For each set of simulations fixed assumptions will reflect the specific DM aggregator business model strategy, including:

- The level of reward/payment they are prepared to pass through to the consumers
- The configuration of system services / revenue streams the business model is trying to access

Within each individual strategy the simulated distribution of aggregator cashflows helps to inform the potential risks of a mismatch between provision of DM from the consumer and the aggregator's ability to secure revenue from utilising this flexibility. The comparison between strategies then informs the understanding of trade-offs between different aggregator strategies and which types of service it is better placed to target, given how mmainstream PiV consumers are likely to respond. It is proposed that up to 8 strategies are explored in this task, with the exact configuration determined during the task and agreed with ETI.

Outputs

- A standalone report describing the analysis and insights
- Supporting Excel workbook of analysis

6 Task 7.6 – Market Design and System Integration Analysis Update

Tasks 7.2 to 7.3 will provide an updated set of Analytical Tools and input data assumptions reflecting the key insights that the Stage 2 trial has provided into consumer-facing factors driving mass market ULEV uptake and use.

Task 7.6 will then use the refined Analytical Tools to update the Stage 1 analysis. This includes re-running the Stage 1 Narratives/Sensitivities to directly compare the effects of the updates against the existing results. Producing new results includes running the whole framework, including infrastructure tools, CPAT, ECCo, ESME and producing the results workbooks. The results dashboard might also be modified to show additional information if required.

We expect the update to focus on the six core Narratives, and the low/ high ULEV uptake Sensitivities for three of these Narratives, which were explored originally in the Stage 1 analysis. In addition, it is proposed to create a new 'composite' Narrative as described at a high level in the final Stage 1 report (D1.3), which reflects a combination of some of the more desirable features for encouraging ULEV uptake and use that were identified during the Stage 1 analysis.

However, if data from the trial suggests that it would be interesting to explore other sensitivities it may be possible to reduce the number of original Narratives/sensitivities which are re-run to provide time for this (the amount of time saved relative to the effort for creating a new sensitivity would need to be equivalent[7]).

A new sensitivity may also require inputs that are not from the trial data itself, and in this case we would aim to base these on the most similar Narrative that has already been defined in Stage 1, with sensible variation if necessary. Potential examples of new Sensitivities that were identified in the Stage 1 modelling and include:

- Changing the underlying service demands for transport in the longer-term driving different levels of car use and/or travel patterns
- Understanding the implications of poorer demand management of electrified heating on PiV uptake, use and its own role in demand management
- Decomposition of the drivers in the current sensitivity analysis to better understand the separate drivers of fuel prices, greater decarbonisation and vehicle prices
- Further sensitivities related to the role and use of PHEVs (e.g. changing the share of electric versus liquid vkm, removing the restriction on having overnight charging access for consumers to consider these vehicles within their choice set) to better understand the balance in choice and desirability for the wider system between these and BEVs

[7] Alternatively the sensitivity could be explored via the budget available for additional analysis in Task 7.4

- Further sensitivities related to hydrogen infrastructure (e.g. lumpiness, timing and costs of investment) to understand whether there are conditions that could require intervention sooner in the pathway

The analysis of the updated Narratives and/or new sensitivities will take into account the systematic sensitivity analysis in Task 7.7, to eliminate duplication of effort and consider the insights with regard to the most sensitive drivers of ULEV uptake and use (acknowledging that the systematic sensitivity analysis will be undertaken prior to the Stage 2 tool updates).

6.1 Policy evidence and recommendations

Whilst the modelling analysis provides a detailed, integrated and holistic picture of the impacts and interactions within each Narrative, a high-level comparison across Narratives needs to be made in order to assess the trade-offs between Narratives and thus the conditions required to incentivise ULEV uptake to an 'appropriate' extent (e.g. balancing the competing requirements of driving ULEV uptake and use in a cost-effective manner, whilst minimising any gap in Government revenue).

In Stage 1, this was facilitated by analysing a set of success metrics (and wider results) for each of the Narratives and sensitivities and using these to identify the key elements of a 'good solution' for ULEVs, categorising them into:

- Essential
- Desirable
- Ineffective or unnecessary

The updated Stage 2 analysis would explore whether these key elements are still valid, whether some appear more or less important and whether there are new elements (as a result of quantifying new factors within the modelling).

In addition, two further areas would be considered as part of determining the final insights and policy evidence and recommendations from the Stage 2 trial:

- The more detailed analysis of the DM aggregator framework in Task 7.5
- The standalone analysis of the outcomes of each individual trial from WPs 1 and 2 (as distinct from the updated system level analysis in this Task 7.6), particularly further qualitative insights which are not possible to capture directly in the updated modelling framework.

Where relevant, we would also look to update the analysis of how the elements of a good solution might be 'delivered', for example where a new essential or desirable element is identified or where the WP5/6 or Task 7.5 outputs suggest a more complex set of risks or barriers that would have to be managed.

