Programme Area: Energy Storage and Distribution

Project: Consumers, Vehicles and Energy Integration (CVEI)

Title: D1.3. Market Design and System Integration (full report)

Abstract:

This report represents Deliverable D1.3, Market Design and System Integration. The purpose of this report is to illustrate structures that can facilitate efficient, mass-market, deployment and use of Ultra-Low Emission Vehicles (ULEV) and their integration into the energy system and to help inform the high level design parameters of the trial to be conducted in Stage 2 of the project.

This document should be read in conjunction with the D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report, from WP4 as the information in D4.2 has been used to inform the scope of analysis conducted in WP1a. From the review of evidence to date it was clear that there had been limited work undertaken to explore how mass-market roll-out and use of ULEVs could be facilitated when considering a more holistic assessment across the four key dimensions of the:

• Customer Proposition.
• Physical Supply Chain.
• Commercial Value Chain.
• Market and Policy Framework.

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.

Consumers, Vehicles and Energy Integration Project: TR1006_D1.3. Market Design and System Integration

Full Report

CLIENT: Energy Technologies Institute

DATE: 03/05/2017

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Version History

Version	Date	Description	Prepared by	Approved by
V1_0	09/05/2016	Draft	JG, EP, NB, OR (Baringa) CC, TD, AS (Element Energy)	DS (Baringa) SS (TRL)
V2_0	02/12/2016	Updated draft	JG, EP, NB, OR (Baringa) CC, TD, AS (Element Energy)	DS (Baringa) SS, DN (TRL)
V3_0	03/04/2017	Final draft	JG, NB, OR (Baringa) CC, TD (Element Energy)	SS (TRL)
V4_0	03/05/2017	Final	NB, OR (Baringa)	SS (TRL)

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0 Glossary and acronyms

A list of acronyms and glossary of terms used across the project are provided in Table 1 and Table 2, respectively. The terms that are included in the glossary are capitalised throughout the report.

Table 1 List of acronyms

Item	Description
ALCS	Auxiliary Load Control Switch
ASC	Alternative Specific Constant
BB	Building Block
BEV	Battery Electric Vehicle
BIK	Benefit in Kind
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CDCM	Common Distribution Charging Methodology
CP	Customer Proposition
CPAT	Commercial and Policy Accounting Tool
CPO	Charging Point Operator
CVC	Commercial Value Chain
CVEI	Consumers, Vehicles and Energy Integration (Project)
DCC	Data Communications Company
DfT	Department for Transport
DNO	Distribution Network Operator
DM	Demand Management
DSR	Demand Side Response
DUoS	Distribution Use of System
EBIT	Earnings Before Interest and Tax
ECCo	Electric Car Consumer Model
ESME	Energy System Modelling Environment
ETI	Energy Technologies Institute
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
GHG	Greenhouse Gases
HAN	Home Area Network
HRS	Hydrogen Refuelling Station
ICEV	Internal Combustion Engine Vehicle
LDN	Local Distribution Network
LPG	Liquefied Petroleum Gas

MCA	Multi Criteria Analysis
MCPT	Macro Charging Point Tool
MEDT	Macro Electricity Distribution Tool
MHDT	Macro Hydrogen Distribution Tool
MLDT	Macro Liquid Distribution Tool
MPF	Market and Policy Framework
NEDC	New European Driving Cycle
NTS	National Transmission System
OEM	Original Equipment Manufacturer
PiV	Plug-in Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PSC	Physical Supply Chain
RAB	Regulated Asset Base
RIIO	Revenue = Incentives + Innovation + Outputs
ROCE	Return on Capital Employed
SDR	Social Discount Rate
SEC	Smart Energy Code
SGR	Stage Gate Review
SMMT	Society of Motor Manufacturers and Traders
SMR	Steam Methane Reforming
ToU	Time of Use
TCO	Total Cost of Ownership
TNO	Transmission Network Operator
TSO	Transmission System Operator
ULEV	Ultra-Low Emission Vehicle (zero tailpipe emission)
WACC	Weighted Average Cost of Capital
WP	Work Package
V2G	Vehicle to Grid
VAT	Value Added Tax
VED	Vehicle Excise Duty

Table 2 Glossary of terms

Item	Description
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.
Building Blocks (or BBs)	Individual components that influence ULEV deployment and use within each Dimension. A selected subset of BBs and their respective values or states (e.g. technology costs) constitute the tangible components of each Narrative.
Dimensions	The set of 4 highest level areas categorising the BBs' impact on ULEV deployment and use, namely: Customer Proposition (CP), Physical Supply Chain (PSC), Commercial Value Chain (CVC), and Market and Policy Framework (MPF).
Narrative	An internally consistent set of BBs covering _**all**_ Dimensions and collectively characterising a rational and distinctive model for facilitating mass deployment and use of ULEVs in the UK.
Sensitivity	A sensitivity on a single Narrative or set of Narratives, changing one specific parameter to establish its effect.
Success Metrics	Metrics used to determine what 'good' looks like for each Dimension as part of the assessment of a Narrative. These are divided into quantitative metrics, which are quantifiable via the Analytical Tools, and qualitative metrics.
User-Managed Charging	User-Managed Charging is represented by an assumed consumer response to Static ToU tariffs, whereby the consumer shifts their load to cheaper periods, changing their charging profile.
Supplier-Managed Charging	Supplier-Managed Charging is represented by more complete load shifting, controlled by a third-party. The term 'Supplier'-Managed Charging refers to charging that is Managed by any third-party acting as a 'DM provider' – the supplier, a standalone DM aggregator, DSO or other third-party.
Social Discount Rate	The social discount rate (SDR) is the rate often used in Impact Assessments, as these normally consider costs and benefits together from the point of view of society as a whole, rather than from the point of view of a single stakeholder group. The recommended UK public service discount rate is the Treasury Green Book rate of 3.5%.
Mainstream	'Mainstream' consumers refer to a large, diverse group of consumers – in the Diffusion Model, non-Innovators encompass all those in the Early

	adopter, Early majority, Late majority, and Laggard segments: for the purposes of this report, they shall be referred to as 'mainstream' consumers.
Pathway	The time horizon used in the Analytical Framework: 2015 to 2050.
Customer Proposition	What the consumer sees at the point of interacting with a ULEV e.g. is the consumer buying or leasing the vehicle.
Physical Supply Chain	The technologies and infrastructure required to deliver the vehicles and their energy requirements e.g. Plug-in Vehicles and charging points and energy distribution for electricity, liquid fuels and hydrogen.
Commercial Value Chain	The commercial entities (and their business models) that sit across one or more parts of the PSC to collectively deliver the CP that the consumer sees – e.g. an electricity retail supplier or hydrogen distributor.
Market and Policy Framework	Government and regulatory intervention in the form of setting the overarching market framework for commercial entities (e.g. regulatory incentives for network infrastructure) or more direct policy intervention (e.g. in terms of taxes or subsidies at the point of the consumer).
Private Consumers	Private Consumers base their decision upon a number of attributes such as cost, state of charging infrastructure, range, and the availability of their preferred model / make. For cars, this consumer group is further divided into six consumer segments (e.g. 'innovators', 'cost-conscious greens')
Fleet User Choosers	Fleet User Choosers are company owned cars where the driver has been given free choice in the purchase decision. The purchase decision therefore resembles that of a Private Consumer but with a different set of values placed on each attribute.
Fleet Non-User Choosers	Fleet Non-User Choosers are also company owned vehicles where the purchase decision lies with the company or fleet manager, based upon the possibility of fulfilling the daily duty cycle on a single charge. All new van buyers are modelled as Fleet Non-User Choosers.
Fleet Car Sharing	Fleet Car Sharing is used to model the purchase of cars by car sharing companies. The purchase decision resembles the economically rational requirements of Fleet Non-User Choosers.

1 Introduction

1.1 Background and context

The Consumers, Vehicles and Energy Integration (**CVEI**) Project, commissioned and funded by the Energy Technologies Institute (**ETI**), has been established to examine how to deliver mass deployment and use of Ultra-Low Emissions Vehicles (ULEVs) in the UK. It is focused on cars and light vans – including Plug-in Hybrids (PHEVs), Battery Electric Vehicles (BEVs), hydrogen Fuel Cell Vehicles (FCVs) and Internal Combustion Engine Vehicles (ICEVs) – and addresses the challenges and opportunities of ULEV integration with the full energy system over the period from 2015 to 2050.

Decarbonisation of light transport is important to consider in meeting 2050 carbon targets, particularly as, due to quicker progress in decarbonising the power sector and the industrial sector, the transport sector now has the highest annual GHG emissions of all sectors in the UK[1].

The project is comprised of two stages:

- **Stage 1** aims to characterise the Market and Policy Frameworks, business propositions, and the integrated vehicle and infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles.
- **Stage 2** aims to validate key elements of the above through a mass-market trial with real users.

Within **Stage 1** there are five Work Packages (WP):

- **WP1a:** Market design and system integration
- **WP1b:** Trial design, methodology and business case
- **WP2:** Consumer and fleet usage behaviours and attitudes to adoption
- **WP3:** Vehicle energy supply management systems and technologies, and
- **WP4:** Energy infrastructure management systems and technologies.

This report represents deliverable *D1.3 Market Design and System Integration Report*, completed under WP1a. The separate *D1.3 Market Design and System Integration Report Summary* document is a summary of this report. The purpose of these reports is to help understand the most promising structures to facilitate efficient, mass-market, deployment and use of ULEVs and their integration into the energy system and to help inform the high level design parameters of the Stage 2 trial.

This document should be read in conjunction with the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report,* from WP4 as the information in this document has been used to inform the scope of analysis in WP1a.

[1] https://www.theccc.org.uk/wp-content/uploads/2016/06/2016-CCC-Progress-Report.pdf

1.2 Overarching project objectives and approach

The key scope, or 'exam questions', from the original project scope have been summarised in Figure 1, along with a brief summary of how they are addressed through Work Packages 1 and 4.

Figure 1 Overview of key project questions

	Key questions	*How they are addressed*
1	**Understanding impacts** What are the impacts on costs and operation of the system as a whole, from substantively different configurations of ULEV deployment & use and their integration with the wider system?	***Analytical Framework*** provides an *integrated, holistic* tool for quantifying (and qualitatively) assessing the impacts on infrastructure, consumers and commercial models across the system
2	**What does 'good look like'** How do we determine which configurations are good or "more optimal" than others; considering issues related to the consumer, infrastructure, commercial models and policy?	Carefully construct 'promising' set of future ***Narratives*** and ***use framework*** to help characterise good solutions and potential pathway implications
3	**Delivering a good solution** What is needed for delivery of good, tightly integrated system solutions considering technology, commercial structures, market structures, customer propositions?	***Deeper qualitative analysis*** of structures (principally around market and policy arrangements) identified as key to efficient deployment of ULEVs, and how they can be implemented

The broad approach to Work Packages 1 and 4 is summarised as follows:

1. Literature review and workshops to highlight and appraise factors relevant to ULEV use and deployment
2. Development of Narratives and the *D1.2 Analytical Framework* (i.e. a suite of modelling Analytical Tools) to allow integrated, quantitative and qualitative analysis
3. A 'broad' analysis using contrasting Narratives in the above framework to assess holistically their effectiveness and impacts across the system to help understand the key elements of a 'good' solution
4. Detailed, largely qualitative analysis, on factors identified as most significant in delivering mass deployment of ULEVs, and associated recommendations, and
5. Identification of key gaps, areas of uncertainty and / or high materiality that could be tested and verified through the Stage 2 trial.

1.3 Structure of this document

This document is structured as follows:

- **Section 2** describes how the scope and approach to the analysis have been framed
- **Section 3** describes how and why the Narratives were constructed

- **Section 4** provides an overview of the Analytical Tools used to assess the Narratives and key gaps
- **Section 5** provides an overview of the Narrative results and elements for a ‘good’ solution
- **Section 6** provides further thematic analysis of key areas within the Narratives
- **Section 7** assesses the key factors associated with delivery of a ‘good’ solution
- **Section 8** outlines the implications for the Stage 2 trial design, and
- **Section 9** concludes.

2 Framing the analysis

2.1 Purpose

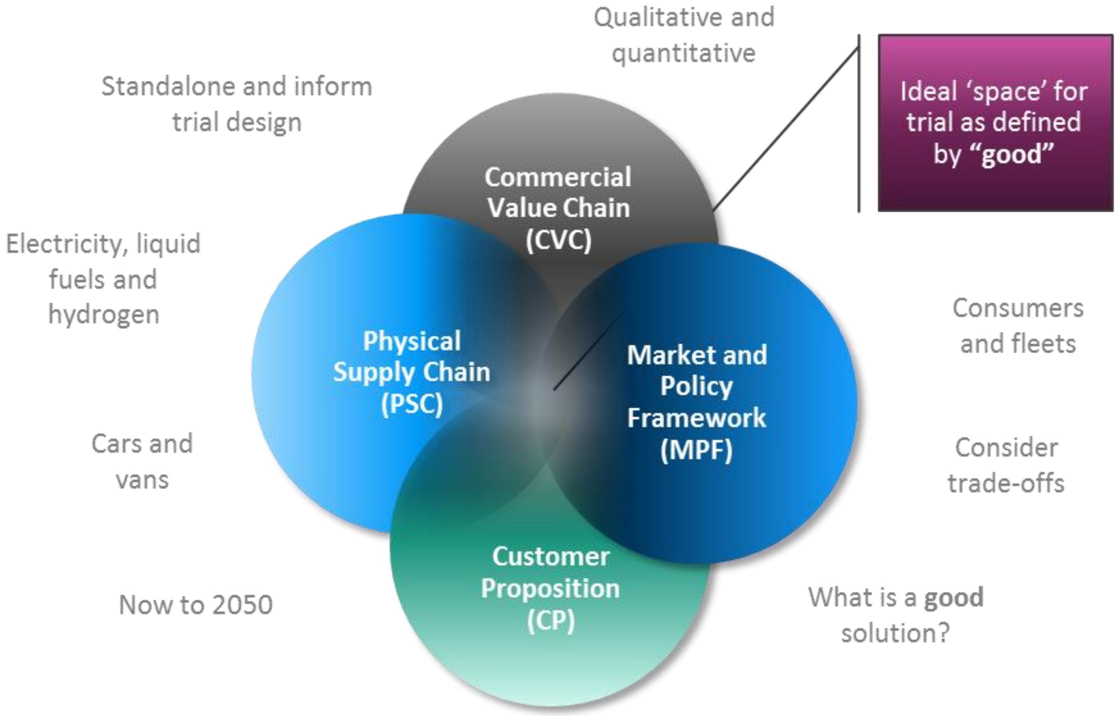
The purpose of this *D1.3 Market Design and System Integration Report* is to help understand the most promising structures to facilitate efficient, mass-market, deployment and use of ULEVs and their integration into the energy system and to help inform the high level design parameters of the Stage 2 trial. In order to quantitatively assess these structures, the *D1.2 Analytical Framework* was created to provide a holistic, Multi Criteria Assessment (MCA) of what 'good' looks like for successful mass deployment and use of ULEVs. The *D1.2 Analytical Framework* has been used to further understanding of how effectively the choices fit together across the four overarching Dimensions that are being considered:

- **A) Customer Proposition (CP)** – what the consumer sees at the point of interacting with a ULEV e.g. is the consumer buying or leasing the vehicle
- **B) Physical Supply Chain (PSC)** – the technologies and infrastructure required to deliver the vehicles and their energy requirements e.g. Plug-in Vehicles and charging points and energy distribution for electricity, liquid fuels and hydrogen
- **C) Commercial Value Chain (CVC)** – the commercial entities (and their business models[2]) that sit across one or more parts of the PSC to collectively deliver the CP that the consumer sees – e.g. an electricity retail supplier or hydrogen distributor, and
- **D) Market and Policy Framework (MPF)** – Government and regulatory intervention in the form of setting the overarching market framework for commercial entities (e.g. regulatory incentives for network infrastructure) or more direct policy intervention (e.g. in terms of taxes or subsidies at the point of the consumer).

The framework is designed to provide a quantitative (where possible) and qualitative assessment and operate as both a standalone piece of analysis in Stage 1 of the CVEI project, as well as to help inform the design of the potential trial in Stage 2. This is illustrated in Figure 2.

[2] See Appendix A of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* and the *D4.2 Building Blocks Catalogue* spreadsheet for further information.

Figure 2 Scope of the *D1.2 Analytical Framework*



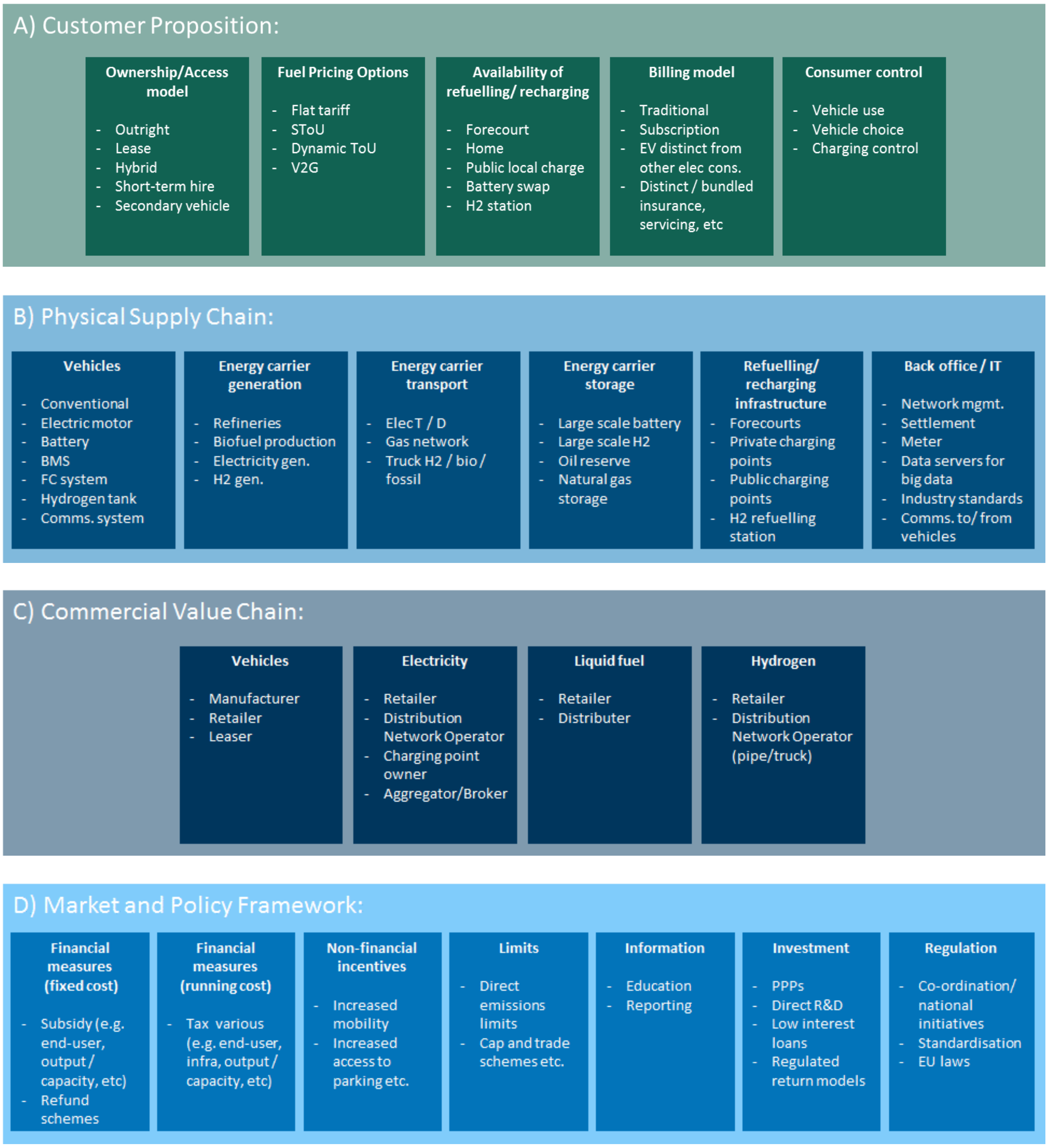
2.2 Concepts and terminology

The *D1.2 Analytical Framework* uses a number of concepts which are defined below.

- **Dimensions:** the four high level areas categorising all of the issues that could impact ULEV deployment and use, as outlined above.
- **Building Blocks (BB):** Individual components that influence ULEV deployment and use within each Dimension[3]. Examples of BBs across each Dimension are shown in Figure 3.
- **Narratives:** An internally consistent set of BBs covering all Dimensions to enable a holistic assessment of ULEV mass-market deployment and use.
- **Success Metrics:** metrics used to determine what 'good' looks like for each Dimension as part of the assessment of a Narrative.

[3] See the *D4.2 Building Blocks Catalogue* spreadsheet for further information.

Figure 3 Examples of BBs considered



2.3 Multi-Criteria Analysis and Success Metrics

The ultimate aim of the *D1.2 Analytical Framework* is to compare the proposed Narratives against each other (and in particular against the Business as Usual, 'BaU', Narrative) to understand the aspects that may facilitate better successful mass-market deployment and use of ULEVs, and where any particular trade-offs or key decision points may occur.

Trade-offs may occur at many points across the framework, but a simple example is in the form of Government intervention. If ULEV penetration is not as high as expected, it would be easy to increase Government funding (either directly or indirectly) to reduce the costs seen by consumers, but at the expense of taxpayers (both ULEV and non-ULEV owning).

The assessment is, however, complicated by two issues:

- Even within an individual Narrative the underlying Dimensions are sufficiently different that they cannot all be assessed using a *common* metric, and
- Not all of the issues that need to be explored to understand 'what good looks like' can be quantified due to practical limitations (e.g. available data, timescales for the project).

As a result a series of *Success Metrics* have been defined *that are specific to each Dimension* and which must be considered collectively within an MCA to first understand how each Narrative 'performs' across the Dimensions (subject to any fine tuning) and to then explore how the Narratives compare against each other. These are divided into quantitative Success Metrics and qualitative Success Metrics, with the former quantified by the set of Analytical Tools described in section 4. The Success Metrics are described in Table 3 and Table 4. In addition, there is further qualitative analysis of what it might take in practice to deliver the elements of a 'good' solution in section 7.

Table 3 Quantitative metrics

Dimension	Metric(s)	Description	Unit	Rationale	Calculation
Customer Proposition	Low carbon vkm in ULEV use	– Maximises proportion of total (tank-to-wheel[4]) low carbon vkm (of consumers and fleets covered by scope of this study[5]) that is undertaken with a ULEV (i.e. in electric only mode for PHEVs).	%	Are the aspects of the Customer Proposition (both price and others such as refuelling availability) sufficiently attractive to spur uptake and use by consumers and fleets.	Electricity and Hydrogen vkm in 2050.
	Car user transport costs	– Overarching cost of delivering the underlying transport service for car users.	p/km	Understand the combined impact of vehicle, wider system energy costs, car sharing, Government subsidies / taxes on the costs of transport.	Total cost of vehicles (spend on fuel and electricity, insurance, maintenance, VAT, VED, congestion charge, retailer/ leasing company revenues and income from plug-in car grant) / total km. These are the costs to all users excluding car sharing using a holistic approach (e.g. taking into account maintenance and tax).
Physical Supply Chain	Residual CO_2 cost	– Present Value (at Treasury Social Discount Rate, SDR) of residual transport carbon emissions over pathway, assuming UK meets its overarching GHG targets (carbon budget and 2050) i.e. tCO_2 /year multiplied by the carbon price in each year necessary to achieve the targets for the UK as a whole.	£bn	The level of abatement across the physical energy system both within and outside of transport (including the delivery of fuels) must be consistent with the UK's overarching targets and be cost-effective given balance of abatement options across the wider energy system.	Residual carbon cost: CO_2 price (£/t) x residual CO_2 volume ($MtCO_2$/year) in 2050 and across the pathway (present value of total cost to 2050 at the SDR of 3.5%).

[4] Whilst this metric is only focused on tank-to-wheel emissions, it should be noted that total well-to-wheel emissions are captured via the analysis of the whole energy system and the emissions associated with hydrogen, electricity and biofuels production. As the total UK-wide emissions for each Narrative must be consistent with the UK's targets the level of decarbonisation required in the production of these energy vectors is then reflected in their wholesale price.
[5] I.e. does not include HGVs.

Dimension	Metric(s)	Description	Unit	Rationale	Calculation
		– Undiscounted cost of residual carbon emissions in 2050 only.	£bn/year	This metric allows a comparison with abatement over the pathway, by understanding the cost-effectiveness of the abatement position at the end of the pathway only, as this level is likely to be maintained going forwards.	
Commercial Value Chain	Commercially viable	– Present value of the total upfront subsidy needed to ensure that all commercial entities modelled meet their required WACC (weighted average cost of capital) or margin over the pathway.	£bn	Commercial entities should be viable over the pathway to 2050 (potentially with Government support) to deliver the required Customer Proposition and supporting infrastructure (e.g. given risks of asset stranding).	Assumes the commercial entities need to make a return equivalent to their weighted average cost of capital.
		– Vehicle manufacturer penalties provide an illustration what they might have to pay due to challenges in meeting the EU new vehicle CO_2 targets, given expected uptake.	£bn	This gives an indication of whether the carbon targets are too stringent (i.e. development of further vehicle improvements may prove too costly and manufacturers elect to pay a penalty instead).	If the emissions target is missed the Original Equipment Manufacturer (OEM) pays a penalty of £70 x gCO_2/km above target x vehicles sold.

Dimension	Metric(s)	Description	Unit	Rationale	Calculation
Market and Policy Framework	'UK Plc' appropriate spending	– Present value (at Treasury Social Discount Rate) of the gap over the pathway between direct transport related income (revenues less subsidies) and a target share for transport related income[6].	£bn	Government net tax and spend directly associated with transport are hard to separate from wider government objectives as not all revenue is hypothecated. This metric reflects a proxy for the broad maintenance of existing revenues.	The target level of income is the share of calculated transport-related revenue in 2015, which is then assumed to grow in line with real GDP / capita to reflect a share of transport related taxation which rises broadly in line with consumer incomes. The net income is the total spend on plug-in vehicle grants and subsidies on fuels and the income from taxes (CO_2 tax, company car tax, congestion charge, distance tax, fuel duty, VAT on fuels, VED and VAT on vehicles). The pathway value is the present value of total gap to 2050, at the SDR.
		– Undiscounted gap in revenue in 2050 only.	£bn/year	This metric allows a comparison with the revenue gap over the pathway, by understanding at the end of the pathway only, as this level is likely to be maintained going forwards.	

Table 4 Qualitative metrics

Dimension	Metric(s)	Rationale
Customer Proposition	Transport utility	Consumers should ideally not experience a material impact on their transport utility (considering factors such as convenience; choice, certainty and flexibility of travel patterns) as a result of mass deployment and use of ULEVs (e.g. for either ULEV or non-ULEV owners, or urban versus rural)
Market and Policy Framework	Wider impact on UK economy	Potential impact on e.g. jobs, innovation, competitiveness, developing domestic supply chain

[6] The 2015 share of ~2% given the coverage of consumer / fleet vehicle policy measures modelled, assumed to grow in line with real GDP/capita.

2.4 Combined MCA

For each Narrative the *D1.2 Analytical Framework* provides:

- A set of quantitative Success Metrics for each Dimension using the Analytical Tools
- A set of qualitative Success Metrics for each Dimension, and
- Overarching qualitative discussion of how each Narrative performs relative to the BaU.

From these it is possible to assess areas of commonality across the Narratives and implications for major decision points over the pathway to 2050. The framework is also used to assess more holistically the materiality of key factors within and between Narratives, and how effectively the choices fit together across the 4 overarching Dimensions in each Narrative.

Although quantified, the Success Metrics for each Dimension are not all on a directly comparable basis. At this stage it is not proposed to formally weight the Success Metrics, as per some forms of MCA[7], and create an aggregate score for each Narrative so that they can be ranked explicitly against each other. This weighting is highly subjective and is primarily a decision for policy makers. The analysis instead provides an important evidence basis to understand the implications of applying more weight to one Dimension over another.

In addition, each Narrative is constructed around a **'***ULEV strategy'* that can be delivered by the various actors involved (Government, industry, or indirectly by consumers). The Sensitivities are used to explore how robust that Narrative is to circumstances, which are outside the control of UK entities (e.g. international fossil fuel prices) and whether some Narratives are more sensitive to changes in these conditions than others.

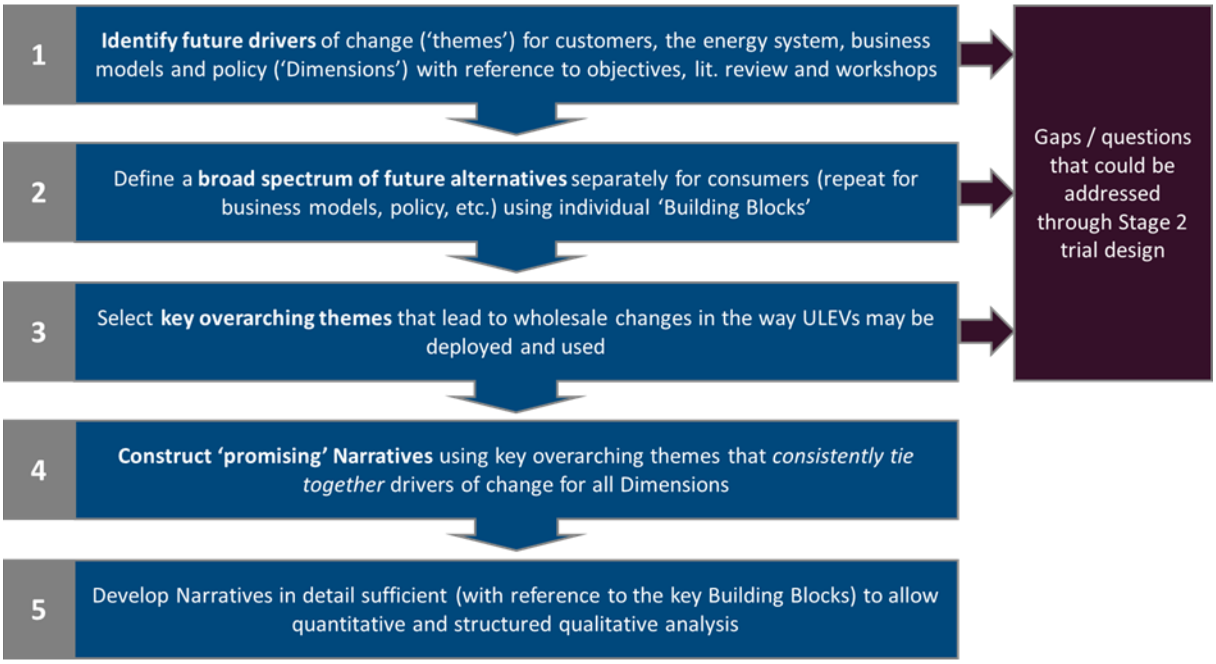
[7] See DLCG MCA manual for further information https://www.gov.uk/government/publications/multi-criteria-analysis-manual-for-making-government-policy

3 Narrative design

3.1 Approach to structuring the Narratives

The Narratives define alternative environments, encompassing physical, commercial, policy and consumer factors, in which ULEV deployment and use takes place. They represent internally consistent sets of BBs, collectively providing the assumptions necessary to undertake an analysis of ULEV deployment and use. The approach to developing the Narratives is outlined in Figure 4.

Figure 4 Approach to development of Narratives



This section documents the approach, and describes the Narratives resulting from this. During the development of the Narratives (and supporting BBs in the *D4.2 Building Blocks Catalogue* spreadsheet) three workshops were held to help draw on insights from the wider CVEI Project Team and ETI review panel, including the 'Vision workshop' with the ETI review panel on the 2nd October. These workshops enabled stakeholder views to be accounted for in the development of the approach and Narratives, and feedback from the workshops has been incorporated in the Deliverables.

3.1.1 Insights from literature to frame Narratives

The review of literature as part of this Deliverable and the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* has provided a significant volume of information targeted around specific groups of BBs, such as the development of particular technologies (e.g. PiVs versus FCVs), the economics of different vehicle types, and consumer surveys / trials. The results of the review are captured in detail in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* and the supporting *D4.2 Building Blocks Catalogue* spreadsheet.

In addition, the initial, bottom-up assessment of the relative importance of individual BBs has highlighted potentially important BBs across ***all*** of the Dimensions, with ***significant interdependencies*** across the Dimensions (e.g. the availability of widespread PiV charging or hydrogen refuelling infrastructure dependent on commercial models that can viably invest in these).

However, it is apparent from the review that there has been very limited work to date trying to frame a holistic, quantitative, and forward-looking assessment of how mass-market ULEV uptake and use can be facilitated, covering the four key Dimensions of interest to try to understand the potential interactions and trade-offs that may be required. This is driven in large part by the fact that deployment to date has been limited and future studies tend to focus on a small number of elements to make the analysis more tractable.

As a result, the Narratives under consideration necessarily cover a ***broad*** spectrum of possible futures and BBs (in sensible, internally consistent combinations) such that this holistic assessment can be undertaken. This is in contrast to a deep dive into one particular group of BBs, which would miss the wider insights from the holistic assessment.

On the one hand this re-affirms the value of undertaking such a study, but on the other it means that the starting point of framing questions for the Narratives necessarily starts from first principles. The Narratives therefore need to explore a sufficiently ***broad range of key – and holistically framed – questions*** including:

- To what extent is incremental / organic improvement delivered primarily via OEMs, with limited Government support, sufficient to deliver mass uptake and use of ULEVs?
  - To what extent does more organic development complicate the delivery of new large-scale supporting infrastructure, in particular with respect to the role of hydrogen?
- To what extent does a more coordinated, but technology neutral, push for ULEVs facilitate their uptake and use as 'maintaining optionality'?
  - What are the additional costs and broader requirements for providing a meaningful hedge such that mass rollout of either PiVs and / or hydrogen vehicles could both be undertaken in the later stages of the pathway to 2050?
- How effective is a coordinated push towards on one particular technology route such as hydrogen and FCVs?
  - Is this route materially more expensive and where?
  - What are the potential implications of getting it wrong?
- What is the value of a shift away from direct vehicle ownership towards delivering mobility as a service (e.g. in terms of requiring fewer vehicles with higher utilisation given that the majority of the transport energy system costs are in the capital cost of the vehicles)?
  - Is this more viable in some areas than others (e.g. urban)?
  - How significant are the implications likely to be for consumers as part of this shift and can the savings from better integrated services be used to compensate for any perceived or material reduction in an individual's 'transport utility' (e.g. less convenience)?

Results from the analysis have been used to answer these questions (directly or indirectly) in section 5.5.5.

3.1.2 Building Blocks

A detailed analysis of the individual BBs that could influence ULEV uptake and use was undertaken within the separate *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* (including underlying detailed *D4.2 Building Blocks Catalogue* spreadsheet which contains further information and sources). The report describes:

- A brief synthesis of the underlying evidence and literature, along with a high level view of likely materiality in terms of impacting ULEV uptake and use
- Areas for further research or known gaps in the literature, and
- BBs which are important for the *D1.2 Analytical Framework* and why they have been proposed for inclusion or exclusion within the proposed Narratives. Note that the Analytical Tools which comprise the *D1.2 Analytical Framework* are described in section 4 and Appendices A through D.

It is important to note that the purpose of the *D1.2 Analytical Framework* and Narratives is to provide a holistic assessment of very different potential pathways for future ULEV deployment and use. As a result many of the identified BBs are used – and indeed required – in at least one Narrative, rather than being excluded completely. The application of the BBs within the Narratives also tends to cover a wide range of states including the ends of the spectrum (e.g. no charging control to Supplier-Managed Charging) so that this drives more meaningful insights from the analysis, rather than minor variations.

The reasons that some BBs are not used, or are not quantified, are discussed in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report.* Where a Building Block is not included in the Narratives this is due to one or more of the following:

- The initial view that it is of low materiality and does not warrant inclusion given the maximum number of Narratives and Sensitivities that can be explored within the scope
- It cannot be assessed quantitatively and there is limited evidence to inform a meaningful qualitative assessment, but these are potential candidates for further exploration in the Stage 2 trial and updated Stage 2 analysis, or
- The impact is likely to be very similar to other - already included - BBs, given necessary simplifications required in the approach to modelling, and hence additional insights from including it are likely to be minimal.

The analysis within the separate *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* is *not repeated here*, but:

- An overview of the full set of BBs reviewed is summarised in Table 5 to Table 8 below, relating to section 8.3 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report.* BBs that have been 'considered qualitatively' are those that have been referred to in section 7 of this report.
- A summary of how a subset of these are applied to Narratives is contained in section 3.4.
- The gaps or areas for further research relevant to the Stage 2 trial are summarised in section 8.2.

Table 5 Overview of BBs considered within the CP

Application within Narratives
Considered quantitatively only (directly or indirectly)
Considered qualitatively only
Considered quantitatively and qualitatively
Not considered within Narratives / out of scope

Customer Proposition				
Ownership / access model	**Fuel pricing options**	**Availability of refuelling / charging**	**Billing Model**	**Consumer Control**
1. Outright purchase	10. Static ToU tariffs (User-Managed Charging)	15. Private charging	24. Subscription model	29. Sole vs shared use (e.g. of vehicle)
2. Contract purchase[8]	11. Dynamic ToU tariffs (Supplier-Managed Charging)	16. Public charging in motorways and A-roads (rapid)	25. Support for price certainty (e.g. data prices at charging points)	30. Charging control (manual to automated)[9]
3. Hybrid purchase (battery lease)	12. Demand Management tariffs	17. Public charging in local points (mid-level)	26. Traditional pay per unit model	31. Vehicle choice (brand, body-type, etc.)
4. Contract hire	13. Flat tariff	18. Workplace charging	27. Multi-modal (e.g. payments for PiV charging integrated with public transport)	
5. Short-term hire/car sharing	14. Vehicle to Grid/House (V2G/H)	19. H_2 refuelling stations	28. Separate account (e.g. fuel provided as part of bundled payment)	
6. Secondary market for vehicles[10]		20. Battery swapping		
7. Bundled installation of charging points		21. Electrolyte charge		
8. Maintenance, servicing and insurance[11]		22. Dynamic charging (e.g. wireless)		
9. Access to other vehicles or forms of transport when ULEV unsuitable		23. Forecourts (H2, Liquid)		

[8] Only contract hire and outright purchase are modelled (no contract purchase) so that the Narratives are sufficiently distinct
[9] Charging control is considered quantitatively in the 'inconvenience cost' payment that consumers receive under Supplier-Managed Charging.
[10] The secondary market for vehicles is assumed for fleets transferring to Private Consumers via adjusted costs in the Total Cost of Ownership (TCO) calculation.
[11] Maintenance, servicing and insurance costs are adjusted for car sharing schemes as noted in section 5.2.

Table 6 Overview of BBs considered within the PSC

Physical Supply Chain					
Vehicles	Energy Carrier Generation[12]	Energy Carrier Transport	Energy Carrier Storage[13]	Refuelling / charging infrastructure	Back office / IT
1. Battery (cost, range, etc.)	8. Electricity generators	12. Electricity distribution network	17. Large batteries	21. Private charging	25. Industry standards (e.g. for public charging)
2. Battery Management System	9. H_2 generation plants (localised, centralised)	13. Electricity transmission network	18. Large underground H_2 storage	22. Public charging	26. Assets needed for settlement purposes (e.g. smart meters)
3. Fuel cell system	10. Biofuel plants	14. H_2 distribution (tankers, pipes)	19. Oil strategic reserves	23. H_2 refuelling stations	27. Assets needed for communication/coordination across networks (e.g. for Active Network Management)
4. Generic high technology readiness components (e.g. chassis, engine)	11. Refineries	15. Trucks for liquid fuels[14]	20. Natural gas storage	24. Forecourts (liquid)	28. Data servers for big data
5. Electric motor		16. Gas network			29. Assets needed for communication from/to vehicles (e.g. for autonomous vehicles, charging management)
6. Vehicle H_2 tank					
7. Communication systems (within vehicle to wider system e.g. for Supplier Managed Charging)					

[12] Electricity generators, centralised hydrogen generators and biofuel plants are represented in the ESME model of the wider energy system (see Appendix D.1). Refineries are included via exogenous assumptions for petrol/ diesel wholesale costs.

[13] Batteries and hydrogen storage are represented in ESME.

[14] Trucks for liquid fuels are not modelled explicitly; however, the cost of these is small and is captured in the overall costs of the liquid forecourt operator.

Table 7 Overview of BBs considered within the MPF

Market and Policy Framework						
Financial – Upfront / Fixed Costs	**Financial – Running Costs**	**Non-financial incentives**	**Emission limits**	**Information**	**Investment**	**Other regulation**
1. Gov. grants to consumers	7. Fuel price subsidies	18. Increased mobility (e.g. access to bus lanes)	22. Direct CO_2 tax (e.g. on liquid fuels)	26. Education / marketing (e.g. on battery range, charging point availability)	28. Government funding / investment (direct funding of e.g. charging infrastructure)[15]	33. Adequate access to infrastructure (e.g. sufficient infrastructure ahead of need)[16]
2. Private grants to consumers	8. Vehicle excise duty	19. Simplification (e.g. of multiple vehicle-related taxes)	23. Direct emissions limit (e.g. EU vehicle standards)	27. Mandatory / voluntary reporting (e.g. data on pollution, costs of running, etc.)	29. Leveraging Private investment (e.g. regulated return models for new infrastructure)[17]	34. Other laws / wider energy sector regulations
3. VAT on vehicles	9. Company car tax	20. Status (e.g. more explicit differentiation of ULEV ownership)	24. Emissions cap and trade scheme		30. Investment in R&D	35. Commitment (from Gov. e.g. exemplar schemes, subsidy lengths)
4. Purchase/ registration tax[18]	10. Fuel duty	21. Increased access to parking	25. Emissions credits scheme		31. Capital allowances (e.g. for ULEVs)	36. Role of local authorities (e.g. vs direct central Gov. action)
5. Refund schemes	11. VAT on fuel				32. Government guarantees (e.g. loans)	37. Standardisation (e.g. infrastructure/ planning)
6. Subsidies for other fixed costs (insurance, breakdown cover etc.)	12. Cheaper mobility (e.g. avoidance of congestion charges)					38. Co-ordination National initiatives (e.g. between industry and central / local Gov.)
	13. Cheaper access to parking					39. Planning regulations (e.g. new infrastructure)
	14. National insurance (e.g. lower for employers providing ULEVs)					
	15. Subsidies for other running costs					
	16. Road pricing[19]					
	17. Weight tax					

[15] Direct subsidy for infrastructure has been quantified.
[16] Access to charging is quantified in the *D1.2 Analytical Framework*.
[17] Included quantitatively through the business models of the *D1.2 Analytical Framework*.
[18] Incorporated within the ECCo model.
[19] Captured as a technology neutral mechanism, together with a fixed per-vehicle cost mechanism, as part of the Success Metrics.

Table 8 Overview of BBs considered within the CVC

Commercial Value Chain			
Section of value chain	**Generic business model type**	**Modelled[20] as stand-alone commercial entity**	**Building Block Name**
Vehicles	**Manufacturer**	×	1. Vehicle manufacturer
		×	2. Vehicle manufacturer and Charging Point Operator (CPO)/ owner
	Retailer	✓	3. Vehicle retailer (retail arm of manufacturer)
	Leaser	✓	4. Vehicle leaser
		×	5. Battery leaser
		✓	6. Vehicle sharing scheme
Electricity	**Retailer**	✓	7. Electricity supplier
		×	8. Electricity supplier with vehicle manufacturer
	Network Operators	✓	9. Electricity Distribution Network Operator (DNO)
		×	10. Electricity DNO as Distribution System Operator (DSO)
		×	11. Electricity DNO / DSO with charging point network
	Charging point owner	✓	12. Charging Point Operator / network/ owner
		×	13. Charging Point Operator/ network/ owner with electricity supplier
		×	14. Battery swapping
	Aggregator	✓	15. Demand Management (DM) aggregator
		×	16. IT/ data provider
Liquid Fuel	**Retailer**	✓	17. Liquid forecourt retailer
	Network Operator	×	18. Liquid fuel road distributor
Hydrogen	**Retailer**	✓	19. Hydrogen retailer (at forecourt)
	Localised producer	✓	20. Localised hydrogen producer
		×	21. Localised hydrogen producer with forecourt retailer
	Distribution Network Operator	✓	22. Hydrogen network operator (pipe)
		✓	23. Hydrogen road distributor
	Centralised producer	×	24. Centralised hydrogen producer

[20] In terms of the representation of the cash flows associated with the commercial entity. For wholesale production of electricity, centralised hydrogen and liquid fuels the wholesale prices are estimated via the *D1.2 Analytical Framework* but the associated commercial entity cash flows are not modelled explicitly. Similarly the TSO and TNO savings are quantified in Narratives with Supplier Managed Charging, although the entities are not modelled in the CVC. See section 4 for further details.

3.1.3 Considering future alternatives within each Dimension

Due to the myriad different Building Bocks across the Customer Proposition and other Dimensions it is difficult to jump directly from these to create a set of detailed, overarching Narratives. As an intermediate step it was necessary to first consider the possible future alternatives within each Dimension. To do this a number of themes that could drive future change were identified from the existing literature and via project workshops, these are summarised in Figure **5** to Figure 8.

Figure 5 **Customer Proposition themes**

BB category	Consumer Proposition Thematic Axes	
Ownership or access model	Vehicle purchase	Vehicle rental
	Personal vehicle	Shared vehicle
	ULEV as primary vehicle	ULEV as secondary vehicle
Refuelling pricing	Consumer price certainty	Business cost reflectivity
Refuelling availability	In-home	Centralised
	Fast fuelling	Slow fuelling
Monetised perks	ULEV privileges	Common treatment
Billing model	Bundled products	Unbundled products
Consumer control	Consumer response (voluntary)	Network control (mandatory)
	Conventional driving	Autonomous vehicles

Figure 6 Physical Supply Chain themes

BB category	Physical Supply Chain Thematic Axes	
Vehicles	ICE BAU efficiency improvements	ICE radical efficiency improvements
	Hydrogen	Plug-in Electric
	Single fuel	Hybrid
	Consumer operated	Autonomous
Energy carrier generation	Distributed	Centralised
Energy carrier transport	Fixed networks	Tanker transport
Energy carrier storage	Vehicles as energy demand	Vehicles as flexibility
Refuelling infrastructure	Fast fuelling	Slow fuelling
	Distributed	Centralised
	On demand	Controlled
Back office/IT	Isolation (no standards)	Interoperability (standards)

Figure 7 Commercial Value Chain themes

Commercial Value Chain Thematic Axes	
Vehicle sale	Vehicle rental
Personal vehicles	Shared vehicles
Bundled provision of products	Unbundled provision of products
Distributed provision of products	Centralised provision of products
Competitive markets	Regulated markets
Vehicle manufacturer driven value chain	Retailer driven value chain
Data centric	Transport centric

Figure 8 Market and Policy Framework themes

Market and Policy Framework Thematic Axes	
'Mandating' the outcome	'Incentivising' the outcome
Incentivising the good	Disincentivising the bad
Mitigate upfront barriers (cost, etc)	Mitigate ongoing barriers
Infrastructure focus	Vehicle focus
Consumer/fleet focus	Supply chain focus
Technology targeted	Technology neutral
Regional	National
Government financed	Leveraging private investment

Using this approach, a number of future alternatives were outlined in each Dimension, including a Business as Usual alternative and a radically different 'on demand' alternative, based on short-term rental of vehicles. These are summarised in Figure 9, and have been developed in more detail where selected to form part of a Narrative, as outlined in Sections 3.3.1 to 3.3.6.

Figure 9 Summary of future alternatives by Dimension

Physical Supply Chain	Commercial Value Chain	Customer Proposition	Market & Policy Framework
▶**BaU:** continued ICE efficiency gains, limited ULEV deployment ▶**On demand:** long range BEVs, novel charging technology, moderate DM, role for autonomous vehicles ▶**Smart grid / FCV role:** active network management, some FCVs ▶**Active network management / manual DM / fast charging:** some DM and some fast charging with active network management ▶**Active network management / automated DM / fast charging:** very high DM, including V2G ▶**High FCV:** tanker transport and on site centrally managed electrolysis ▶**High PiV / central network management:** centrally managed charging ▶**Depot charging:** large BEV fleet with depot charging	▶**BaU:** traditional vehicle retail model ▶**On demand:** fleet providers of short term rental cars ▶**Smart cars:** car OEMs expand services, uncertain energy integration ▶**Final mile:** more integrated multimode transport, with cars providing end destination leg ▶**Hydrogen:** take up clustering around production locations ▶**Regulated infra:** regulated business models for new infrastructure	▶**BaU:** vehicle ownership and consumer freedom ▶**BaU+:** as BaU, plus access to additional services, such as fast charging ▶**BaU++:** as BaU, plus access to extensive hydrogen infrastructure ▶**On demand:** subscription to vehicle services, role for autonomous vehicles ▶**Opt-in sharing:** more car sharing arising organically ▶**Indirect restriction:** end user sees little impact on choices ▶**Direct restriction:** greater restriction on choices	▶**BaU:** limited grants for vehicle purchase and favourable VED ▶**On demand:** publicly sponsored charging infrastructure, framework for autonomous vehicles ▶**Infrastructure focus:** focus intervention on infrastructure ▶**Market driven:** private investment and taxation of undesirable options ▶**Consumer focus:** focus intervention on consumers ▶**Consumer led:** information focus, low public investment ▶**Government led:** incentives focussed intervention across the value chain ▶**Centrally planned:** directed, mandated, intervention ▶**Regionally led:** regional / city governments lead change

3.2 Narrative development

3.2.1 Framework development

Approach to shaping the Narratives during the scoping phase

Narratives describe the overarching environment for ULEV deployment and use. They represent a plausible and internally consistent reflection of possible futures across each of the key Dimensions under consideration.

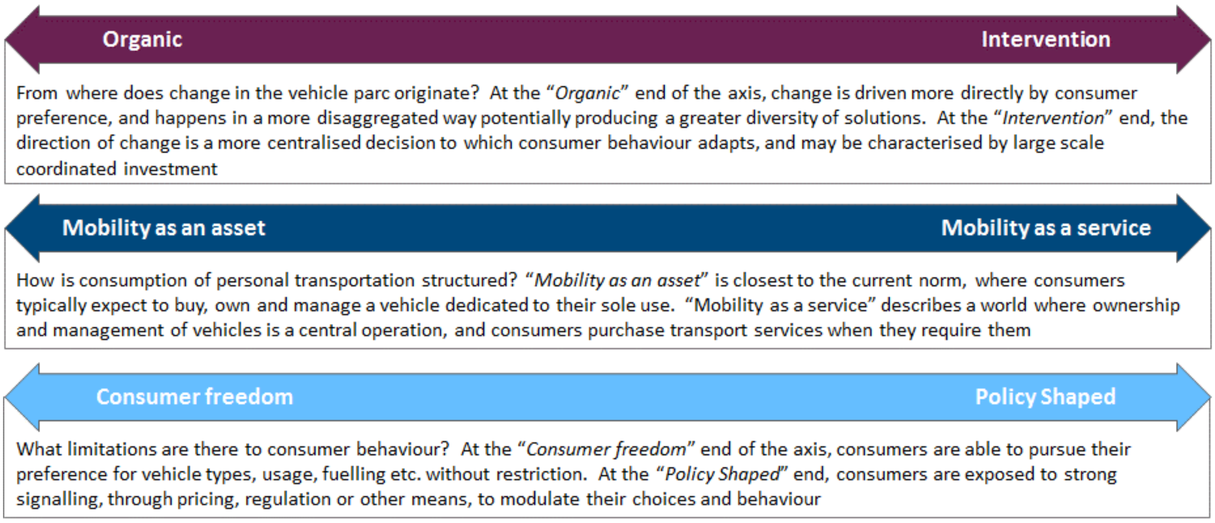
The approach to developing the Narratives in the scoping phase has been to identify overarching axes describing important and opposing themes that could describe the evolution of the road transport sector. The period to 2050 could encompass significant change in the way ULEVs are perceived and utilised as part of the car and van fleet and so by necessity the Narrative themes represent some of the fundamental future drivers for this part of the transport sector.

The specific BBs, guided by the future alternatives considered within each Dimension discussed in section 3.1, then provide a clear and systematic structure to define what is contained within each Narrative, which is complicated by the breadth of issues under consideration.

The Narrative axes were developed within the CVEI Project Team through workshops, informed by the Building Block analysis and then refined through consultation with the ETI and its members. The opposing states of these axes can then be combined to develop contrasting contexts for ULEV deployment and use, and so facilitate development of the Narratives in a systematic way.

The initially proposed thematic axes are illustrated in Figure 10, followed by the process for refining this initial set to create the final themes used to define the Narratives in Figure 11.

Figure 10 Initial Narrative overarching thematic axes



The potential for these overarching thematic axes were then reviewed, with the following conclusions.

- **Organic <> Intervention:** this axis directly drives distinctive Narratives from a Market and Policy Framework perspective, and indirectly the Physical Value Chain. Suitably redefined, this axis could also capture action on ULEV deployment and use that is planned and coordinated across multiple parties, without necessarily representing a top-down intervention.
  - Decision by the team to expand this theme to cover elements of the others below
- **Mobility as an asset <> Mobility as a service[21]:** the ends of this axis directly imply distinctively different Narratives for the Customer Proposition and Commercial Value Chain Dimensions in particular. They imply different outcomes for ULEV deployment and use, as the service model drives higher utilisation and better economics, more rational investment decisions and more planned charging.
  - Decision by the team to keep as a clear differentiator for the final Narratives
- **Consumer freedom <> Policy shaped:** this axis chiefly drives change in the Customer Proposition Dimension, making it difficult to draw out material distinctions in combinations with the Mobility as an asset / Mobility as a service axis. Distinctions intended to be drawn out by this axis, around charging behaviour and mandated migration to a particular technology, could emerge from the themes of other axes.
  - Decision by the team to consolidate this theme with the others

Other candidate axes were commonly identified through the consultation process, as follows:

- **Urban focus <> Universal solution:** although of relevance, in a relatively small and densely populated country such as the UK, the difference across this axis alone may not be significant enough to drive materially different Narratives. Relevant aspects of this issue can be incorporated in the Narratives suggested by other axes.
  - Decision by the team to accommodate key aspects of this theme within the others
- **Standardisation / cooperation <> Incompatibility / fragmentation:** this axis particularly concerns the potential for multiple, incompatible standards to emerge for charging and data, with impacts primarily on the Physical Supply Chain and Commercial Value Chain Dimensions. The Organic / Intervention axis could be broadened to incorporate this issue.
  - Decision by the team to accommodate key aspects of this theme within the others

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[21] For the purpose of the modelling in the *D1.2 Analytical Framework* the exact proposition as seen by the end consumer is not specified – rather it is assumed that fleets of vehicles are notionally accessed by consumers hour-by-hour as required, such that vehicles are driven by multiple users throughout the day sharing the underlying asset. The underlying journey pattern requirements of the users are maintained (i.e. no modal shifting is assumed); however, there is some accounting for 'dead mileage' to reflect that the vehicles may need cover more miles to enable access by multiple users. More optimal routing in the future and modal shifts may lead to reduced consumer mileage overall, compared to current journey requirements, but this is not reflected in Stage 1. There is limited evidence on how consumers would engage with the concept of vehicles as shared assets and this engagement is presupposed for the purposes of the relevant Narratives. The focus of the *D1.2 Analytical Framework* is therefore to help understand the potential economics, energy system impacts and carbon savings from a significant increase delivery of consumer requirements through asset sharing.

Final Narrative themes

The thematic axes as defined for further development are illustrated in Figure 11. Also listed here are ***example characteristics*** in each Dimension, consistent with the themes at each end of the axis.

A further independent axis of time was identified, describing the timeframe over which change occurs, from rapid, early transition at one extreme to later, gradual transition at the other.

Figure 11 Final Narrative overarching thematic axes

Mobility as an asset	**Mobility as a service**

How is consumption of personal transportation structured?

"*Mobility as an asset*" is closest to the current norm, where consumers typically expect to buy, own and manage a vehicle dedicated to their sole use

- Direct commercial associations: less bundling of products
- Indirect policy implications: focus on end users rather than supply chain, upfront barriers rather than operating barriers
- Direct customer associations: vehicle ownership, less vehicle sharing
- Indirect physical implications: less intense vehicle usage; slower more distributed electric charging

"*Mobility as a service*" describes a world where ownership and management of vehicles is a commercial operation, and consumers purchase transport services when they require them

- Direct commercial associations: more bundling of products
- Indirect policy implications: focus on supply chain rather than end users, operating barriers rather than upfront barriers
- Direct customer associations: vehicle rental, more vehicle sharing
- Indirect physical implications: more intense vehicle usage; faster more centralised electric charging

Organic change	**Coordinated action**

From where does change in the vehicle parc originate?

At the "*Organic change*" end of the axis, change is driven more directly by consumer preference, and happens in a more disaggregated way potentially producing a greater range of solutions

- Indirect commercial implications: more scope for commercially led change, with expansion along the value chain
- Direct policy associations: a more laissez-faire approach to policy at national level, more regional variation
- Indirect customer implications: more restricted availability of refuelling
- Direct physical associations: a more incremental approach to infrastructure deployment

At the "*Coordinated action*" end, change is a result of central coordinated action to which consumer behaviour adapts, and may be characterised by large scale programmed investment

- Indirect commercial implications: more regulated business models
- Direct policy associations: more directive, interventionist policy, implemented on a national scale
- Indirect customer associations: wider availability of refuelling
- Direct physical associations: more scope for new infrastructure deployed on a national scale

Rapid, early transition	**Late, gradual transition**

All Narratives will have a rate of transition associated with them

The axes selected have been developed to be as independent of each other as possible, in order that the Narratives they drive define a broad space of possible futures. This is important to enable comparisons to be made and identification of those BB's that characterise efficient environments for ULEV uptake and use.

3.2.2 Principles

As part of developing the detail within each Narrative a set of principles, as outlined below, was developed to ensure that the Narratives are consistent and useful tools to aid analysis of strategies for promoting ULEV deployment and use.

1. Narratives should be plausible and internally consistent.
2. Narratives should represent distinctively different environments for ULEV deployment and use.
3. Narratives should be capable of being located in the space defined by the thematic axes, in order to facilitate interpretation and comparison.
4. Narratives should not be designed explicitly to achieve different levels of ULEV deployment and use. Rather, different levels of ULEV deployment and use should be an outcome, within broad *bands* of expected deployment and use.
5. Narratives should focus on different strategies that could be facilitated by policy makers and / or industry participants to influence ULEV uptake, rather than different market conditions outside their influence (such as international commodity prices which can be tested in a Sensitivity).
6. Narratives should assume that significant technology development and availability is driven at a global level[22], and is common across Narratives – with variations tested as Sensitivities.
7. Narratives must meet UK targets for CO_2 reduction for the energy system as a whole.
8. Narratives should assume the same level of overall transport service demand as a starting point (i.e. total car / fleet vkm), unless there a fundamental case for why this should be different for a given Narrative (e.g. mobility as a service Narratives may have fewer overall vehicles with some being utilised more highly).
9. Narratives should describe end-states and the pathway by which the end-state will be achieved via the transition over time.

Key amongst these principles is that each Narrative should be focused around active choices or strategies that can be delivered by the various actors involved (such as Government, industry, or indirectly by consumers). Exogenous conditions that are outside of the control of these actors, such as international fossil fuel prices, are tested by Sensitivity rather than driving differences in the Narratives themselves. Sensitivities are used to explore how resilient a given ULEV strategy is to these changing external conditions.

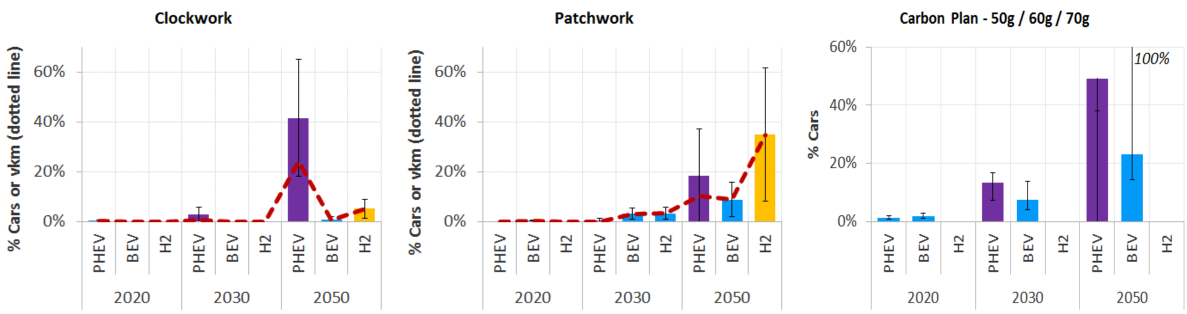
[22] In terms of vehicle costs, battery performance, etc.

3.2.3 Framing ULEV uptake levels

In order to ensure a common understanding of 'mass deployment and use', it is informative to refer to other comparable studies where this has been considered. Figure 12 illustrates ULEV deployment outputs (in terms of % of the car vehicle parc) for ETI's published Clockwork and Patchwork scenarios[23], and the UK Government's Carbon Plan[24].

The error bars in the charts represent +/- one standard deviation in the case of the ETI scenarios, and the 70 gCO_2/km and 50 gCO_2/km scenarios in the case of the Carbon Plan. The dashed line in the Patchwork / Clockwork scenarios also shows the share of low carbon vkm, scaled to the share of electricity consumption in the case of PHEVs.

Figure 12 ULEV deployment and use in comparable studies



The Patchwork and Clockwork scenarios frame a wide range of ULEV uptake from around 25% to 75% in terms of share of ULEV vehicles by 2050 – the averages for share of vkm are between 30% to 50% depending on the share of PHEVs. However, some scenarios (such as the Carbon Plan 50g) show almost complete replacement of the fleet by ULEVs by 2050.

The precise ULEV deployment and use in terms of the share of vkm within each Narrative is primarily an outcome of the Narrative, but the above scenarios help shape expectations within broad ranges. For example BaU is likely to reflect up to ~30% vkm by ULEVs driven primarily by current and proposed EU regulation on new car / van fleet gCO_2/km averages.

3.3 Summary of Narratives and high level questions

Using the overarching thematic axes developed in section 3.2.1, and the principles in section 3.2.2, a set of Narratives has been developed in addition to a BaU case. The results can be compared to draw out conclusions about the role of key BBs in producing an environment for efficient mass deployment and use of ULEVS. In addition, taking the Narratives as a whole, higher level thematic questions can be considered, to help tie together conclusions across Narratives. The key question(s) posed or to be tested by each Narrative are also highlighted:

[23] http://www.eti.co.uk/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system/
[24] https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2

- **Guided OEMs – 'OEM'** *(organic change / mobility as an asset)*: vehicle OEMs make ULEVs attractive to consumers, by increasing desirability and enhancing functionality through integrated digital services which facilitate use of the vehicle (e.g. real-time access to maps of public charging stations and electricity prices at these stations[25]). Proprietary motorway charging networks complement the dominant mode of home charging. To some extent this Narrative may be seen as an extension of current trends (a form of BaU+), where a number of manufacturers and technology developers are creating new and distinctive vehicles and offering a range of services around them. Policy at a central Government level is directed at a limited, but importantly ongoing, pull towards ULEVs. For example through differential rates of Value Added Tax (VAT) rather than a fully coordinated, heavily subsidised approach, consumers receive some grant towards the capital cost of their vehicle but less so than in other Narratives.
  - To what extent is incremental / organic improvement delivered primarily via OEMs, with some Government support, sufficient to deliver mass uptake and use of ULEVs?
  - To what extent does this complicate the delivery of new large-scale supporting infrastructure, in particular with respect to the role of hydrogen?
- **City Led – 'City'** *(organic change / mobility as a service)*: city regions drive the transport agenda, focussing on local environmental issues such as air and noise pollution and congestion. Consumers use multiple modes of transport as an integrated service including cars, but these are provided more through short-term rental and car clubs. Urban car rental fleets are charged at public / work locations. Outside of urban areas vehicles are still owned predominantly as assets by their users.
  - What is the value of a partial shift towards delivering mobility as a service - in urban areas where this appears more viable (e.g. in terms of requiring fewer vehicles with higher utilisation)?
- **ULEV Enabled – 'ULEV'** *(coordinated action / mobility as an asset)*: Government provides a supportive regulatory environment for charging and hydrogen infrastructure, reducing consumer anxiety in choosing a ULEV, and enabling a free choice between hydrogen and electrical energy sources.
  - To what extent does a more coordinated, but technology neutral, push for ULEVs facilitate their uptake and use?
  - What are the additional costs and broader requirements for providing a meaningful hedge such that mass rollout of either PiVs and / or hydrogen vehicles could both be undertaken in the later stages of the pathway to 2050?
- **Hydrogen Push – 'H2P'** *(coordinated action / mobility as an asset)*: central Government makes a decision to promote mass transition to hydrogen, through supporting both infrastructure deployment, and consumers purchasing hydrogen vehicles.
  - How effective is a coordinated push towards hydrogen as the primary ULEV route, given that this mirrors many of the current aspects of the Customer Proposition (e.g. owning asset, no range issues, 'hub' refuelling) as current ICEVs and liquid refuelling infrastructure?
  - Is this route materially more expensive compared to other Narratives (such as City and Transport on Demand), which tend towards electric vehicles and where does this

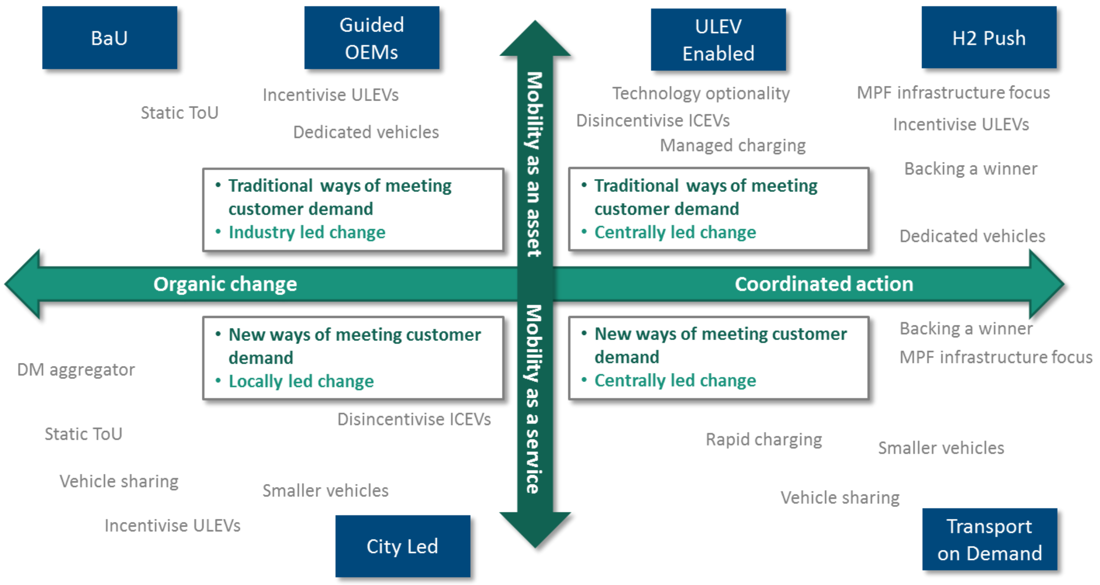
[25] Particularly as part of any move to more dynamic electricity pricing.

cost difference materialise (e.g. fuel production versus additional infrastructure), and how effectively does early coordinated action reduce these costs?

- **Transport On Demand – 'ToD'** *(coordinated action / mobility as a service)*: central Government identifies widespread social benefits in a smaller, more intensively used vehicle parc. Intervention provides a common standards and widespread infrastructure enabling vehicle fleets to offer an on demand transport service to consumers.
  - What is the value of a systemic, coordinated shift towards delivering mobility as a service, going significantly beyond that in the City Narrative (e.g. in terms of requiring fewer vehicles with higher utilisation)?
  - How significant are the implications likely to be for consumers as part of this shift and can the savings from better integrated services be used to compensate for any perceived or material reduction in an individual's 'transport utility' (e.g. less convenience)?

Results from the analysis have been used to answer these questions (directly or indirectly) in section 5.5.5. The structure used to frame the Narratives is summarised in Figure 13.

Figure 13 Narrative summary



Some *simplifying modelling assumptions* have been used as discussed in section 5.6.1.

In addition to these, a Narrative representing continuation of existing conditions (**BaU**) is included, to provide a baseline against which the results of other Narratives can be compared. Within the space defined by thematic axes, BaU sits in the same quadrant as OEM (organic change / mobility as an asset), but ULEVs remain as a premium or niche product, and lower ULEV deployment and use is expected as a result.

The Narratives should be read in conjunction with the D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report, which provides a detailed mapping of how individual BBs are used to provide the foundation of each Narrative. The descriptions below provide a snapshot of each Narrative.

3.3.1 Business as Usual

This represents a baseline with a continuation of current trends, where a modest increase in ULEV deployment and use is achieved but is limited at least in the near to medium-term to premium and niche sectors of the vehicle market. Lower long-term decarbonisation is achieved in the transport sector relative to other Narratives, meaning greater effort would be required in other sectors if overall targets are to be met.

In the Physical Supply Chain, change to the energy system is incremental. Limited deployment of hydrogen refuelling stations occurs on a commercially led basis, co-located at existing liquid fuel stations or depots. PiV charging largely occurs overnight at home.

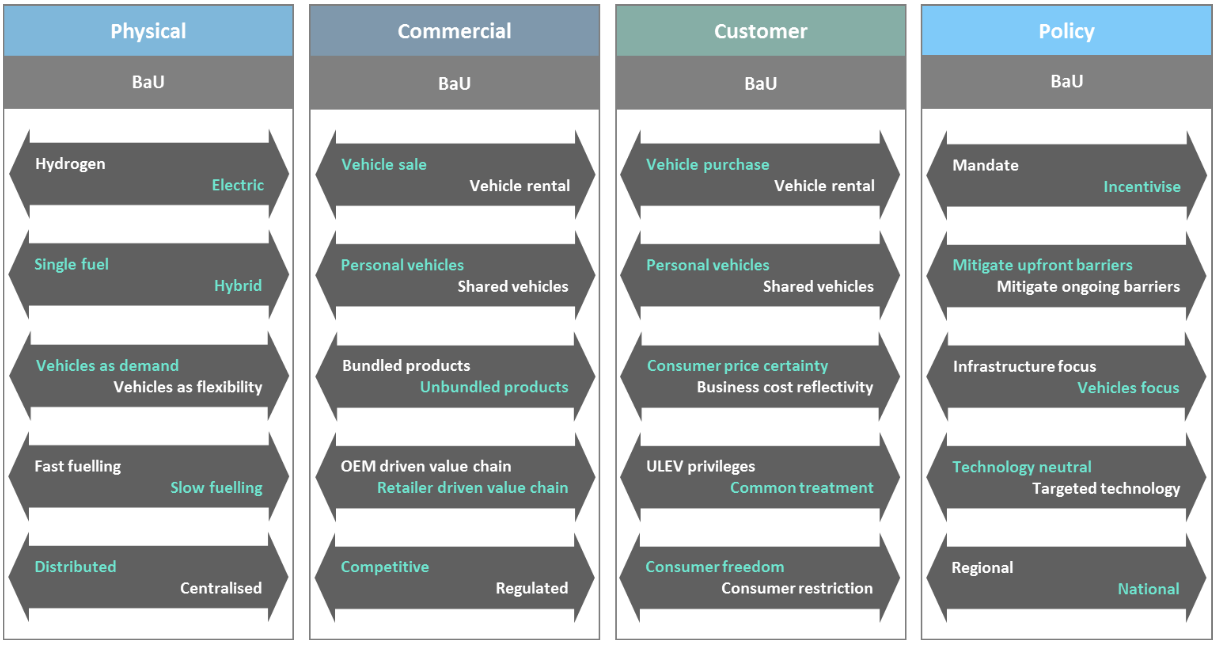
Consumers continue primarily to make outright purchase of vehicles (over half of current private purchase is outright) for their own use whilst fleets typically use contract hire schemes; associated services such as insurance and maintenance continue to be procured separately. Consumers are primarily charged using flat tariffs, and hence have less visibility of price signals and minimal load shifting occurs.

The policy environment is moderately supportive of ULEVs, with limited grants available to support purchase in the very near term only and advantageous Vehicle Excise Duty (VED) rates reducing ongoing running costs. One of the primary reasons that consumers choose ULEVs is to save money on fuel, especially as consumers can sometimes charge for free.

No major changes to the Commercial Value Chain occur.

The themes used to help frame the Narrative are summarised in Figure 14 for BaU and in Figure 15 to Figure 19 for the other Narratives. In these figures, typically one end of each axis is shown in green to indicate the predominant applicability of that end of the axis and consequent BB selection. In some cases both ends of the axis are in green, e.g. for Narratives in which there is no strong preference for single fuel or hybrid vehicles, and for Narratives in which both infrastructure and vehicles are key areas of focus.

Figure 14 Themes used within BaU Narrative



3.3.2 Guided OEMs

The Guided OEMs (OEM) Narrative is one where manufacturers lead change by producing innovative ULEVs, which provide their users with additional services and functionality, and which are very desirable. An analogy might be found in the development of smart phones from earlier mobile phones. To some extent this Narrative may be seen as an extension of current trends (a form of BaU+), where a number of manufacturers and technology developers are creating new and distinctive vehicles and offering a range of services around them.

From a physical perspective, change is incremental. PiVs dominate ULEV purchases, with the choice between BEV and PHEV determined by relative economics and consumer preference. Charging is mainly overnight at or near the home, complemented by the gradual development of a rapid charging network. Impact on the electricity system is moderated through widespread adoption of Time of Use (ToU[26]) tariffs, though the disaggregated provision of infrastructure means more advanced options for integration (dynamic ToU and active network management) are not widely adopted. Hydrogen vehicles are available but their popularity is determined by relative cost and access to fuelling infrastructure. In this latter regard, private investment supports a limited network located at liquid fuel forecourts, and supplied by centralised production and road tanker distribution.

Consumers tend to buy vehicles for dedicated personal use, making increased use of hire purchase schemes to overcome high upfront costs. Vehicles offer more connectivity, interacting with other devices and the home to provide consumers greater convenience and appealing personalised digital services. An ongoing subscription with the vehicle OEM covers these services, making maximum use of the additional data available to tailor services including insurance, maintenance and breakdown cover. This subscription also provides drivers with access to a limited network of trunk road fast

[26] Where prices vary more closely with the underlying costs of production across the day.

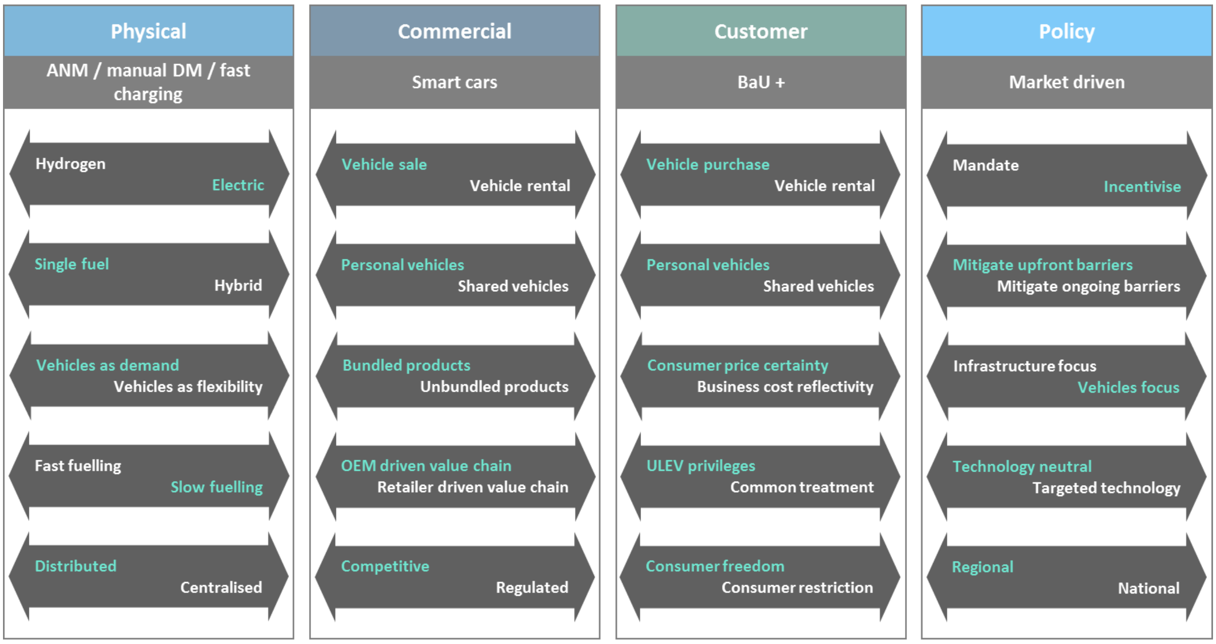
charging stations to facilitate longer journeys, though as not all manufacturers' equipment is interoperable most use a traditional pay-per-unit billing model.

Policy at a central Government level is directed at a limited, but importantly ongoing pull towards ULEVs, for example through differential rates of VAT. Consumers receive some grant towards the capital cost of their vehicle or charging point, but less so than in other Narratives, and can benefit from exchange schemes for old batteries from a combination of OEM and Government schemes.

Commercially, business models in the energy sector are mainly unaltered. However, vehicle OEMs expand down the value chain, offering additional services, such as constructing and operating their own charging point networks; partnering with electricity suppliers to offer tariffs for PiV charging; and bundling services which drivers had previously obtained separately, such as insurance.

The themes used to help frame the Narrative are summarised in Figure 15.

Figure 15 Themes used within OEM Narrative



3.3.3 City Led

The dominant theme of the City Led (City) Narrative is of change driven by city regions, with action focused on relieving issues with local impact, such as air pollution and congestion. This leads to greater divergence of modes of transport used for longer inter-city journeys, and those used for shorter intra-city journeys. Especially in cities, car ownership loses some of its appeal to consumers as a symbol of freedom or as an essential component of a modern lifestyle.

Urban vehicles tend to be smaller and more utilitarian, better adapted to more intensive use. Urban vehicle rental fleets are fuelled in depots, some of which may be hydrogen fuelled using localised electrolyser production, and at public hubs. Where fleets are PiV based, there is a more concentrated nature of charging facilitates and ToU tariffs. Rural areas tend to opt for PHEVs.

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Private purchase of vehicles becomes less common consistent with a shift in consumer attitudes away from vehicle ownership. Instead, fleet operators expand to represent a large proportion of vehicle purchases, making economically rational investment choices. End consumers, especially in urban locations, move away from vehicle ownership and towards renting vehicles through car clubs, use of taxis, and other vehicle sharing schemes. There is some further shifting of consumer service demands to light duty vehicles as part of increasing use of home delivery services. Outside urban areas, where users tend to retain vehicles for dedicated personal use, leasing is more common. Longer distance trips are often accomplished across multiple modes of transport using integrated ticketing, with cars providing transport from a more significant hub to the final destination.

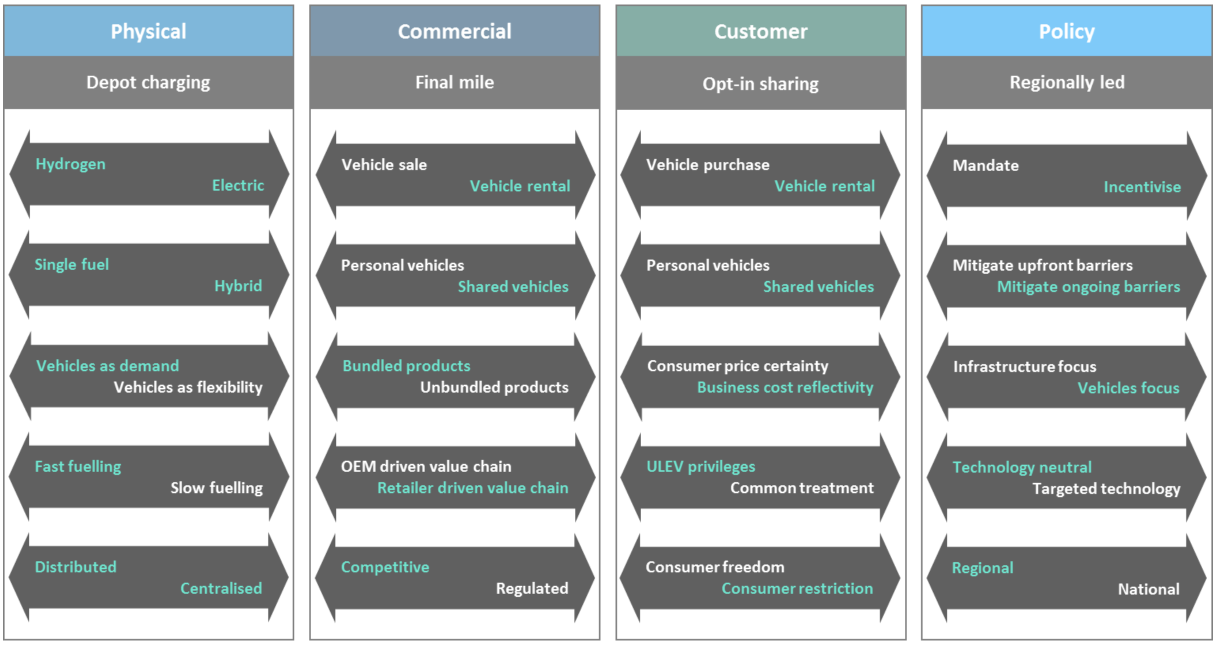
Policy is driven by individual city authorities seeking to improve urban environments through implementing initiatives that provide cheaper mobility and increased access, such as congestion charging and low emission zones. In the earlier years of the modelled pathway, measures such as preferential access to high occupancy vehicle / bus lanes may be employed, but these become unsustainable as ULEV penetration increases. These authorities also help facilitate the change in travel through supportive planning policy for charging depots and other infrastructure. These perks are in part used as a means to advertise ULEVs, as local authorities play an active role in marketing ULEVs and educating the consumer. Central Government encourages a move away from conventional vehicles with differential rates of VED, upfront grants and VAT differentiation for ULEVs in the near-term[27], with a shift to a carbon tax on liquid fuels from the medium-term.

From a commercial perspective, the most notable change versus current or BaU conditions is the increase in vehicle fleet operators, providing vehicle services to end consumers on a short-term basis, such as through car sharing schemes. As vehicle ownership becomes rarer, remaining private users shift towards leasing models rather than outright purchase. The possibility of providing flexibility at charging depots also provides business for aggregators of such services.

The themes used to help frame the Narrative are summarised in Figure 16.

[27] In Norway, for instance, BEVs are exempt from VAT (except for when leased). Under the current rules, EU Member States need to stick to a pre-defined list of goods and services when it comes to applying zero or reduced VAT rates. Vehicles are not included in this list. However, in the past the reduced VAT rate of 5% was extended to energy-saving materials supplied under the Home Energy Efficiency Scheme and similar schemes. The European Commission is to publish a proposal in 2017 for the definitive VAT system for EU cross-border trade together with a reform of the VAT rates. In the latter case it anticipates two options: allowing all States the same rights to apply zero and reduced VAT rates, while regularly reviewing the list of goods and services; or, allowing States to set reduced rates as they wished, provided any changes did not generate tax distortions. http://researchbriefings.files.parliament.uk/documents/SN02683/SN02683.pdf

Figure 16 Themes used within City Narrative



3.3.4 ULEV Enabled

The ULEV Enabled (ULEV) Narrative envisages technology neutral intervention by government focussed on providing widespread and standardised infrastructure. This is designed to neutralise consumer anxiety over ULEVs and enable choice in ULEV technologies.

In the Physical Supply Chain, overnight charging is available to a significant proportion of users. DNOs use active network management to mitigate the impact on their network via charging Demand Management, and expand their businesses to own and operate the charging point networks, recovering costs through regulated use of system charges. A skeleton network of hydrogen refuelling stations is available, co-located with liquid fuel forecourts, supplied by road tanker distribution in the short-term and transitioning to a system of transmission pipelines (with ongoing tanker distribution from this) to forecourts as demand for hydrogen grows from both vehicles and in the wider system (e.g. for industry and power).

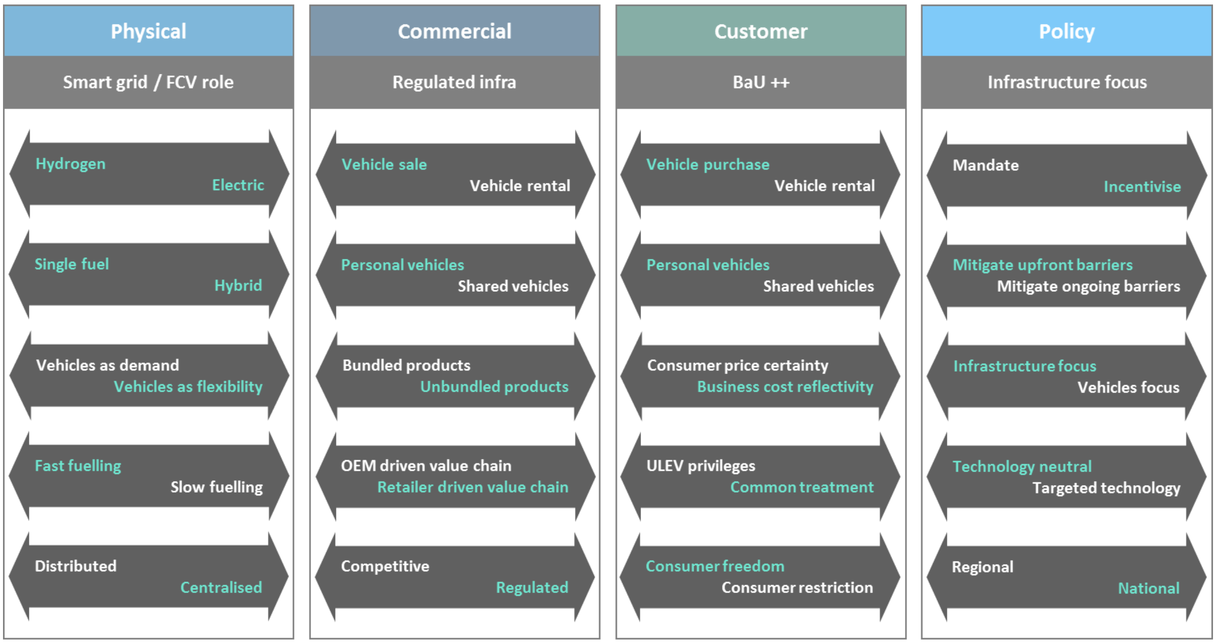
Consumers continue to purchase vehicles for private use, and enjoy wide access to refuelling infrastructure. Government-supported infrastructure reduces consumer anxiety over range, access to fuelling, or being left stranded with non-standard technology. For PiV users, new information services help manage dynamic ToU charging.

Government policy is to leverage private investment in infrastructure through providing regulated returns, allowing supply to anticipate demand to some extent. Coordination between different layers of Government ensures the deployment of standard charging infrastructure in residential areas, providing a high proportion of the population with access to overnight charging. Government aims to create a level playing field for ULEVs by targeting incentives at reducing the cost differential between PiVs and FCVs, stimulating demand for hydrogen and supporting private investment in infrastructure. Incentives such as direct grants, VAT on assets and refund schemes are provided to encourage ULEV purchase and replacement of the conventional vehicle parc in the nearer term, with a transition towards a carbon tax on liquid fuels from the medium-term onwards.

Regarding the Commercial Value Chain, regulated business models support deployment of charging infrastructure and hydrogen networks in the longer term. New aggregator services also emerge to deliver benefits to the network and system operators, such as avoided network reinforcement, from the management of PiV charging.

The themes used to help frame the Narrative are summarised in Figure 17.

Figure 17 Themes used within ULEV Narrative



3.3.5 Hydrogen Push

Hydrogen Push (H2P) is a Narrative where central government decides to actively pursue mass transition to hydrogen based road transport, employing a range of policy measures to achieve this goal.

In the Physical Supply Chain, larger volumes of hydrogen are produced at large scale facilities, making use of off peak electricity from nuclear power stations or Carbon Capture and Storage (CCS) enabled routes based around Steam Methane Reforming (SMR) or coal / biomass gasification. This is piped to an extensive network of forecourts where vehicle users refuel. Dedicated hydrogen infrastructure is created, rather than re-purposing of the gas network.

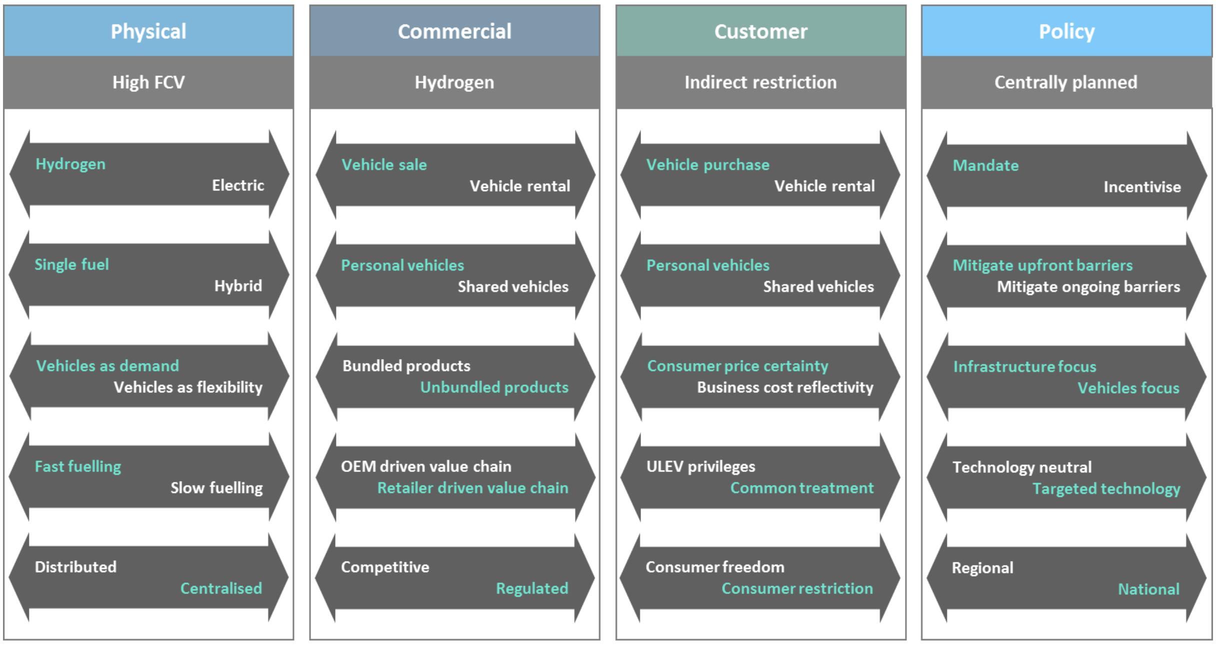
The Customer Proposition is very similar to today's fossil fuel based offering. Consumers buy vehicles for dedicated private use, and refuel them at a network of hydrogen refuelling stations with similar density to today's liquid fuel network. The price paid per unit exhibits some variation over time based on market conditions. Policy seeks to influence purchasing behaviour strongly in the direction of hydrogen vehicles.

Significant policy intervention is required to achieve mass conversion. Government supports the development of a hydrogen delivery infrastructure by providing regulated returns to investors, allowing infrastructure investment to anticipate demand. Government policy also acts to bring down the barriers to purchasing a hydrogen vehicle, through direct grants and VAT. Government also leads by example, through early conversion of its own vehicle fleets to hydrogen.

Regarding the Commercial Value Chain, new businesses centred on production and distribution of hydrogen are created, receiving public support in initial years before hydrogen vehicles predominate.

The themes used to help frame the Narrative are summarised in Figure 18.

Figure 18 Themes used within H2P Narrative



3.3.6 Transport on Demand

In this Transport on Demand (ToD) Narrative, central Government identifies that transition to a smaller, more intensively used low emission vehicle fleet offers significant benefits of reduced congestion, more efficient mobility and improved public health and safety. This therefore becomes a policy priority, and a centrally coordinated programme for rolling out a widespread and standardised charging network is embarked upon. This transition is assisted by changing public preferences. New generations become disenchanted with the costs and administrative burden of car ownership. Vehicles lose their role as a mode of personal expression and the object of aspiration, and the transport service they provide becomes commoditised in the public perception. In the longer-term this service is increasingly provided by autonomous vehicles, as centrally coordinated action allows for the establishment of the necessary standards and regulatory framework.

With regard to the Physical Supply Chain, the centrally planned roll-out of a standardised charging infrastructure opens opportunities for active network management and Demand Management of charging, helping to moderate impact on the electricity distribution network. Standardisation provides the potential for novel and convenient charging solutions to be deployed and for vehicle-to-vehicle communications and ultimately autonomous vehicles.

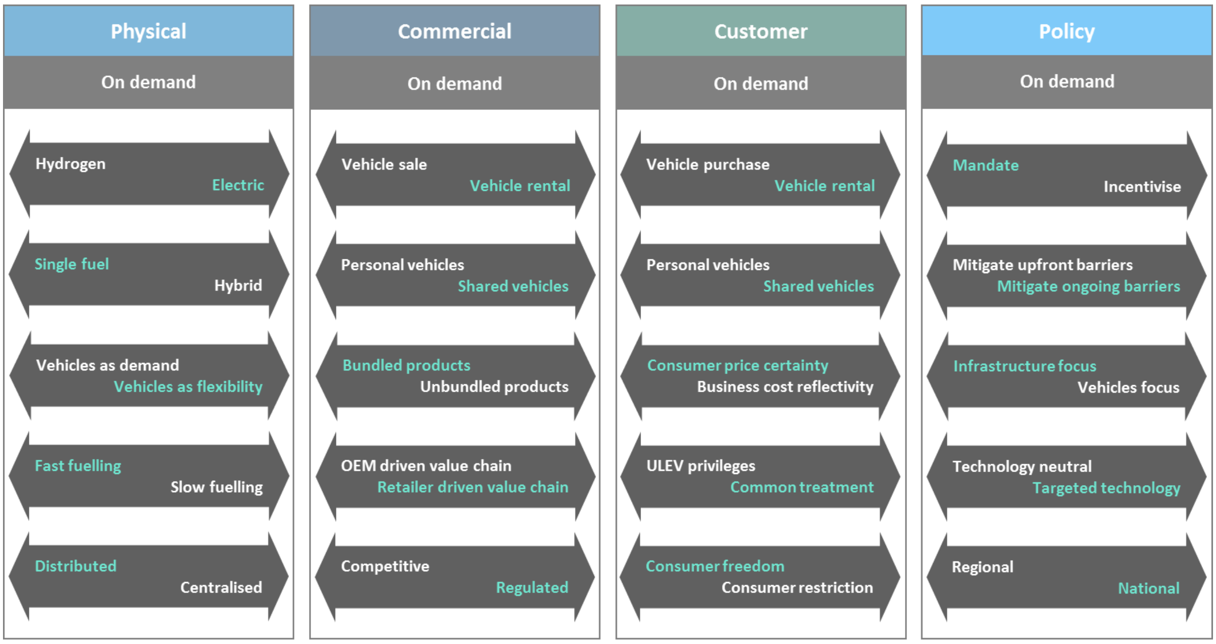
From the consumer perspective, private purchase of vehicles becomes rare, with fleet purchasers expanding to represent the major proportion of new vehicle sales and vehicle sharing schemes widely used. End consumers access vehicles when they need them through subscription packages providing levels of usage tailored to their needs. Charging occurs via an extensive network in public locations and rapid charging points on the trunk road network rather than at homes.