Output:

- An updated D7.3 Market Design and System Integration report reflecting new insights and policy evidence and recommendations
    - Note: it is not proposed to write this document in a format which directly compares Stage 1 and 2 results, but to create it as a standalone document reflecting the combined learning from both Stage 1 and 2
- An updated set of tools/results consistent with the Narrative and Sensitivity analysis

7 Other activities

7.1 Task 7.7 - Systematic sensitivity analysis

A key request from the Stage 1 analysis is to gain a more systematic understanding of the drivers of uncertainty in relation to ULEV uptake and use outside of the Narrative- and ECCo-specific sensitivities that have already been undertaken.

The issue is complicated by the large number of input parameters across the modelling tools, which drive the results in an *interdependent* manner. It is not possible to test all plausible combinations of inputs across the full set of tools as the number required grows exponentially and the run-time would be prohibitive. For example considering all Low/Medium/High cost combinations for ICE, FCV and PIV prices leads to 27 separate test combinations. Layering the equivalent L/M/H ranges for liquid, hydrogen and electricity prices as well leads to 729 combinations.

A four-stage process is proposed to more systematically explore the sensitivity of key results to changing inputs in a manner consistent with the resources available for this task:

- **A)** Define the "composite central pathway" discussed in Stage 1 as the base case and run the full set of results across the modelling tools
- **B)** Identify the range of direct (exogenous) and indirect (calculated via other tool) parameters that drive uptake and use in ECCo
  - For direct exogenous factors define L/M/H ranges where not already available from Stage 1
  - For indirect factors work backwards through the preceding tools and use simple spot tests / existing Stage 1 results to understand the sensible range of possible inputs that could eventually go into ECCo (e.g. the L/M/H range of retail electricity prices and the exogenous assumptions that originally drive these from ESME and the other tools)
- **C)** Using the composite pathway as the starting point "spot check" the sensitivity of uptake results in ECCo only to as many combinations of the L/M/H ranges for factors identified under B) as is plausible in the time available.
  - This gives a first order view of the relative importance of the difference inputs within ECCo (acknowledging that this may not always hold considering the equilibrium position across all of the tools) and a larger number of test runs is possible given the relatively quick ECCo run time.
  - Some additional tool development effort would likely be required to automate all of these runs in a single batch.
- **D)** Using insights from B) and C) create up to 8 bespoke sensitivity runs anchored around the "composite central pathway", which will help to more systematically explore the space of impacts on ULEV uptake and use, by testing the equilibrium position across the full suite of tools

Examples of key input factors to explore both direct and indirect to explore through steps B) and C) are shown in Table 2.

Table 2: Examples of key input factors

ECCO – Direct factors	ECCO – Indirect factors
− Vehicle prices (underlying cost, margin, insurance, maintenance, with/without subsidy) for ICEVs, PiVs, FCVs, − Charging start time profiles – SToU / MC − Vehicle efficiencies / % electric vkm in PHEVs − Battery size − Transport service demands − Fleet related parameters (time horizon, suitability curves, purchase mode)	*Retail energy prices* − Liquid retail o ESME - wholesale fossil fuel assumptions / biomass availability / min number of LRS required / carbon price − Electricity o ESME - technology costs / ESME availability of CCS or nuclear / biomass availability / ability to smooth electrified heat load / resource costs for gas, oil, biomass − Hydrogen o ESME – as per electricity drivers, but including direct hydrogen producing technology costs o MHDT – distribution infrastructure capex / opex costs, first year of pipeline build / lumpiness of investment *Access to charging* − MCPT - long-run density factors / charging capex / charging rate

Output: These will include

- A concise slide deck on the process and insights from the sensitivity testing on the Stage 1 tools (insights from this task will also feed into the updated Stage 2 report in Task 7.6)
- An updated set of tools/results consistent with the sensitivity analysis

7.2 Task 7.4 – Additional System Analysis

The aim of this task is to carry out (at/from the start of Stage 2) additional analysis of the System, with amendments to the Analytical Framework and Additional Tools if required, to address key areas of value to be specified in detail by the ETI.

There are key areas of valuable analysis, and potentially enhancements to the Analytical Framework and Additional Tools, which the ETI wishes to see completed, beyond those delivered during Stage 1.

A budget has been allocated to this Task 7.4. The ETI, TRL and Baringa will agree the specific activities required, subject to a maximum cost not exceeding this budget.

Output: Dependent on the specific task, but could, for example, include updated tools, slide packs, etc.

- D7.6 – Additional System Analysis (concise slide pack detailing work undertaken and findings from the analysis, for initial reporting);
- Chapter in Deliverable D7.4, with details in an appendix of D7.4, for subsequent capture (to enable dissemination with other reported material); and
- Models and tool results files consistent with the analysis

8 Timeline

An indicative timeline for activities in Work Package 3 is shown in Figure 3 below.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Task 7.1: Data Inputs for Consumer Charging Trials																		
Task 7.2: Analytical Framework Update																		
Task 7.3: State of Health model update																		
Task 7.5: DM aggregator framework																		
Task 7.6: Market Design and System Integration Analysis Update																		
Task 7.7: Systematic sensitivity analysis																		
Task 7.4:Additinal System Analysis																		

Figure 3: Indicative timeline for Work Package 3

D1.4 Stage 2 Trial Design, Methodology and Business Case

TRL
Crowthorne House, Nine Mile Ride,
Wokingham, Berkshire, RG40 3GA,
United Kingdom
T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

ISSN

ISBN