In the Market and Policy Framework Dimension, a supportive regulatory framework underwrites creation of a dense national charging network, and subsidises the cost of electricity that it provides for mobility in the near term. Incentives focus on ongoing some direct subsidy for PiVs and measures such as VED and fuel duty.

Regarding the Commercial Value Chain, regulated provision of charging infrastructure provides a new, low risk business model. Operation of vehicle on demand services represents another substantial new business model. More peripherally, increased intensity of use expands business opportunities in recycling vehicles and batteries.

The themes used to help frame the Narrative are summarised in Figure 19.

Figure 19   Themes used within ToD Narrative



3.4 Summary of key quantitative Building Blocks used

A summary of the key BBs applied to the Narratives that directly impact the quantitative analysis is outlined in Table 9. These are exogenous inputs and broadly align to the key themes of the Narratives as follows:

- **Mobility as an asset / mobility as a service:** the former is associated with addressing upfront barriers to ULEV adoption – consumers own their vehicle at this end of the axis –

and the latter to ongoing barriers to ULEV adoption – consumers do not buy the vehicle and therefore the ongoing costs hold greater importance.

- **Organic change / co-ordinated action:** the former is associated with disincentivisation of conventional vehicles whilst remaining neutral between ULEV technologies, with actions focussed on consumers and at a regional level. The latter is associated with active incentivisation of ULEVs, potentially targeting particular ULEV technologies. Interventions encompass both the supply side and the consumer, and are implemented at a national level to drive towards a chosen outcome.

Each Narrative is placed at one end or the other of the each of the two axes.

Further details on the BBs are provided in:

- The *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report, and*
- Excel workbook of input data assumptions and sources within the *D1.2 Analytical Framework Assumptions Book.*

Note that Table 9 sets out the direct exogenous inputs, or choices affecting these inputs, to the Analytical Framework and how these differ across the Narratives for each BB included. There are a number of additional BBs identified in Table 5 to Table 8 that have not been included in **Table 9** because they are either not considered further in the analysis, are assessed qualitatively only, or are assessed quantitatively but in an indirect manner (as explained in Table 5 to Table 8 where relevant).

Table 9 Overview of key quantitative BBs considered within each Dimension

Customer Proposition						
Building Block	**BaU**	**OEM**	**City**	**ULEV**	**H2P**	**ToD**
Narrative position on axes	**Organic, Mobility as an Asset**		**Organic, Mobility as a Service**	**Coordinated, Mobility as an Asset**		**Coordinated, Mobility as a Service**
Outright purchase vs. contract purchase/ hire	Fleet leasing, consumer purchase	2-4 year lease depending on user group to overcome upfront cost barrier		As per BaU - upfront purchase with Government subsidies overcoming cost barrier		2-4 year lease depending on user group to overcome upfront cost barrier
Short-term hire/car club	N/A		Car sharing (urban areas)	N/A		Extended car sharing[28]
Charging	Flat tariff as per standard domestic supply contract	Static ToU tariff and User-Managed Charging		Supplier-Managed Charging at Home / Work	Flat tariff as per standard domestic supply contract	Supplier-Managed Charging at Home / Work
Demand Management Payment	N/A			DM aggregator – differentiated payments to BEV, PHEV users	N/A	DM aggregator – differentiated payments to BEV, PHEV users
Private charging	Access to overnight charging based on survey data			Car as per BaU Higher level of overnight access for vans	As per BaU	Car as per BaU Higher level of overnight access for vans
Rapid charging	Trend towards long-run density factor with deployment linked to PiVs and higher level of deployment per PiV in the near term					
Public charging	Low density of charging points per PiV	Medium density of charging points per PiV	High density of charging points per PiV (to support car sharing in urban areas)	Medium density of charging points per PiV	Low density of charging points per PiV as focus is on hydrogen	High density of charging points per PiV (to support extended car sharing)
Work charging	Medium density of charging points per PiV		Low density of charging points per PiV	High density of charging points per PiV	Medium density of charging points per PiV	Medium density of charging points per PiV
H_2 refuelling stations	Built in proportion with car, van and Heavy / Medium Goods Vehicles (HGV/ MGV) and bus demand adjusted to ensure sufficient density of stations for consumers at lower volumes					
Vehicle choice	As current		Distribution of vehicles favours smaller cars (for car sharing schemes)	As current		Distribution of vehicles favours smallest cars (for extended car sharing)

[28] Part of the Narrative story is to have plenty of public charging and car sharing, thus public charging in subsidised in line with this.

Physical Supply Chain (PSC)						
Building Block	**BaU**	**OEM**	**City**	**ULEV**	**H2P**	**ToD**
Narrative position on axes	**Organic, Mobility as an Asset**		**Organic, Mobility as a Service**	**Coordinated, Mobility as an Asset**		**Coordinated, Mobility as a Service**
Battery/ Fuel cell cost and other vehicle components	Central case projections for vehicle costs, efficiencies and battery range					
Depreciation	Converges for ULEV and non-ULEV by early 2020s					
Electricity generators	Wholesale prices varying in response to scale and shape of electricity demand (ULEVs and wider energy system), varying due to tariff structure and use of Managed Charging under Customer Proposition					
H_2 generation plants	Centralised production - wholesale prices varying in response to scale demand (ULEVs and wider energy system)		Localised water electrolysis	As BaU		
Electricity distribution network Electricity transmission network	Reinforcement due to ULEVs / wider peak demand growth			Reinforcement due to ULEVs / wider peak demand growth impacted by Demand Management of charging	As BaU	Reinforcement due to ULEVs / wider peak demand growth impacted by Demand Management of charging
H_2 distribution	Centralised distribution to forecourts using tankers		Localised production at forecourts	National Transmission System (NTS) pipeline from centralised production with tankers for distribution	NTS + Local Distribution Network (LDN) pipeline + 'last mile' tankers	As BaU
Liquid fuel distribution	Current network closed subject to ongoing economics of operation (driven primarily by volumes of liquid fuels) to minimum skeleton network					
Public charging	Work, Public and Rapid charging points depend on vehicle density factors. Work, Public (and Home) charging rate increases from 3 kW to 7 kW over time. Rapid charging at 50 kW		Shift to faster (22 kW) public charging over time	As BaU		Shift to faster (22 kW) public charging over time
H_2 refuelling stations	Built in proportion with car, van and HGV/ MGV and bus demand adjusted to ensure sufficient density of stations for consumers at lower volumes					
Liquid forecourts	Current network closed subject to ongoing economics of operation (driven primarily by volumes of liquid fuels) to minimum skeleton network					

Market and Policy Framework (MPF)[29]

Building Block	BaU	OEM	City	ULEV	H2P	ToD
Narrative position on axes	**Organic, Mobility as an Asset**		**Organic, Mobility as a Service**	**Coordinated, Mobility as an Asset**		**Coordinated, Mobility as a Service**
Gov. grants to consumers	**Current:** scheme to 2018 only (up to £5k/£8k depending on vehicle)	**Modest:** ULEVs receive min. of £500 (1k vans) or delta to non-ULEV equivalent from 2021 onwards	**Moderate:** ULEVs receive min. of £1k (2k vans) or delta to non-ULEV equivalent from 2021-2030	**Generous:** ULEVs receive min. of £2k (4k vans) or delta to non-ULEV equivalent from 2021-2030	**FCVs only**, receive min. of £3k (6k vans) or delta to non-ULEV equivalent from 2021 onwards	**PiVs only**, receive min. of £1k (2k vans) or delta to non-ULEV equivalent from 2021 onwards
VAT on assets	Current 20%	5% for ULEVs	5% for ULEVs – Phased out by ~2030		5% for FCVs only	5% for PiVs only
Fuel price subsidies	N/A					~Up to 10 p/kWh for non-home charging until 2030
Vehicle excise duty	Current policy ~zero rate for ULEVs					
Company car tax (Benefit in Kind, BIK)	Current policy ~reduced rates for ULEVs					
Fuel duty	Electricity and hydrogen still exempt, fossil fuel duty increasing in line with GDP/capita growth					As BaU but kept flat from 2035 under assumption that road pricing likely to be introduced with widespread vehicle sharing
VAT on fuel	Current 5% electricity, 20% other fuels			5% VAT on hydrogen	As BaU	
Cheaper mobility	London congestion charge maintained, gCO_2/km exemption threshold declines over time		Extend congestion charge to next 199 cities with >100k pop.	As BaU		
Direct CO_2 tax	No CO_2 price		Full CO_2 price pass through from ~2030 to offset phasing out of ULEV grant / VAT differentiation		Incremental pass through of CO_2 price above ULEV differentiated subsidy / tax, etc. (effectively 0 given above)	
Direct emissions limit	EU new car/van standards to 2021, tightened to 2030 and flat to 2050					

[29] A relatively large number of Building Blocks have been identified in the Market and Policy Framework. In many instances there are multiple suitable Building Blocks that could achieve similar effects. Furthermore, when implemented in the *D1.2 Analytical Framework*, many Building Blocks will effectively be indistinguishable from each other, as they will be represented as either an increase or decrease in the cost of owning, operating or using a vehicle. For these reasons the mapping of specific Market and Policy Framework Building Blocks to the Narratives has focused on a few core Building Blocks.

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Commercial Value Chain (CVC)						
Building Block	**BaU**	**OEM**	**City**	**ULEV**	**H2P**	**ToD**
Narrative position on axes	**Organic, Mobility as an Asset**		**Organic, Mobility as a Service**	**Coordinated, Mobility as an Asset**		**Coordinated, Mobility as a Service**
Vehicle retailer	Margin included in vehicle cost					
Vehicle leaser	Fleet leasing, Consumer outright purchase	2-4 year leasing depend on user group, margins and operating cost included in retail price		As per BaU		2-4 year leasing depend on user group, margins and operating cost included in retail price
Vehicle sharing scheme	N/A		Margins and operating costs included in retail price (and addition to underlying leasing of vehicle)	N/A		Margins and operating costs included in retail price (and addition to underlying leasing of vehicle)
Electricity supplier	Margin and overheads included in retail electricity price					
Electricity DNO	Return on capital and overheads included in retail electricity price					
Charging Point Operator	Return on capital and operating cost included in retail electricity price			As per BaU, but Public, Work and Rapid WACC lower (regulated model)	As BaU	As per BaU, but Public, Work and Rapid WACC lower (regulated model)
DM aggregator	N/A			DM aggregator business model, payments to PiV users and income from services to DNO, Transmission Network Operator (TNO), Transmission System Operator (TSO)	N/A	DM aggregator business model, payments to PiV users and income from services to DNO, TNO, TSO
Liquid fuel forecourt retailer	Operating cost to maintain forecourts with some economic closures down to skeleton network, overheads included in retail price					
Hydrogen retailer (forecourt)	Built in proportion with car, van and HGV/ MGV and bus demand with adjustment for densities at low volumes, return on capital and operating cost included in retail price					
Localised hydrogen producer	N/A		Localised production at forecourts, return and operating cost in retail price	N/A		
Hydrogen network operator (pipe)	N/A			NTS pipe network, return on capital and operating cost included in retail price (no re-purposing of the gas network)	NTS + LDN pipes, return on capital and operating cost in retail price (no re-purposing gas network)	N/A
Hydrogen road distributor	All ULEV H_2 delivered by tankers, return on capital and operating costs included in retail price			Tankers from NTS to forecourt, return on capital and operating costs included in retail price	Tankers from LDN 'last mile' to forecourt, return on capital and operating costs in retail price	All ULEV H_2 delivered by tankers, return on capital and operating costs included in retail price

3.5 Sensitivities

As stated in the previous sections each Narrative is constructed around active choices or strategies that can be delivered by the various actors involved (such as UK Government, industry, or indirectly by consumers). Exogenous conditions that are outside of the control of these actors such as fossil fuel prices are explored by Sensitivity rather than drive differences in the Narratives themselves.

The Sensitivities help to assess how 'resilient' a given '*ULEV strategy'* might be to changing external conditions (away from a 'central view'). The Sensitivities outlined in Table 10 have been analysed in Stage 1 of the analysis. These are aimed at driving higher and lower uptake and use of ULEVs relative to the core assumptions. Further Sensitivities are likely be explored in Stage 2, but their structure may be dependent on the outcome of the Stage 2 trial, which will provide improved input data in a number of areas.

Table 10 Description of modelled Sensitivities

Sensitivity	Description and Rationale	Key Narratives
Exogenous drivers for higher uptake and use of ULEVs	This covers the combination of: – A higher requirement for decarbonisation in transport: to understand the extent to which high PiV / hydrogen use looks 'better' in a world where transport needs to decarbonise more to meet the overarching CO_2 target. This is proxied by a failure of Carbon Capture and Storage in the analysis and higher CO_2 price signal, but could also be driven by e.g. limited progress in decarbonising other sectors such as heat – Higher liquid fuel prices indirectly making ULEVs more competitive	BaU OEM ULEV
Exogenous drivers for lower uptake and use of ULEVs	This covers the combination of: – The extent to which Narratives with high ULEV deployment and use look 'worse' when coupled with slower reduction in associated ULEV vehicle prices. – Lower liquid fuel prices indirectly making ULEVs less competitive	BaU OEM ULEV
Further downside (low uptake) case	As per the low case, but in addition using the further downside long-term assumptions for ICEV costs, which are assumed to be significantly lower in the second half of the pathway compared to the core Narratives. This is assumed to be a result of manufacturers not continuing to improve the efficiency of ICEVs over the long-term due to gradually diminishing returns	BaU OEM ULEV

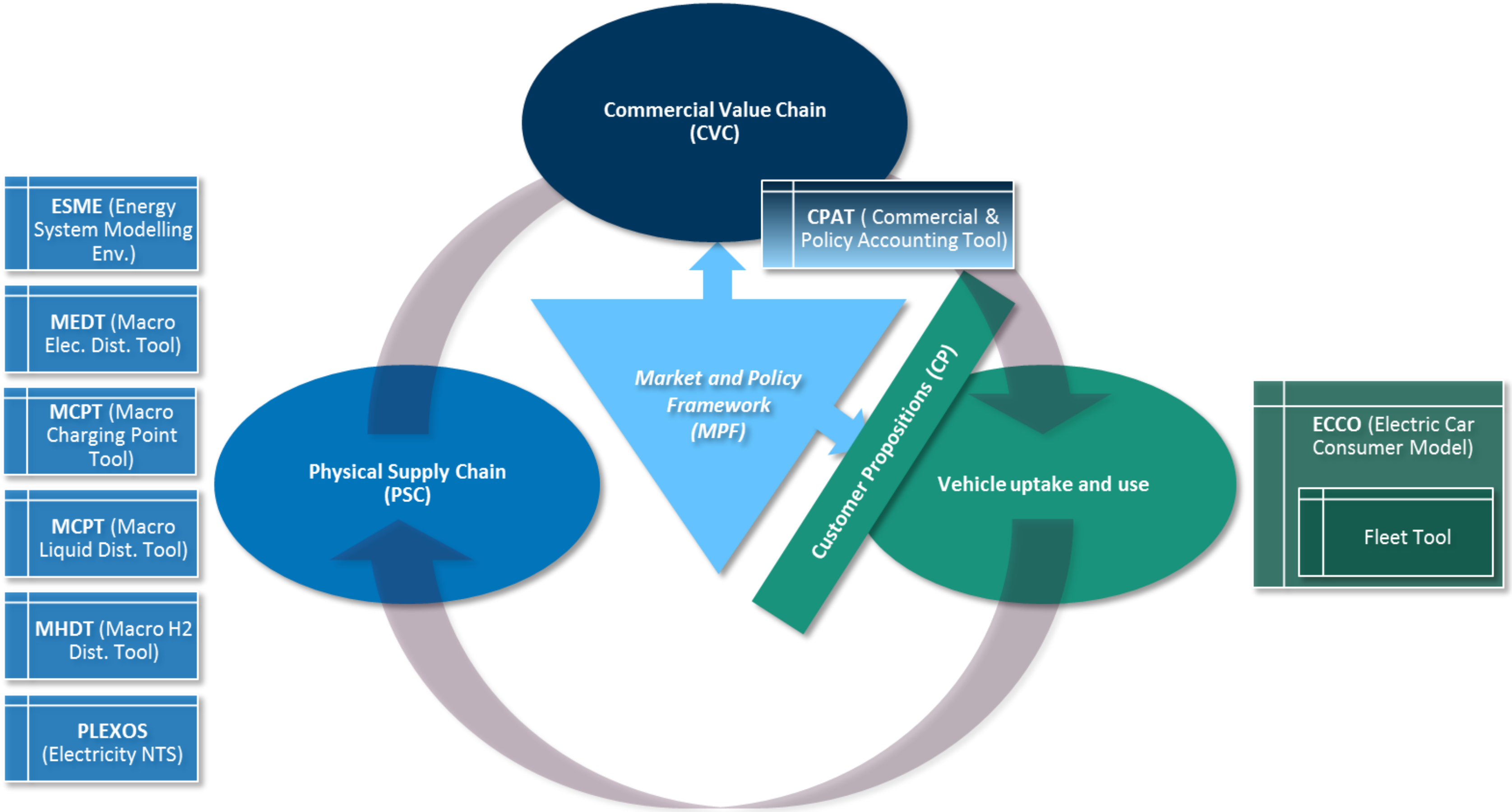
4 Overview of Analytical Tools

4.1 Overview

The purpose of the *D1.2 Analytical Framework* is to quantify, where possible, the Success Metrics for each Narrative. This is supported by a set of qualitative metrics where quantification is not feasible. To support the quantification a suite of Analytical Tools has been combined in an integrated, holistic assessment framework (see Figure 20).

The different Narratives are quantified at the UK-level – i.e. to reflect the uptake and use of ULEVs within the overall national vehicle parc, along with the infrastructure requirements and corresponding financial and physical flows. The breadth of the factors to be quantified, the need to look over a pathway from now to 2050, and the complexity involved in hard-linking a diverse set of tools mean that the resolution of analysis needs to be targeted appropriately to ensure effort is focused on the most material factors.

Figure 20   Overview of Analytical Tools by Dimension



The Analytical Tools comprise a mix of pre-existing ETI tools (which have been adapted to varying degrees as required to enhance or integrate them as part of this framework) and new tools developed for this project. The Analytical Tools align with the overarching Dimensions and broadly divide into three groups:

- Tools used to assess the use of technologies and scale of underlying investment on the **Physical Supply Chain**. This is bounded by the use of the ETI's whole energy system model **ESME (or Energy System Modelling Environment)**, which gives a consistent picture of how the UK can meet its Greenhouse Gas (GHG) targets in a feasible manner, for both transport and the wider energy system. As part of this it provides internally consistent estimates of, for example, wholesale electricity and hydrogen costs which are used elsewhere by the other tools.
  - By considering the whole system, ESME is naturally less detailed on a sector by sector basis and it is supplemented by tools to understand the costs of infrastructure investment for electricity (via the **Macro Electricity Distribution Tool - MEDT**), hydrogen distribution (via the **Macro Hydrogen Distribution Tool - MHDT**), liquid fuels (via the **Macro Liquid Distribution Tool - MLDT**) and charging infrastructure (via the **Macro Charging Point Tool - MCPT**).
  - In a similar manner, **PLEXOS**[30] is used as a means to explore the operational feasibility of the electricity system in more detail. PLEXOS is not used within the core suite of Analytical Tools for every Narrative or Sensitivity, but to support the understanding of the feasibility of system dispatch in the BaU Narrative and those where there is high PiV uptake and or less direct control over charging – i.e. where the electricity system is more likely to be stressed.
- A tool to understand the response of consumers and fleets to different **Customer Propositions** (price and other behavioural aspects such as perception of access to charging) on the uptake and utilisation of ULEVs.
  - This is based on the **ECCo** (Electric Car Consumer Model)[31] developed originally as part of the ETI's 2011 Plug-In Vehicles project, but with a number of significant improvements, for example to the way that fleets are represented by incorporation therein of a new Fleet Tool.
- A new **Commercial, Policy and Accounting Tool (CPAT)** - to represent the flows across the **Commercial Value Chain** (CVC) as this acts as *two-way* interface between the demands placed on the Physical Supply Chain by the uptake and use of ULEVs and the prices seen by the end ULEV-consumers as part of the Customer Proposition.
  - The CPAT calculates the cash flows for (and between) each of the business entities who exist on the CVC (e.g. to recover the investment in developing and operating infrastructure and energy supply, and to provide various ULEV-related goods and services). From this it constructs an estimate of the *retail prices* that need to be charged to attempt to make these entities commercially viable - in line with the

[30] http://energyexemplar.com/software/plexos-desktop-edition/
[31] Which models a range of power trains beyond electric vehicles, including hydrogen.

quantitative Success Metrics - and thus the prices seen by the consumer at the end of the CVC[32].

- The **Market and Policy Framework** is also included within CPAT, both to track various transport-related Government revenue streams (taxes, subsidies, wider investments), but also because the impact of Government policy acts either directly on commercial entities or at the intersection point between the CVC and the final price the consumer sees (e.g. in the form of VAT).

Further summary information is provided in the following sections, with more detailed information on the key Analytical Tools contained in the Appendices. It should be noted that the framework has been designed both to help inform some of the high level parameters of the trial design in Stage 1, and also to be able to accommodate new input data gathered from the trial itself to help refine the analysis as part of Stage 2.

4.2 Key inputs and interactions between the Analytical Tools

The Analytical Tools are used in an integrated manner to assess each Narrative, which requires consideration of a number of key issues, described below.

- **Exogenous assumptions** that are a direct input to the framework (i.e. are not calculated endogenously as part of each tool) e.g. the cost of vehicles or fossil fuel prices - inputs that are exogenously specified are the BBs set out in section 3.4 under **Table 9**.
- **Data flows between Analytical Tools** due to endogenously calculated parameters e.g. one of the key functions of CPAT is to help translate the underlying wholesale prices and associated costs of infrastructure investment into retail prices seen by the consumer.
- **Iteration** between the tools to understand the broad supply / demand equilibrium position for the scale of the market for ULEVs (i.e. the uptake) and the price of the Customer Propositions as there will be an interaction between the two. For example, increasing uptake and use of PiVs will drive increasing network reinforcement leading to higher electricity prices which may in turn reduce demand for EVs, all else being equal.
  - To enable this the tools are run in a sequential loop for each Narrative until a convergence criterion is met (the number of remaining conventional vehicles in the parc in 2050) which reflects the overarching equilibrium position.
- **Data consistency issues** between the tools, e.g. ECCo is being used as the primary, more realistic determinant of real ULEV uptake, whereas by default ESME also endogenously calculates the uptake of ULEVs as part of its whole system solution (albeit with a simpler representation and very different conceptual framework[33]). Hence the impacts of the vehicle parc chosen by ECCo (such as the scale and shape of the associated energy demands to run the vehicles) must be passed to ESME so that it considers these when it is

[32] For example, how wholesale electricity prices are converted into retail electricity prices considering distribution network charges, retail supplier costs, the costs of any charging infrastructure, taxes, etc.

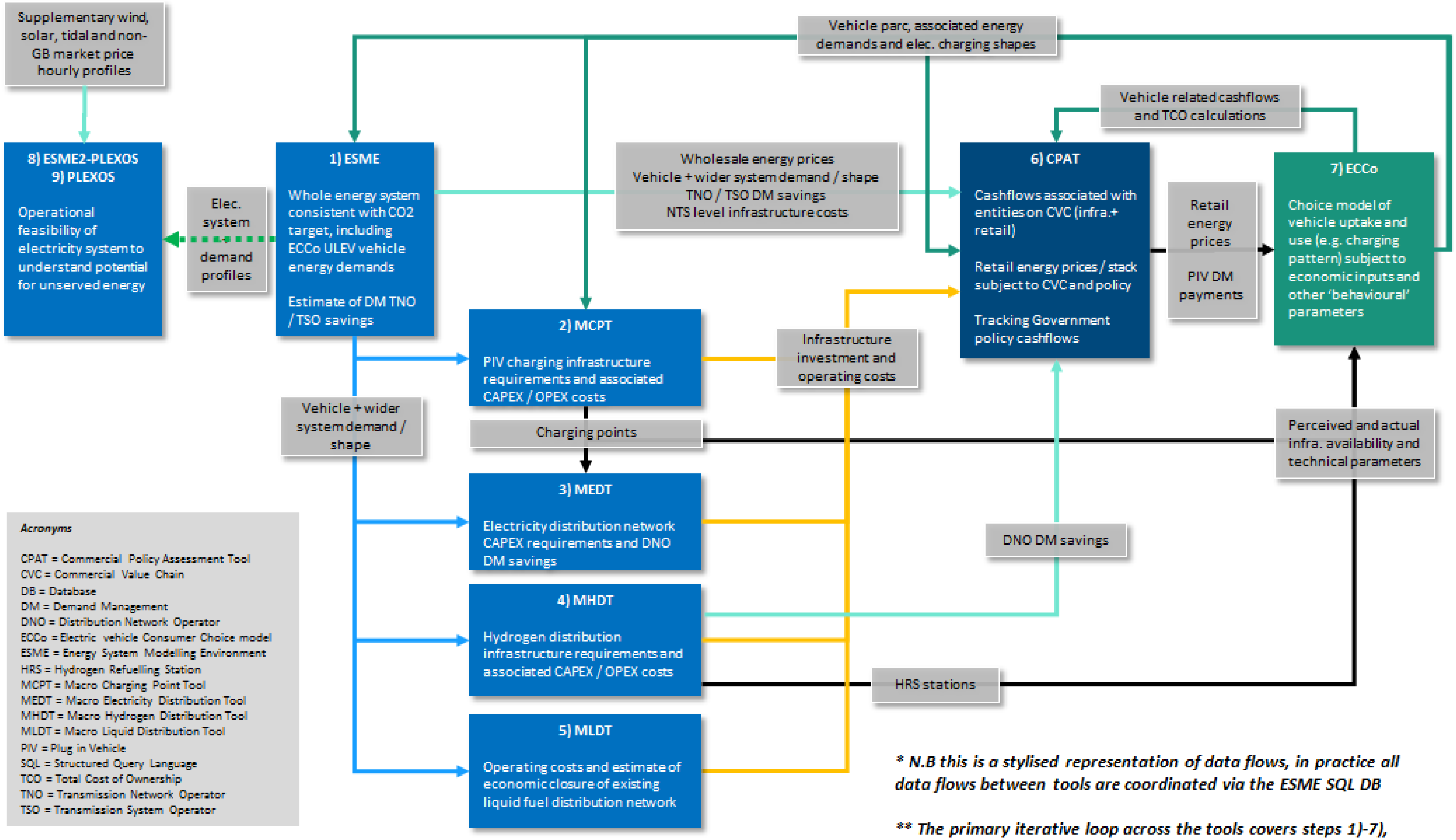
[33] Perfect foresight, least cost optimisation from the perspective of society as a whole *versus* individual agent-based choice modelling founded on a myopic assessment of costs of ownership (and other factors).

calculating how to provide an overall energy system solution consistent with the UK's targets.

A schematic of the interactions between the Analytical Tools is provided in Figure 21.

The Analytical Tools are accompanied by the *D1.2 Results Dashboards,* which show key results charts and data for each Narrative.

Figure 21 Schematic overview of interactions between the *D1.2 Analytical Tools*



Acronyms

CPAT = Commercial Policy Assessment Tool
CVC = Commercial Value Chain
DB = Database
DM = Demand Management
DNO = Distribution Network Operator
ECCo = Electric vehicle Consumer Choice model
ESME = Energy System Modelling Environment
HRS = Hydrogen Refuelling Station
MCPT = Macro Charging Point Tool
MEDT = Macro Electricity Distribution Tool
MHDT = Macro Hydrogen Distribution Tool
MLDT = Macro Liquid Distribution Tool
PIV = Plug in Vehicle
SQL = Structured Query Language
TCO = Total Cost of Ownership
TNO = Transmission Network Operator
TSO = Transmission System Operator

** N.B this is a stylised representation of data flows, in practice all data flows between tools are coordinated via the ESME SQL DB*

*** The primary iterative loop across the tools covers steps 1)-7), steps 8)-9) performed on an 'equilibrium' solution*

4.3 Overview of key data sources

The suite of Analytical Tools requires a significant quantity of input data. The inputs, their primary sources and any transformations or supplementary assumptions are described in detail in the supporting *D1.2 Analytical Framework Assumptions Book.*

Some of the key input data includes:

- *Vehicle costs and consumer behavioural assumptions* in ECCo, which were updated as part of a major study for the Department for Transport (DfT) in 2015[34]. In addition:
  - Battery and management system costs and performance have been updated as part of a separate work package in Stage 1 of this project, and
  - The representation of fleet vehicles was significantly enhanced based on detailed analysis of RouteMonkey's[35] fleet database.
- *Wider energy system data (i.e. non car / van related)* in ESME, covering power, other transport, industry, buildings, resources, etc. These are based on the ETI's most recent ESME v4_0 dataset.
- Future vehicle service demands for vehicle km, consistent at a high level with the ESME v4_0 dataset.
- *Baseline charging profiles for* Private Consumers and fleets, these have been based on published data from a number of PiV trials (the Department for Energy and Climate Change's Plugged in Places data, SSE's My Electric Avenue, Northern Power Grid's Customer Led Network Revolution), the Department for Transport (DfT) National Travel Survey data and insights from RouteMonkey's fleet vehicle database.
- *Costs and technical parameters of charging infrastructure and electricity distribution network reinforcement,* from a mix of ETI background intellectual property (for distribution networks) and published reports for the Committee on Climate Change, European Climate Foundation etc. for charging points.
- *Costs and technical parameters of hydrogen distribution networks,* from a mix of ETI background intellectual property for pipe networks, and published reports from the European Climate Foundation, H_2 Mobility, Low Carbon Vehicle Partnership and US Department of Energy etc., for other distribution related technology (e.g. tankers, compressors, localised producers).

The design of the Stage 2 trial is also intended to provide a range of new quantitative data (primarily in relation to whether consumers decide to purchase a ULEV and their charging patterns) to refine the input data and update the analysis. This is described in more detail in section 8.

[34] Research conducted by Element Energy for the DfT in 2015, contract PPRO 04/91/66: ECCo updates – Environment and international transport analysis
[35] One of the consortium partners for this project.

5 Overview of Narrative results

5.1 Summary results

The different Narratives are framed by a number of key input assumptions, which together result in substantially different levels of ULEV uptake and use across the Narratives. The relative total cost of ownership of ULEVs versus ICEVs is a key determinant of the type of vehicle chosen when the purchase decision is made; this depends on fixed costs, such as the vehicle and battery costs which do not change between Narratives, and variable costs, such as the retail electricity and fuel prices that are Narrative-specific. These descriptive results are used in this section to give an initial and overarching view of each Narrative and further detail is provided on specific themes in section 6.

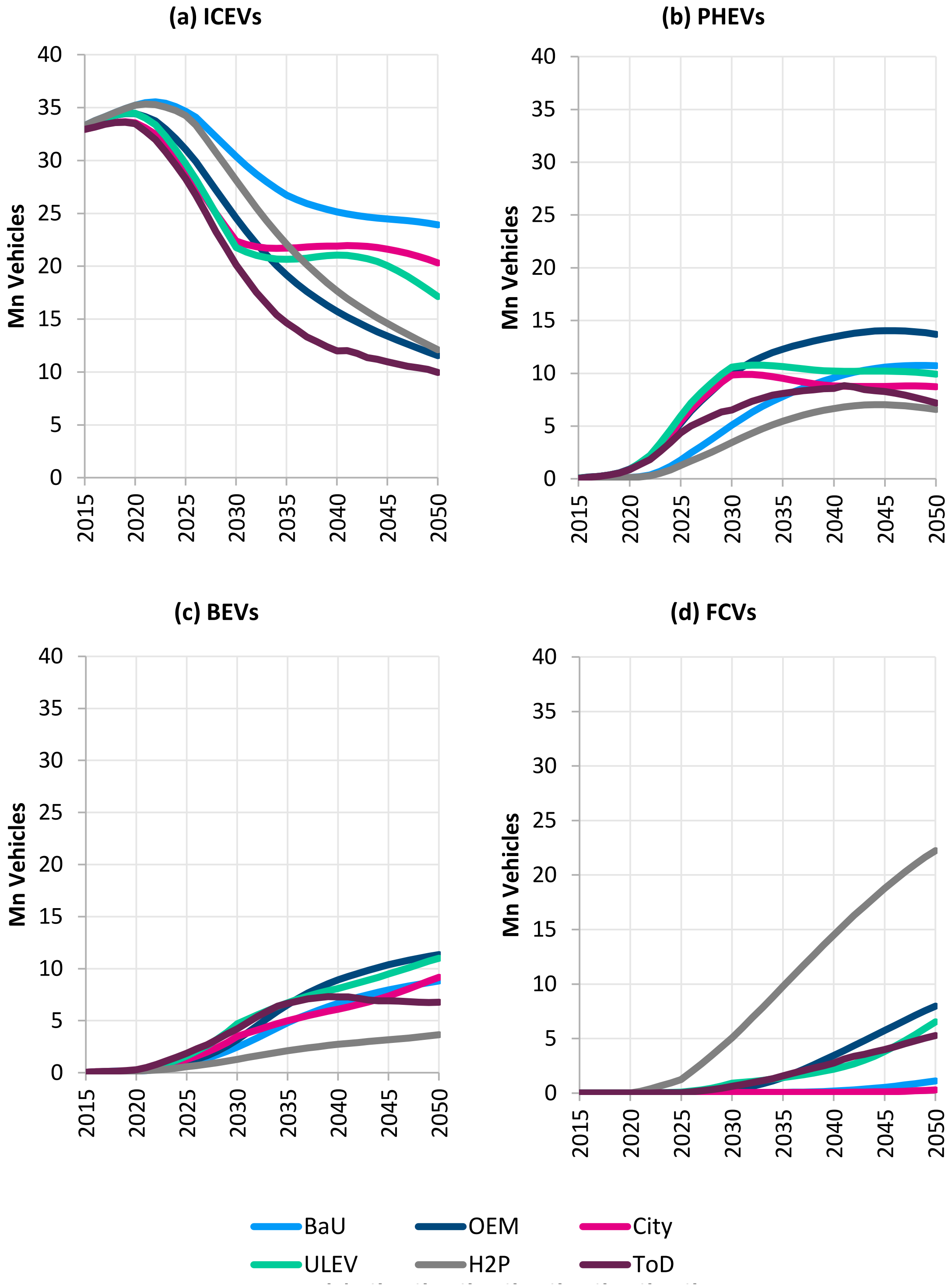
The ULEV uptake pathways are also described in the separate *D1.3 Market Design and System Integration Report Summary* document.

5.1.1 Vehicle parc, service demand and sales

The Narratives lead to different proportions of low carbon vkm by 2050, the range and cost of which is explored through the quantitative Success Metrics – the actual km travelled by each vehicle type are shown in Figure 23[36]. The vehicle uptake pathways to this point vary substantially, as shown by the vehicle parc in Figure 22 (i.e. the number of vehicles in the parc at any one time) and by the corresponding new vehicles sold and leased in each year, shown cumulatively in Figure 24 A key input that drives the absolute uptake level, in addition to the total km travelled, is the extent of car sharing, which is shown in Figure 25 as a proportion of the vehicle parc An explanation of how car sharing affects vehicle sales is given in section 6.4.

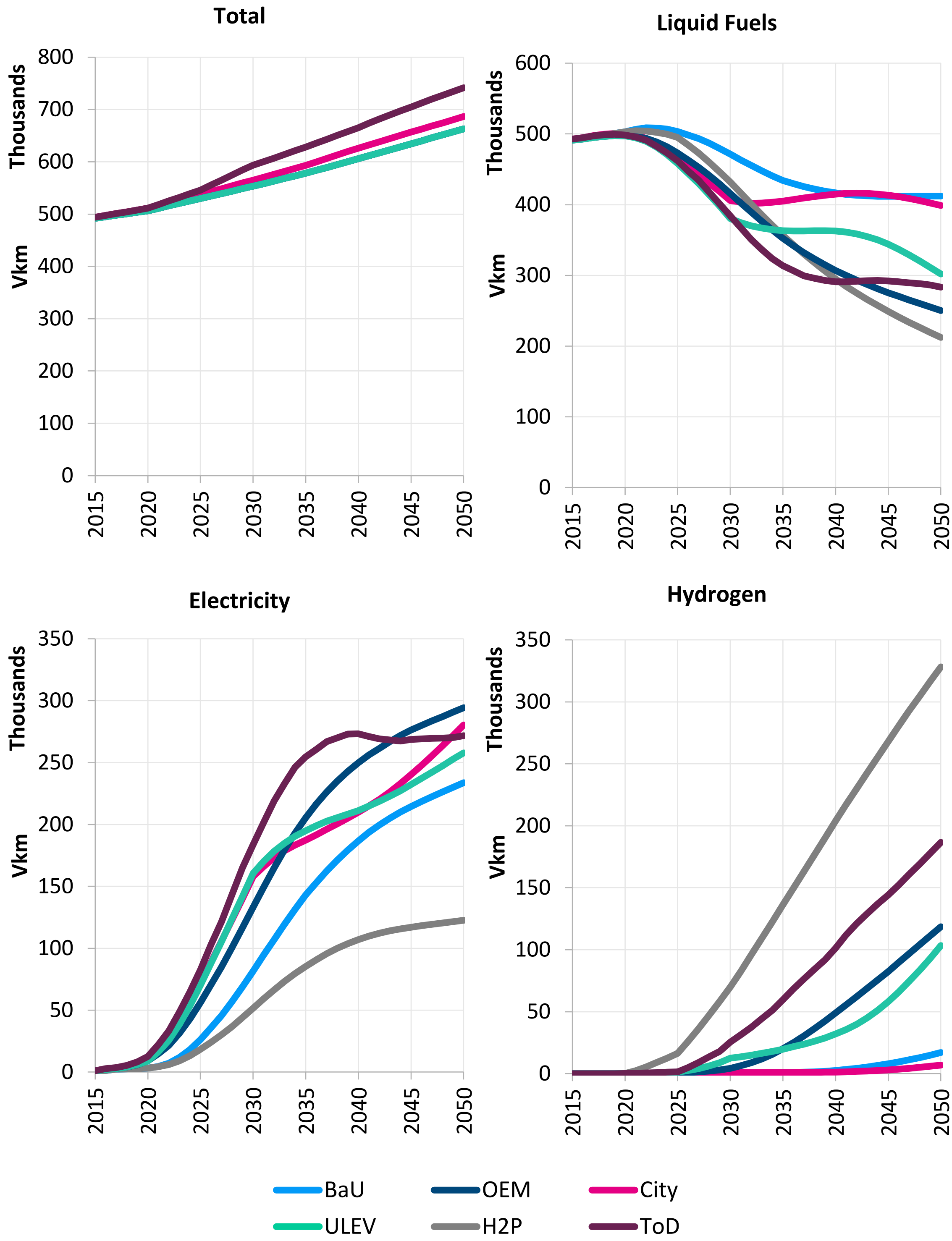
[36] The total km travelled each year is higher for car sharing Narratives

Figure 22 Vehicle parc in different Narratives for (a) ICEs, (b) PHEVs, (c) BEVs and (d) FCVs[37]



[37] Note that the PHEV category includes both mechanical and electrical drivetrains.

Figure 23 Total vehicle km travelled and split by fuel type across the Narratives



Note: In the 'total' figure, all Narratives except the car sharing Narratives (City and ToD) follow the same path.

Figure 24 Total cumulative new vehicles sold and leased across the Narratives for (a) ICEs, (b) PHEVs, (c) BEVs, (d) FCVs and (e) in total

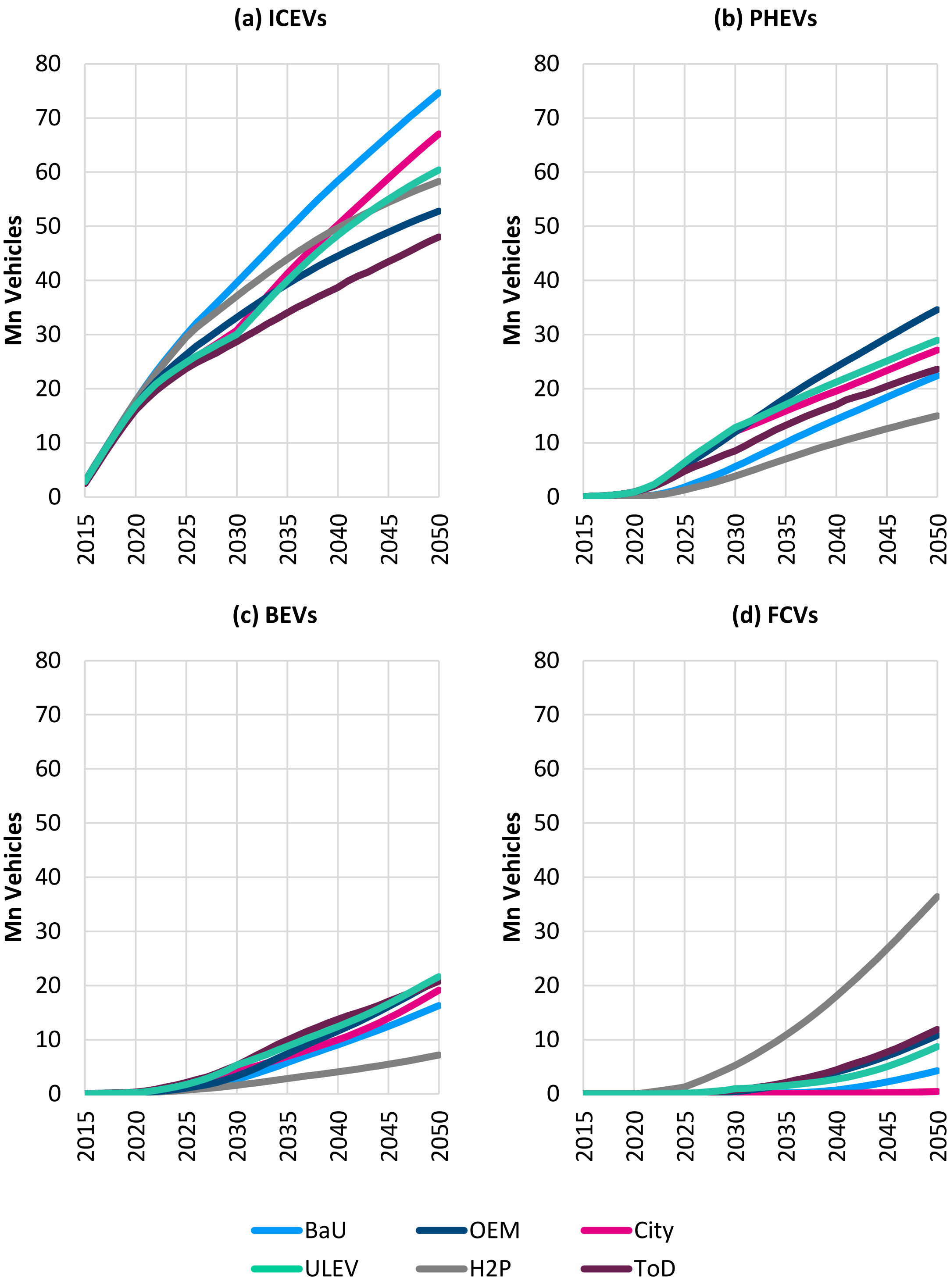


Figure 24 Total cumulative new vehicles sold and leased across the Narratives for (a) ICEs, (b) PHEVs, (c) BEVs, (d) FCVs and (e) in total

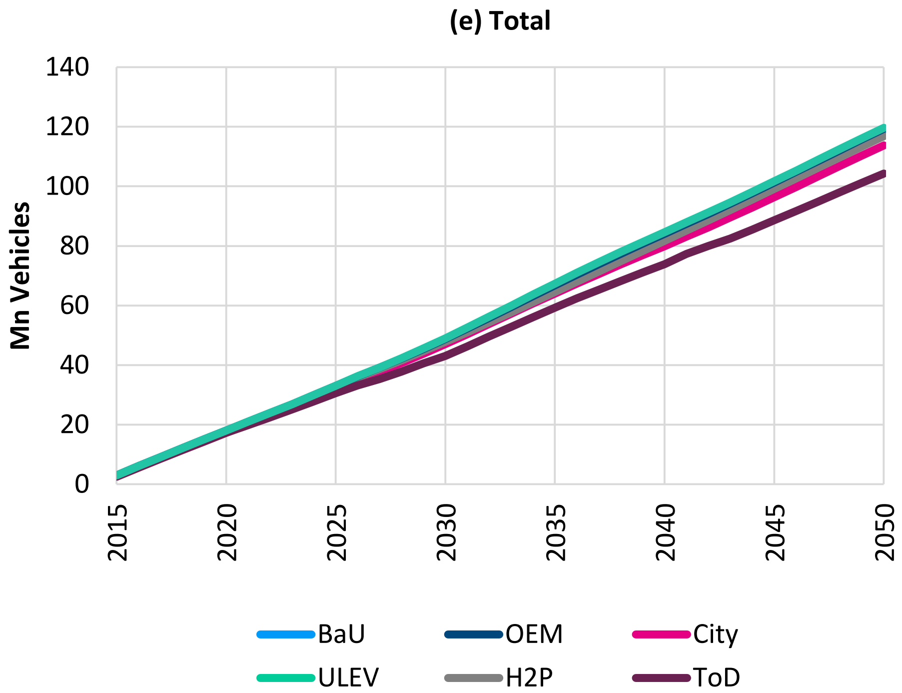
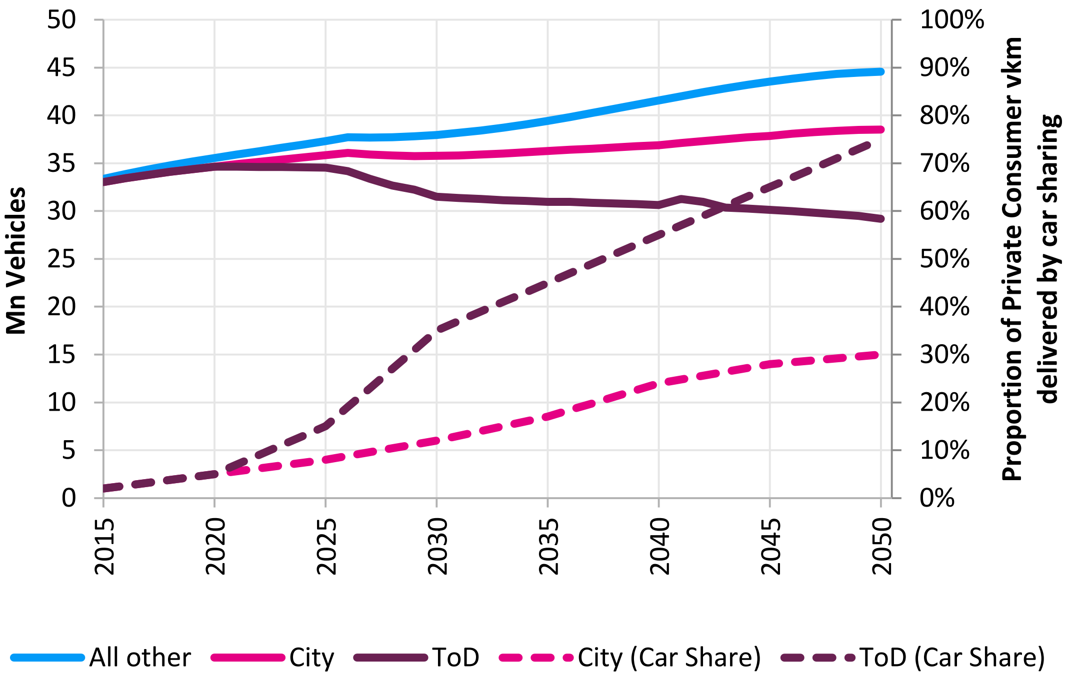


Figure 25 Total vehicle parc (solid lines, left) and proportion of car sharing (dotted lines, right)[38]



[38] Note that in BaU there is no car sharing assumed.

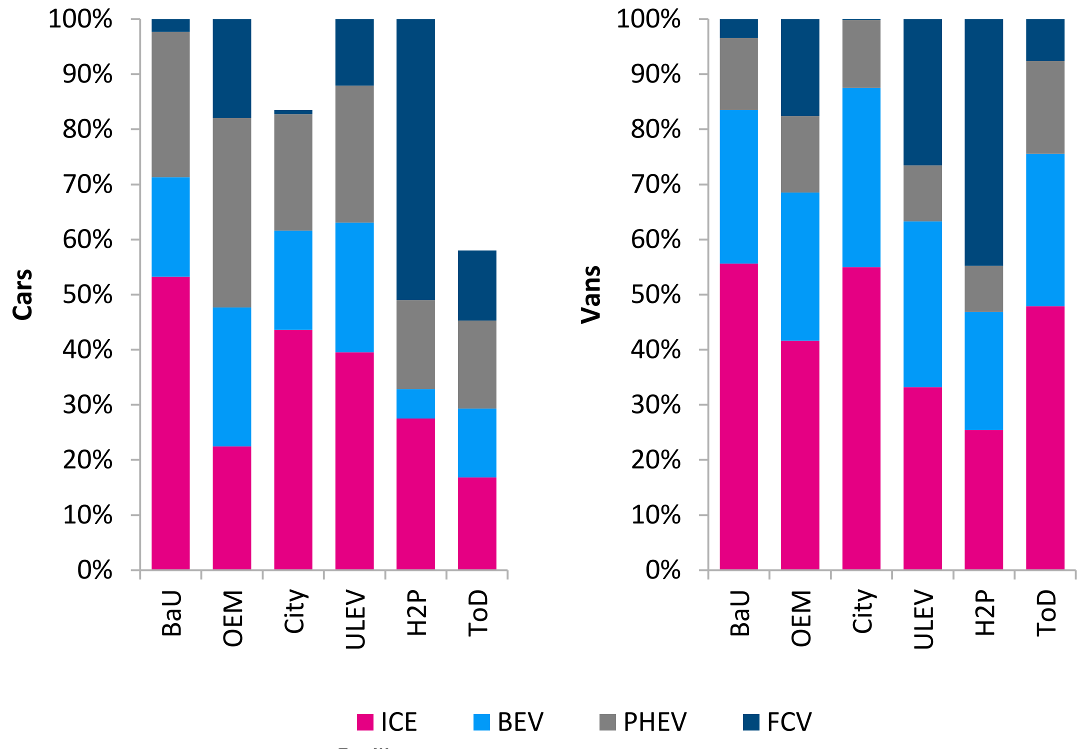
Highlights of the vehicle uptake across the different Narratives include:

- **A decrease in the absolute size of the vehicle parc in later years in the ToD Narrative** due to extensive use of car sharing. In City, where car sharing is focused in urban areas, the size of the parc increases by less than 20% in absolute terms compared to 2015, whereas in all other non-car sharing Narratives it increases by almost one-third by 2050. Note that this does not account for any potential modal shift – i.e. from walking, cycling and buses to car sharing, which could mean the vehicle parc does not fall in practice.
- **In the near and medium-term the uptake of BEVs and PHEVs is much greater than FCVs.** For instance, there is a gradual increase in BEVs and PHEVs such that by 2030 they represent between 12-40% of the parc across the Narratives, compared with FCVs which account for up 2% of the parc across the Narratives (except H2P at 13%).
- **However, towards the end of the pathway all Narratives show non-trivial penetration of FCVs (even outside of H2P).** By 2050, FCVs represent 14-18% of the vehicle parc across three of the Narratives, with around 50% in H2P. In BaU, around 3% of the parc is FCVs by 2050. City Led has a lower percentage of FCVs, in keeping with the Narrative of extensive car sharing of PiVs in cities.
- **Van fleets are restricted by their 'duty cycles'** (i.e. they must be able to drive the required distance to complete their jobs each day without needing to stop and charge throughout the day) and **this tends to reduce the potential role of PHEVs, compared to the role of PHEVs for Private Consumer cars** – BEVs can be used to cover for short duty cycles and ICEVs or FCVs can be used for longer duty cycles. As there is no opportunity to charge a PHEV during the duty cycle the proportion of miles driven on electricity is therefore small, raising their running costs. The proportion of PHEVs in the van parc by 2050 is 8-17% across the Narratives, compared with 16-34% the car parc, as shown in Figure 26.
- **In the last few years of the pathway there is a gradual decline in the absolute size of the PHEV** parc whereas BEVs and FCVs continue to increase. This is because the economics of PHEVs seem less favourable by this time – the battery capacity and range of BEVs is sufficient for the vast majority of journeys and, when insufficient, FCVs can be used (especially as the effective retail price of hydrogen is by then similar to that of electricity, accounting for the different energy densities and vehicle efficiencies).
- **There is a decrease in conventional vehicles even under BaU conditions** (in which they fall from 99.8% of the parc in 2015 to 54% in 2050) driven by a reduction in ULEV costs and improvement in battery range. However, ICEVs still reflect a substantial proportion of the parc by 2050, around a quarter to half for cars and between one-third and half in the case of vans (the latter is due to the higher differential in ULEV and ICEV van costs).
- **A marked change in the rate of deployment around 2030 in City and ULEV, reflecting the removal of subsidy and VAT differentiation and the replacement of this with a carbon tax on liquid fuels**, which at this point in the pathway is insufficiently strong to maintain the momentum in ULEV uptake. Note that this, coupled with the continuing subsidy in OEM, leads to a higher uptake of ULEVs by 2050 in OEM than in the ULEV Narrative. The policy measures are not fully optimised, rather different policy measures have been

implemented with the aim to understand the impact of these and thus maintaining a distinctiveness in the policy decisions put in place in different Narratives is important.

As shown previously in Figure 12, the 2050 proportions of ULEVs in the car parc in the published ESME Patchwork scenario is relatively balanced with around 20% PHEVs, 10% BEVs and 35% FCVs. By comparison the ESME Clockwork Scenario is dominated by PHEVs (over 40% with around 5% FCVs).

Figure 26 Proportion of cars and vans by vehicle type in 2050 as a percentage of the BaU parc



Note: The total number of cars in City and ToD is less than in the other Narratives due to car sharing, thus the total number of cars as a proportion of the BaU parc is less than 100%.

5.1.2 CO_2 emissions from transport

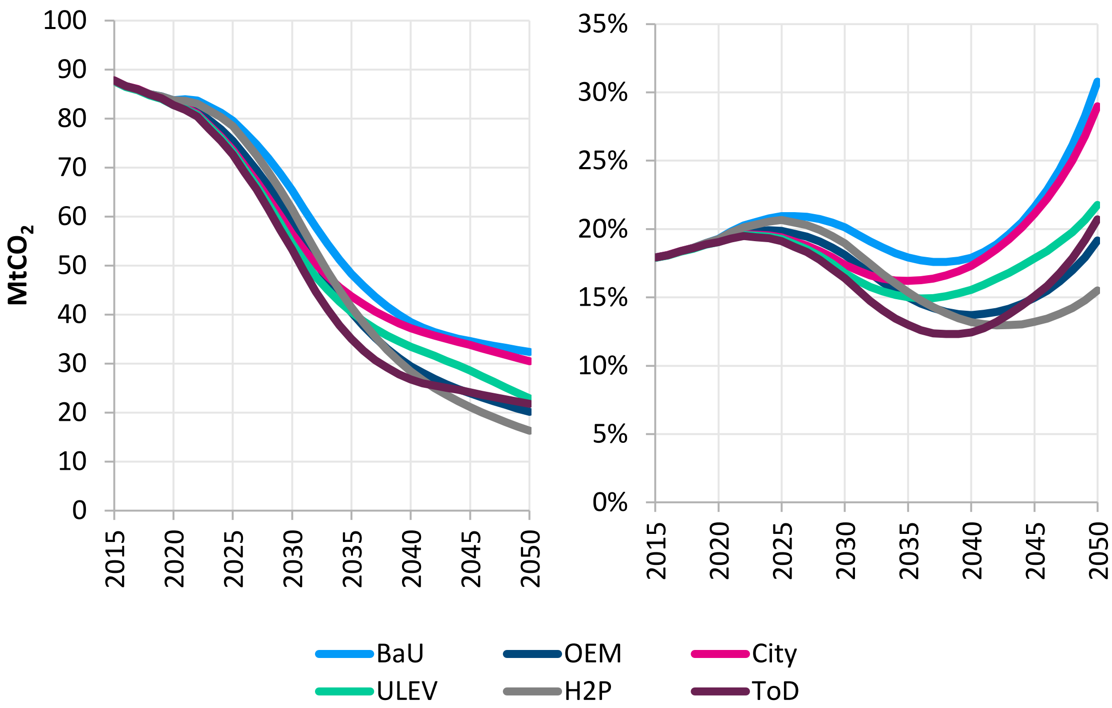
In 2005, the power sector had the highest annual GHG emissions at around 175 $MtCO_2e$/year, the industrial sector followed at around 160 $MtCO_2e$/year and then transport at around 130 $MtCO_2e$/year. However, due to quicker progress in decarbonising the power sector and the industrial sector, *the transport sector now has the highest annual GHG emissions of all sectors in the UK, at around 130 $MtCO_2e$/year,* representing 24% of the total domestic UK greenhouse gas emissions of 497 MtCO2e in 2015[39]. Note that CO_2 emissions generally account for around 80% of the total GHG emissions[40].

[39] https://www.theccc.org.uk/wp-content/uploads/2016/06/2016-CCC-Progress-Report.pdf
[40] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2014

By 2050, the limit on CO_2 emissions only for the entire wider energy system in the UK is 105 $MtCO_2$/year[41] - the share from transport demand is expected to increase over time as other sectors such as power and buildings are considered more cost-effective to decarbonise before transport.

The quantitative Success Metric for the Customer Proposition shows that by 2050, the proportion of low carbon vkm clusters close to 40% or 70%, as shown in Table 12. This translates into total carbon emissions from car and van transport of *between 16 and 32 $MtCO_2$/year,* compared to almost 90 $MtCO_2$/year in 2015. Note that this figure is the proportion of low carbon kilometres across all vehicle kilometres driven by light vehicles.

Figure 27 Total CO_2 emissions in the transport sector and % share of total limit from cars and vans



The *D1.2 Analytical Framework* does not include a full geographic representation and consequently the low carbon vkm in the Narratives corresponds to all trips and does not distinguish between those using low speed urban roads and those on high speed motorways and dual carriageways (accounting for 32% of all UK mileage[42]). This is particularly important for PHEVs, which tend to travel a lower proportion of miles in electric mode when on motorways and dual carriages than when on low speed urban roads. Currently the average proportion of mileage that PHEVs drive under electric power is estimated to be 62%, based on overall trip statistics from the National Travel Survey, however, this falls to just 16% when motorway journeys are considered alone (see Appendix B.6). Whilst this has no impact at the overall system level, it is important to recognise that the proportion of low carbon vkm will differ across road types. For example, under ULEV, 54% of total vkm travelled are expected to be low carbon in 2050, however, this falls to around 45% when just considering journeys on motorways and dual carriageways only. Table 11 presents the share of low carbon vkm on different road types for each Narrative.

[41] Representing over an 80% reduction in carbon emissions from 1990 levels.
[42] DfT Road Traffic Forecasts 2015.

Table 11 % of low-carbon vkm in 2050 for different road types under each Narrative

Narrative	PHEVs only			All vehicles		
	Overall	M-way & dual carriageway	Urban & low-speed rural	Overall	M-way & dual carriageway	Urban & low-speed rural
BaU	64%	20%	79%	38%	28%	41%
OEM	64%	20%	79%	62%	49%	67%
ULEV	65%	20%	80%	54%	45%	58%
ToD	63%	21%	77%	62%	53%	65%
City	64%	21%	79%	42%	33%	45%
H2P	65%	19%	81%	68%	61%	70%

Note: For PHEVs in all Narratives it is assumed that motorways and dual carriageways account for 32% of vkm travelled, and urban and low-speed rural roads account for 68%. This is the average for all vehicles based on current travel patterns.

All Narratives reach a lower level of carbon emissions from cars and vans than the Patchwork and Clockwork scenarios published previously by the ETI, which were around 34 and 42 $MtCO_2$/year respectively. The Committee on Climate Change proposed that the total GHG emissions from surface transport (i.e. excluding aviation and shipping) should be *between 2 and 26 $MtCO_2e$/year in 2050*[43], the former being the maximum and the latter accounting for some barriers to decarbonisation – the latter is an 80% reduction from current levels.

In the CVEI analysis, there is no $MtCO_2$ target being enforced for the transport sector. Instead ESME finds the best way to meet overall Mt target, for a given transport vkm and energy demands (coming out of ECCo) and the wider energy system's emissions. In all Narratives, ECCo applies a 2030 target of 65 gCO_2/km for cars and 100 gCO_2/km for vans, and these are held constant from 2030 onwards. Failure to comply with this target results in the contravening OEM having to pay a penalty.

The effectiveness of Government intervention through use of market and policy measures to drive this decarbonisation is discussed in more detail in section 6.3.

5.1.3 Retail fuel and electricity prices

The retail fuel and electricity prices vary between the Narratives depending on the demand, the extent / cost of the infrastructure built, the underlying wholesale prices and the combination of different VAT on fuels, fuel duty and carbon tax applied (see Table 5). The infrastructure and other cost components that make up the retail prices are discussed further in section 6.2.

Hydrogen and retail electricity prices are shown in Figure 28. In the City Narrative, the use of localised electrolyser hydrogen production leads to higher prices (due to significant increases in electricity prices over time). In the ULEV Narrative, VAT on fuel is reduced to 5% for hydrogen compared to 20% in the other Narratives, which keeps hydrogen prices relatively low. In the H2P Narrative, the cost of the extensive transmission pipeline *and* distribution network pushes up H_2

[43] https://www.theccc.org.uk/archive/aws/IA&S/CCC_IAS_Tech-Rep_2050Target_Interactive.pdf. Assuming CO_2 emissions continue to be around 80% of total GHG emissions, this would be around a 20% share of the total CO_2 emissions in 2050.

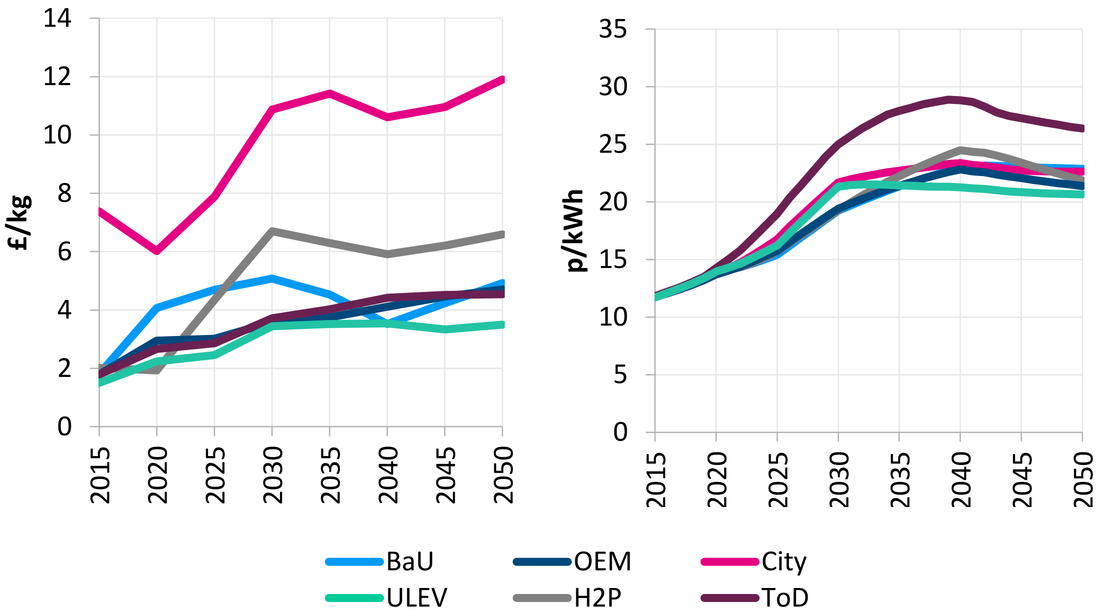
prices, whereas in the ULEV Narrative only a transmission pipeline is constructed and distribution is through road transport.

Retail petrol and diesel prices are shown in Figure 29. For both the City and ULEV Narratives, the UK CO_2 price[44] (shown in Figure 30) is passed through in full into liquid fossil fuel prices (accounting for any biofuel blending) from 2030, causing the steep increase in petrol and diesel prices. In the ToD Narrative, increases in fuel duty are stopped in 2035 as it is assumed that road pricing is likely to be easier to introduce alongside widespread use of car sharing.

Electricity prices tend to increase more rapidly in the first half of the pathway before plateauing from around 2030 onwards. This is driven in large part by sharply rising wholesale prices[45] to over £110 /MWh in 2030 across the Narratives (a rise of over 75% from 2015) as the electricity system decarbonises relatively early, supporting economy-wide decarbonisation. Wholesale prices then increase more gradually to around £115 to £135 /MWh by 2050.

Retail electricity prices at home (Figure 28) also reflect the cost of the home charging unit, and the effective p/kWh this adds to typical retail prices depends on the level of utilisation. In the ToD Narrative a 10 p/kWh subsidy is applied to non-home charging until 2030 and as a result there is a shift in consumer behaviour to maximise more of their charging at non-home locations[46]. This pushes up the effective per unit price of home charging, given that that the consumer is always expected to purchase a home charging unit regardless of how much this is used.

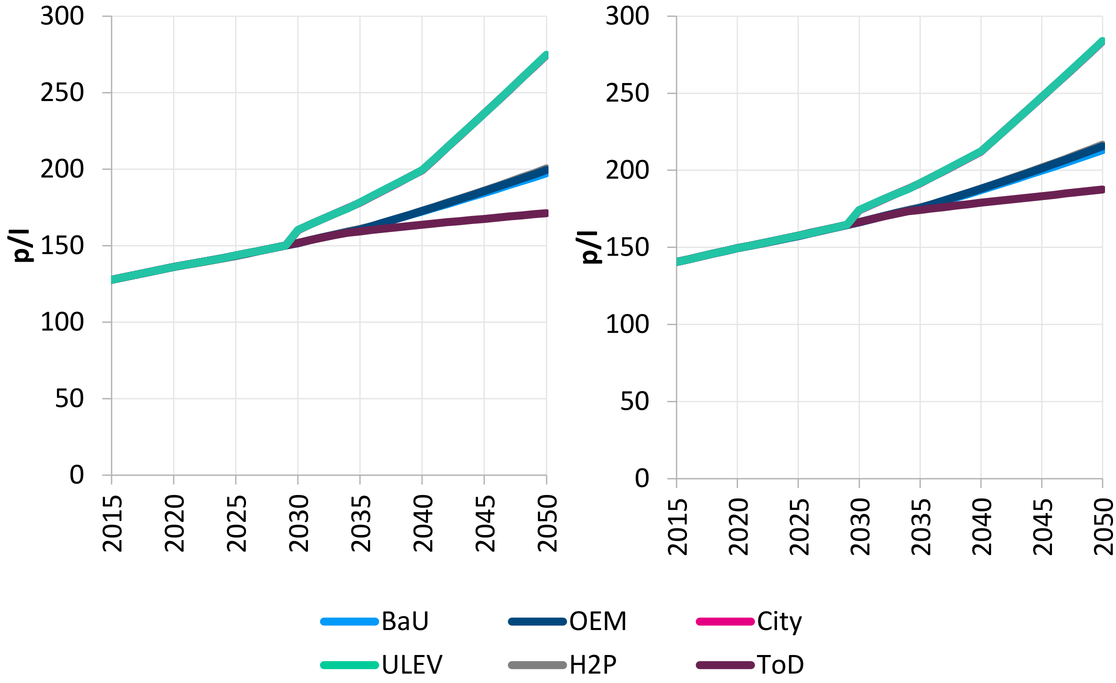
Figure 28 Retail H_2 prices (left), retail electricity prices for consumers at home[47] (right)



Note: BaU follows City.

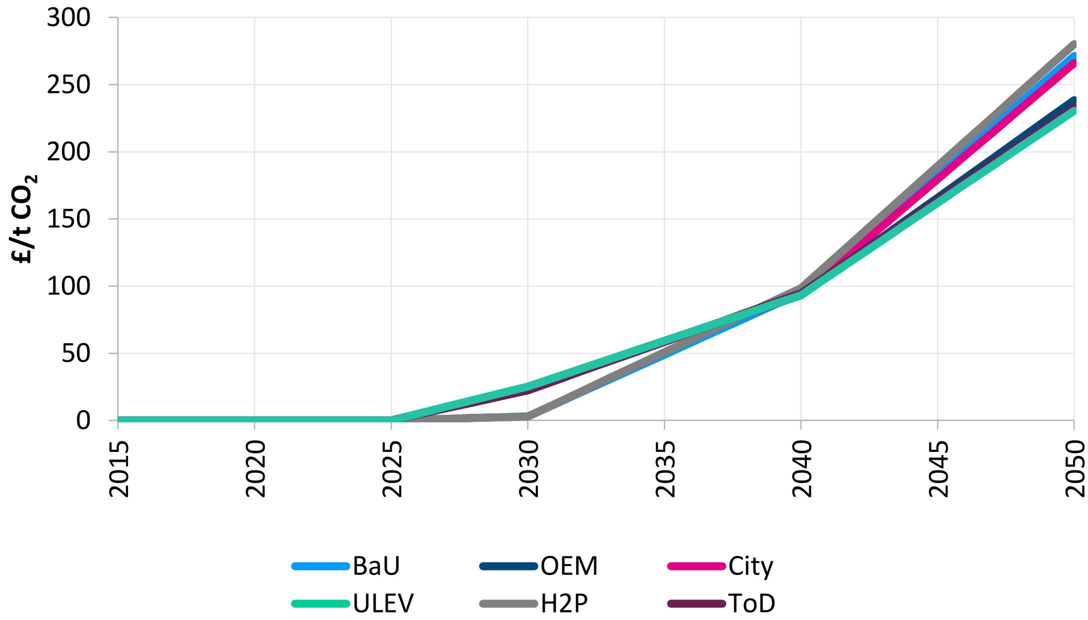
[44] The price needed to drive a level of economy-wide decarbonisation consistent with the UK's CO_2 targets.
[45] The model calculates wholesale prices at a level that recovers all variable, fixed and capital costs of generation.
[46] Part of the Narrative story is to have significant public charging and car sharing, thus public charging in subsidised in line with this.
[47] Average across time periods and timeslices.

Figure 29 Retail petrol (left) and diesel (right) prices



Note: H2P follows BaU/ OEM and City follows ULEV.

Figure 30 Carbon price[48]



Note: ToD, OEM and ULEV follow a similar trajectory. BaU and H2P follow a similar trajectory. City follows the ULEV trajectory until 2040. This is zero before 2025 as the carbon constraint is not binding i.e. emissions do not exceed carbon targets.

[48] Marginal cost of carbon from ESME.

5.2 Quantitative Success Metrics and key messages

The aim of the analysis is to compare within and between the Narratives. The Success Metrics as defined in Table 3 have been quantified and the results of this analysis are shown in Table 12.

The Success Metrics aim to answer the following questions:

- What proportion of consumer demand for road transport services is being met through low carbon vkm?
- What are the effective prices seen by consumers for transport services?
- What is the residual cost of unabated carbon emissions (tonnes of carbon multiplied by the estimated carbon price) both cumulatively in present value terms over the pathway and in 2050?
- What is the present value of the upfront subsidy that would be required to help de-risk and directly bridge any cost gap for new infrastructure investment over the pathway to 2050?[49]
- Will vehicle manufacturers have to pay penalties due to the challenges of meeting the EU new vehicle CO_2 targets?
- What is the gap in Government's transport-related net tax and spend (as impacted by the various subsidy and tax measures in place in each Narrative) compared to a desired target level of income, both in present value terms over the pathway and in 2050?
- In addition, the cost of a technology neutral mechanism to fill the gap in Government net tax and spend, between the target share for transport-related income and the modelled transport-related income, is illustrated for both a fixed cost per vehicle[50] and a cost per km travelled. For each mechanism, the cost is calculated assuming only that mechanism is utilised.

The metric calculations are set out in Section 2.3.

The quantified Success Metrics were used to assess each Narrative individually and at a high level to establish answers to questions such as 'BaU appears cost-effective but does it go far enough in terms of carbon reduction?' and 'H2P appears good for carbon reduction but is it too expensive?' Comparing the Narratives against each other highlighted a number of key messages across the Dimensions, which are summarised in Table 13 to Table 16, and identified areas that needed to be investigated in more detail. Deep dives into specific themes, providing further information on the underlying drivers of these messages can be found in section 6.

[49] Only for those commercial entities that have been modelled explicitly - Charging Point Operations, hydrogen distribution infrastructure and DM aggregators. DNOs are not included as they are modelled as regulated business so investment is implicitly recouped from consumers.

[50] The tax per vehicle is the revenue gap at the SDR / vehicle parc per year or the vkm per year. The average is shown across the pathway.

Table 12 Results for key quantitative metrics in the Narratives

Narrative scores poorly relative to other Narratives → Narrative scores favourably relative to other Narratives

Key quantitative metrics			BaU	OEM	City	ULEV	H2P	ToD	Context
Consumer	Low carbon vkm 2050	%	38%	62%	42%	54%	68%	62%	The corresponding transport emissions across the Narratives are 16-32 $MtCO_2$/year in 2050, compared to 88 $MtCO_2$/year in 2015. The share of total emissions from transport is around 16-31% across the Narratives, compared to 18% in 2015 - only decreasing in H2P.
	Car transport costs 2050	p/km	24.9	26.6	30.7	25.8	23.1	21.4	In 2015, the average cost of transport is 29 p/km in BaU.
Physical	Present value of residual carbon cost over pathway (@SDR)	£bn	33.2	28.2	36.0	31.3	23.2	27.6	The present value of the residual carbon cost if emissions continue at 2015 levels ranges from £78-84bn across the Narratives.
	Undiscounted residual carbon cost in 2050	£bn/year	8.8	5.4	8.1	6.1	4.6	5.8	The residual carbon cost in 2050 if emissions continue at 2015 levels ranges from £23-25bn across the Narratives.
Commercial	Present value of subsidy required over pathway for selected entities (@WACC/margin)	£bn	0.1	0.4	0.1	3.8	8.0	0.4	The subsidy represents up to 6% of the total discounted capex spend over the pathway for the CPOs and up to 16% or 37% of the H_2 infrastructure, with and without pipelines respectively.
	Present value of vehicle manufacturer penalty	£bn	*5.2*	*2.0*	*1.7*	*1.2*	*3.5*	*0.8*	The manufacturer penalty represents <1% of the retailer revenues on an NPV basis over the pathway and a maximum of 3% in any one year across the Narratives.
Government	Present value of net tax and spend gap over pathway (@SDR)	£bn	261	287	135	311	378	332	The 'gap' is between 15-45% of the taxes received from transport due to spending on grants and subsidies. Net revenues from transport represent around 2.5% of GDP in 2015, reducing to 0.5-1.5% across the Narratives by 2050.
	of which direct subsidy	*£bn*	*0.7*	*18*	*12*	*26*	*52*	*38*	
	Undiscounted net tax and spend gap in 2050	£bn/year	38	46	15	35	57	44	
To fill PV of MPF gap (@SDR)	*Average vehicle tax*	*£/veh/year*	*178*	*193*	*102*	*216*	*257*	*299*	Currently VED which, from 2017, is a fixed £/veh cost independent of the vehicle type is £140/year.
	Average road pricing	*p/vkm*	*1.2*	*1.3*	*0.6*	*1.5*	*1.8*	*1.6*	On average this represents 5-16% of the actual cost of transport in the Consumer metric.

Table 13 Summary of key messages from quantitative analysis for the Customer Proposition

Key Message (CP)	Supporting Information
Moderate uptake of ULEVs is seen by consumers and fleets even with limited Government intervention and uptake can be significantly increased with more intervention.	- The proportion of low carbon vkm is similar to the published ETI Clockwork scenario which is 33%. For comparison in the published Patchwork scenario ~51% of vkm are low carbon by 2050. - In BaU, 38% of vkm are low carbon by 2050, compared to 0.1% in 2015. - It is possible to reach around 50%-70% of low carbon vkm by 2050 via a variety of different pathways. The OEM Narrative delivers this with relatively small additional levels of Government spending, whereas others such as H2P cost considerably more.
Reducing upfront ULEV costs (via subsidy, VAT differentiation and / or leasing) is crucial to driving enhanced uptake particularly in the near to medium-term.	- Upfront cost is a key barrier in the decision to purchase a ULEV. The effect is seen when comparing OEM with BaU for example, as in the former the upfront incentives of £500 per car and £1000 per van results in 25% of low carbon vkm by 2030, compared to 15%.
Operating cost differentiation such as a carbon tax on liquid fuels or an extended gCO_2/km based congestion charge is not really a significant driver of ULEV uptake until the later stages of the pathway.	- Beyond 2040 there is a marked increase in wholesale electricity and carbon prices as it becomes more expensive to decarbonise the wider energy system, whilst at the same time the vehicle costs of ULEVs and ICEVs have narrowed substantially from the start of the pathway; the combination of these means that operating costs become a more important factor in driving ULEV uptake closer to 2050.
The benefits of shared cars and a more 'on demand' transport service appear material from a consumer cost perspective (i.e. in terms of lower p/km costs compared to private ownership) and become greater the more efficiently the fleet is used.	- Car sharing, used substantially in the ToD Narrative, leads to a steady decline in the vehicle parc over time as the vehicles are utilised more over their lifetime. However, the lower costs of driving that would result from this are offset to some degree by a higher turnover of the vehicle stock, significantly increased costs for maintenance and insurance and the potential impact of 'dead miles'[51]. - Within City, car sharing again shows substantially lower costs compared to private ownership. By 2050, road transport costs are around 25 p/km with car sharing in cities (accounting for dead miles) – compared to 31 p/km without car sharing – and the reduction in road transport costs becomes greater the more efficiently the car sharing fleet is used (i.e. when there are no dead miles included the road transport costs fall to 21 p/km). However, the

[51] Dead miles are the miles travelled by the vehicle that are not directly related to the consumer's underlying service demand, e.g. driving from or returning to a base not fully aligned with the consumer's desired start or end destinations.

Success Metrics show a more expensive p/km due to the combined impact of Government policy from extended congestion charging and a carbon tax on liquid fuels.

PHEV car deployment tends be similar to BEV car deployment in most Narratives, providing some fuel flexibility and system resilience, whilst modest FCV deployment is seen at the end of the pathway in many of the Narratives outside of H2P (where they are heavily subsidised). However, for van fleets duty cycle restrictions tend to exacerbate the split between BEVs for short duty cycles and ICEVs for longer duty, reducing the potential role of PHEVs compared to Private Consumer cars.

- It appears difficult to raise the proportion of low carbon vkm significantly above 60% in any Narrative, even with additional Government intervention to make ULEVs appear more economic. In most Narratives, the proportions of PHEVs, conventional vehicles and BEVs in the parc remain fairly flat from around 2040, suggesting that choice and flexibility in the vehicle parc is important to meet the service demand requirements and consumer travel patterns for private users.
- However, there is some gradual decline in the absolute size of the PHEV parc observed in the last few years of the pathway, whereas BEVs and FCVs are still increasing. This would tend to suggest that there is a tipping point whereby the increasing costs of fossil fuels (particularly where the cost of carbon is passed through) and declining gap in BEV / FCV costs to conventional vehicles drives a split in the economics of the choice for short versus long journeys. Where the battery range is sufficient for virtually all journeys a BEV becomes more suitable, whereas for long journeys FCVs become more economic. PHEVs, which up to this point have helped to bridge the gap between journey distances, become squeezed given the additional costs for the battery component, but limited potential benefits due to a cap on the proportion of vkm that can be delivered via electric mode.
- Van fleet duty cycle restrictions and a limited ability to charge during the day (i.e. outside of the depot) also mean that the BEV economics appear more suitable where the battery size is sufficient to meet a shorter duty cycle. By contrast, for longer duty cycles the proportion of vkm that would be driven in electric mode in a PHEV would be limited, reducing the potential economic benefits compared to an ICEV (due to the increased cost of the PiV). With the exception of H2P, FCVs are not selected until later in the pathway (post-2030) due to the high upfront cost of the vehicle.

Table 14 Summary of key messages from quantitative analysis for the Physical Supply Chain

Key Message (PSC)	Supporting Information
The push for decarbonisation from ULEVs needs to be considered together with decarbonisation of other sectors such as industry, building heat and power generation.	- In general, lower decarbonisation of transport (i.e. lower proportion of low carbon vkm) leads to a higher cost of abatement for the residual emissions. - Although OEM leads to a relatively high proportion of low carbon vkm at the lowest level of absolute subsidy, it is ULEV that is likely to be more representative of an efficient long-term level of decarbonisation by 2050 in transport relative to the wider energy system. In this Narrative the primary signal to shift to ULEVs is a carbon tax on liquid fuels, removing the distortion of other policy mechanisms from the true cost to decarbonise. This effect can be seen by comparing the carbon and revenue gap 2050-only metrics for these two Narratives against the equivalent Present Value metrics for the whole pathway: by 2050 more is spent in OEM compared to the value of the additional CO_2 saving. - H2P gives the lowest residual cost of unabated carbon in transport because the heavy roll-out of FCVs means that residual emissions are low. However, this is detrimental to the cost of carbon abatement in the wider energy system, and the 2050 carbon price[52] in this Narrative is the highest of all Narratives. This is due in part to the requirements associated with production of large volumes of hydrogen.
Demand Management leads to sizeable potential TSO savings (due to a lower requirement for peaking plants and more efficient management of the electricity system) and avoided network reinforcement costs at DNO level.	- If management of electrified heating load is more difficult than expected this would also reinforce the need for management of PiV load. - TSO savings are up to £2.2 bn/year across the Narratives considered and avoided network reinforcement cost savings at DNO level are up to £800 mn/year in the Narratives.

[52] I.e. the implied UK carbon price necessary to drive a level of abatement which would meet the overarching decarbonisation targets

Table 15 Summary of key messages from quantitative analysis for the Commercial Value Chain

Key Message (CVC)	Supporting Information
Many of the infrastructure commercial entities modelled[53] appear potentially profitable in the longer term, but may face lengthy loss making periods or the need to fund multiple investment cycles in a rapidly changing market environment. They may require upfront subsidy to help de-risk and directly bridge any cost gap in the investments, unless alternatives such as more regulated return models (potentially with cap and floor structures) are applied. However, the requirement for any infrastructure subsidy appears modest compared to that required to stimulate consumer demand for greater ULEV uptake.	- Some modest subsidy support may be required for the various infrastructure commercial entities as part of helping to de-risk and support the investment over the pathway to 2050 (up to £0.4bn or up to £8bn over the pathway to 2050 in Narratives without or with a hydrogen pipeline network respectively). The breakdown of the different CVC subsidy elements is shown section 6.3. However, the scale of this is secondary to the level of subsidy and foregone tax revenue (as indicated in the Government net tax and spend gap metric) necessary to drive consumer uptake and help stimulate market demand for the infrastructure (up to £52bn in direct subsidy across the Narratives, spent by Government over the pathway). Further, the subsidy is also small in comparison to the revenues of the entities (e.g. accounting for 4% in ULEV). - This is particularly the case for those making 'lumpy' investments such as hydrogen pipelines, due to the greater anticipation of demand required, and hence the greater delay in profitability. However, in the case of pipeline infrastructure these would likely be combined with some form of regulated regime (given the potential monopoly structure), which would also help to de-risk the investment, such as a cap and floor regime. A transmission-only hydrogen pipeline network appears almost viable (in ULEV) with some limited support due to significant demand for hydrogen outside of transport; extending this to include a high pressure distribution network that delivers hydrogen to the refuelling stations (in H2P) also appears viable with support, although it takes longer to become profitable. - Other businesses such as charging point operators and distributors of hydrogen with tankers are generally viable as the infrastructure can largely be deployed to meet demand. Narratives which only deploy charging infrastructure tend to have significantly lower subsidy requirements compared to those with hydrogen infrastructure. However, an additional challenge is the need to manage multiple cycles of investment over the pathway when consumer demand is changing rapidly.
Vehicle manufacturer penalties, due to challenges in meeting the new EU vehicle CO_2 target are most significant in BaU due to the	- However, the scale of the penalties for manufacturers is small (e.g. representing <0.5% of the revenues received by the manufacturers in BaU) when compared to the scale of investment required in new infrastructure.

[53] Retail electricity supplier; Electricity charging point operators (rapid, work, other public); Distribution Network Operator; Demand Management aggregator; hydrogen truck and pipeline distribution, localised hydrogen producers and hydrogen refuelling stations; liquid fuel forecourt operator

slower uptake of ULEVs in the nearer term (and more prominent in the case of vans compared to cars).	
The Demand Management aggregator business model appears viable at a high level (subject to the complexities of implementing this in practice which are discussed further in section 7.2), but is dependent on savings from TSO balancing operations rather than avoided network reinforcement in the longer term.	- This is because the DNO costs are driven by the need to ensure the network can cope with increasing levels of peak demand and so the need for reinforcement is driven by a mix of ULEV and wider energy system demand (e.g. from electrified heating, which contributes around 21 GW to peak demand in BaU in 2050, whereas by comparison PIV peak load is approximately 8 GW at that time). See Figure 57 for more detail on the contribution of vehicle and heat demand to the peak demand. - Considerable savings can also be delivered through User-Managed Charging in response to static ToU tariffs. However, both this and the savings from Supplier-Managed Charging[54] are sensitive to the assumed consumer response which will be explored further in Stage 2.
There is likely to be a need to support liquid fuel stations to ensure appropriate geographic coverage and security of supply, even though the 'average' station can cover costs.	- The retirement of a proportion of the existing network broadly matches the decline in the volumes of liquid fuel in a manner that means that average operating costs per litre are broadly unchanged. However, there are likely to be some distributional impacts between, e.g. urban and rural stations. Given the desire to maintain rural stations for reasons of social equity some specific targeting of subsidies in rural areas may still be necessary - currently a 5p/l subsidy is granted at forecourts in rural areas. Further assessment of the need for subsidy depending on the location of the forecourt (e.g. on motorways, in urban or rural areas) could be investigated as part of Stage 2.

[54] The term 'Supplier'-Managed Charging refers to charging that is Managed by any third-party acting as a 'DM provider' – the supplier, DM aggregator, DSO or other third-party. See section 3.4.1 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* for further information.

Table 16 Summary of key messages from quantitative analysis for the Market and Policy Framework

Key Message (MPF)	Supporting Information
The size of the revenue gap (due to subsidy or foregone revenue from taxes) is significant under BaU, and encouraging greater carbon abatement above this, by driving change at the consumer end of the chain, appears costly compared to the additional value from the avoided emissions. However, it is important to balance the cost over the pathway with the long-term position going forwards from 2050.	- The exception is City, which has a higher proportion of low carbon vkm for a smaller gap in Government revenues, due to the application of a carbon tax, together with sizeable revenues from extended congestion charging and higher vehicle utilisation and sales leading to greater VAT payments. - When comparing the delta in revenue gap between BaU and the other Narratives, around half to two-thirds of the increase in the gap is driven by additional direct subsidy spend (on vehicles and / or fuel) as opposed to foregone tax revenue.
There is a limit to how far the revenue gap can be closed using measures that differentiate between ULEVs and conventional vehicles given revenue cannibalisation[55], and therefore a technology neutral mechanism of some form appears important in this respect.	- Even in Narratives where a direct carbon tax is applied, together with other taxes (e.g. City), there is still a sizeable gap between the target Government revenues and those received. This suggests that technology neutral policies such as an additional vehicle tax (£/year) on top of VED or a vehicle utilisation policy such as road pricing (e.g. applied in terms of p/km) would be needed if Government revenues from the transport sector are to be maintained. - More stringent application of differentiated taxes on ICEVs would further accelerate the decline in the base (vehicles and / or liquid fuels) to which the taxes are applied, leading to a downward spiral of revenues.
Policy measures to reduce the upfront cost differential versus ICEVs are more effective in driving uptake than ongoing measures, but should be prioritised more in the medium-term.	- In the near term, given the lower value of reducing carbon emissions and the reasonable uptake of ULEVs without significant intervention in BaU, it appears that it is not necessary to *significantly* incentivise consumer

[55] Reduction in revenue as the result of an action taken to increase revenue i.e. the Government may tax conventional vehicles in order to get revenues; however, this increases the operating cost for these vehicles leading to fewer vehicles and shrinking the base upon which the taxes are applied - thus reducing Government revenues.

Key Message (MPF)	Supporting Information
	uptake, though some incentive may be useful to support early adopters, and encourage manufacturers to continue to innovate and reduce costs. - Similarly, towards the end of the pathway the price signal from a CO_2 tax on liquid fuels starts to become strong enough to drive a continuing move towards ULEVs. - Hence it is primarily in the medium-term (late 2020s to 2030s) where subsidy support for consumers is likely to be most effective in ensuring that the momentum in early uptake is not lost, without overly subsidising the level of abatement through transport.
There are significant additional costs associated with deploying hydrogen vehicles and infrastructure early on the pathway, even in a world where production and distribution costs benefit from economies of scale due to hydrogen production and use in the wider energy system.	- H2P is the most costly of the Narratives based on the gap in Government net tax and spend, whilst OEM reaches close to the same proportion of low carbon vkm in a more cost-effective way and with more balance between the different vehicle types in the parc.

5.3 Sensitivities

Sensitivities have been used to explore how resilient the Narratives are to changing external conditions. The set of Sensitivities assessed is set out in Table 9 and is summarised as follows:

- 'High' – the core Narrative with higher anticipated ULEV uptake driven by a faster reduction in ULEV prices, greater need to decarbonise the transport sector as CCS technologies are not built leading to a higher CO_2 price signal (which is passed through to the transport sector via a CO_2 tax on liquid fuels in the ULEV Narrative), and coupled with higher liquid fuel prices.
- 'Low' – the core Narrative with lower anticipated ULEV uptake driven by a slower reduction in battery and fuel cell costs and lower liquid fuel prices[56]. Changes to vehicle costs in these Sensitivities have the effect of making PHEVs a little more expensive and the BEVs significantly more expensive.
- 'Very Low' – a variation on the 'Low' Sensitivities with further decline in ICEV costs was also assessed. This employs the ICEV cost trends from the ETI's vehicle cost and performance model, which forecasts greater reduction in the production costs of ICEVs compared with the baseline dataset. ULEV costs were not updated with the cost trends from the ETI's vehicle cost and performance model since it does not yet include the latest battery cost forecasts from WP3 of this study. ULEV costs therefore remain unchanged from the "Low" scenario. This results in a very low uptake of ULEVs.

The wholesale fuel prices and vehicle uptake across the Sensitivities are shown in Figure 31 and Figure 32. In the ULEV and OEM Narratives the general movements in the vehicle uptake are similar to those in BaU, although there are minor variations in some aspects due to the differences in the definition of the Narratives.

In the High Sensitivities, hydrogen prices are more expensive due to lack of CCS in the wider system, and have a significant detrimental effect on the sales of FCVs. The impact is also seen in electricity, but to a more limited extent given the greater range of potential substitutes for producing low carbon electricity compared to hydrogen.

In the Low Sensitivity, the slower decline in vehicle costs pushes down the uptake of FCVs as well as PiVs, whereas in the High Sensitivity, the increase in hydrogen price more than offsets any potential increase in FCVs. In ULEV-High, the reduction in FCVs also means that far less hydrogen transmission pipeline is built because the threshold hydrogen volume at which pipeline construction occurs (substituting hydrogen distribution by tanker), is not reached. Accordingly, there is less subsidy required in the CVC over the pathway.

By contrast, the increased uptake of BEVs is more consistent in the High Sensitivities, with less tailing off towards the end of the pathway, thus changing the support needed for the commercial entities and the relative importance of Government revenue streams. Here the impact of higher electricity system prices is more than offset by push away from conventional vehicles from the combination of higher liquid fuel wholesale prices, as well as carbon tax in the case of the ULEV Narratives.

[56] Wholesale fuel price scenarios use ESME scenario data – Reference Case for base Narratives, Sharing Economy for lower fuel prices and Great Stagnation for higher fuel prices.

Figure 31 Wholesale prices and carbon price (2014 terms) in ULEV Sensitivities

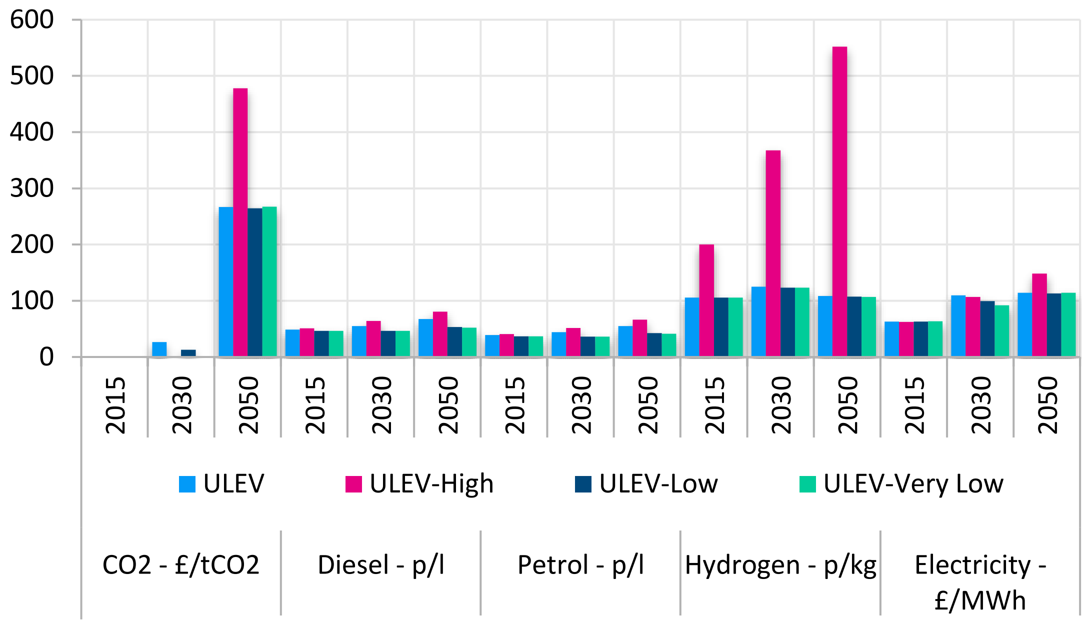
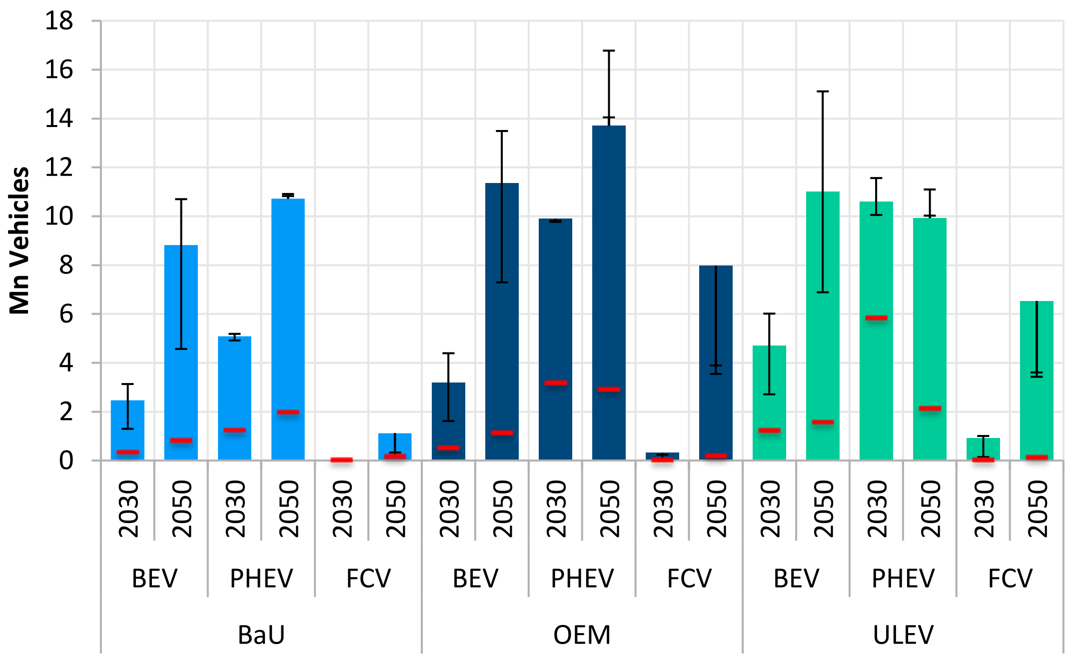


Figure 32 Vehicle parc in Sensitivities



Note: Core Narratives and High / Low Sensitivities in error bars, Very Low Sensitivity as red standalone marker

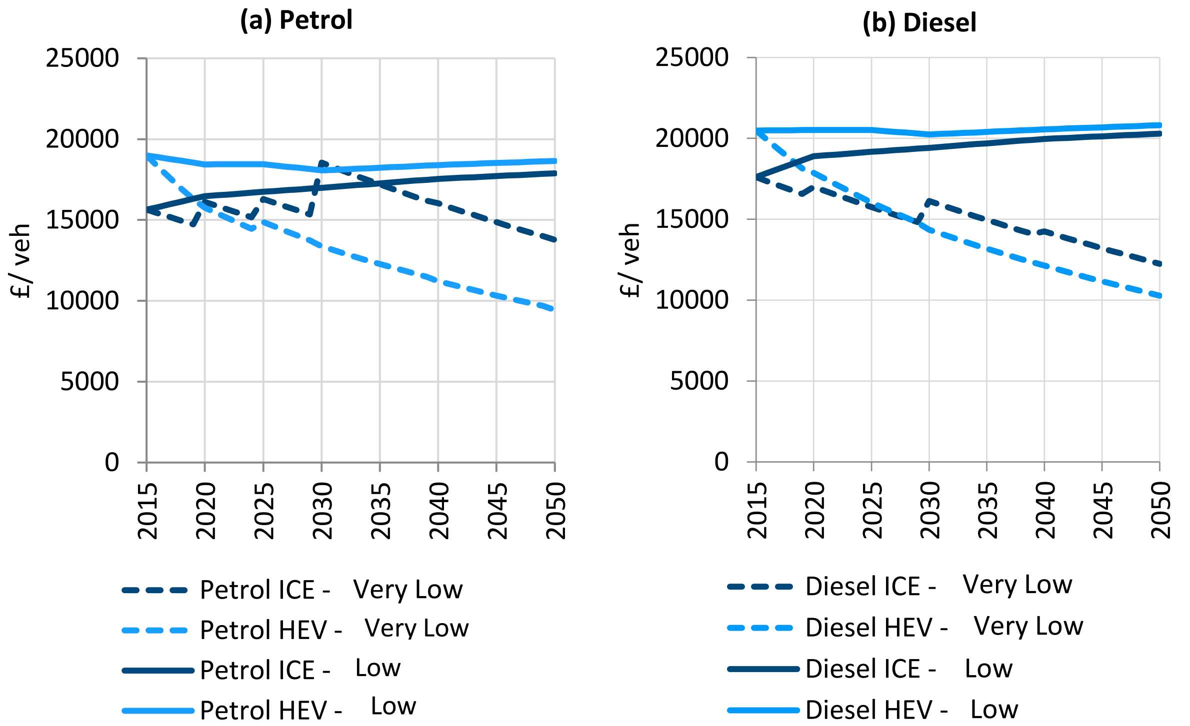
In the Low Sensitivities, it appears that a slower decline in ULEV costs and lower liquid fuel prices has a much greater potential impact. The uptake of PHEVs is fairly similar in both the core Narratives and

Sensitivities, but there are significant downward swings in BEVs given the compounding effect on their relative costs from the above factors.

In the 'Very Low' Sensitivities, the decline in ICEV costs leads to an increase in the number of ICEVs in the parc by 2050 and a very low uptake of BEVs, FCVs and diesel and petrol PHEVs combined. Applying strong cost reductions in the manufacture of ICEVs only, while assigning ULEVs the costs from the 'Low' dataset, leads to a much larger ULEV purchase premium than in the base dataset. In reality, many of the cost reductions made in manufacturing of ICEVs would also apply to ULEVs. However, incorporating the latest battery cost assumptions into the ETI's vehicle cost and performance model was not possible at the time, and so this mixed dataset should be treated as an extreme case. See Appendix B.3 for further details on the origin of this alternative dataset.

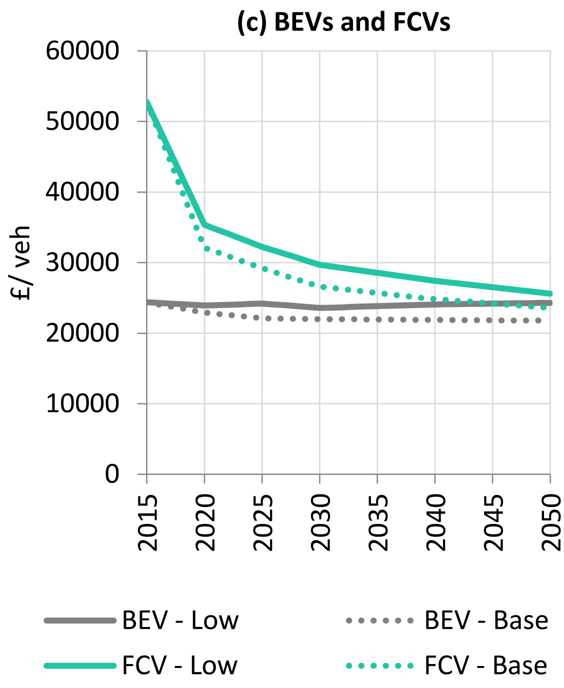
The purchase price for segment C (medium-sized) cars is shown in Figure 33 (and the vehicle parc resulting from the cheaper ICEs in Figure 32). Note that the FCV and BEV purchase price is higher in the Low sensitivities than the base Narratives; the higher FCV and BEV costs are used in both the Low and Very Low sensitivities. Additional work will be carried out in Stage 2 of this project (WP7, task 7.4) to further integrate the base and ETI datasets, such that the relevant cost trends are also applied to ULEVs.

Figure 33 Purchase price of segment C cars in the Base, Low and Very Low Sensitivities for (a) petrol[57], (b) diesel[58] and (c) BEVs and FCVs[59]



57 Low is the same as the core Narrative (Base)
58 Low is the same as the core Narrative (Base)
59 Very Low is the same as Low.

Figure 33 Purchase price of segment C cars in the Base, Low and Very Low Sensitivities for (a) petrol[60], (b) diesel[61] and (c) BEVs and FCVs[62]



The key quantitative Success Metrics for the Sensitivities, along with the results already presented for the equivalent core Narrative are shown in Table 17.

[60] Low is the same as the core Narrative (Base)
[61] Low is the same as the core Narrative (Base)
[62] Very Low is the same as Low.

Table 17 Results for key quantitative metrics in the Sensitivities

Key quantitative metrics			BaU	BaU-Low	BaU-High	BaU-Very Low	OEM	OEM-Low	OEM-High	OEM-Very Low	ULEV	ULEV-Low	ULEV-High	ULEV-Very Low
Consumer	Low carbon vkm 2050	%	38%	27%	40%	5%	62%	48%	57%	7%	54%	40%	56%	7%
	Car transport costs 2050	p/km	24.9	25.0	25.1	19.0	26.6	27.5	27.1	21.9	25.8	26.6	26.2	21.1
Physical	Present value of residual carbon cost over pathway (@SDR)	£bn	33.2	36.4	63.1	40.7	28.2	30.9	53.0	39.9	31.3	33.9	54.1	39.4
	Undiscounted residual carbon cost in 2050	£bn/y	8.8	10.4	15.1	12.2	5.4	7.5	11.5	11.9	6.1	8.2	11.1	11.8
Commercial	Present value of subsidy required over pathway for selected entities (@WACC/margin)	£bn	0.1	0.04	0.05	0.01	0.4	0.3	0.2	0.005	3.8	3.2	4.7	3.5
	Manufacturer penalty	£bn	*5.2*	*8.2*	*2.9*	*19.4*	*2.0*	*3.6*	*1.4*	*12.0*	*1.2*	*2.2*	*0.7*	*12.6*
Government	Present value of net tax and spend gap over pathway (@SDR)	£bn	261	242	267	267	287	243	287	182	311	273	294	284
	Undiscounted net tax and spend gap in 2050	£bn/y	38	35	39	35	46	40	44	29	35	27	29	22
To fill PV of MPF gap	*Average vehicle tax*	*£/veh/y*	*178*	*165*	*182*	*183*	*193*	*163*	*194*	*122*	*216*	*191*	*206*	*199*
	Average road pricing	*p/vkm*	*1.2*	*1.1*	*1.2*	*1.3*	*1.3*	*1.1*	*1.3*	*0.8*	*1.5*	*1.3*	*1.4*	*1.4*

A number of key insights can be inferred from the Sensitivities:

- **In the 'High' Sensitivities the overarching difficulty in decarbonising the wider energy system (due to a lack of CCS) also leads to higher electricity and substantially increased hydrogen prices, acting indirectly to limit ULEV uptake.** Although the CO_2 price signal is higher as a result of no CCS (if this applied to transport via a tax) and liquid fuel prices are higher in this scenario, this is stymied by higher electricity and hydrogen prices.

  For example, in the ULEV-High Sensitivity the proportion of low carbon vkm is almost the same as the core Narrative at just over 55%, implying that the benefit to ULEVs of a higher CO_2 tax and liquid fossil prices are broadly offset by higher electricity and hydrogen prices. By comparison, the OEM-High Sensitivity, which lacks the CO_2 tax signal, actually shows a lower % of low carbon vkm due to the higher ULEV fuel prices.

  This highlights that difficulties in decarbonising one part of the system potentially (directly and indirectly) impact the role of transport decarbonisation in different ways (due to changing roles of electricity, biofuels and hydrogen) and will not necessarily be offset by a greater decarbonisation in the transport sector. Lack of CCS is selected as it is one of the key potential failure points in the ability to decarbonise; however, the failure of decarbonising the heat sector may have different ramifications and this could be explored as part of the sensitivity analysis in Stage 2.
- **Passing through a signal on the cost of carbon abatement to consumers (e.g. as a direct carbon tax) appears to be an effective method of ensuring ULEV uptake whilst also managing the gap in Government net tax and spend compared to, for example, continuing to drive uptake through subsidies for ULEVs only.** If a carbon tax was applied to Narratives that do not currently include it (OEM and BaU), this would likely also drive down the gap in Government net tax and spend (which e.g. is ~£5bn /year lower in ULEV-High versus the core Narrative) and maintain the proportion of low carbon vkm in the High Sensitivities in a manner similar to the equivalent core Narrative.
- **The downside potential of lower than expected ULEV uptake and abatement appears greater than the potential for a significantly higher uptake.** In the 'Low' Sensitivities this is due to the cost differential to conventional vehicles being maintained at a greater level for longer, leading to a share of low carbon vkm which is over 10% lower than the core Narrative. As a result in the BaU and OEM-Low Sensitivities significant additional Government spending is likely to be required to achieve the same level of low carbon vkm and abatement as the core Narratives.

5.4 Qualitative Success Metrics

Whilst the quantitative Success Metrics are the key focus of the analysis, a high level comparison of the qualitative Success Metrics versus BaU is outlined in Table 18. There are further qualitative factors not included in this table that should be considered when defining how the 'good' aspects that have been identified could be delivered, and what risks and barriers are associated with these.

Qualitative factors that have been given further consideration include:

- Avoiding exploitation of consumers in the provision of transport services

- Understanding how different types of investment can be de-risked and how barriers to entry can be minimised for commercial entities, and
- Ensuring that multiple overlapping policies do not lead to unintended consequences.

These are discussed in more detail as part of section 7, which explores what might be needed in practice to facilitate delivery of the key elements of a 'good' solution identified through the analysis.

Table 18 Qualitative metrics

Narrative scores poorly relative to BaU — Narrative scores favourably relative to BaU

Metric	OEM	City	ULEV	H2P	ToD
Transport utility					
	Consumers still retain ownership of the vehicles as an asset A moderate amount of infrastructure is built to try to ensure that any adverse implications for transport utility (e.g. restricted refuelling[63] / charging and the implications) are minimised. However, this is still likely to result in some loss of utility compared to the BaU Narrative.	Vehicle sharing, particularly at lower levels of penetration may lead to some loss of flexibility in transport utility (e.g. booking ahead and fixing patterns to secure availability of a vehicle) as well as reduction in choice, as it is likely that the full available range of sizes / styles of vehicles might be reduced compared to a BaU world. In addition widespread application of congestion charging may also impact adversely on desired travel patterns, but with different distributional impacts for different types of vehicle users. For ULEV users the impact in the near-medium-term is likely to be mitigated due to exemptions from the charge, and hence the impact may be more acute for non-ULEV owners. Greater use of vehicle sharing concentrated in urban areas may impose some additional restrictions on flexibility for longer distance journeys (e.g. increasing reliance on public transport given the economics of owning a vehicle used purely for these journeys).	Consumers still retain ownership of the vehicles as an asset. A significant amount of infrastructure is built to try to ensure that any adverse implications for transport utility (e.g. restricted refuelling / charging and the implications) are minimised. However, at best this is still likely to result in a level of transport utility comparable to BaU Narrative.	As per ULEV Enabled	Vehicle sharing, particularly at lower levels of penetration may lead to some loss of flexibility in transport utility (e.g. booking ahead and fixing patterns to secure availability of a vehicle) as well as reduction in choice, as it is likely that the full available range of sizes / styles of vehicles will be reduced compared to a BaU world. However, at higher levels of penetration this may be offset to some extent by other benefits such as a freeing up of land used for parking due to a smaller absolute size of vehicle parc.

[63] Part of the Narrative story is to have plenty of public charging and car sharing, thus public charging in subsidised in line with this.

Wider impact on UK economy					
	OEM's focus on additional services (e.g. maximising convenience or information services for the consumer) and / or better integration of current services (e.g. maintenance) is likely to lead to some additional innovation and economic benefit compared to the BaU Narrative. However, the expectation is that this is modest compared to the core developments related to power trains and direct infrastructure.	Vehicle sharing, particularly at higher levels of penetration, leads to a higher stock turnover (vehicles are typically retired at twice the rate of Private Consumer vehicles). This could provide a potential boost for manufacturers and other related entities on the supply chain as returns from new innovation may be realised more quickly, given the more rapid cycling of the stock; along with generally boosting the gross value added, jobs etc. associated with higher sales of vehicles per year.	A combined Government and OEM focus on different aspects of additional services (e.g. maximising convenience or information services for the consumer) and / or better integration of current services (e.g. maintenance) is likely to lead to some additional innovation and economic benefit compared to the BaU Narrative. However, the expectation is that this is modest compared to the core developments related to power trains and direct infrastructure.	A significant and focused pull towards hydrogen as the only core ULEV energy vector could result in a greater rate of innovation in FCVs and associated technologies (assuming the UK is a leader in related areas). In addition, this could be accelerated further for other parts of the hydrogen value chain when considering hydrogen production and transmission for ULEVs in conjunction with the use of hydrogen in the wider energy system (in particular for power and industry).	As per City Led.

5.5 Key elements of a ‘good’ solution

The analysis has been used to infer potential aspects of what constitutes a ‘good’ solution, framed by the four Dimensions. These have been identified through cross-comparison of the Narratives and considering further details from the key thematic analysis in section 6. These have been classified into those thought to be:

- Essential
- Desirable
- Provisional, and a number that are considered
- Ineffective or unnecessary.

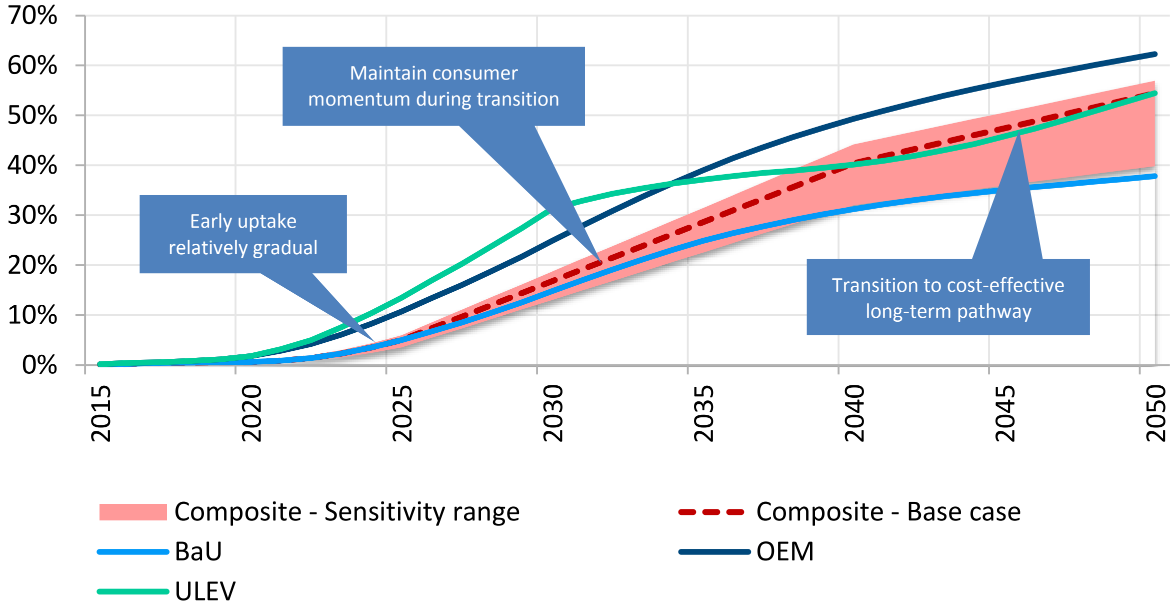
The potential risks and barriers to key aspects of a ‘good’ solution are discussed in section 7.

A ‘good’ solution attempts to strike an appropriate balance of decarbonisation in transport versus the wider system at a low overall cost of Government intervention, and in a manner that successfully engages the consumer to achieve critical mass-market uptake and use of ULEVs at the appropriate points in time. A range of essential and desirable elements are applied in a ‘good’ solution, which can be considered as the key principles that lead to robust outcomes. The categorised aspects are assumed to apply equally to Private Consumers and fleets unless otherwise stated.

A ‘stylised’ representation of such a pathway is shown in Figure 34. From a deployment perspective, a ‘good’ solution appears to be a pathway that helps to balance some of the more promising aspects of the BaU, OEM and ULEV Narratives. For example:

- Following the BaU level of uptake in the nearer term and not encouraging uptake too early via excessive Government intervention, given the significantly higher costs of abating emissions from transport compared to other parts of the energy system at this point in time.
- Maintaining momentum through the middle of the pathway (around the 2030s) through careful ULEV-differentiated subsidy measures in the medium-term in a manner similar to OEM, and supported by a ‘gradual’ tightening of the EU new vehicle CO_2 target to continue to stimulate innovation and help provide a floor under the level of transport decarbonisation in the medium-term. Charging infrastructure, particularly rapid charging, needs to be developed slightly ahead of need so as not to act as a barrier to uptake due to consumer perceptions of charging availability.
- Followed by a shift towards the end of the pathway to a level of decarbonisation akin to the ULEV Narrative via the application of a CO_2 price signal.

Figure 34 Example of stylised 'good' pathway for low carbon vkm



Clearly, the absolute numbers on a pathway are indicative only, and there may be circumstances (such as a more rapid drop in ULEV costs) which facilitate more rapid uptake with limited negative consequences. However, the underlying principle is that intervention needs to be carefully managed to neither do too little, nor conversely too much, at different points across the pathway when balancing the various objectives of decarbonisation, Government spend, the need to stimulate mass-market uptake and provide appropriate supporting infrastructure, etc.

5.5.1 Essential

Upfront cost mitigation for ULEVs

Overcoming the upfront cost of ownership in the near to medium-term is necessary *to create a pull towards ULEVs and a push away from ICEVs for both Private Consumers and fleets.*

- In ULEV, subsidies (£2000 per car and £4000 per van) are used until 2030 and after this they are removed which causes a slowdown in the vehicle km that are low carbon. A similar level of low carbon vkm is achieved in OEM to 2030, with lower subsidies (£500 per car and £1000 per van), suggesting that only a modest level of subsidy is required.

EU emission regulations

However, ***provided there is a reasonable underlying regulatory driver (e.g. in the form of tightening new vehicle CO_2 targets) to encourage innovation and learning in the near-term that consequently reduces the cost of ULEVs, it appears unnecessary to subsidise too much and too soon*** *(given more cost effective sources of carbon abatement elsewhere in the energy system, such as buildings and the power sector).*

- The introduction of these subsidies could be delayed until the late 2020s when it would likely have a greater impact on consumer uptake and low-carbon vkm (ensuring that the momentum in early uptake is not lost, without overly subsidising the level of abatement through transport). By this time, the wholesale cost differential between ULEVs and ICEVs should have narrowed, effectively reducing the upfront cost 'barrier' associated with ULEVs. Other sectors will have undergone some decarbonisation by this point and further abatement from such sectors is likely to be more costly and much closer to the cost of decarbonisation of the transport sector.

- In OEM, subsidies are applied across the entire pathway and this is a primary driver of the significantly higher share of low carbon vkm in OEM compared with BaU or ULEV, but this is at higher cost than is strictly needed given the value of the avoided carbon emissions, shown in Figure 80.
- Barriers to the implementation of a support (subsidy) scheme revolve primarily around political questions of spending priorities. A well-designed support scheme would have the objective of establishing a competitive position for ULEVs in the vehicle market around the 2030s, after which the emphasis of policy intervention would switch towards disincentivising ICEVs.
- Regardless of the specific structure, the scheme should allow entities to innovate and to adapt to evolving market conditions and should not over-subsidise the value chain as this may not drive entities to decrease costs and may breed an industry dependent on Government support. A 'degression' mechanism could provide a model for adjusting the value of support offered under a subsidy scheme and, if the step down is done in a mechanistic and forecastable way, could provide a signal to industry on the need to innovate and reduce costs.
- It may be preferable, for social policy reasons and uptake, to focus the support provided on lower priced models and / or the second-hand market to make ULEVs more accessible to a greater cross section of society rather than favouring certain sectors, such as higher income groups.
- The effectiveness of reducing the upfront cost will depend on the transport landscape (for example, with extensive sharing of vehicles it may be more important to target the reduction of the short-term hire costs, rather than the upfront vehicle cost paid by the fleet owner). It is also important to consider the level of support to overcome the costs of ULEV ownership against the level of improvement being driven directly by regulation[64]. For example, if the EU new vehicle CO_2 target is not tightened beyond 2020, this may require additional Government support to spur ULEV uptake.

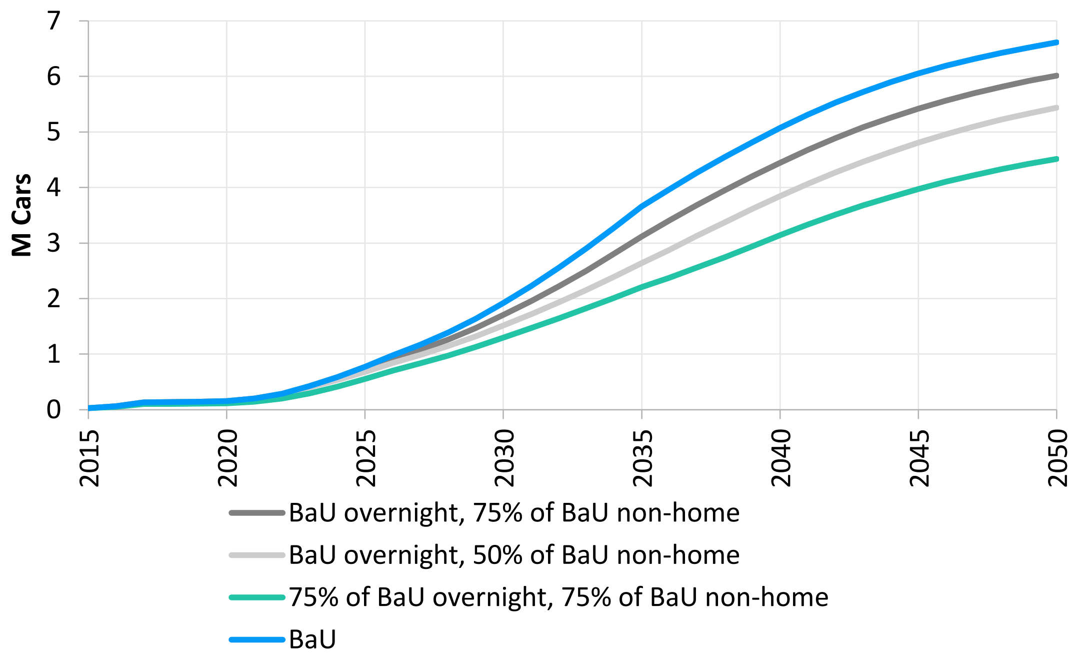
Rapid charging infrastructure investment

For Private Consumers (and home-based fleets), the primary place of charging is at home and having access to overnight charging overnight is key. To supplement home charging points and give certainty of access to charging outside of the home, a widespread, dense network of non-home charging points is desirable in the near to medium-term*. This should* ***focus on the development of (public) rapid charging*** *(i.e. 50kW and greater) as there is a more limited long-term role for (standard) public charging (i.e. up to 22kW) and workplace charging.*

[64] See Appendix B.8 for further details.

- Access to overnight charging is more important than access to other charging points. However, as range anxiety is one of the main barriers to ULEV uptake, access to other types of charging is also necessary.
- Whilst some modest deployment of work and public charging may be beneficial the analysis suggests that over the medium to longer term the increase in battery size means that a combination of overnight and rapid charging is sufficient for PiVs. The exceptions are more extensive public / work charging to facilitate car sharing and / or access to those without overnight charging access at home. For fleets, non-depot charging is deemed to be less important given the limited ability for fleets to recharge during the day as part of their duty cycle.
- Some initial government intervention may be desirable to ensure standardisation in the absence of this being delivered by industry. Support of the development of geographically comprehensive network by the Commercial Value Chain may also be required.
- The analysis shows that the electricity demand is similar at workplace and at rapid charging posts even though there are several times more workplace charging posts installed than rapid posts (e.g. 480,000 vs. 20,000 in Business as Usual by 2050), meaning that the rapid charging posts are better utilised. As a result the business models look consistently positive for the rapid charging point operator across all of the Narratives.
- It is unclear exactly how far non-home charging infrastructure needs to be rolled out to facilitate uptake. However, it is important to have enough such that the perceived access is not too low. Figure 35 demonstrates that the impact of reduced access at the overnight location, e.g. to 75% of that in the BaU Narrative, is much greater than the impact of reduced access at non-'home' (i.e. overnight) locations.

Figure 35 BEV parc with different access to charging levels – BaU[65]



[65] This tests the impact on uptake using ECCo only as an indicator, rather than a full Sensitivity

H_2 appraisal | H_2 infrastructure de-risking /investment

In the longer-term, after 2040, the modelled vehicle sales suggest that FCVs may be favoured over PiVs for incremental ULEV uptake. Major decisions on Government support for FCVs and associated infrastructure can be postponed until the later 2020s or early 2030s *to allow time for uncertainty over long-run costs to reduce. If a strong, coordinated 'push for hydrogen' is preferred (i.e. that includes the use of FCVs instead of, rather than in addition to, BEVs) then decisions may need to be taken earlier, given the time needed to plan and execute large-scale infrastructure projects such as pipeline networks. The potential for a transmission-only pipeline network for hydrogen (supported by local tanker distribution from the transmission network points into urban areas) should be assessed, as this may prove commercially viable in the long-term if the cost can be shared effectively with the other sectors using hydrogen (such as the power sector).*

- FCV infrastructure should focus on incremental tanker distribution and should track behind the investment made by the CPOs, with more focus towards the end of the pathway. From around 2040, in general the vehicles in the parc remain roughly constant for ICEVs, PHEVs and BEVs in most Narratives, whereas the uptake of FCVs continues. This suggests that FCVs are more important later in the pathway and therefore the roadmap for investment in infrastructure should reflect this and significant decisions can be postponed until there is greater certainty around the likely long-term costs of hydrogen vehicles and production.
- The greater cost of FCVs means a decision on enabling actions is not required until the later 2020s or early 2030s. FCVs are assumed to be available to mainstream consumers in 2020, by which time the FCV purchase price is expected to have reduced from around £53,000 to £32,000 for a segment C (medium-sized) car, through a combination of UK and global innovation. This is still around £9,000 higher than its closest rival, the BEV, and around twice the price of a petrol car. By 2050, the purchase price has declined further to around £24,000 which is considerably closer to petrol cars and BEVs, which at that time are expected to cost around at £18,000 and £22,000 respectively.
- The convergence in the cost of ownership of FCVs and PiVs is accelerated by the changes in the wholesale fuel costs, which are driven by changes in the wider energy – under Business as Usual, the wholesale hydrogen price falls from around 128 p/kg in 2020 to around 108 p/kg in 2040, whereas the wholesale electricity price rises from around £87 /MWh in 2020 to around £127 /MWh in 2040 (this price includes the Long-Run Marginal Costs necessary to recoup the full investment, including capital and fixed costs). As a result, in 2040 a private consumer would pay 2.9 p/km for the electricity to run a BEV, compared with 2.2 p/km for the hydrogen to run a FCV on a TCO basis.
- In the Narratives with a transmission pipeline network it takes almost 20 years for the transmission pipeline owner to make a positive return on capital, given the sizeable level of non-ULEV hydrogen demand seen as part of the UK meeting its overarching GHG target. The overall weighted return on capital is positive across the modelled pathway but does not exceed the cost of capital for investing in this infrastructure, which suggests some support would be needed to make the business model viable. Investment in a transmission pipeline network can be deferred until at least 2030 and made subject to a

minimum threshold of hydrogen volumes and the business model Success Metrics appearing positive.

- Both a transmission and high pressure distribution hydrogen pipeline network together appears less desirable as the distribution network is used solely to distribute hydrogen for transport purposes and the demand over which the cost of the infrastructure can be spread is much smaller. A full hydrogen pipeline network may look more desirable if the other uses of hydrogen were for industries that required local, lower pressure connections, rather than large-scale industry requiring only a transmission connection, but this then raises the question of a re-purposing of the existing gas network, which is likely to be significantly cheaper than a new build hydrogen distribution network. In BaU, the main use for hydrogen outside of transport is for H_2 turbines for power generation; there may be other industry demand going through the distribution network but this is small in comparison.
- An assessment of the need for FCVs in meeting decarbonisation targets may be required in the early 2020s. If this shows that FCVs are necessary then a full 'H_2 Appraisal' should take place in the mid-2020s. The detail of the appraisal will depend on the market and policy landscape at the time and it should at least incorporate an evaluation by the Government and regulatory authorities of the need to support a widespread hydrogen network, whether that is comprised of pipelines and /or trucks.
- This would not preclude private initiatives from developing hydrogen infrastructure in the nearer term. However, the key issue is stimulating a sufficient consumer market size either from ULEVs or other sectors (e.g. HGVs), which the analysis suggests would require support an order of magnitude greater than that for the associated infrastructure. A challenge for providers of hydrogen refuelling infrastructure is that can expect to operate on low volumes of hydrogen fuel sales initially and consequently prices will need to be high (to recover fixed and capital costs), which may act as a barrier to further growth in sales. In practice, the developers of new infrastructure may need to endure a period of loss making operation (in the absence of a subsidy regime) in order to achieve volume growth and profitability at a later date. This issue will be particularly acute where investment is more 'lumpy', and occurs further ahead of need. As these 'ahead of need' investments will be based on an assumed level of future demand, it is important that there is no uncertainty around policies that affect ULEV uptake as this will only serve to further exacerbate the investment risk.

Road pricing

The market and policy measures implemented, together with the declining ICEV parc, results in a sizeable gap between the net revenues received by Government from the transport sector and a 'target' revenue (based on growth of the current revenues with GDP per capita).

- The present value of the gap in Government revenues over the period from 2015 to 2050 relative to this target ranges from £135-378bn across the Narratives. Net revenues from transport represent around 2.5% of GDP in 2015, reducing to 0.5-1.5% across the Narratives by 2050. The Government cash flows in the BaU Narrative are illustrated in Figure 73 (note that there are other measures beyond current schemes that are not included in this Narrative but that are tested in other Narratives, for example a subsidy on fuel and a tax on CO_2). The Government could use other routes to bring down spending or obtain tax receipts from elsewhere in the economy; however, this project has explored options to meet the target revenue for road transport from within the road transport sector.

The gap between the projected net revenue and the assumed Government target revenue would need to be filled through the use of a technology-neutral mechanisms such as road pricing in order to produce a sustainable and substantial source of tax revenue from the road sector *and avoid the long-term revenue cannibalisation that could be expected if only measures that differentiate ULEVs from ICEVs are used (i.e. the Government may raise taxes on conventional vehicles only in order to increase its revenues, however, there will be a tipping point after which higher taxes could lead to lower uptake of ICEVs thus having the effect of reducing tax revenues overall).*

- A CO_2 tax on liquid fuels is used in City and ULEV to offset the phasing out of other MPF mechanisms in 2030, but this in itself is not sufficient to close the gap in Government net tax and spend. Continuing to apply measures that actively penalise conventional vehicles or incentivise ULEVs will have the effect of cannibalising Government revenues, through increasing the level of subsidy given or tax revenue lost.
- A proposed technology-neutral mechanism is road pricing, which would apply to drivers based on their distance travelled. The analysis indicates that the cost of this could range between 0.6 and 1.8 p/km on average across the pathway, representing between 5% and 16% of the actual cost of transport across the Narratives. Extensive taxation of road usage would require new technology such as increased data telemetry capability in vehicles, but this is expected to become more prevalent in future in any case. Charges could be differentiated by type of road and time of travel to help address congestion, unless simple congestion charges (which could also support long-term revenues) are already in place. It is likely that, since road capacity will not grow to match demand, some mechanism for managing peak road usage will be necessary in order to make use of this very limited resource in an economically efficient manner (regardless of the extent to which the vkm travelled are low-carbon).
- In City, the value of the congestion charging is not insignificant, equivalent to around 10% (or ca. £5bn /year) of the revenues from various taxes[66] by the end of the pathway or around 5% over the pathway[67] and whilst this is second order compared to the potential revenue from a CO_2 tax on liquid fuels it could still be an efficient way of recovering revenues whilst also providing secondary benefits such as reduced congestion.
- A supplementary per-vehicle annual tax is an alternative structure for a technology-neutral mechanism and the analysis indicates that the tax should range from around £100 to 300 /vehicle/year. This would be a significant increase on the current annual rate of vehicle excise duty, which is to be applied uniformly across all non-zero emission vehicles at £140 /year from 2017 (previously this was differentiated by vehicle, depending on the emissions level). A per-vehicle tax could also change consumer attitudes towards mobility, for example encouraging a shift to car sharing and increased use of public transport. However, the inability of this type of mechanism to simultaneously tackle congestion and apportion costs to use may make it a less appealing policy option.

[66] Including direct CO_2 tax, company car tax, fuel duty, VED, VAT on fuels and VAT on vehicles
[67] At the social discount rate

DM shared services framework

- Demand management is good from a system cost perspective and the savings are especially evident in balancing costs and for the DNO as illustrated in section 6.1. The Customer Proposition is discussed further in section 3.2.1 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*.
- Within the wider energy system, the electricity demand for heat is assumed to be managed effectively and further, even in the ULEV Narrative counterfactual with Unmanaged Charging (i.e. reflecting a world with high BEV uptake and stressed electricity system), there is no unserved energy demand[68]. However, the available capacity margin is significantly reduced without Supplier Managed Charging leading to a complete reliance on flexibility from interconnectors at some points. In reality there may be some additional capacity built in response but overall Demand Management reduces the costs of maintaining adequate security of supply. If management of electricity demand for heating is more difficult than expected this reinforces the need for careful management of PiV load.
- Once the roll-out of smart metering has occurred, the technical barriers to the delivery of ToU tariffs for User-Managed Charging should be low – User-Managed Charging is represented by an assumed consumer response to static ToU tariffs, whereby the consumer shifts their load to cheaper periods, changing their charging profile. Some additional communications infrastructure is likely be required to enable active Supplier-Managed Charging (i.e. to understand the state of charge of each PiV under the external agent's control and respond dynamically to price signals) – Supplier-Managed Charging represents more complete load shifting, controlled directly by a third-party acting as a 'Demand Management provider' (e.g. the supplier, DM aggregator, DNO or other third-party). This is unlikely to be technically difficult and may require the establishment of standard communication protocols between the on-board vehicle charger, the charging points and the electricity system.
- The wider market arrangements will also need to evolve to ensure that there are clear routes-to-market that enable the use of the flexibility provided by Supplier-Managed Charging and there need to be clear price signals, including half-hourly (or shorter) settlement and ToU/ dynamic DUoS charging. At its simplest this could reflect the adoption of a shared services framework setting out how the DM resource could be shared between DNOs and the System Operator.

5.5.2 Desirable

User-Managed Charging use | Supplier-Managed Charging use

If Private Consumers and fleets take advantage of Managed Charging propositions, they stand to receive a direct cost benefit, as well as enabling a substantial cost reduction in infrastructure, particularly for the System Operators and the Distribution Network Operators.

[68] In Narratives with Supplier-Managed Charging, the counterfactual with Unmanaged Charging has also been assessed in order to determine the incremental benefit of Managed Charging – see section 6.1 for more details.

- Assuming a 'modest' level of consumer response through User-Managed Charging leads to a sizeable reduction in costs compared to Unmanaged Charging. More significant savings appear possible under Supplier-Managed Charging. The Demand Management aggregator business model appears viable at a high level (subject to the complexities of implementing this in practice) but is dependent on savings from TSO balancing operations rather than avoided network reinforcement in the longer term.
- Across the Narratives in which a form of Managed Charging is implemented, users save on average around £13 to £21 /PiV/year on their charging costs due to load shifting (this represents up to 16% of their annual charging cost) and in addition users benefits from an assumed 'reward' paid by the DM Aggregator to users for their engagement in Supplier-Managed Charging (£50 /vehicle/year for BEVs and £25 /vehicle/ year for PHEVs, excluding car sharing fleets). It does not account for any redistribution of TSO savings, for example, back to Private Consumers and fleets. Consumer savings are shown in Figure 44. At this point in time, there is little evidence that can be used to understand whether the stated levels of savings and rewards would be large enough to encourage consumers to choose a Managed Charging tariff, hence the consumer response to a range of savings will be tested in the Stage 2 trials.
- Potential savings in the costs of balancing the system in the longer-term associated with the TSO are substantial, with the present value of the savings across the pathway accounting for between £7 and £20bn across the Narratives (at most, with Supplier-Managed Charging, this rises from £330mn /year in 2020 to £2.3bn /year by 2040). Whilst termed 'TSO' costs, these are the long-run avoided costs of (more expensive) energy balancing plant, covering part of the balancing market, short term operating reserve and additional peaking plant (i.e. within the capacity market). Avoided network reinforcement by the DNOs accounts for savings of between £1bn and £4.5bn. Avoided costs for the TSO are shown in Figure 42 and for the DNO in Figure 43. The avoided reinforcement costs for the Transmission Network Operator (TNO) have also been considered but are negligible by comparison.
- A key area that will be tested in the Stage 2 trials is whether the level of consumer engagement (i.e. the shift in charging profiles) that has been assumed in the modelling for both types of Managed Charging is likely to materialise in practice. See Section 3.4.1 of the D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report for further discussion on the Customer Proposition relating to Demand Management.

Coordinated DM procurement → Central DM platform

To supplement a DM shared services framework, more complex intervention and market redesign would allow for coordinated procurement and use of electricity for PiV charging through the establishment of a central market platform.

This would facilitate the trading of the demand for – and supply of – flexible resources (including DM aggregation of PiV charging), allowing the resource to be directed to where it is of most value across the electricity system. The market would need a locational and dynamic element to be added to its design to recognise the localised requirements of the DNOs. Developing, operating and regulating such a platform would be complex and costly, though the cost would not have to be borne only by the transport sector if the platform could also be used to manage heating demand. This step is only likely to be justified once DM becomes a significant activity and the additional benefits from a more efficient market structure outweigh the costs of such a platform.

Tightening emissions regulations

It appears desirable to further tighten national CO_2 limits on new cars and vans beyond the values already set by the EU for 2020/21*, as both a backstop measure to enforce decarbonisation and as stimulus for manufacturer innovation. However,* ***it is important to set a gCO_2/km target that is neither too lax*** *(resulting in very little decarbonisation)* ***or too stringent*** *(where decarbonisation may prove too costly and manufacturers elect to pay a penalty instead).*

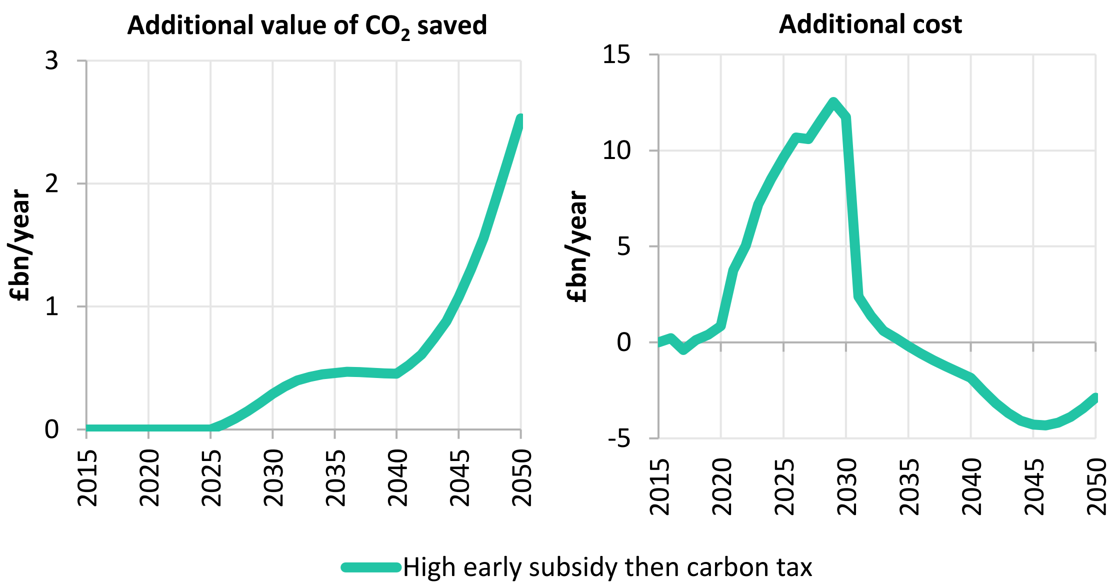
- The penalties imposed on manufacturers relate to the European Commission's 'excess emissions premium', applied as a price of *£70 x gCO_2/km above target x vehicles sold*, however, there may also be other penalties involved in not meeting EU regulations on carbon, or following guidelines on factors such as air quality. The current target is for new cars sold in the EU to emit on average 95 gCO_2/km by 2021, and for new vans 147 gCO_2/km by 2020. In all Narratives, the target is assumed to decrease to 65 gCO_2/km for cars and 100 gCO_2/km for vans (as measured on the New European Driving Cycle test procedure) by 2030, and held constant thereafter.
- The total penalty relating to UK vehicle sales ranges from £1.2 to £5.2bn across the Narratives in present value terms, though this could be higher if the potential cost of reputational damage were also included. As with infrastructure, the manufacturer penalties suggested by the analysis are small compared to the scale of the entities (i.e. having a total present value over the pathway of less than 1% of the revenues associated with the retail of the vehicles across the Narratives with a maximum of 3% in a single year).
- Holding the gCO_2/vkm target flat from 2020 as opposed to tightening it to 2030 leads to around 10% fewer ULEVs in the parc in the Business as Usual Narrative by 2030 (note this is based on a single pass of the model and not fully optimised as with the core Narratives and Sensitivities). In the model, manufacturers respond to lower CO_2 targets by cross-subsidising their ULEVs with higher-priced ICEVs. Beyond 2025, there are no penalty payments made in Business as Usual, which implies that the rate of emissions reduction is steeper than the target trajectory thus a much more stringent target would be needed for a more material impact.
- For vans, a more gradual tightening to 2030/35 may be preferred, due to the greater challenges involved in decarbonising this vehicle segment compared to cars. The near-term cost differentials between ICEV and ULEV vans and the additional restrictions imposed by duty cycles prevent BEV vans from being deployed more widely until there are improvements in driving ranges. See section 6.3.4 and Appendix B.8 for further details.

Carbon price pass through for liquid fuels

A long-term CO_2 tax appears to be worth implementing in addition to emissions standards, *to support Government revenues and drive an economically-efficient level of investment in ULEVs and the supporting infrastructure.*

- The price of carbon (i.e. an economy-wide estimate of what is needed to drive a cost-effective level of decarbonisation across the UK energy system to meet its overarching CO_2 targets) increases gradually in the near to medium-term before increasing more rapidly after 2030, up to £270 /tCO_2 in the Business as Usual Narrative. This is due to the increasing cost of further carbon abatement after cheaper options have been exhausted. As noted previously, the higher costs of ULEVs versus conventional vehicles results in a relatively high cost of decarbonisation of road transport in the nearer-term. Therefore it makes sense to carefully balance the level of Government support over the pathway to 2050, to incentivise ULEVs at times when the value associated with the resulting carbon abatement is greatest.
  - Figure 36 compares Business as Usual (in which the value of the CO_2 saved reaches £9bn /year by 2050) with the ULEV Narrative, which has a high early subsidy which is removed in 2030 and replaced with the pass through of the CO_2 price as a tax (applied as a component in the liquid fuel retail price for both petrol and diesel). This shows the impact of shifting away from subsidising ULEVs directly (creating a market pull to ULEVs) to taxing conventional vehicles (creating a market push away from ICEVs) in terms of the value of CO_2 savings (i.e. the combination of the amount of CO_2 saved and the price of CO_2) and the cost of making these savings (i.e. the cost to Government of implementing these policies)Prior to 2030, when there is a market pull, the additional gap in Government revenues (on top of the gap that already exists in the Business as Usual Narrative) is significant due to the high subsidies in place (£2000 per ULEV car and £4000 per ULEV van). However, although the subsidies help drive uptake, they do not drive high CO2 savings at this time.
  - Post-2030, when there is a market push, the new CO_2 tax on liquid fuel means that the value of the CO2 savings is greater, whilst the cost to Government is less (in part as subsidies towards the upfront cost of the vehicles are no longer awarded). This indicates that a long-term CO_2 tax could be worth implementing.

Figure 36 Value of CO_2 saved and cost (i.e. gap in Government revenues) in ULEV versus BaU



Note: The value of CO_2 saved is the additional abated emissions above those in Business as Usual at the carbon price of the Narrative. The cost of saving that CO_2 is represented by the additional gap in Government revenues above that in Business as Usual, which depends on both the subsidies applied and taxes received. As these are Narrative results they also include the effect of other factors that vary between Narratives.

Facilitation of urban car sharing / Initial car sharing implementation	Support for larger scale car sharing/ Mass-market car sharing implementation

The economics of car sharing appear positive for Private Consumers, *especially when widespread car sharing is used, though* ***priority should be given to car sharing in urban areas*** *as this is likely to lead to more efficient use of the vehicles.*

- Car sharing appears positive insofar as the p/km cost for using shared cars is in general lower than that of owning and using private cars, for example around 15% to 30% lower in the City Narrative (see Figure 88 in section 6.4 for further details). However, some of these benefits are offset by a higher turnover of the stock and associated insurance and maintenance costs, which are several times higher than that for private users.
- 'Car sharing' in this context refers to fleets of vehicles that are notionally accessed by consumers hour-by-hour as required, such that vehicles are driven by multiple users throughout the day (i.e. the vehicle assets are shared rather than used solely by one individual). The underlying journey patterns and requirements of the users are maintained (i.e. no modal shifting is assumed). However, there is some accounting for 'dead miles' – the miles travelled by the vehicle that are not directly related to the consumer's underlying service demand, e.g. driving from or returning to a base not fully aligned with the consumer's desired start or end destinations. Reducing the 'dead miles' that these vehicles drive is important as this will reduce the cost of transport further. The use of the cars has been limited by an assumption of ~25% to ~30% of dead mileage, in City and ToD respectively. There may be potential to lower the proportion of dead miles over time as shared vehicles account for more of the parc.
- Technological advancement, specifically the advent of autonomous vehicles, could significantly enhance the prospects of car sharing and enable more efficient and intensive use of vehicles. From a consumer's perspective, vehicles could then be delivered and deposited at locations of maximum convenience, rather than being tied to docking stations. The implications for vehicle manufacturers are unclear. Greater acceptance of sharing may lead to consumers regarding vehicles as interchangeable, commoditised providers of a service, rather than objects of aspiration or personal expression, which may require the vehicle manufacturers to adapt their business models.
- Government revenues may be largely unaffected, or even positively impacted, by car sharing despite a smaller overall vehicle parc (although this depends on the taxation policy as noted above). For example, under extended car sharing the total parc in 2050 is around one-third less than the parc without car sharing. However, because of higher utilisation the vehicles are generally retired more quickly, leading to a more rapid stock turnover and higher associated levels of VAT on new sales (and leading to higher revenues from road pricing if implemented).

***Similarly, leasing models appear desirable from the consumer perspective** due to the shift in costs that the consumer pays from an upfront to an ongoing basis.*

- This has a more positive impact on ULEVs than on conventional vehicles. In 2015 the 'upfront' cost of a BEV is around 90% of the Total Cost of Ownership whereas for an ICEV it is around 70%. The TCO is comprised of the underlying vehicle cost, including VAT and the margins of the manufacturer and retailer, together with the insurance, maintenance, fuel costs and other taxes. Lease payments somewhat mitigate the upfront cost barrier by indirectly forcing the buyer to account for the residual value of the vehicle and thus to recoup around 30% of the upfront cost. To ensure the Narratives are sufficiently distinct contract (lease) hire is modelled as the alternative to outright purchase. However, consumers could in reality also choose a contract purchase scheme, whereby they still purchase the vehicle after a number of years leasing it. In this model, there would likely still be a perceived benefit of shifting upfront costs to the less considered ongoing costs.

Limited coordination and support for rapid charging

Some de-risking and direct support for new ULEV-related infrastructure is required to encourage investment. However, this appears modest and the optimal timing depends on the type of infrastructure. For charging points investment is more important in the nearer term and should primarily be targeted at rapid charging and depots, and less so at public charging (except where this is needed to facilitate car sharing).

- The qualitative analysis in section 7.3 suggests that to a large extent, charging point infrastructure could be deployed on a commercial basis. The required support may therefore be limited to infrastructure deployed in locations of lower demand to support development of a geographically or socially comprehensive network.
- The subsidy needed to build the required infrastructure is small in comparison with the capital cost of building the infrastructure, representing up to 6% of the total discounted capital expenditure over the pathway for the charging point operators, and up to 37% for hydrogen entities (pipeline and tanker distributors, localised producers and refuelling stations) depending on the scale of the pipeline network. Excluding a hydrogen pipeline network, the present value of the required subsidy from 2015 to 2050 is less than £0.5bn in total for all other entities considered in the *Commercial Value Chain* (and around £36mn for just the charging point operators in Business as Usual). This increases to around £3.8bn with a transmission hydrogen pipeline network and around £8bn if this is extended to include a distribution hydrogen pipeline network.
- The requirement for infrastructure subsidies is generally small in comparison to the subsidies attributed to vehicles and electricity / fuel to encourage uptake (around £24–146bn in present value terms across the Narratives).

Social transition support

Around the point of transition from upfront incentives for ULEVs to ongoing disincentives for ICEVs, a programme may be needed to prevent vulnerable sectors of society from being left stranded with increasingly expensive to run fossil fuel vehicles.

5.5.3 Other provisional support

Competition monitoring

Some of the new businesses established as part of the switch to ULEVs (e.g. charging networks or car sharing businesses) should benefit from natural economies of scale. As these mature and consolidate later in the modelled pathway, market supervision and competition law protections may become necessary to ensure fair treatment of consumers and avoid formation of oligopolies.

5.5.4 Ineffective or unnecessary

A full push to FCVs in the near to medium-term does not look cost-effective *given the scale of intervention required on the consumer side (i.e. to reduce the upfront cost of the vehicle) in order to stimulate the necessary market demand.*

- However, there may be an industrial benefit associated with being an early mover (i.e. the vehicle manufacturers might base themselves and invest in those countries leading the way in policy and funding support for hydrogen). This has not been considered in this project but should form part of the 'H_2 Appraisal' identified in the roadmap.

There is likely to be a need for intervention to ensure that the geographic coverage of liquid fuel forecourts remains sufficient *(i.e. through some specific targeting of subsidies in rural areas). However, a* ***widespread, general subsidy appears unnecessary to justify keeping a skeleton network of liquid fuel forecourts open*** *as there are a sufficient number of conventional liquid fuel vehicles on the road in 2050 in all Narratives to allow an 'average' forecourt (in present day terms) to recover its costs.*

- This assessment is based on a forecourt that has an 'average' usage and does not account for the variation in system dynamics across individual forecourts or 'types' of forecourt (i.e. by size, location and ownership). Understanding the need for targeted subsidies requires a more detailed investigation that considers a range of forecourt types and usage patterns (including any short-term shifts between electricity and liquid fuels, driven by PHEVs).
- Note that the modelling does not include geographic representation of commercial entities and instead considers them across the Commercial Value Chain at a UK-level.
- For the 'average' forecourt, the utilisation is sufficient to allow recovery of the fixed costs of operation and distribution of the fuel, without the need to pass through higher operating costs into the liquid fuel retail price.
- Even in ToD where extensive car sharing exists, there are still around 7mn ICEVs and over 5mn PHEVs in the parc by 2050, refuelling at liquid forecourts. A skeleton network of 2,000 broadly distributed stations is assumed to be maintained[69] and the widespread liquid fuel demand supports reasonable utilisation of the forecourts such that the operating cost component of the liquid fuel retail price remains low. This indicates that

[69] For comparison, there are currently around 1,800 LPG filling stations in the UK, required for a much smaller number of vehicles - over 100,000 cars and light-duty vans currently use LPG.

the remaining network reasonably balances demand for forecourt use and availability of the forecourts.

A regulated regime for investment in charging point infrastructure appears unnecessary[70]. *The potential subsidy required for the charging point operators is relatively small compared to the capital outlay, implying they are likely to be commercially viable. They also have the advantage that the lead-time for investment is relatively short, allowing investment to be undertaken on an incremental basis and to be tailored to meet demand. Given the greater scope for competing providers, the charging point operators are not considered a natural monopoly to the same extent as hydrogen pipeline or electricity network.*

- Subsidy may be needed to support the commercial business models in some instances where investment significantly ahead of demand is considered desirable. However, for the public, work and rapid charging point operators, this is relatively small, of the order of 10s to 100s of millions of pounds, and these operators' business models appear to a substantial degree to be viable on a purely commercial basis.
- This suggests that, whilst a regulated regime may lower the risk of the investment, it is not particularly necessary for the charging point operators, who can respond quickly to demand for their services. Furthermore, regulating the operations of these entities may result in unnecessary complexity, and lack of innovation in service offerings.
- To date, the Government has supported the deployment of charging infrastructure, e.g. through the Plugged-in-Places grant scheme to 2013 and subsequently through further investment. However, in the longer-term, it expects investment on a purely commercial basis, and does not foresee support through a regulated asset base system of underwritten returns. It should be noted that some forms of regulation may still be necessary in the future, e.g. to ensure interoperability across networks or sufficient transparency in electricity pricing information.

Localised hydrogen production seems expensive compared to centralised hydrogen production*, even allowing for some ancillary services revenues and the avoided costs of transporting the hydrogen from centralised production to the forecourt. Consequently, the uptake of FCVs is suppressed in the Narratives that deploy localised hydrogen production.*

- Higher localised production costs are driven primarily by the long-term increases in electricity prices (even accounting for some benefits of being behind the meter) and higher per unit electrolyser costs compared with large, centralised production, which in the analysis comes primarily from gasification-based routes with CCS. Economies of scale and a wider range of production routes, such as Steam Methane Reforming (SMR) or gasification with CCS, even with the additional distribution network CapEx needed for centralised production, make centralised hydrogen production appear more cost-effective than small-scale localised producers. In City, the Narrative with localised production, the uptake of FCVs is by far the lowest across all Narratives, with longer-term hydrogen retail prices increasing to more than double those seen under BaU. Almost two-thirds of the long-term localised retail price is driven by electricity costs.

[70] There may still be good reasons for needing other forms of regulation in the future, e.g. interoperability, location and availability information, transparent price information, etc.

- Localised production is modelled at a UK-level and includes the benefits associated with the reduced transportation of hydrogen (as the production is on site).

5.5.5 Insights from overarching Narrative questions

A series of high level questions emerging from the process of structuring the Narratives was outlined in section 3. The summary described above, supported by further thematic analysis in sections 6 and in section 7 on delivery of a 'good' solution, suggests the following conclusions.

The questions in section 3 have been grouped, with reference to the overarching themes:

- **The role of Government intervention (a 'Coordinated' rather than 'Organic' approach to uptake)**
  - To what extent is incremental / organic improvement delivered primarily via OEMs, with limited Government support, sufficient to deliver mass uptake and use of ULEVs?
  - To what extent does a more coordinated, but technology neutral, push for ULEVs facilitate their uptake and use?
- **The role of hydrogen**
  - To what extent does this complicate the delivery of new large-scale supporting infrastructure, in particular with respect to the role of hydrogen?
  - How effective is a coordinated push towards hydrogen as the primary ULEV route, given that this mirrors many of the current aspects of the Customer Proposition (e.g. owning asset, no range issues, 'hub' refuelling) as current ICEVs and liquid refuelling infrastructure?
  - Is this route materially more expensive compared to other Narratives (such as City and ToD) which tend towards electric vehicles and where does this cost difference materialise (e.g. fuel production versus additional infrastructure), and how effectively does early coordinated action reduce these costs?
  - What are the additional costs and broader requirements for providing a meaningful hedge such that mass rollout of either PiVs and / or hydrogen vehicles could both be undertaken in the later stages of the pathway to 2050?
- **The value of transitioning to 'Mobility as a Service'**
  - What is the value of a partial shift towards delivering mobility as a service - in urban areas where this appears more viable (e.g. in terms of requiring fewer vehicles with higher utilisation)?
  - What is the value of a systemic, coordinated shift towards delivering mobility as a service, going significantly beyond that in the City Narrative (e.g. in terms of requiring fewer vehicles with higher utilisation)?
  - How significant are the implications likely to be for consumers as part of this shift and can the savings from better integrated services be used to compensate for any perceived or material reduction in an individual's 'transport utility' (e.g. less convenience)?

The role of Government intervention (a 'Coordinated' rather than 'Organic' approach to uptake)

As described at the start of section 5, the key issue for Government relates to careful targeting and timing of any more direct intervention over the pathway to 2050. The analysis shows that there is likely to be a strong but gradual ULEV deployment, focused around PiVs rather than FCVs, even without significant intervention, but that this may not deliver the most cost-effective long-term level of ULEV uptake given the UK economy's overarching decarbonisation objectives.

In the near-term Government intervention may be cost-effectively deployed in supporting the roll-out of non-home charging infrastructure, particularly for rapid charging, as the level of support required for the operators to de-risk and / or directly support their investments is likely to be relatively small compared to the potential impact on consumer perception of a lack of charging infrastructure. Over the longer term the increase in battery range means that overnight charging coupled with a well-developed rapid charging network is likely to be sufficient, with only limited and targeted requirement for public and work charging unless this is to facilitate car sharing.

It is important to note that whilst direct subsidies help both to de-risk investment and to bridge an explicit cost gap there are other mechanisms, particularly regulated return-type mechanisms (such as cap and floor regimes) that can also help to de-risk investments in new infrastructure.

Stimulating the consumer side of the market requires considerable Government spending (i.e. to subsidise the vehicle and reduce the upfront cost). However, the analysis suggests that this is better targeted for a limited period during the middle of the pathway (around the 2030s) to maintain momentum in the roll-out of ULEVs (assuming a reasonable level of uptake in the near-term without subsidies as seen in BaU), if coupled with a sensible, gradual tightening of the current vehicle CO_2 targets from 2020-2030. The cost to Government can be minimised towards the later stages of the pathway by moving policy away from a targeted pull to ULEVs (from subsidy schemes and tax differentiation) towards a consolidated push away from remaining ICEVs (e.g. via a carbon tax on liquid fuels).

Government also needs to actively pursue interventions which relate to the enabling market framework for ULEVs. For example, this includes improving the level of coordination in the way that Demand Management is used over the longer term (from both PiVs and other sources) to maximise the value to the wider system and consumers, e.g. across multiple services such as balancing and avoiding network reinforcement. This is discussed further in section 7.2.

The role of hydrogen

In terms of transport and distribution infrastructure for hydrogen an incremental, industry-led deployment in future focused around more flexible tanker based transport to forecourts appears feasible. Some Government support is likely to be needed to de-risk and stimulate initial investment, but should be relatively small in magnitude as shown in Table 10.

The two key challenges for wide spread use of hydrogen are:

- Large scale, low carbon, centralised production of hydrogen to generate economies of scale. This is contingent on either the widespread roll-out of CCS or substantial off-peak and low variable cost electricity generation capacity (e.g. new nuclear), whose viability is intertwined with the wider challenges involved in decarbonising the overall energy system as opposed to transport by itself.

- Generating the market demand for FCVs. Current costs are significantly above those for PiVs and, even though they are expected to decline rapidly, the tipping point to start driving significant consumer uptake (with reasonably-sized ULEV-neutral grants) appears to be 10 to 15 years beyond that of PiVs.

There may still be a significant and valuable long-term role for hydrogen, but given the higher current vehicle costs, uncertainty over how quickly these will come down and long-term dependencies with the wider energy system, there appears to be no pressing need to intervene strongly now to generate consumer demand, particularly given the high costs associated with doing this. It would appear acceptable to defer any decision on the need for strategic intervention in hydrogen for transport for at least 5 to 10 years, which does not preclude industry-led developments from occurring over this period.

The value of transitioning to 'Mobility as a Service'

The high level analysis, through exploration of the City and ToD Narratives, has flagged the potential at the system level for significant consumer cost savings comparing the cost of car sharing versus other privately owned cars within each Narrative[71]. Prioritising implementation in urban areas is likely to be more effective as the parc can be used more efficiently.

It has been assumed for the purpose of the analysis that consumers will engage with such a shift. An important focus for any subsequent analysis would be to better understand the drivers that would make such a wholesale shift acceptable to mainstream consumers, beyond the purely economic. It is also important to better understand the extent to which consumers' underlying travel patterns may be affected.

Similarly, the analysis has assumed that extensive car sharing is not delivered initially by widespread use of autonomous vehicles, and the estimates of consumer benefits are more conservative as a result (e.g. in terms of the potential reduction in dead miles). Further analysis is required to understand the extent to which autonomous vehicles can play a pivotal role in maximising the full set of benefits that might be achieved from widespread vehicle sharing.

5.6 Areas of uncertainty

The Narratives have been constructed in such a way as to facilitate a broad, holistic analysis of different factors influencing ULEV uptake and use, and how they do or do not form part of a 'good' solution. Although the analysis is fairly wide-reaching, there are some key areas of uncertainty discussed in this section, some of which can be explored via further Sensitivity analysis in Stage 2, and others that are genuine unknowns.

A number of gaps or limitations in the current understanding have already been identified that can be investigated in the Stage 2 trials, e.g. consumer response to new electricity tariffs and what this means for charging behaviour, what level of financial compensation is required for any perceived loss of convenience in the use of Supplier-Managed Charging, various indirect factors affecting the

[71] Although the average p/km cost appears higher in City this is the result of additional revenue raised from congestion charging and hence the primary point of comparison is car sharing versus non-car sharing *within* each of these Narratives.

decision to purchase a ULEV over a conventional vehicle, and rationality of fleet decision making. These are discussed in more detail in section 8.2.

5.6.1 General modelling and data limitations

In developing and combining the Analytical Tools and dataset that form the *D1.2 Analytical Framework*, various simplifying assumptions were made and boundaries formed, in order to practically address the key questions.

General data uncertainties include:

- Forward looking assumptions around commodity prices and technology costs (or potential new technology breakthroughs) and performance are inherently uncertain. These have been taken from ESME, with the exception of vehicle costs (ECCo)[72] and hydrogen / charging point / liquid fuel infrastructure costs (from various sources including the ETI Infrastructure Cost Calculator)[73]. The impact of some of these factors (liquid fuel prices, vehicle costs) has already been tested via the initial set of Sensitivities, but a significant number of additional Sensitivities would be required to more systematically explore the impact on the solution space for results.
- Uncertainties in the wider energy system such as cost or ability of other sectors to decarbonise. These have been explored only to a limited degree via the incorporation of a no-CCS requirement in one of the Sensitivities.
- Assumed closures of the liquid fuel forecourts have been driven by trends in the last few decades. However, data on the operating cost and margin of the retailer is limited and high level. The 'average' forecourt has been represented in terms of throughput and operating cost. However, in reality there are different sizes typically referenced as supermarkets, oil companies and independent operators, and there may be more closures for one of these segments than others.

Simplifying modelling assumptions include:

- Customer Proposition
  - Price elasticity has been represented only in the sense that the solutions are iterative and therefore prices and demand for vehicles themselves reach an equilibrium based on a stable number of conventional vehicles in the parc. Beyond this, demand elasticity such as a change in the number of underlying vkm demanded in response to the cost of transport is not represented.
  - Charging points: vehicle users are required to have off-street parking in order to be given the option of adopting a PiV (with the exception of car sharing fleets that charge overnight at public charging points). However, this may not always be a limiting factor in the purchase decision. Where access levels have been based on survey data, this is assumed to remain constant over the pathway due to lack of more robust data. Similarly, access to charging at other locations could have more or

[72] Key sources of vehicle cost uncertainty include: key components which are still in the early years of production, such as batteries and fuel cells, which are likely to experience the greatest change in cost; and the cost of efficiency technologies, and to what extent OEMs will deploy these in order to meet tailpipe emissions regulation.
[73] ETI Infrastructure Cost Calculator 2 - Cost Database Ver 6.57

less of an impact on the probability of a user choosing a PiV than is currently represented, and the importance of this relative to overnight charging access may change.
  - The UK's overarching carbon emissions targets must be met and this is one of the key drivers of ULEV uptake. Air quality is considered qualitatively.
- Physical Supply Chain
  - Electricity system: temporally contiguous peaks have been assumed across the LDN and NTS level, which may overstate coordination benefits from Managed Charging – in reality these peaks may occur at different times which may reduce the scope for load shifting under Managed Charging.
  - Geography and rural / urban split has been incorporated where particularly necessary, for instance, in assessing the cost of electricity distribution network reinforcement, in mapping a hydrogen transmission pipeline network, through identifying the vehicle parc in 'cities' for congestion charging and in the wider energy system modelling in ESME. However, the *D1.2 Analytical Framework* represents a UK-wide system and does not provide a nodal representation of transport and pro-rating assumptions have been used to translate the parc into the different geographical representations.
- Commercial Value Chain
  - The business models of the commercial entities have been simplified as they are modelled pre-tax and represented as single entities operating in a perfectly competitive environment (where not a regulated monopoly). These and other simplifying assumptions are discussed further in Appendix C. Average entities are considered, thus the variability of subsidy (e.g. with location for liquid fuel forecourts) and the viability of individual businesses (e.g. of costs for Charging Point Operators with the distribution network area of operation) are not assessed.
  - The cut-off in the modelling pathway at 2050 means that some aspects are not captured, such as the cash-flows for commercial entities associated with the continued operation of long-life assets beyond that point, potentially with some cost-effective refurbishment to extend the technical life.
- Market and Policy Framework
  - The Government could use other routes to bring down spending or obtain tax receipts from elsewhere in the economy; however, this project assumes that a target revenue must be met from within road transport.

Note that this project has not looked specifically at the Government's Manifesto commitment to develop the ULEV market so that by 2050 nearly all cars and vans are zero emission. This could be tested as a sensitivity in Stage 2, where Government intervention drives toward this result, even though from a system perspective it may not meet climate change objectives, although it may still meet air quality and industrial objectives.

5.6.2 Uncertainty around key messages

This section discusses remaining uncertainties, framed using the key messages in section 5.5, although it should be noted that not all of the key messages have distinct areas of uncertainty associated with them.

Some de-risking of infrastructure is required to encourage investment; however, this is modest and timing depends on the type of infrastructure. For charging points this is more important in the nearer term, whereas significant support for hydrogen can be delayed.

- The charging point and hydrogen infrastructure assumptions include some degree of anticipatory investment in all Narratives, therefore the implications of underinvesting early on are not fully understood, although some simple Sensitivity tests on the impact of lower perceived availability of charging infrastructure are shown in section 5.5. Further Sensitivity testing would be needed to explore this and to understand the trade-offs between over-investing and investing only in the infrastructure needed to exactly meet demand[74].
- Underinvestment may have a disproportionate effect on consumer choices (e.g. if the consequence is low perceived access to charging) compared to the scale of investment that needs to be put into infrastructure, and particularly in relation to that required when subsidising consumers.

Demand management is important for reducing overall system costs and is also desirable in terms of managing the operation of the system as it reduces the costs of maintaining adequate security of supply. A large proportion of the benefits of optimised Supplier-Managed Charging seem achievable through User-Managed Charging in response to static ToU tariffs, assuming that consumers are adequately incentivised to shift load as expected.

- The same electricity demand profile has been used when assessing the costs of the distribution and transmission network and as a result, the peaks are coincident across the electricity networks, which may not be the case in practice. However, the analysis shows very limited savings from NTS-level reinforcement due to PiV load with the bulk from TSO-level savings from operating the system and avoided network reinforcement at LDN-level. In reality, DNO constraints and their management will be highly location specific within each DNO's network.
- Based on the analysis there is some ambiguity around the extent to which altering different parts of the wider energy system drive peak demand. Strong management of electrified heating is modelled via ESME, but if this proves difficult it may increase the benefits of, and requirement for, demand management of PiV charging.
- Vehicle to Grid services are not the primary focus of analysis in Work Package 1, but may have bearing on the scale of the benefits that can be made through use of Demand Management and how these can be accessed. While V2G services have not been modelled in Work Package 1, they have been considered in the analysis of the battery degradation costs associated with providing demand management Work Package 3.

[74] The density of the charging point network is defined exogenously according to the theme of the Narrative and could be tested further.

Market and policy measures put in place in the Narratives are such that there is a sizeable gap between the target revenue for Government and the actual revenue received – this would need to be filled through use of technology-neutral mechanisms[75].

- The target that has been used for Government revenue is based on an assumption that the required sum increases in line with real GDP per capita. In practice, how future Governments will perceive the desired level of revenue from transport is unknown.

The economics of car sharing appear positive when widespread car sharing is used in ToD and in addition it may be worthwhile to implement widespread car sharing for the secondary benefits it brings.

- Assumptions have been made about the dead miles resulting from shared vehicle usage but these will vary depending on the proportion of car sharing in the parc and the utilisation, journey length and location. The impact of different extents of car sharing on travel patterns and dead mileage could be significant but is not yet clear. The International Transport Forum has suggested that nearly the same mobility could be delivered with 20% of the cars in an 'on-demand' world (in which self-driving cars pick up and drop off single passengers sequentially, replacing all car and bus trips)[76]. By contrast, the ToD Narrative appears conservative, leading to a drop of 35% in the absolute size of the car parc when delivering 75% of underlying passenger vkm via sharing of car assets (see Figure 25).
- A complete modal shift or very high penetration of shared vehicles may change consumer mileage requirements and travel patterns, and the impact of this is unclear.

Applying an extended congestion charge can also support Government long-term revenues.

- The congestion charge applied in the modelling is based on the London scheme and scaled by population, whereas other cities may have substantially different travel patterns with corresponding impacts on the revenue obtained.

From the point of view of the consumer a widespread, dense network of non-home charging points is desirable in the near to medium-term to give certainty of access to charging outside of the home – the latter being the primary place of charging for Private Consumers. The non-home charging can be focused around development of rapid charging given the more limited long-term role for public / work charging (except where this is needed to facilitate car sharing) and the perception of access needs to be balanced with the commercial viability of the CPOs.

- Infrastructure availability for charging points (and their associated prices) reflect an oversupply in the near to medium-term given requirements for consumer access at low levels of ULEV penetration, before moving to a long-run density factor under an assumption of a perfectly competitive environment. However, in reality competition between multiple providers of infrastructure may not be perfect, leading to some level of redundancy and higher prices, given lower typical levels of utilisation per charging point.

A transmission-only pipeline network for hydrogen may prove cost-effective if the cost is shared with other sectors (particularly power) that can also make use of the network to transport large volumes

[75] Assuming the revenue gap must be met, and must be met from within road transport.
[76] http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf

of hydrogen, but a decision can be deferred until at least the middle of the pathway (around the 2030s).

- The economics of hydrogen pipelines depend on the volume they convey, for both transport and other sectors, which is highly uncertain. The transmission pipeline network is assumed to be used for other industries, particular power, whereas the high pressure distribution network is not, but this may not be the case for either network.
- The FCVs are assumed to be distributed across the country in proportion to the underlying vehicle service demand, whereas it is unclear whether this would be the case in reality. This affects the demand for hydrogen and may in turn affect the timing of pipeline build (e.g. ownership of FCVs could cluster around available refuelling infrastructure in the near term, potentially helping to reduce costs as infrastructure is incrementally deployed).

It is potentially desirable to further tighten CO_2 limits on new cars and vans beyond the values already set for 2020/21 as both a backstop measure to enforce decarbonisation and as stimulus for manufacturer innovation such as the range of different types of ULEVs offered across the different vehicle segments. However, it is important to set the level such that it is neither too high (encouraging costly decarbonisation) nor too low (such that manufacturers choose to pay the penalty).

- The EU target in 2050 is currently unknown, and even the 2030 target has a high degree of uncertainty attached. To avoid greatly increasing the cost of driving, previous targets set for 2015 and 2021 have not required a significant deviation from current trend in average emissions.
- Further, the exact response by OEMs to a lower target is not clear and in reality, whilst the OEMs may cross-subsidise by lowering the cost of ULEVs in order to achieve sales, and raising the price of conventional vehicles to compensate, they will also consider the price elasticity of each vehicle to ensure they are maximising value of the subsidy. OEMs may also choose to deploy more efficiency measures in highly polluting vehicles.

There are a sufficient number of conventional liquid vehicles on the road in 2050 in all Narratives to justify keeping a skeleton network of liquid fuel forecourts open without leading to an increase in average operating costs, but some specific targeting of subsidies in rural areas may still be necessary.

- The lack of need for subsidy is based on the ‘average’ station, and some differentiation may still be needed for a subset of rural stations, as is currently the case. This subsidy may be compensating for potentially lower throughput and higher fixed operating costs at these stations, which could be exacerbated by lower forecourt shop sales. Further investigation of the need for subsidy depending on the location of the forecourt (e.g. on motorways, in urban or rural areas) could be undertaken as part of Stage 2.
- The liquid fuel stations are closed based on an economic decision, considering operating costs and fuel demand. Although this is based on available historic data, the relationship may not hold in the future.

Localised hydrogen production looks expensive given significant long-run increases in electricity prices, even allowing for reasonable ancillary services revenues, and therefore supresses uptake of FCVs.

- The localised hydrogen producers are assumed to be able to capture some revenues from provision of ancillary services (primarily frequency response) and this continues over the modelling pathway. Changes to the assumed size of the market are reflected but there is less certainty about future clearing prices for ancillary services and the types of products available. However, this is likely to be second order compared to the underlying driver of significantly increasing electricity prices, which makes localised electrolyser production appear considerably more expensive than centralised production.

6 Further thematic analysis of Narratives

6.1 Role of demand management

6.1.1 Demand shifting

The Narratives explore the relative impact of different tariff structures such as static ToU, with partial shifting of load via User-Managed Charging, and Supplier-Managed Charging with hourly pricing[77] and full shifting of load to off-peak where viable. User-Managed and Supplier-Managed Charging are described in more detail in section 4.4.1 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report.*

Demand shifting only occurs at home and work locations[78], and serves to push more of the demand into overnight periods, as shown in Figure 37 and Figure 38.

- The profile for BaU at home is based on data from DfT's Plugged in Places and shows that the majority of electricity demand at home is required in the late-afternoon / early-evening, suggesting that consumers plug in immediately upon getting home and / or before using their vehicle in the evening.
- The profile in the ULEV Narrative is a stylised representation of what might occur under a manged charging regime. It is assumed that charging is focused in the evening and consumers do not plan to charge at all over the course of the day. However, the underlying logic checks that if the vehicle needs to be charged more than the time allows at the base location, then this requirement will be met at non-home locations.
- The work charging profiles reflect that the majority of the demand at work is from Fleet Non-User Choosers, which are likely to be on duty in the day and plugging in at the end of the day. In the modelling, fleets must be able to deliver their duty cycle each day without needing to stop and charge throughout the day. Consumers are able to charge throughout the standard working day; however, they use a relatively small amount of electricity at work because the price differential between work and home charging incentivises them to charge at home instead.

The profiles are exogenously specified, representing an inferred consumer response to different tariffs – static ToU for User-Managed Charging (e.g. in OEM) and fully shaped tariffs (i.e. hourly prices) for Supplier-Managed Charging[79](e.g. in ULEV). There is very limited evidence for how mass market PiV consumers would engage with either of the overarching charging approaches and this is a key focus of the Stage 2 trials. The results of the trials will be central to informing updates to the charging profiles based on actual mainstream consumer response.

[77] Currently power is traded down to half-hourly granularity but here an hourly basis is used, in part to align with the format of existing models in the *D1.2 Analytical Framework*.
[78] Demand shifting could also occur at public points however, there is less scope for this due to shorter plug-in times and in order to be conservative this has not been modelled.
[79] Relatively optimistic profiles have been tested with the charging profiles in order to draw out initial conclusions and to facilitate clear comparisons across Narratives. All future electricity prices are simulated within the model.

Figure 37 Home winter weekday charging profile for flat tariff (BaU), User-Managed Charging (OEM) and Supplier-Managed Charging (ULEV) in 2050[80]

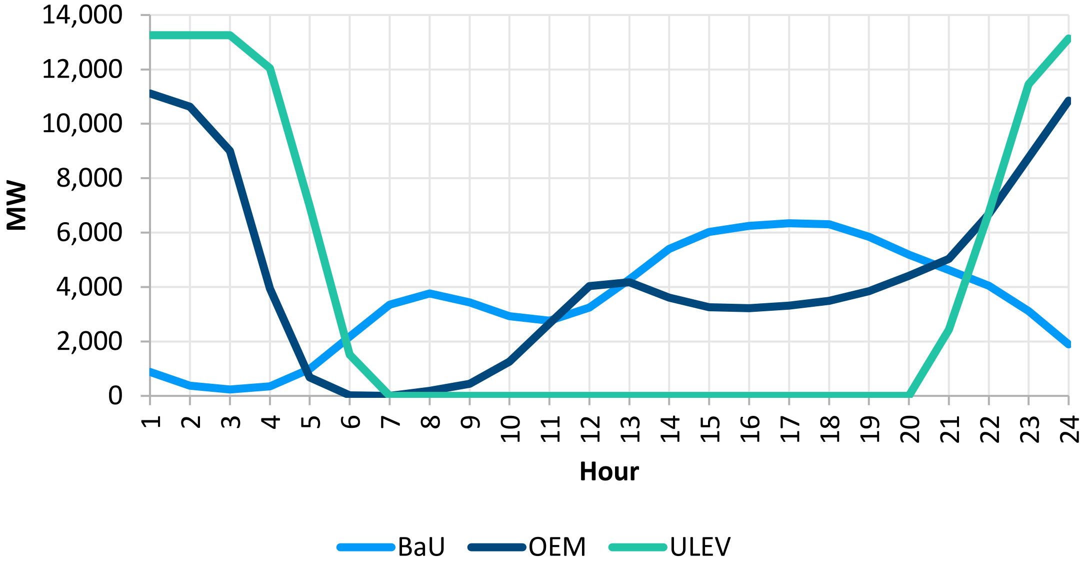
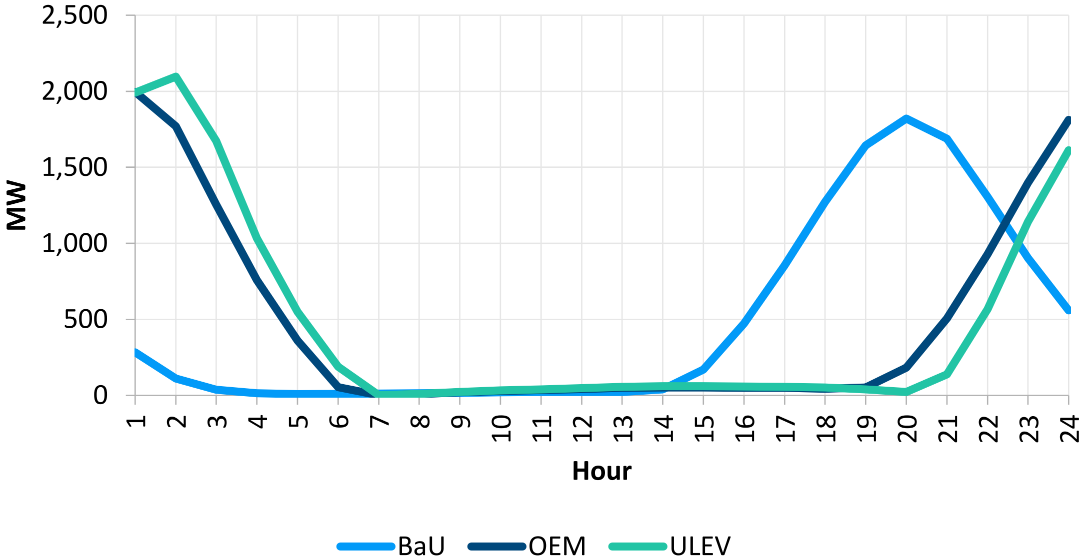


Figure 38 Work winter weekday charging profile for flat tariff (BaU), User-Managed Charging (OEM) and Supplier-Managed Charging (ULEV) in 2050



For the purposes of the Stage 1 modelling the consumer response to a static ToU tariff is assumed to be less marked than the shift under Supplier-Managed Charging i.e. part way between BaU and ULEV, and it was checked that this leads to a cost saving compared to maintaining their original charging profiles under a static ToU tariff. However, the degree of response from mainstream

[80] The managed charging profiles will be refined given further information from the trials, for instance, the potential inclusion of some within day charging.

consumers to such tariffs is a key area of uncertainty that could be investigated as part of the Stage 2 trials.

The shaped tariffs limit the growth in total peak demand on the system, despite growth in the number of PiVs. For instance, the PiV parc in 2030 in the OEM and ULEV Narratives is almost double that in BaU but the overall electricity system demand in the peak hour of a winter weekday is similar, driven by shifting of load, as shown in Figure 39 and Figure 40.

Figure 39 Total winter weekday electricity demand for flat tariff (BaU), User-Managed Charging (OEM) and Supplier-Managed Charging (ULEV) in 2050

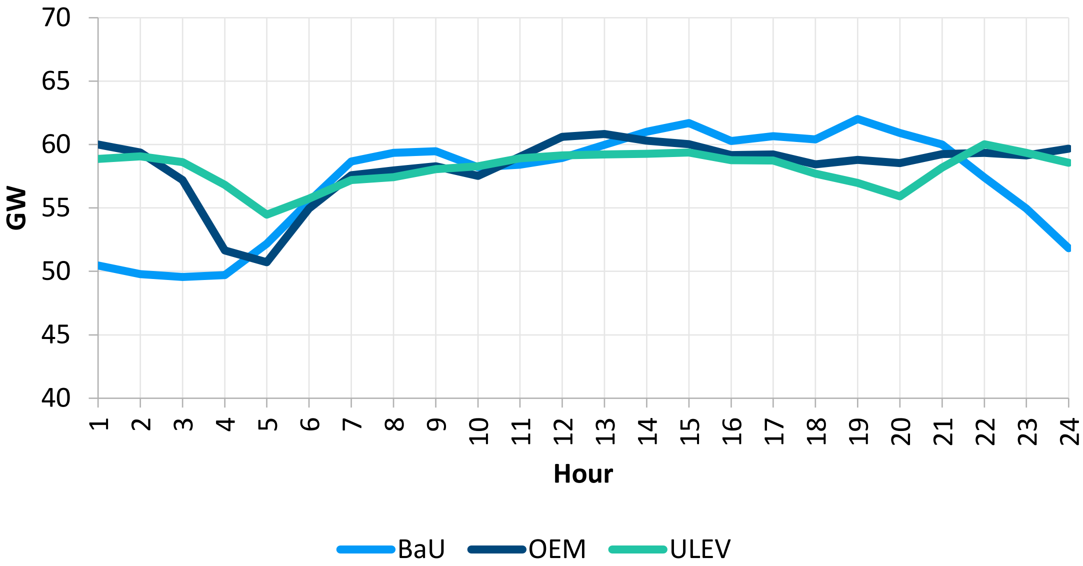


Figure 40 Total winter weekday PiV electricity demand for flat tariff (BaU), User-Managed Charging (OEM) and Supplier-Managed Charging (ULEV) in 2050

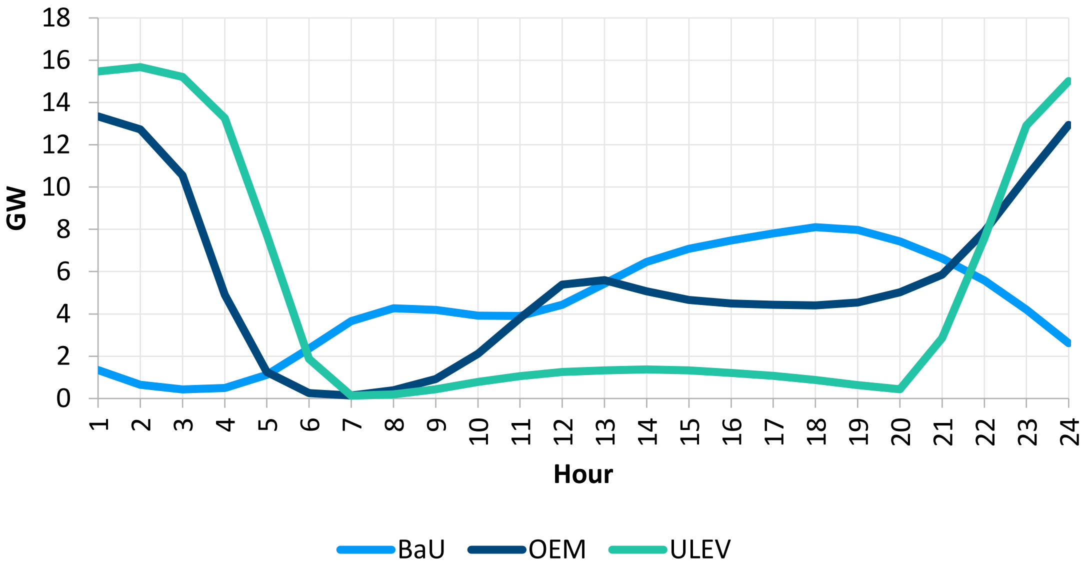
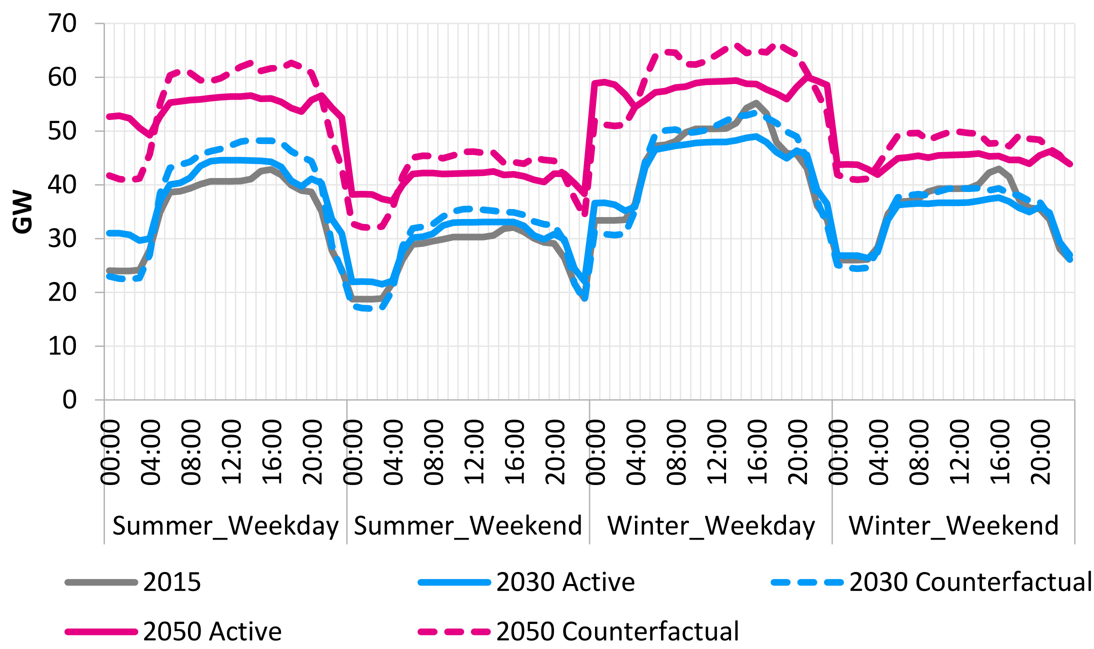


Figure 41 shows that Supplier-Managed Charging in the ULEV Narrative has a significant impact from 2030 to 2050, where a substantial part of the growth in peak demand on a winter weekday (between the dotted counterfactual lines without Managed Charging) is offset by the reduction in peak in 2050 due to Managed Charging (2050 active line).

Between 2015 and 2030 Demand Management reduces the winter weekday peak in 2030 to below the peak in 2015, at which time there is assumed to be no Managed Charging. In general, there is a growth in overall system demand in the summer from 2015 to 2030; this is not the case in the winter due to the effect of efficiency measures in the shorter-term.

The reduction in demand due to Supplier-Managed Charging appears proportionally greater from 2015 to 2030 than from 2030 to 2050[81]. Reinforcement of the distribution network is still required in later years, driven primarily by changes to peak demand in the wider energy system such as electrification of heating.

Figure 41 Daily demand shape in the ULEV Narrative



6.1.2 Impact on network reinforcement and balancing costs

Managed Charging reduces electricity system costs, in particular balancing costs associated with the TSO, and network reinforcement by the DNOs. TNO cost savings from avoided network reinforcement due to PiV load are also considered, but these tend to be very modest compared to those from the TSO and DNOs.

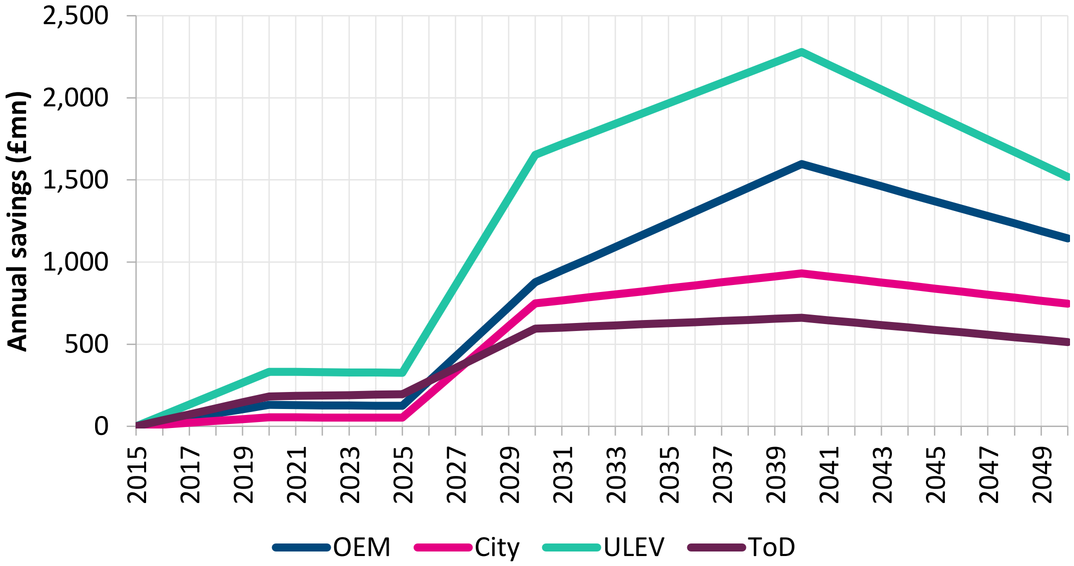
[81] I.e. the increase in demand from 2015 to 2030 is more than offset in some hours by Managed Charging, whereas Managed Charging offsets the increase in demand from 2030 to 2050 by a much smaller proportion.

Savings in balancing costs for the TSO (including additional peaking plant), shown in Figure 42, tend to be the largest component of savings and endure the duration of the pathway to 2050. They are driven primarily by a reduction in the need for flexible plant capacity and operation from OCGTs, hydrogen turbines and CCGTs[82].

User-Managed Charging in response to static ToU tariffs, used in the OEM and City Narratives, provide a reasonable proportion of the achievable savings, provided that consumers respond and shift load in the manner assumed in the modelling. The TSO savings represented here are based on implied improvements in the long-run efficiency of operating the system, for instance through building less peaking plant and operating it less often, rather than the specifics of the current intra-day balancing mechanism and cost recovery mechanisms.

This can be seen in Figure 42 by comparing ULEV with OEM, and ToD with City, as these pairs have a similar uptake of vehicles and different levels of demand shifting (i.e. ULEV and ToD have greater shifting with Supplier-Managed Charging, whereas OEM and City have less under User-Managed Charging). The Stage 2 trials could explore what proportion of the savings available from Managed Charging is achievable through static ToU tariffs.

Figure 42 TSO and peaking plant savings due to application of User-Managed Charging (OEM, City) and Supplier-Managed (ULEV, ToD) Charging

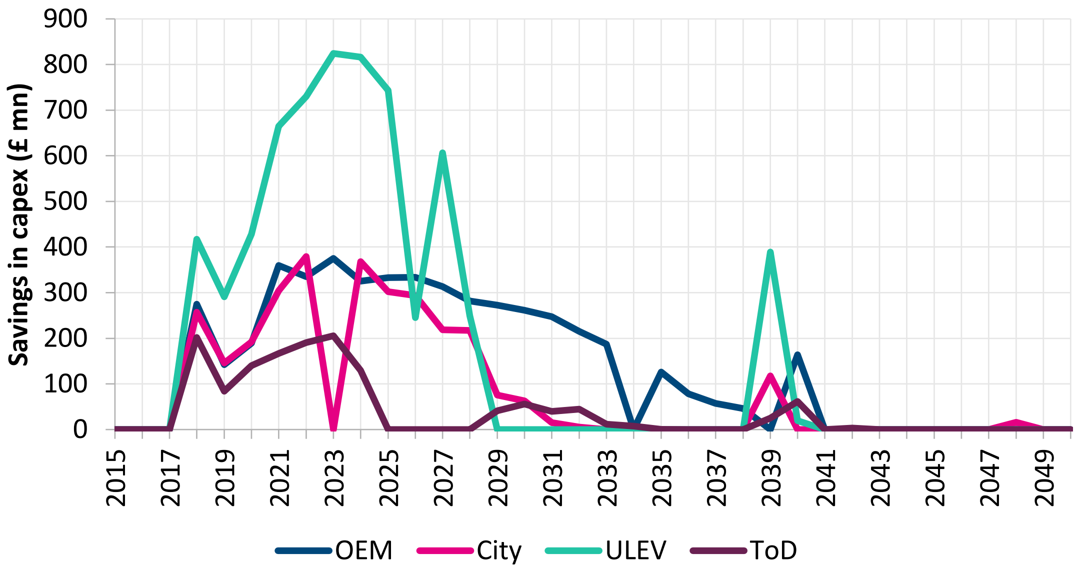


For the DNO, the savings (shown in Figure 43) are largest in the ULEV Narrative as this combines Managed Charging with a high proportion of home charging, and features the most rapid uptake of PiVs early on in the pathway. Most of the DNO savings occur in the period up to early 2030s as, in the absence of Managed Charging (i.e. in the counterfactual), PiV deployment is the main driver for reinforcement, with electricity demand on the wider system declining due to efficiency improvements. However, in the later stages of the pathway investment in network reinforcement

[82] This compares to a spend of £924mn on balancing services in 2015/16. http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Services-Reports/

resumes at similar rate to the counterfactual, and some deferred investment is caught up on, primarily to accommodate electrified heating. As with the TSO savings, User-Managed Charging in response to static ToU tariffs also provides a reasonable proportion of the achievable savings for the DNO.

Figure 43 DNO savings due to application of User-Managed Charging (OEM, City) and Supplier-Managed Charging (ULEV, ToD)



Effect on Consumers

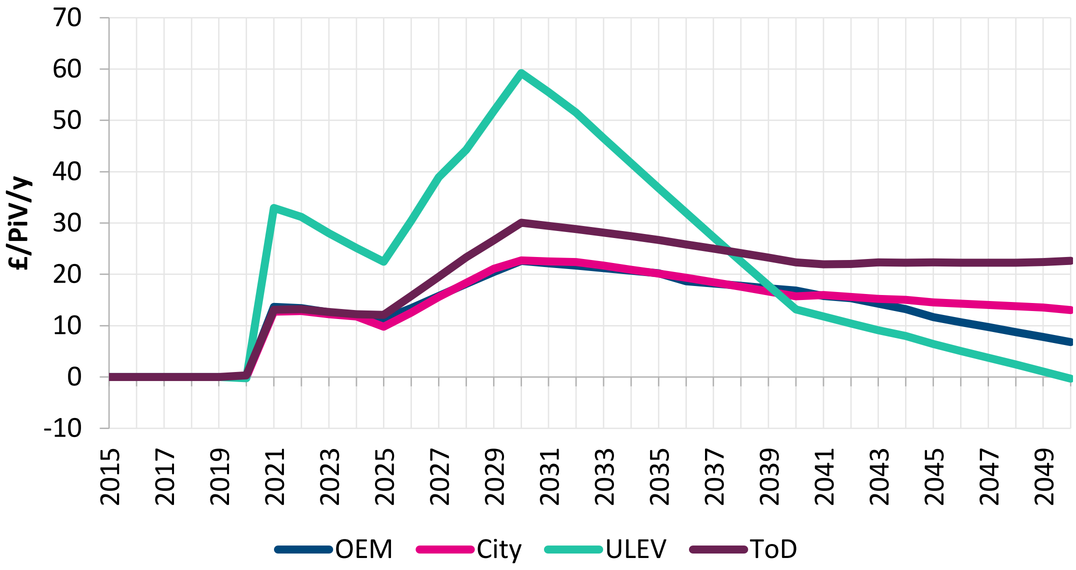
Private Consumers and fleets also reduce their charging cost through load shifting under User-Managed and Supplier-Managed Charging tariffs as more cost reflective pricing (four-periods across the day under User-Managed Charging / static ToU, and hourly prices under Supplier-Managed Charging) mean that the consumers (both Private Consumers and fleets) would have been worse off if they had not shifted their charging profile. The estimated saving as compared to this counterfactual is shown in Figure 44.

Although the savings to the consumer have been modelled as the savings in charging cost due to load shifting in response to more cost-reflective wholesale prices and network charging, in reality the proposition presented to the consumer could take many forms. Some examples are given below with more detail in section 3.2.1 in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*:

- The consumer may be required to specify or accept certain limits or constraints (e.g. specify their desired departure time and required state of charge on departure) – once, at regular times or on an ad hoc basis.
- The interface with the consumer could be via an app on their phone or a smart display in the vehicle.
- The consumer may or may not have visibility of the tariffs ahead of time given the period over which the prices could change (e.g. from fixed annual tariffs through to changing half-hourly prices).

- Reward payments to consumers could be given – an 'inconvenience' cost for allowing a third-party to manage their charging. The amount of reward could vary with the limits that are specified by the consumer or DM provider. The incentives could be provided on an upfront, ongoing, ad-hoc basis. Alternatively, penalties could be administered for not providing the specified level of flexibility under an agreement which provides a 'generous' base tariff.

Figure 44   Average savings in charging cost for consumers per PiV

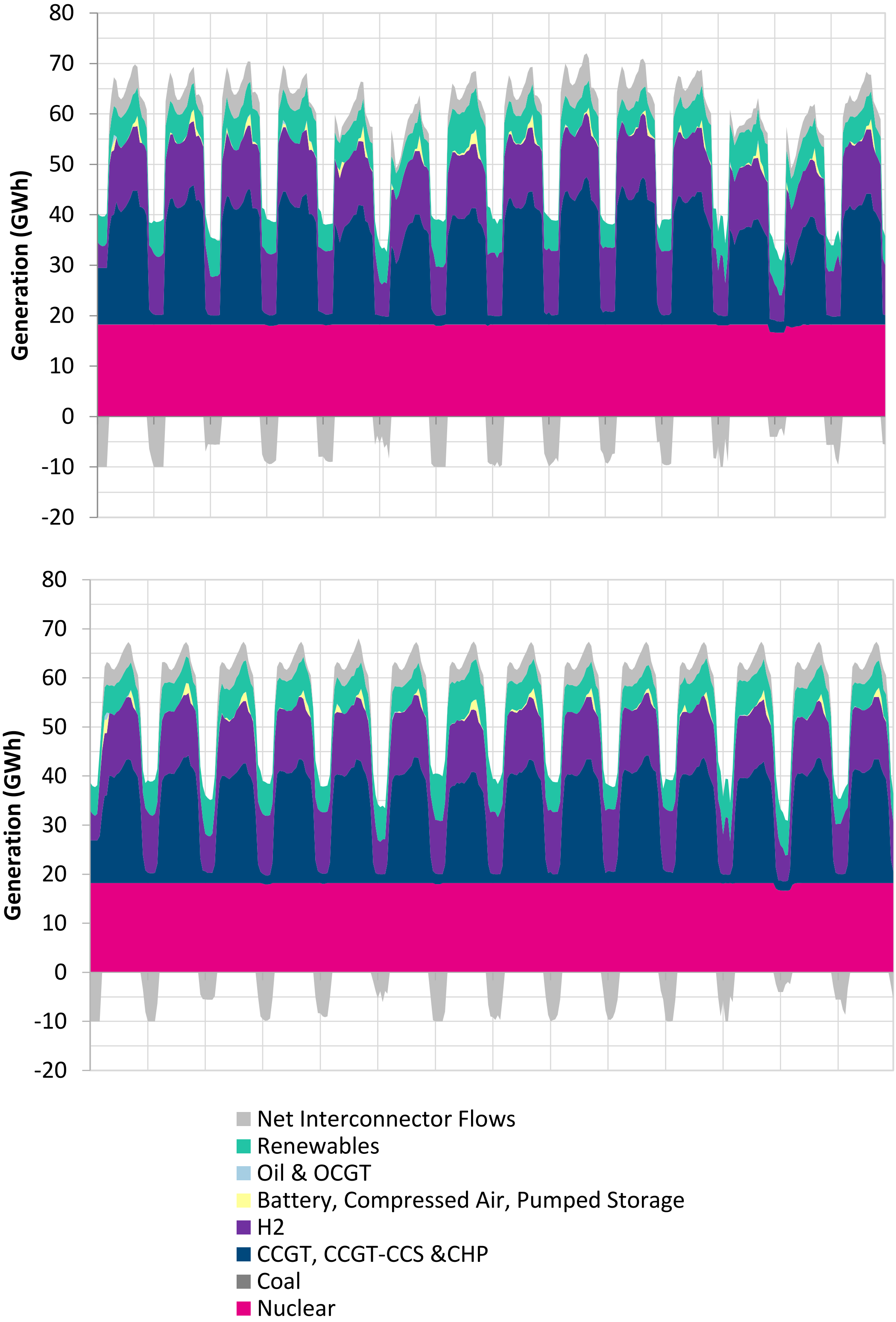


6.1.3 Operational feasibility of the electricity system

The electricity system requires significant short-term flexibility in either its dispatchable supply or via control of demand to ensure operational feasibility and minimise the potential for any unserved energy (i.e. unmet demand). This requirement is likely to increase in future given increasing levels of intermittent renewable generation (such as wind and solar) and increasing levels of electrified demand from PiVs and heating.

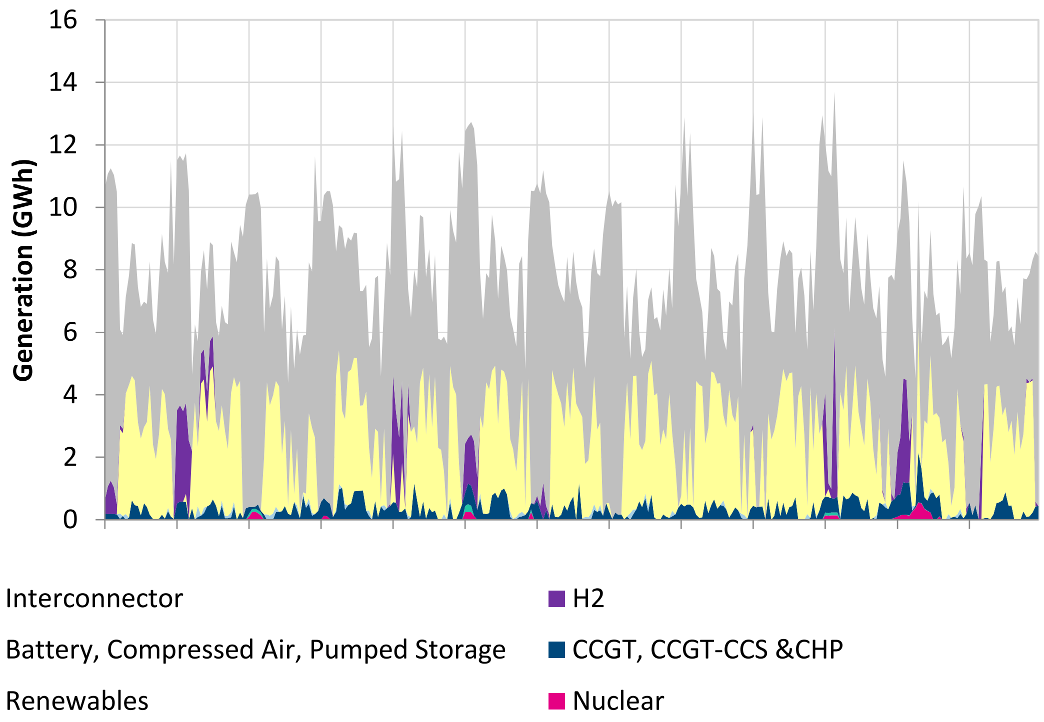
Figure 45 illustrates the hourly dispatch of available plant to meet demand over a two-week peak winter period in 2050 in the ULEV Narrative, which has a high penetration of PiVs by this point. The charts shows the dispatch profile with and without Managed Charging.

Figure 45 **Hourly dispatch for a two week peak winter period in 2050, ULEV – Unmanaged (top) and Managed (bottom)**



The system is peakier in the Unmanaged case but no direct unserved energy is observed[83]. However, the dispatch profile masks the overall tightness of the system at certain points across the system, which is illustrated in Figure 46. In the Unmanaged counterfactual to the ULEV Narrative, the available spare GB capacity on the system from technologies such as batteries and peaking plant drops to zero at certain points across the two week period, with the only remaining source of flexibility being from interconnector imports[84]. The available interconnector capacity is significant in absolute terms, but their ability to import at times of GB system stress is a function of what is happening at the same time in the various interconnected markets.

Figure 46 Hourly remaining available[85] capacity for a two week peak winter period in 2050 ULEV – Unmanaged[86]



[83] Unserved energy could also be driven by network constraints. The PLEXOS model used reflects a simple nodal model of the electricity transmission system, based on the regional geography present in the ETI ESME model.
[84] Although in reality there may be additional plant built in order to maintain an adequate security of supply.
[85] This is a measure of how much generation capacity is available but not utilised given dynamic unit commitment parameters. For example, it reflects the level of spare capacity which is *also* capable of being utilised in the same hour given ramp rates, minimum off times, etc.
[86] The same total amount of installed capacity is available with or without Managed Charging and, although the demand shape is flattened somewhat in Managed Charging, there are still peaks and troughs due to e.g. intermittent renewables generation. The charging profiles have been shifted exogenously, rather than optimised against the economic operation of the electricity system, and consequently the benefit that Managed Charging could have in reducing the tightness of the GB electricity system is potentially underestimated. With a direct understanding of the actual scale of consumer response under Supplier-Managed Charging from the Stage 2 trials it will be possible to configure an optimised response for, at least some portion of, the charging load.

It is also important to note that the modelling of heat electrification in the wider energy system (via the ESME model) is at the more optimistic end of what is likely to be possible in terms of managing heat load patterns. If this is more difficult in practice, it increases the requirement for strong management of PiV load.

6.1.4 Viability of the DM aggregator

The Commercial Policy and Accounting Tool tracks the cash flows associated with a number of commercial entities. A 'stylised' DM aggregator is represented as follows:

- Outgoing costs in terms of its net costs for engaging consumers in a Managed Charging scheme[87], and overheads, which are assumed to mirror those of a retail supplier on a per unit basis given the complexity that the latter faces in, for example, managing imbalance positions across the portfolio[88].
- Incoming revenue from the TSO, TNO, or DNO is provided through a generic, unspecified contractual mechanism. The revenue the DM aggregator receives reflects its outgoing costs plus its required margin. However, the potential revenue is capped at the maximum possible system savings. Therefore if the DM aggregator's costs exceed the maximum system savings, it would make a loss. Where the costs are less than the system savings the difference is effectively a benefit from Managed Charging which accrues to consumers across the wider system, and the paid revenue streams are pro-rated based on the maximum available savings.

The structure of the business model of the 'stylised' DM aggregator is one permutation of a number of different variations of the business model that could be put in place to provide Supplier-Managed Charging. Alternative business models are set out in the Appendix A.2.4 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* and as previously noted, the term 'Supplier'-Managed Charging refers to charging that is managed by any third-party acting as a 'DM provider' – a standalone DM aggregator, a supplier, a DNO / DSO or another third-party.

The standalone DM aggregator modelled in the *D1.2 Analytical Framework* is a UK-wide generic entity – this captures the total avoided reinforcement costs and system operation costs due to Managed Charging, although the actual cash flows may differ between specific individual entities and variations. Different entities are leading research and pilots into Managed Charging, as set out below, and this is likely to guide the exact structure of the DM business models that will evolve in future.

- **DNO-led:** for example, the Management of Plug-In Vehicle Uptake on Distribution Networks project[89], led by several DNOs, aims to recommend a solution that will allow the range of future chargers to interact with a common device located in the local distribution substation for the purpose of load management on the network and direct management

[87] Assumed to be a fixed cost per PiV per annum (differentiated by PHEV and BEV user) and a compensation payment in the rare cases that the DM aggregator's load shifting makes the cost of charging more expensive that it would otherwise have been.
[88] To the extent they have an energy position to manage, i.e. are an aggregator-supplier.
[89] https://www.westernpowerinnovation.co.uk/Mobile/Projects/Collaborations/Management-of-Plug-In-Vehicle-Uptake-on-Distributi.aspx

by the DNOs. The project will take place from 2016 to 2018. Similarly, Western Power Distribution intend to run the My Electric Nation trial, in which a demand control system will be used to change the rate or pause when 'early adopter' participant's PiVs are charging, simulating an event designed to prevent the network being overloaded.

- **OEM-led, partnered with a supplier:** for example, under BMW's Charge Forward scheme, BMW receives instructions from a utility to reduce load and it effects this load reduction by switching off a number of its PiVs on an hour-by-hour basis.

The current trials are largely seeking to address near-term network constraints, using 'command and control' mechanisms to switch off or delay load to prevent PiVs overloading distribution networks, particularly as clusters appear in the early stages of deployment. The Customer Proposition will be very different to that of a DM Aggregator which is seeking to address a longer-term challenge, shifting the charging of the vehicles to lower priced periods and thus reducing the peak on the system and simultaneously the charging cost to the customer. This longer-term approach is more market driven than the current 'interventionist' approaches and will likely require a framework to be put in place to support the interactions of different entities and the changes in consumer behaviour that may be required. The role of DM is discussed in more detail in section 7.2.

Whilst there are key uncertainties around the design of a Supplier-Managed Charging tariff and the effective cost that the DM aggregator would incur in engaging consumers in this (which will be explored further in the Stage 2 trials), the initial analysis shows that the simple DM aggregator model could be profitable in both the ULEV and ToD Narratives. The scale of the system benefits (i.e. the 'size of the prize') appears sufficient to provide a positive cash flow across the pathway, as shown in Figure 47 and Figure 48, but with a heavy reliance on TSO balancing revenue towards the end of the pathway. TNO revenues (for avoided transmission network reinforcement) are very small in comparison – minimal in ULEV and reaching £1mn by the end of the pathway in ToD.

Figure 47 DM aggregator cash flow in ULEV

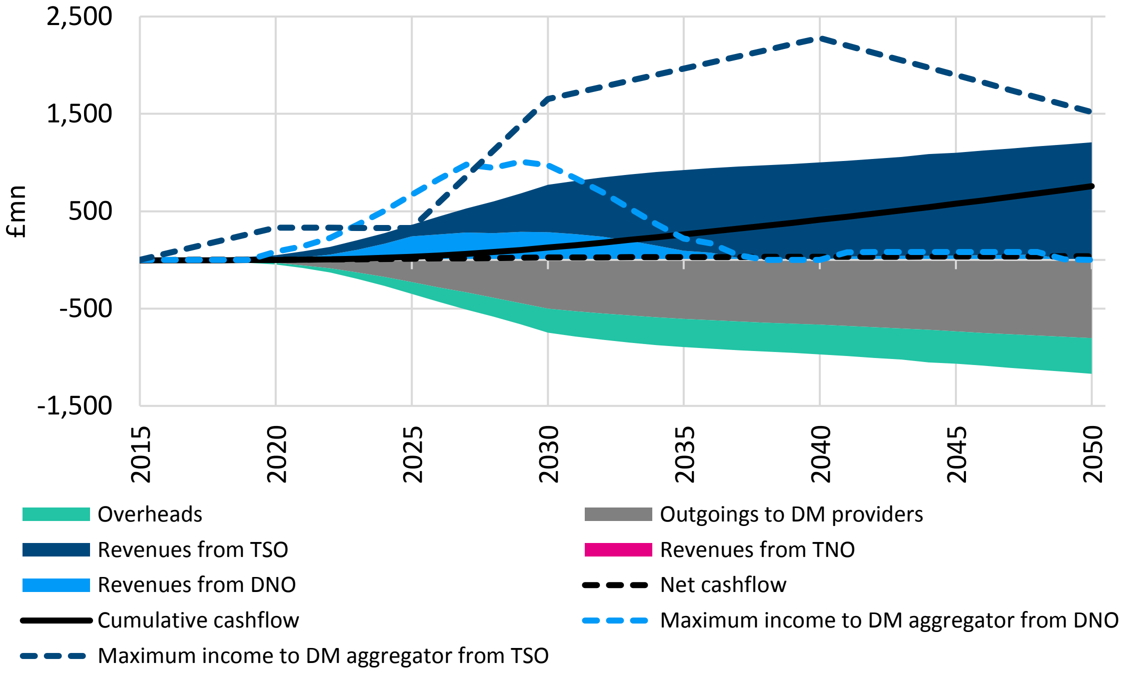
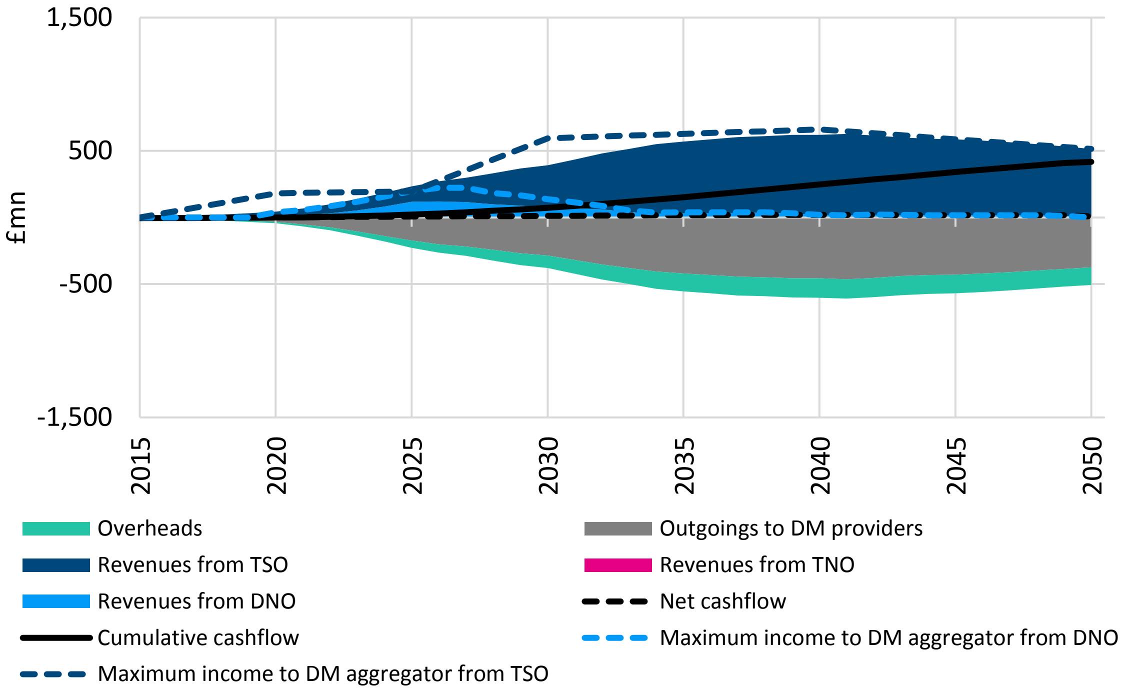


Figure 48 DM aggregator cash flow in ToD



In addition to the uncertainty around the cost of engaging consumers in a Supplier-Managed Charging tariff there are other significant areas of uncertainty that could affect the viability of the business model:

- The income will depend in the longer-term on balancing services. The value of this is much less certain than reduced expenditure on distribution networks, and is subject to competition from other sources which could provide balancing services more cost effectively.
- Over time, the DM aggregator could evolve to manage its costs more carefully (e.g. in areas where reinforcement has already occurred), by more carefully targeting providers to gain maximum benefit at minimum cost, and also potentially combining PiV DM services with those from other sources such as electrified heating.
- Static ToU tariffs and User-Managed Charging appear to provide a significant proportion of the benefits of fully Supplier-Managed Charging with potentially less restriction of consumer choice, although this is premised on the response driving longer-run improvements in efficiency of operation (e.g. reducing the need for build and operation of new peaking plants), rather than being used to support real-time balancing.

These and other more qualitative issues associated with the delivery of DM from PiVs are discussed in more detail in section 7.2.

6.2 Infrastructure and energy prices

The extent of the infrastructure built to support FCVs, PiVs and ICEVs varies across the Narratives depending on the relevant fuel demand and / or the vehicle parc, together with the type of infrastructure included in the Narrative, as defined in section 3.4.

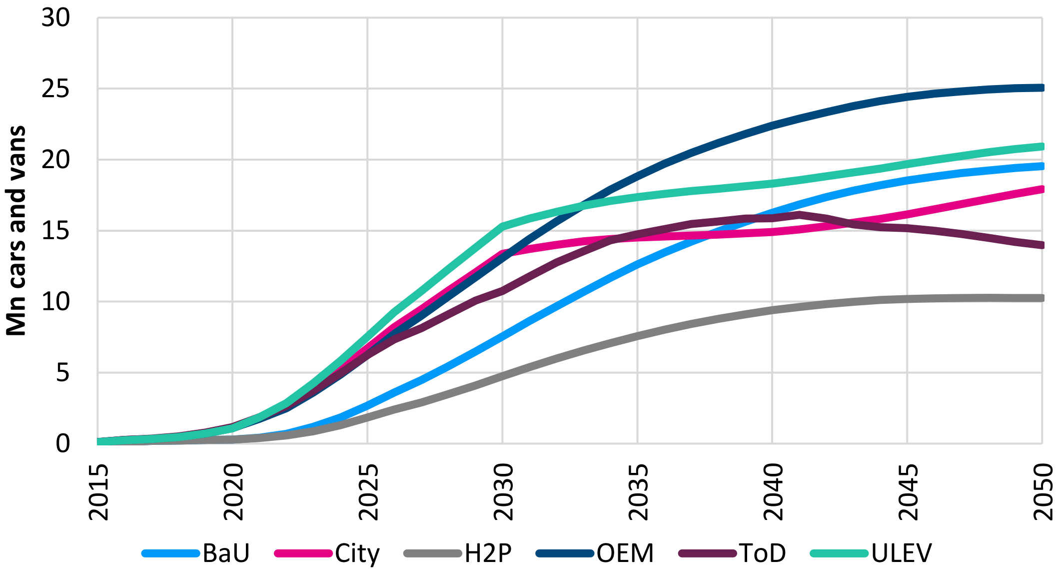
6.2.1 Electricity

PiV charging

Home, work, public and rapid charging points are built to facilitate the charging of BEVs and PHEVs. The extent of the charging infrastructure depends on the vehicle parc and a defined density of posts which is Narrative specific. Although the density of the charging posts is defined at a UK-level, these are then apportioned into rural and urban areas using the same factors as used for apportioning the PiVs. The locations are used in the MEDT tool in order to assess the cost of the distribution network.

Work and public charging posts are built according to the uptake of PiVs (including BEVs and PHEVs, shown in Figure 49), whereas it is assumed that PHEVs will not charge at rapid charging posts, thus the rapid charging points account for BEVs only. At a minimum, the number of posts built meets the required demand at that charging location and a home charging post is built for PiVs that charge at home.

Figure 49 Total PiV parc in different Narratives



Access to overnight charging is a key factor in the decision to purchase a PiV. All the Narratives assume that only those with guaranteed overnight charging access will consider a PiV in their choice set. The location of overnight charging varies with user segment:

- home access for vehicles at home overnight (Private Consumers, Fleet User Choosers and home-based Fleet Non-User Choosers)

- work access for depot-based Fleet Non-User Choosers[90], or
- public and rapid for Fleet Car Sharing.

The level of overnight access at home across consumer segments is based on survey data (conducted in Feb 2015 with over 2,000 UK car buyers)[91]. Overnight access ranges from around 70% to 100% for Private Consumers, with the exact value depending on the consumer type (e.g. pragmatists and innovators). For home-based fleet cars, overnight access is set to 78%, the average for all respondents from the survey data.

Similarly, based on analysis of DfT's Survey of Company Owned Vans, 50% of home-based vans have overnight access at home and 66% of depot-based vans have overnight work access. For depot-based fleet cars, 60% are assumed to have overnight work access, however the impact of this assumption is minimal as these account for only 5% of car sales.

Overnight access is assumed to be a pre-requisite to buying a PiV, and so all PiV drivers have 100% access to their designated overnight location. For vehicles chosen by Private Consumers and Fleet User Choosers, higher perceived access to charging at non-overnight locations improves the utility of PiVs (and hence the probability of purchase). For other fleet vehicles, access to these non-overnight charging locations does not influence the uptake prospects. Although overnight access is important, it is not inconceivable that if there were sufficient rapid charging points coupled with a sufficient battery range some consumers might accept no guaranteed overnight charging.

It should be noted that overnight charging is provided by access to home charging (points installed in private parking spaces) but also by residential charging points, for instance as supported by OLEV funding[92]. These residential charging networks are not yet developed and the budget suggested under 10,000 households[93], therefore they are not explicitly accounted for in the assumption on share of consumers with overnight access (70% to 100%). Nonetheless, if such networks develop in future, the share of consumers with access to overnight charging could be increased. Another potential factor for change could be the increase in battery size and deployment of rapid / public charging points, which together would remove the (currently modelled) need to have overnight access to consider buying a PiV. The deployment is a function of a variety of factors and it is not necessarily the case that this constraint is binding, or that relaxing it (e.g. from 70% to 100%) would result in significantly higher uptake of ULEVs. The maximum proportion of ULEVs in the parc is below 70% in every year for all Narratives, except H2P and OEM, in which it is below 70% until at least 2045. However, the impact of relaxing the overnight access is an assumption that could be tested in Stage 2.

Access to work, public and rapid charging posts is defined according to the level of competition for a charging point at the peak hour of the day[94]. In general, more charging points leads to higher perceived access and therefore higher uptake. Supply anticipates demand to some extent as the

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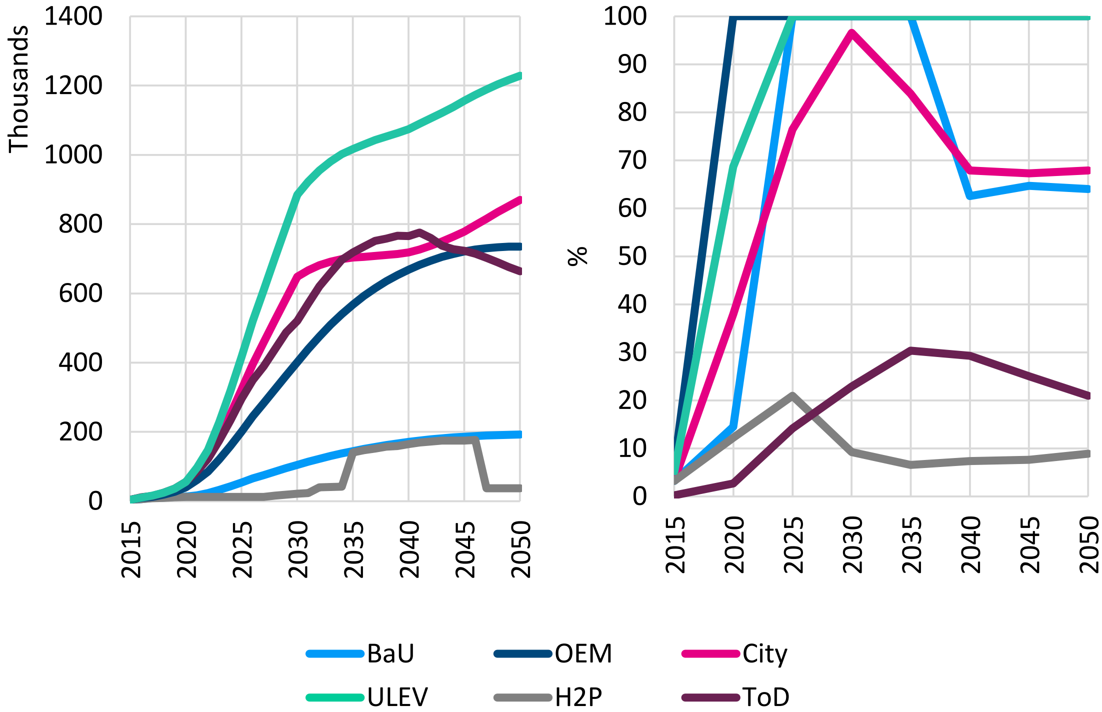
[90] Depot-based only, excludes home-based vans for example.
[91] Study by Element Energy for the DfT (2015).
[92] £3.5mn was announced in October 2016 and £8mn was awarded to London in 2016 Q1.
[93] £11.5m plus 20% match funding would give £13.8m, which can install around 1,400 PiV charging points.
[94] Based on the charging profiles for the Narrative, this is the hour in which the greatest number of vehicles are attempting to access a given charging point at a given location.

density factors follow a power relationship, with higher than average build in the short-medium-term and gradually flattening over the longer-term to the long-run density factor specific to the Narrative.

Public and work charging points

In the ULEV Narrative, consumers enjoy wide access to recharging infrastructure, designed to neutralise consumer anxiety over PiVs. The level of access[95] is high, reaching 100% by 2030 in most Narratives, suggesting that consumers would expect to be able to plug in at a public charging point at the time of day they want to. In ToD, access is low because most of the demand is met through public charging points, whereas in H2P no further charging points are built after 2020 unless absolutely necessary to meet demand[96]. The number of public charging posts built and corresponding level of access in each Narrative are shown in Figure 50.

Figure 50 Installed public charging posts[97] and percent perceived access by Private Consumers



A relatively high number of charging points are also built in ToD, in which a centrally coordinated programme for rolling out a widespread and standardised charging network is embarked upon, including subsidised electricity at non-home charging to 2030. This is in part to aid the transition towards car sharing. In response, charging occurs increasingly at public locations and rapid charging points on the trunk road network, rather than at homes.

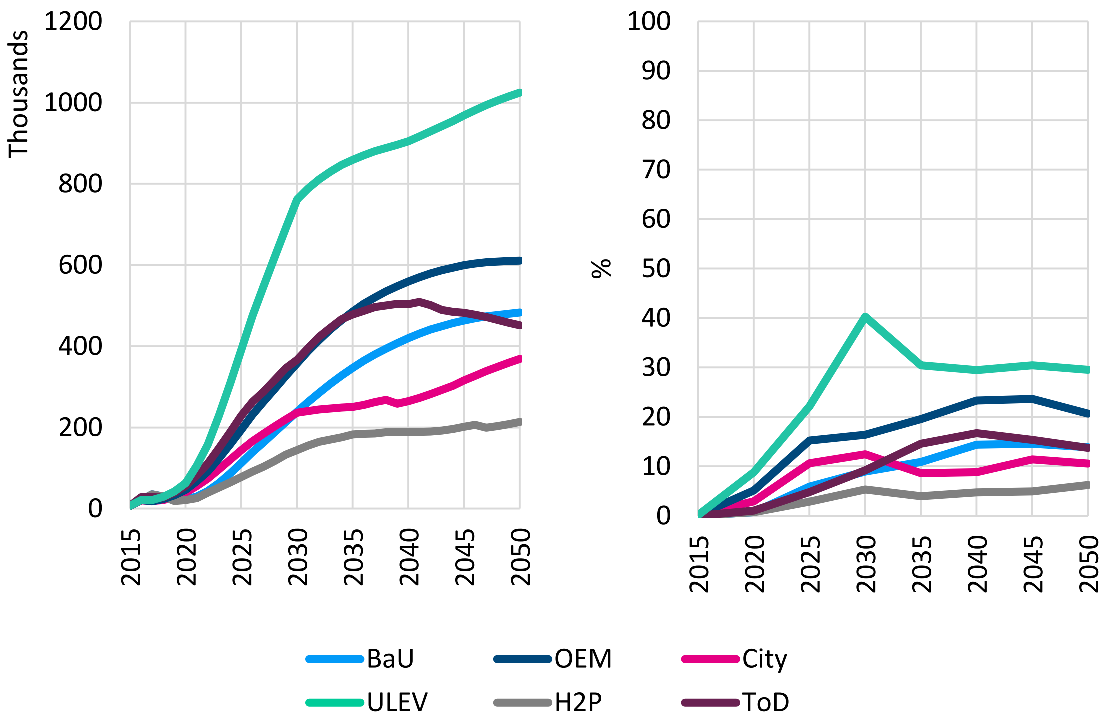
[95] The calculation of access is based on the level of competition and explained in more detail in Appendix D.4.
[96] The minimum requirement to fulfil the demand at each location is calculated in ECCo. This is set equal to the peak number of simultaneous charging events for that location. ECCo divides the day up into 20 minute windows and then calculates the number of cars plugged in during each of those windows. For each location it then looks across all the tariffs (peak weekday, Summer weekend etc.) and finds the window that contains the highest number of people charging.
[97] Two charging points are assumed per public charging post.

In City there is a concentrated nature to charging infrastructure, and a move away from vehicle ownership and towards renting vehicles through sharing schemes – the urban vehicle rental fleets are fuelled primarily in depots and at public hubs. A shift is made from 3 to 7 kW public charging points in all Narratives with the exception of City and ToD where faster 22 kW charging points are installed to facilitate car sharing, leading to a higher proportion of demand met at public charging points. In general, more charging points lead to higher perceived access and therefore higher uptake. In ToD and City, consumers perceive lower access at public charging points because these are highly utilised by shared cars. The number of work charging posts built and corresponding level of access in each Narrative are shown in Figure 51.

Access to work charging is in general much lower than access to public charging e.g. in ULEV there are around 20% fewer work charging points than public but the access is perceived to be much lower, due to longer time at the charge point per event.

In City and BaU there is a rapid drop in the level of access to charging due to the switching logic implemented in the model – the user can choose where they charge in response to price signals, within bounds, i.e. if the retail electricity price at a public charging point is less than at other locations, the user will shift some of their demand to the public points which reduces the perceived access for all users at those points. Although the logic is somewhat simplistic and has a noticeable impact on the access to charging, Figure 35 shows that the access at non-home locations is less important than at home locations.

Figure 51 Installed work charging posts[98] and percent perceived access by Private Consumers



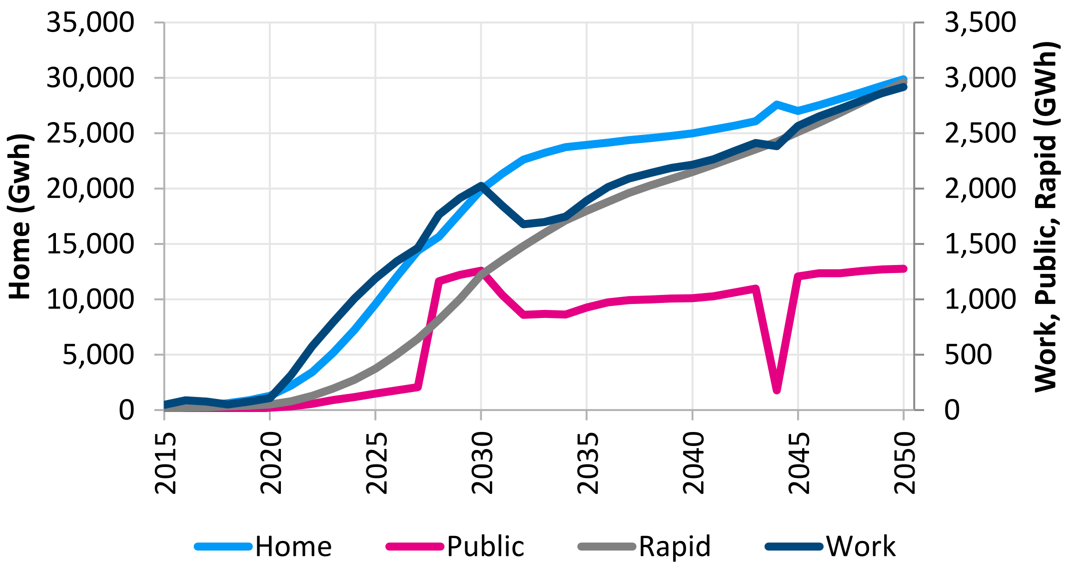
Over time the significant increase in PiV battery size means that there is a more limited role for public / work charging points, outside of their use to facilitate car sharing. A combination of

[98] One charging point is assumed per work charging post.

overnight charging at home, supplemented by a widespread rapid charging network, appears sufficient for Private Consumers, except in Narratives where there is extensive use of car sharing for which a public network is more important.

- Demand at public / work and rapid charging posts is similar even though hundreds of thousands of public and work charging posts are installed compared to tens of thousands of rapid posts. However, as shown in Figure 52 the demand at non-home charging points is much less significant than at home charging points (at which the access to charging has a higher impact on uptake – see Figure 35).
- The lower utilisation of the public and work charging posts and large amount of investment required (£1bn and £0.9bn respectively in present value terms in the ULEV Narrative[99]) suggests that there is limited need for extensive public and work networks, especially as the increases in battery capacities and improvements to BEV efficiency enable longer ranges (average NEDC range increases from 210km in 2015 to 300km in 2040) that could potentially cover all driving needs using only overnight home charging and top-up charging at rapid. This is particularly the case for Private Consumers – the public and work demand in Figure 52 is almost entirely driven by fleets with the majority of home and rapid demand from Private Consumers.

Figure 52 Demand at different charging point locations in ULEV[100]



Rapid charging points

In ToD a relatively high number of rapid charging points are built as more use is made of rapid charging than in the other Narratives:

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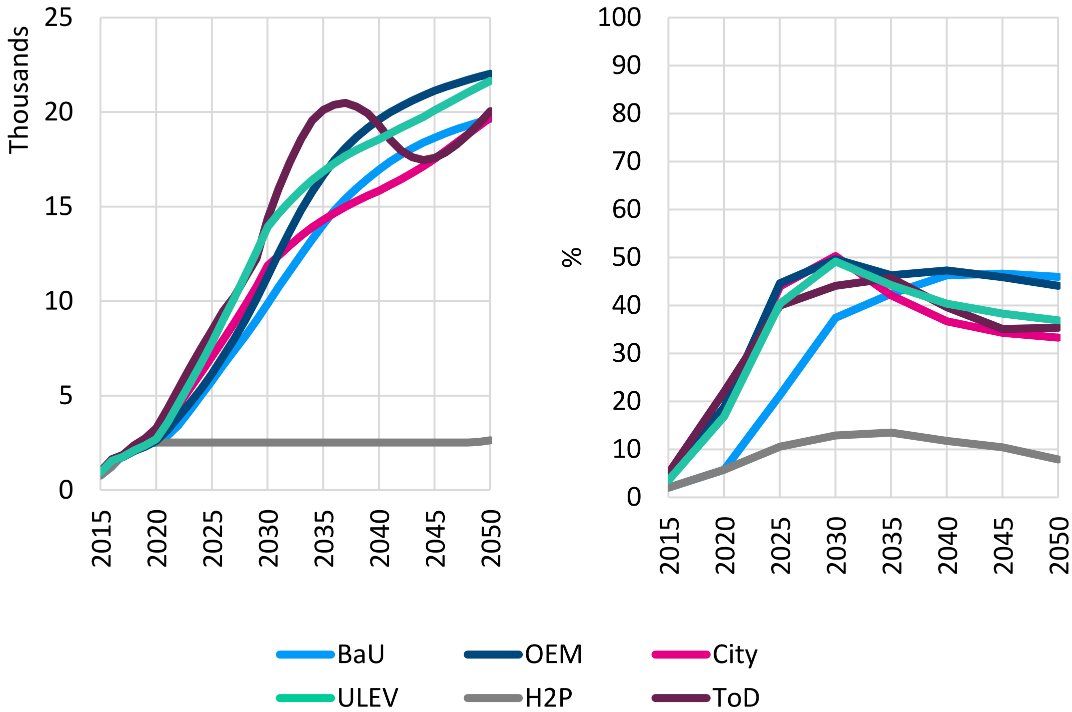
[99] Based on the respective WACCs

[100] The dips in demand at work and public charging points coincide with peaks in home charging. This is due to the logic implemented in the model, whereby users will choose to charge at the cheapest location in that year, subject to minimum and maximum bounds on the ability to switch by location. This switching does not occur at rapid charging points as they are assumed to serve other purposes such as facilitating longer distance journeys.

- In 2035, 20% of the PiV electricity demand is met by rapid charging points, whereas in Narratives without car sharing this ranges from 3% to 8% across the pathway. As a result, from around 2030 the number of charging points built are the minimum needed to meet the required demand – redundancy in the network is reduced and utilisation is high at around 80%.
- After 2040, the vehicle parc starts to decline as car sharing begins to have a larger impact on the total number of vehicles required, and as a result charging points are no longer replaced when they reach the end of the technical life. The total number of rapid charging points is then expected to stabilise in line with the lower absolute size of the vehicle parc.

The number of rapid charging posts built and corresponding level of access in each Narrative are shown in Figure 53.

Figure 53 Installed rapid charging posts[101] and percent perceived access by Private Consumers



The decline in access happens in all the Narratives and this is partly because some anticipatory investment is assumed, whereby there are more charging points installed per vehicle in the short to - medium-term when PiV penetration is lower (i.e. because the density of ownership around the points is assumed to be lower) and in the longer term an equilibrium is reached[102].

In ToD, the PiV parc declines after 2035 – as the uptake of FCVs increases – and consequently as the existing charging points that were installed early on in the pathway retire they are not replaced with new charging points. After 2045 the uptake of Fleet Car Sharing vehicles increases and consequently

[101] Two charging points are assumed per rapid charging post.
[102] The exception in H2P in which no further charging points are installed after 2020 unless they are absolutely necessary to meet demand, as the Narrative is aimed at incentivising FCVs rather than PiVs.

more charging points are required, compensating for the earlier decline – this is particularly evident as shared cars can only be charged at rapid and public charging points.

Charging tariffs

The number of charging points also affects the prices that consumers pay, shown in Figure 54, for charging at a public charging point operator. The retail price is primarily driven by the wholesale price and VAT. However, CPO overheads, CapEx and operating cost also form a substantial component and these per unit costs will vary significantly based on the charging point utilisation.

In OEM, the Narrative with the highest CPO CapEx on a unit basis for most of the modelled pathway, the public CPO capital costs are around 3 p/kWh in 2020 (13% of the retail price) and rise to 10 p/kWh (25% of the retail price) in 2035 as utilisation has fallen and charging is focused primarily at overnight and rapid charging points (outside of the City and ToD Narratives).

In the H2P and ToD Narratives, the capital cost component of the retail price is much smaller and this is because the charging points are utilised more than in the other Narratives. In H2P fewer charging points are built in line with the push for hydrogen, whereas in the ToD Narrative the cost of the infrastructure can be spread over greater electricity demand, as there is a shift to charging mainly at public charging points. In this Narrative, the minimum number of public charging posts are built from the late 2020s, leading to a consistent utilisation of around 50%, compared with OEM where utilisation is <5%.

In City and ToD, charging posts are faster at 22 kW and more expensive. In ToD electricity prices outside the home are subsidised until 2030 to incentivise charging at work, public and rapid locations as part of the shift towards car sharing.

Figure 54 Retail electricity prices for public charging in 2030 (Private Consumers)

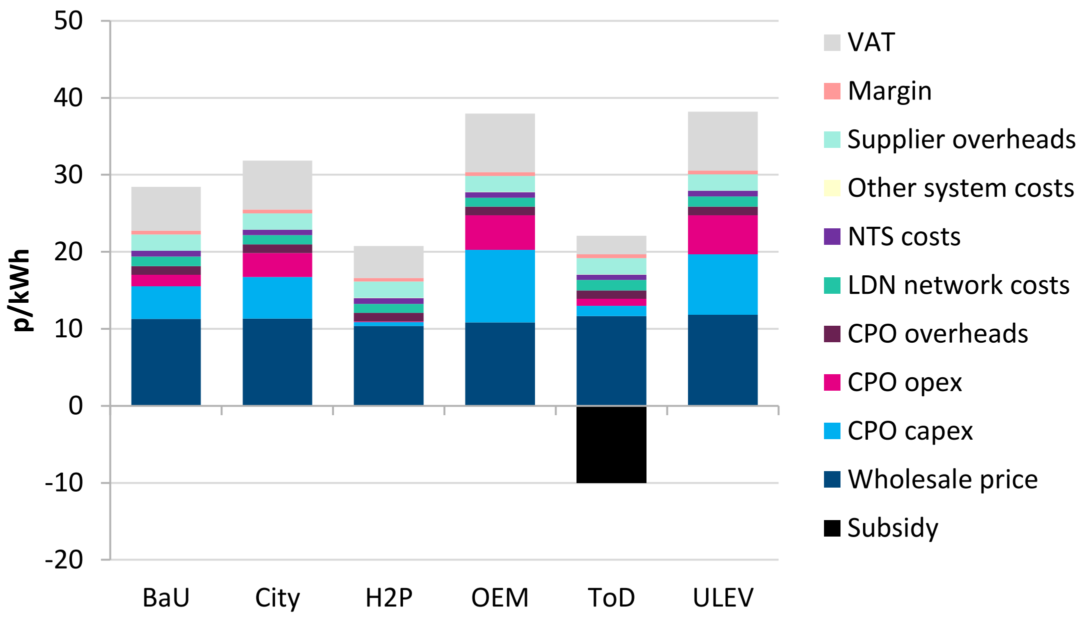
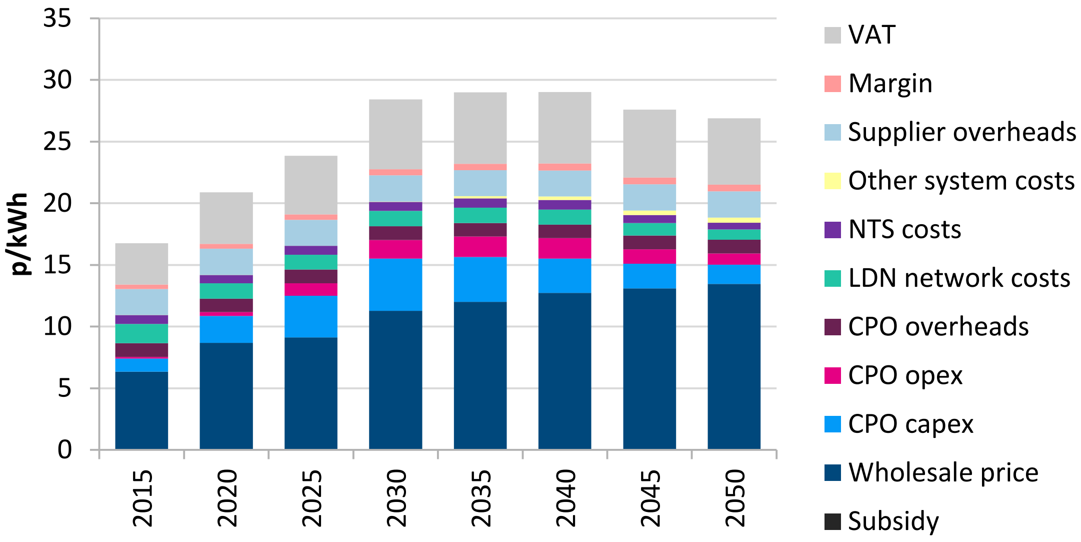


Figure 55 shows that the retail prices increase from around 17 p/kWh in 2015 to around 29 p/kWh in 2050. This is driven by higher wholesale prices[103] as the electricity system provides the focal point for direct and indirect decarbonisation of the wider energy system.

Figure 55 Evolution of the retail electricity price for public charging in BaU



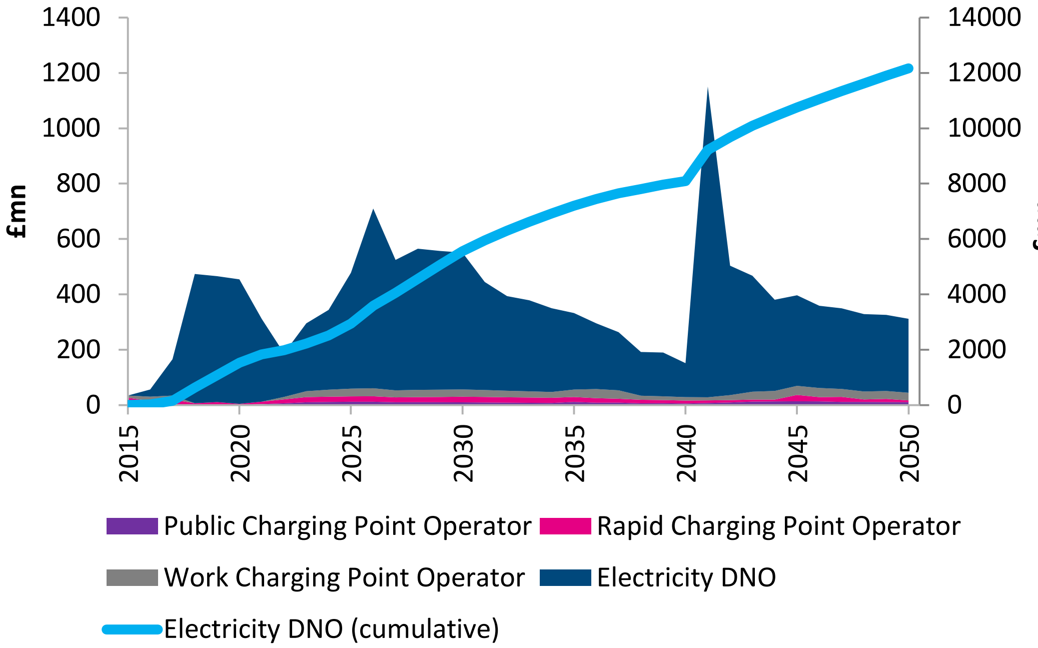
Aside from the CPO costs, margin, overheads, wholesale price and VAT, the stack consists of system costs for the national transmission system[104] and local distribution network, and other system costs (electricity storage, carbon capture and carbon transmission system).

In BaU, the LDN proportion of costs is highest, accounting for around 9% of the stack in 2015, whereas the NTS costs account for around 4% and the other system costs are negligible. By 2050, the LDN and NTS costs are a much smaller part of the stack at around 2-3% each.

Figure 56 shows that, relative to the capital costs involved in manufacturing and installing a charging point network, the costs to reinforce the existing electricity distribution network are far higher.

[103] I.e. wholesale prices reflect the costs necessary to recoup the full investment as opposed to purely the running costs. It is assumed that this is facilitated by appropriate policy support mechanisms.
[104] Including electricity transmission network costs as the main component, with secondary costs associated with CO_2 transmission and storage and the costs of electricity storage at the NTS level.

Figure 56 Electricity charging and distribution network CapEx (above replacement CapEx) for BaU (RHS axis represents cumulative)



The DNO costs are driven by the need to ensure the network can cope with increasing levels of peak demand. This is driven by a mix of ULEV and wider energy system demand (e.g. from electrified heating). Demand Management of ULEV charging can play a key role in lowering the cost of the network reinforcement through load shifting as discussed in section 6.1. In Figure 56 the investment by the electricity DNO is somewhat lumpy, particularly around 2040 when the peak demand on the system begins to increase rapidly, a trend which is also mirrored for heat pumps specifically.

The contribution of vehicle and building heat demand[105] to the total system peak demand is shown in Figure 57 for BaU, OEM (User-Managed Charging) and ULEV (Supplier-Managed Charging). This illustrates that:

- The peak of heat demand across the day under BaU conditions is higher than vehicle demand. Even though heat demand has already been load shifted through building storage, it still represents a significant proportion of demand across the day-time[106].
- In OEM and ULEV some of the vehicle demand has been pushed into the overnight periods due to User-Managed and Supplier-Managed Charging, thus vehicles contribute less to the system peak that remains in the day although overnight demand has increased. If vehicle demand was Unmanaged, the overall system peak would be much higher as shown in Figure 41.

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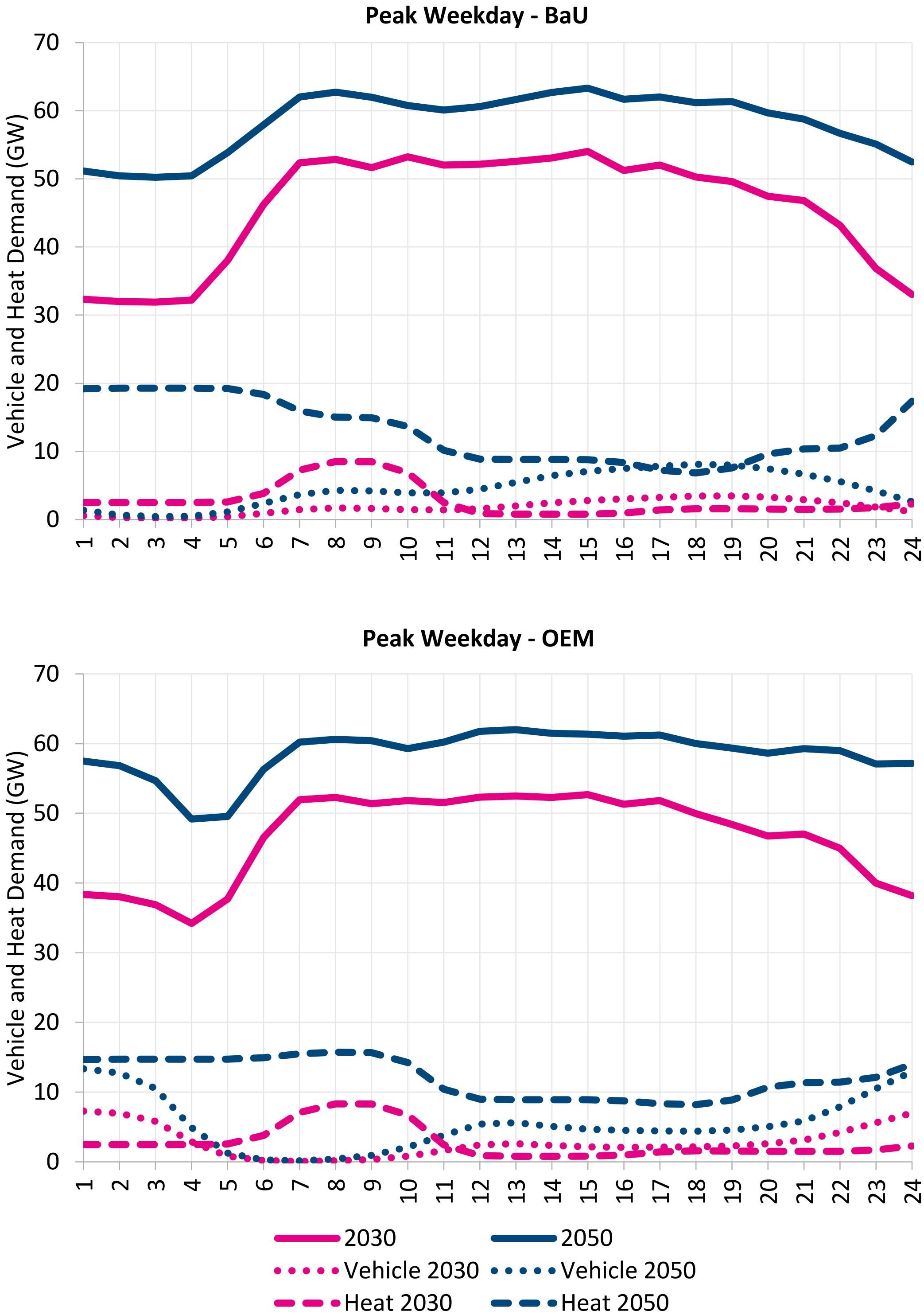
105 Space heat and hot water (excluding 'network' hot water for district heating and large scale heat pumps).

106 Heat demand is not that much more than PiV demand as the majority of heat at peak is provided using gas – in terms of the hot water and space heat provided from electric resistive heating, heat pumps and gas boilers (i.e. excluding district heating, biomass / oil boilers, micro CHP and micro solar thermal), gas boilers contribute around 95% of this in 2015 and 2030, decreasing to around 80% in 2050.

Figure 57 Contribution of vehicle and heat demand to total system demand



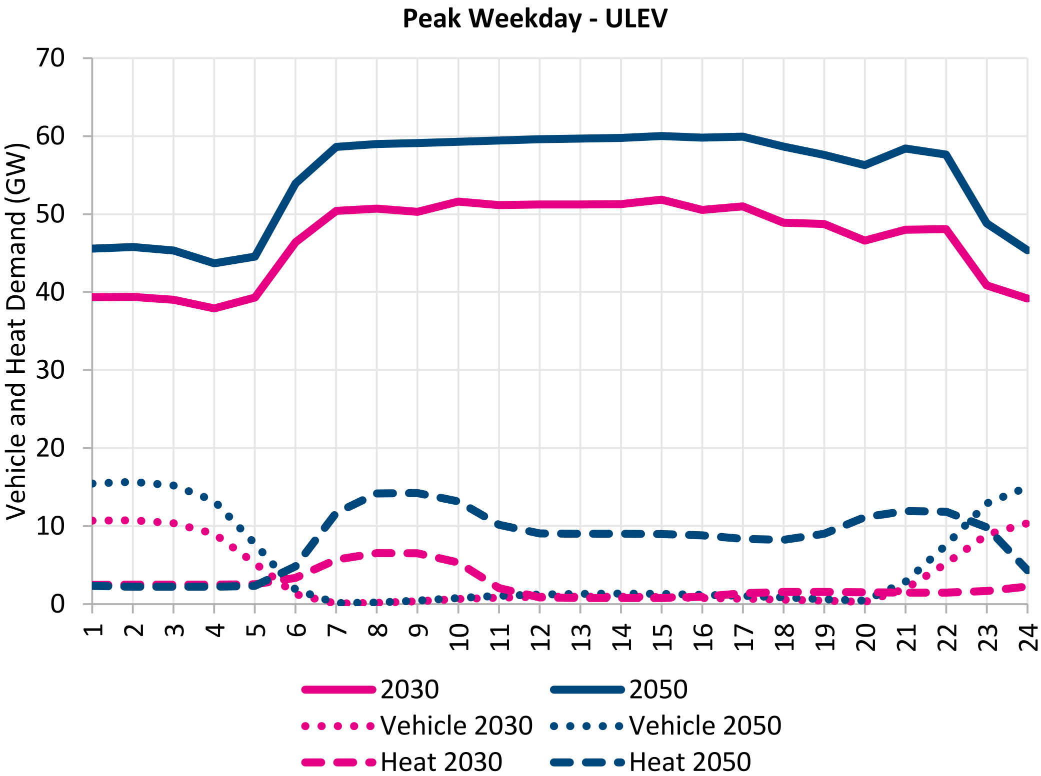
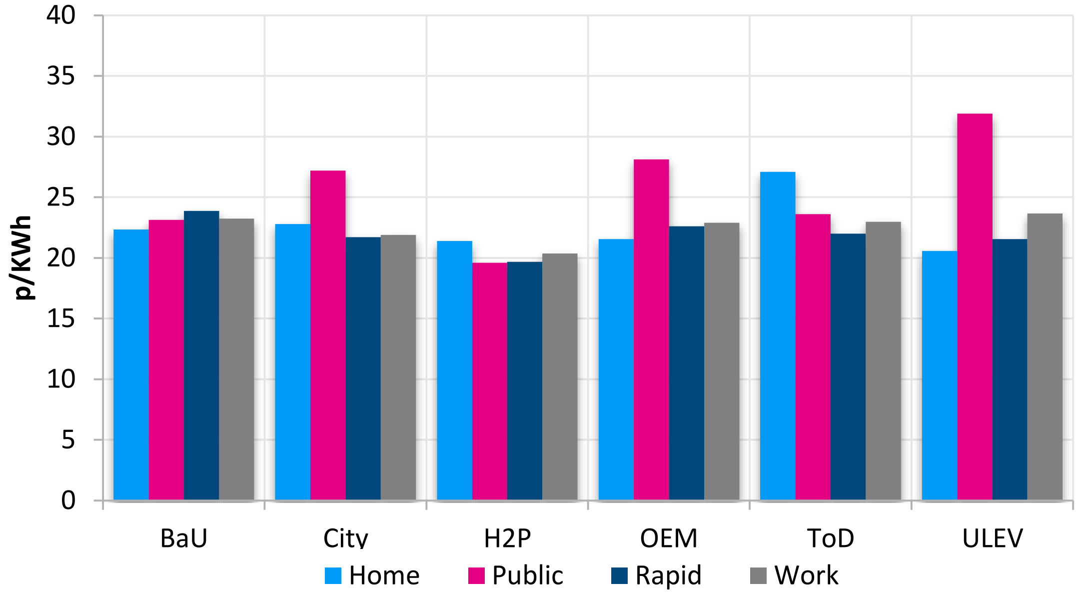


Figure 58 shows the retail prices at different charging locations for consumers. Assuming a competitive landscape, retail prices should be relatively similar across different non-home charging locations (allowing for the enhanced utility of faster charging facilities), which is broadly the case. On average, home charging is cheaper than work, public and rapid charging, with the exception of ToD, in which home charging is limited and charging at non-home locations is incentivised. Utilisation plays a key role in the per-unit costs seen by consumers. Although rapid charging points are more expensive they tend to have significantly higher levels of utilisation.

Figure 58 2050 retail electricity price average across all users



Charging point business models

The charging points are installed to meet the needs of the vehicle parc, specified as a density. Installation is assumed to take place within the same year as investment decision, unlike the case of larger infrastructure investments such as a hydrogen pipeline network, where construction takes several years. This means that there is generally a better match between incurring investment and realising revenue for charging posts, and so the business models should look more favourable.

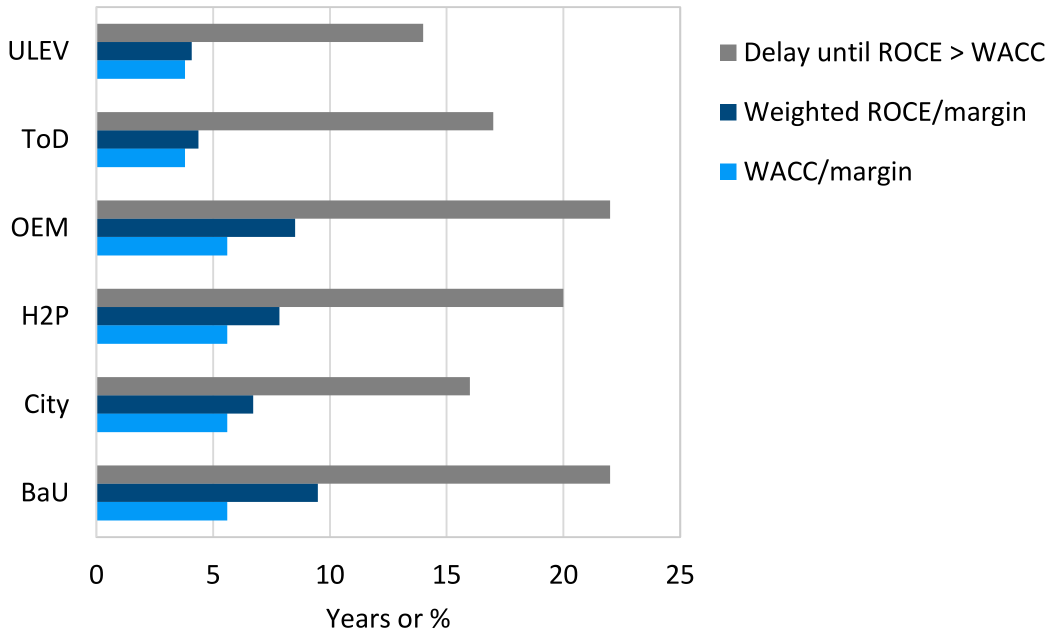
The business models appear to be positive for all Charging Point Operators across all locations. Figure 59 shows that the capital weighted Return on Capital Employed (ROCE) exceeds the Weighted Average Cost of Capital (WACC) for these businesses in all cases. The capital weighted ROCE is used for comparison with the WACC, rather than an Internal Rate of Return (IRR) as the businesses operate to a fixed modelling pathway (i.e. the pathway to 2050), investing in multiple cycles of projects over this period and so are incurring CapEx at multiple points in the pathway. As a result, IRR is not a suitable metric to assess the profitability of each individual business and compare across different types of business, and frequently cannot in any case be calculated.

The metrics calculated are discussed in more detail in Appendix C, but the cut-off in the modelling pathway in 2050 means that the entity may be part way through an 'investment cycle' and hence care must be taken in interpreting the metrics:

- If **weighted ROCE > WACC,** it means that entity is more likely, within the modelled pathway, to achieve its desired WACC. It does *not* mean that the absolute return on the investment will be significantly higher than the WACC, just that a positive business cycle of investing and recouping *sufficient* returns on that investment has already been seen.
- If **weighted ROCE < WACC,** it means that within the modelling pathway the entity has not demonstrated the ability to generate the required level of return. This does not

necessarily mean it will be impossible to generate this over the longer term, but the implication is that this is either more unlikely or that the potential time period before a sufficient return is seen is so long that it adds significantly to the investment risk.

Figure 59 Profitability of Public Charging Point Operator across Narratives



Although the business models appear to be positive for all charging point operators across all locations, there is still some subsidy required – in BaU this is £36mn over the pathway for the CPO's in present value terms. As an alternative to a commercial entity providing the capital with some Government subsidy, the cost of the infrastructure could be recovered directly from consumers. For example, in Ireland, ESB Networks installed a charging network for their 'eCars' pilot project and the cost was recovered through distribution network charges, with the ownership of the charging infrastructure yet to be decided[107].

6.2.2 Liquid fuels

The requirement for liquid refuelling infrastructure is assessed at an aggregate national level as part of the quantitative analysis. In all Narratives the conventional vehicle parc is in decline and therefore no new petrol and diesel forecourts are assumed – rather it is the costs to operate and maintain the existing stations that are captured in the petrol and diesel retail prices.

As the demand for petrol and diesel falls as shown in Figure 60, fewer liquid forecourts are needed to meet demand. As volumes decline, fixed operating costs per litre rise, and the operator's margin is squeezed. Closures occur in order to reduce fixed operating costs and maintain a minimum required margin assuming an average flow, determined from historical data. This continues until only a

[107] http://www.cer.ie/docs/000413/CER16286%20Consultation%20Paper%20re%20the%20ESBN%20Electric%20Vehicle%20Pilot%20%20Ownership%20of%20the%20Assets.PDF

minimum skeleton network is operational, as shown in Figure 61. Appendix D provides further details.

Figure 60 Petrol and diesel demand from cars, vans and HGVs[108]

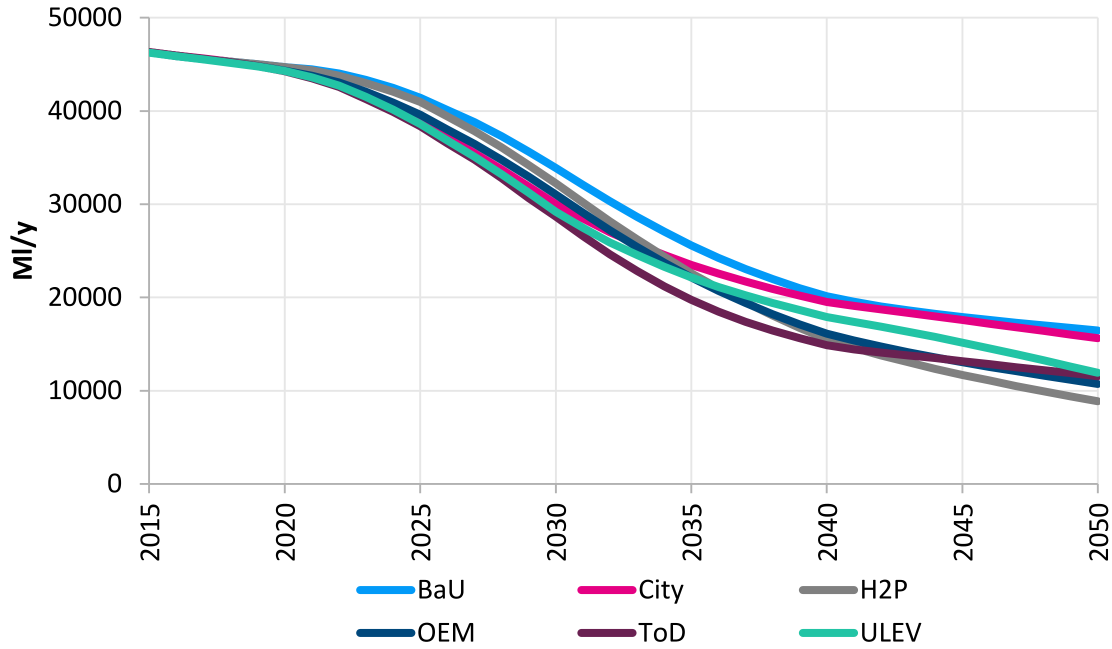
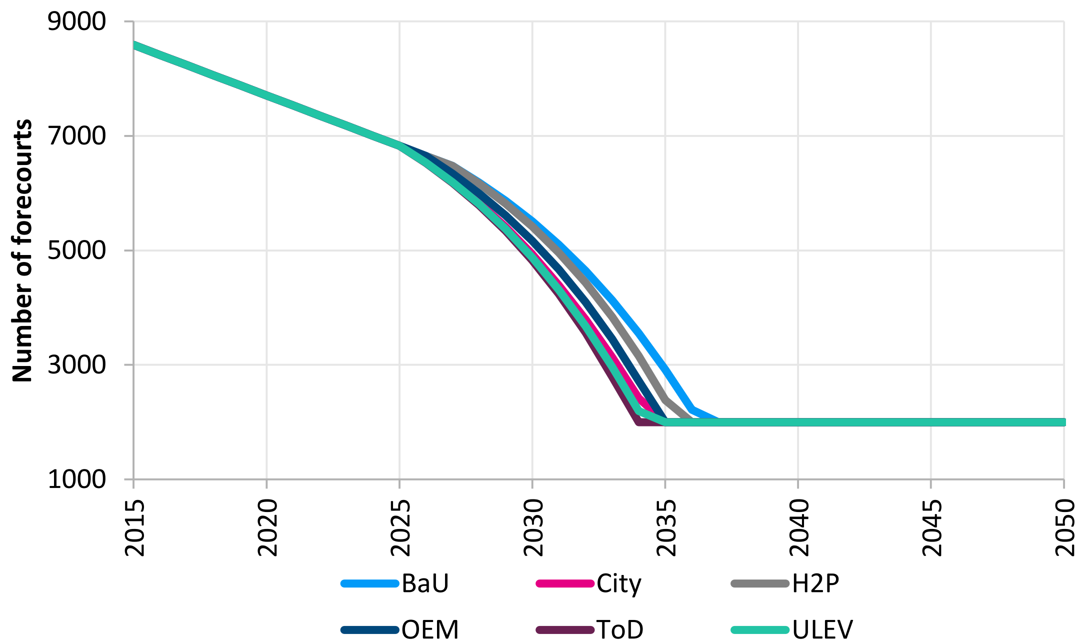


Figure 61 Number of liquid fuel forecourts in operation

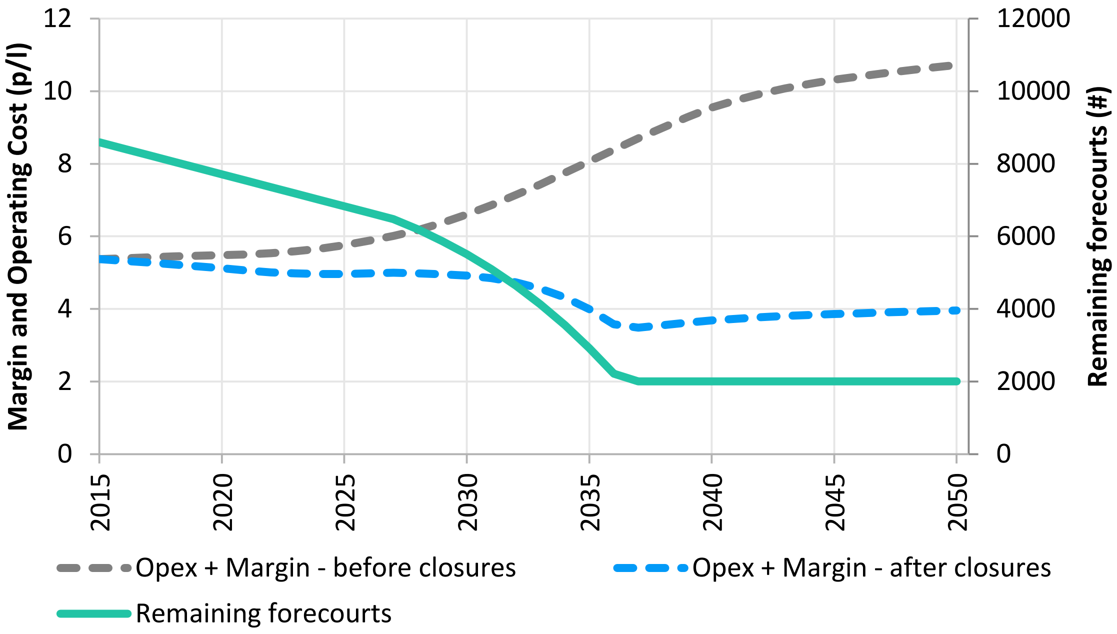


[108] 50% of HGV demand assumed to be met from own depots.

Until around 2025, forecourts are closed at a rate of around 200 per year in all Narratives, following a trend existing since around 2010. After this, the faster decline in petrol and diesel demand leads to a higher rate of closures, although a similar pathway is followed for all Narratives.

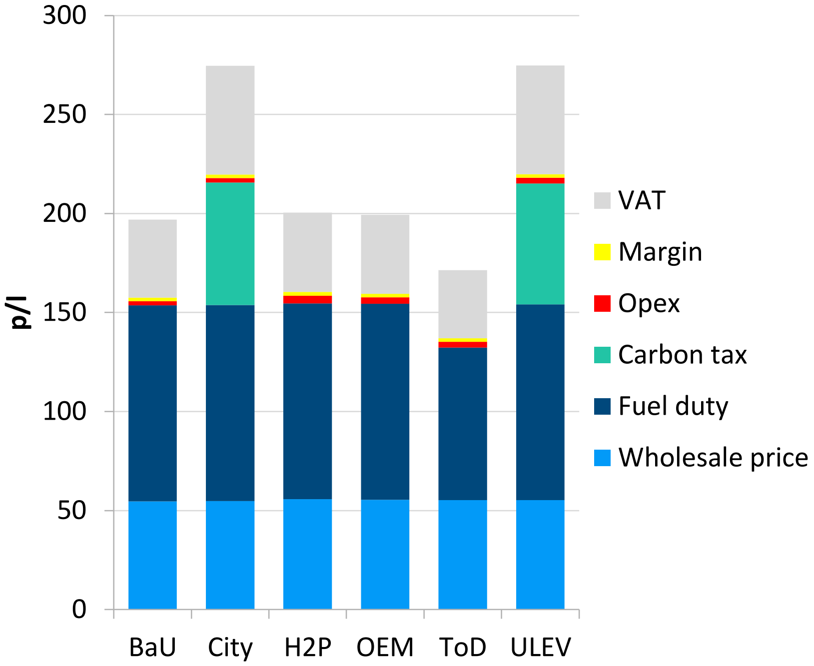
As the liquid fuel demand flattens towards the end of the pathway and a de minimis number of stations required for national coverage is maintained, the operating cost to keep these in operation stabilises at around 4 p/l including both operating costs and the required margin (see Figure 62). Even in Narratives with a stronger push for ULEVs, such as ToD, a substantial demand for liquid fuels remains to the end of the pathway as ICEVs have been replaced in part by PHEVs, as well as by BEVs and FCVs.

Figure 62 Average operating cost and margin before and after liquid fuel forecourt retirements – BaU



At this level, the operating cost represents only a small component of the liquid fuel retail prices, shown in Figure 63. The liquid forecourt operators are a margin business and therefore it is assumed that they recover the operating costs and the required margin as these are passed through to the consumer; hence no subsidy is required to keep the liquid forecourts in operation, at least in terms of an 'average' forecourt. In reality some differentiation is likely to be seen in costs for those forecourts still operating in more rural areas, as well as to provide security of supply, and these may require subsidy (as is currently the case for some locations).

Figure 63 Petrol retail price stack for Private Consumers in 2030[109]



The future of liquid fuel forecourts

Whilst the modelling suggests that there are a sufficient number of conventional liquid fuel vehicles on the road in 2050 in all Narratives to justify keeping a skeleton network of liquid fuel forecourts open without leading to a rise in average operating costs, some specific targeting of subsidies in rural areas may still be necessary for equity reasons, i.e. to maintain a broad geographical spread in the remaining forecourts. For example, currently a 5p/l subsidy is granted at forecourts in rural areas. Further assessment of the need for subsidy depending on the location of the forecourt (e.g. on motorways, in urban or rural areas) could be investigated as part of Stage 2.

As the demand for petrol and diesel declines, forecourt operators will need to adapt their business models – business models are discussed in more detail in Appendix A of *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*. This process has been happening already with operators targeting other revenue streams outside of fuel, for instance adding hot drinks service stations, mini-supermarkets and acting as parcel pick-up points. Other aspects such as smart pump technologies, whereby the consumer can refuel and pay without leaving their vehicle, serving to make the process more user-friendly and increase throughput, could become important. Further, they may need to add different fuel offerings such as hydrogen at the forecourt or rapid charging. The repurposing of liquid fuel forecourts to hydrogen refuelling stations has not been considered at part of this project, but it is clear that, should there be sufficient demand for hydrogen, this could be attractive relative to fully re-purposing the land for other uses.

Subsidy requirements may not be based only on the location of the forecourt. Currently liquid fuel forecourts can be thought of in three categories - independents, oil company-owned, and supermarkets. These typically have different throughputs and may also differentiate their non-fuel

[109] Cost to serve is assumed to be implicit in the operating cost for the liquid fuel forecourt operator

offerings. Subsidies might be related to the size of the forecourt or to other parameters affecting its profitability, such as the size of the owner's consumer base or the level of competition in the area.

The skeleton network in the model is equivalent to 23% of the current forecourt numbers and is based on the Liquefied Petroleum Gas (LPG) refuelling infrastructure; however, in reality the demand to keep forecourts open will be driven by the time taken to drive to a forecourt and the relative density of vehicles per refuelling station[110].

The resilience of the system

As the usage of multiple fuels and electricity increases, further consideration should be given to their ability to support mobility and the energy system across vectors, for instance:

- **The optimum balance between BEV and PHEV:** the requirements for energy infrastructure and the Customer Proposition challenges are different. The results of the analysis using the *D1.2 Analytical Framework* show that in general PHEVs are favoured over BEVs for cars, with the ratio of 1.1 to 1.4 in 2050 for all Narratives except H2P (see Figure 26). This is driven by the lower upfront purchase price of PHEVs until the 2040s. For vans, BEVs are favoured where they are able to meet the underlying duty cycle requirement because van buyers base their decision on the Total Cost of Ownership. Thus, the high purchase price of BEVs is less problematic as it is explicitly contrasted with operating cost savings. Vans also have limited or potentially no window to access charging during their duty cycle, resulting in a smaller proportion of miles driven in electric mode for PHEVs, which reduces the potential operating cost savings.

  However, given the relatively equal split in PHEV vs. BEV across Narratives, *sensitivity analysis would be required in Stage 2 to determine implications of different mixes and the resilience of the system* – i.e., if liquid fuels were not available, what effect would this have on the uptake of different vehicle types and the viability across all Dimensions?

  The consumer preferences on uptake of BEVs or PHEVs is a key aspect of the Stage 2 trials – discussed further in section 8.2.

- **The resilience of the liquid fuel system in itself:** in the face of closing liquid fuel forecourts it is important that the resilience of the liquid fuel system is maintained. Currently the Government has emergency plans in place for fuel shortages and provides guidance on business continuity management – suggesting that in the most extreme of circumstances petrol stations and commercial supplies could be exhausted within 48 hours of a major incident[111] and it could take up to 10 days before stock levels are fully restored[112]. The Petroleum Industry Association released a report in 2010 in which it proposed that the

[110] http://www.ukpia.com/docs/default-source/download/UK_Petroleum_Retail_Market_Study_Final_Report_v3_STC.pdf?sfvrsn=0
[111] A disruption could be caused by a number of factors, including scarcity of supply, a technical problem with part of the fuel supply infrastructure, industrial action or public protest. In the event of such a disruption to supply, it is also possible that stocks could be further depleted through increased consumer demand (panic buying).
[112] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/60552/business-continuity-plan-fuel-nov2008.pdf

level of storage in the UK should be increased, particularly to store more oil products as the domestic oil supplies and refining capacity reduces[113].

There is already a natural buffer in the liquid fuel system because of storage in ICEV / PHEV fuel tanks and at the existing forecourts. In the near-medium-term the storage and flexibility of liquid fuelling infrastructure is likely to be far easier and lower cost to manage compared to storage via the electricity system – i.e., if liquid fuels could be kept at existing forecourts or managed by individual consumers. Over the longer term, the storage capability of the electricity system will become more comparable with the liquid fuel system. This will be driven by lower battery costs and higher battery densities (for both directly grid connected storage and within PiV batteries) resulting in longer (e.g. 300+ km) ranges for electric vehicles (versus 500+ km for liquid fuel vehicles currently). However, storage of liquid fuels is likely to remain more scalable at a lower cost.

- **The interaction between the liquid fuel and electricity systems:** the electricity system will be under additional stress as ICEVs are replaced over time with PiVs. The resilience of the electricity system has been explored via PLEXOS under both regular and peak conditions, as set out in section 6.1.3, but implementation of different forms of Managed Charging will help to mitigate a significant portion of these adverse effects.
- **The interaction between hydrogen refuelling stations and conventional liquid fuel forecourts:** as discussed previously, the hydrogen refuelling stations are modelled as new-builds, rather than as repurposed liquid fuel forecourts. In some cases it may be feasible and make economic sense to offer both products from same stations, and to enable an acceptable geographic distribution of liquid fuel forecourts to be maintained. This may require central coordination or strong policy incentives to achieve the desired geographical spread given equity concerns – e.g. capping maximum travel time to reach a refuelling station.

6.2.3 Hydrogen

The infrastructure built to support the uptake of FCVs varies with the theme of the Narrative, in particular the extent of localised versus centralised production and whether the hydrogen is delivered to refuelling stations by trucks or pipelines.

In order to avoid very high hydrogen prices at the beginning of the investment cycle, the businesses under-recover costs initially when hydrogen demand is low (and investment occurs), and over-recover later on when volumes are greater. The commercial entities as modelled in CPAT set prices in a way that aims to stabilise the price level seen by the consumer over the lifetime of their investments. Under-recovery in the near term is accepted in anticipation of greater volumes later in the pathway. In Narratives in which the volume of hydrogen is growing quickly (BaU and ULEV in Figure 64) the effect of under-recovery early on and over-recovery later is more pronounced[114].

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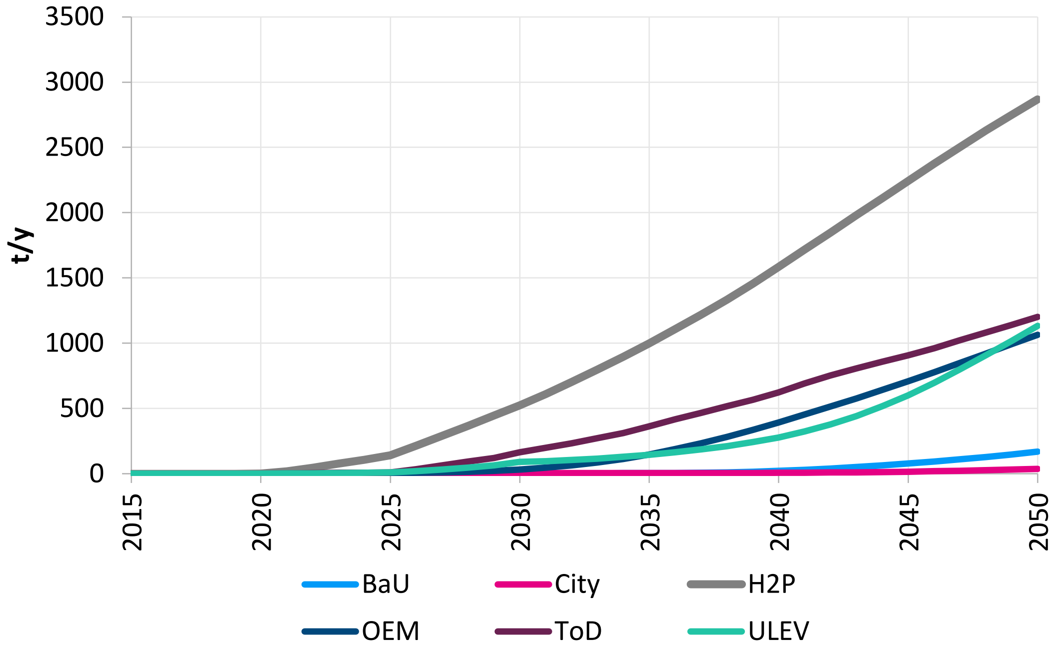
[113] http://www.ukpia.com/docs/default-source/publication-files/1733-downstream-oil-short-term-resilience1.pdf?sfvrsn=0

[114] It is assumed that the entity operates for the entire pathway rather than per individual truck. Each truck makes the return required over its lifetime but because the business keeps investing it under-recovers in the short-medium-term overall. After 2050, volumes are assumed to be flat and the ROCE becomes positive (for both BaU and ULEV).

Figure 64   Hydrogen demand used for transport only - all Narratives



Hydrogen Refuelling Stations

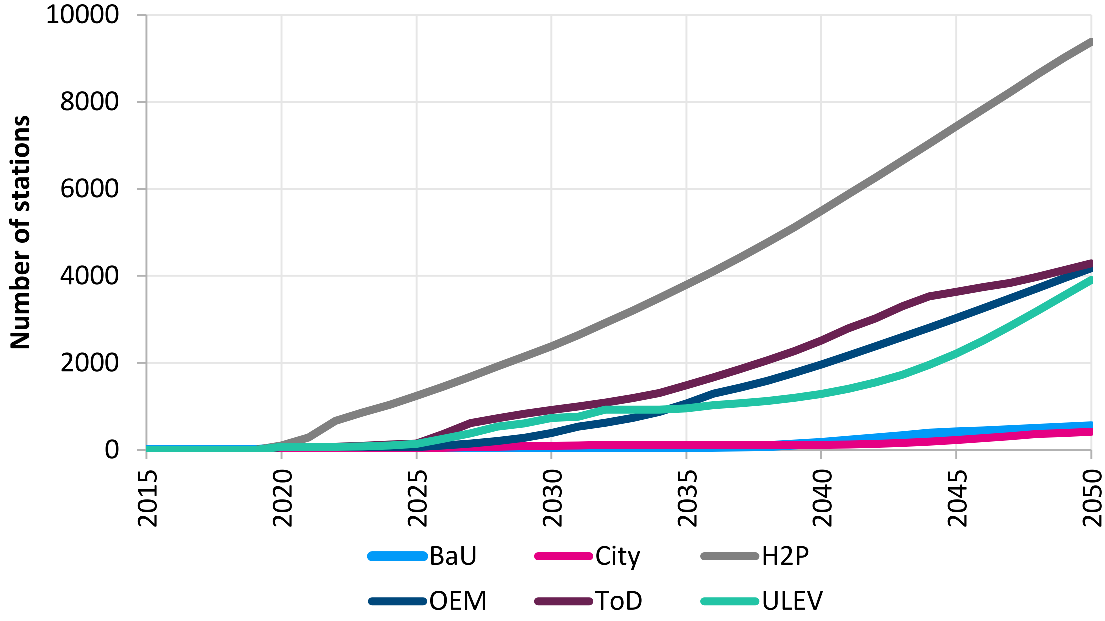
As per the charging infrastructure the number of Hydrogen Refuelling Stations (HRS) depends on the FCV parc and an assumption around the density of stations. Smaller stations are built at first when the demand is lower and a transition to medium and larger stations occurs as the demand increases, e.g. in City there are only small stations, whereas in H2P, larger stations are built from around 2025. The utilisation of the stations reaches around 90% in the Narratives, although the point at which this is reached depends on whether the Narrative is specifically targeting high uptake of FCVs. In addition, there is some overbuild or anticipatory investment at lower levels of FCV uptake to account for the likely lower density of FCVs across the country; i.e. to reflect a more conservative assumption that owners will not necessarily cluster around the refuelling station network as it develops.

The HRS network is formed of new-build stations and is assumed to be independent of the current liquid forecourt network. As liquid forecourts close, the HRS may be sited at these locations. However, any capital cost savings that might arise from doing so are not incorporated in the modelling and are assumed to be minimal.

In H2P there are around 22mn FCVs by 2050 and around 9400 refuelling stations are built to support these, as shown in Figure 65, equivalent to around 2300 FCVs per station. Comparing this with the current number of liquid fuel forecourts[115] suggests that this network would be more than sufficient to enable refuelling[116].

[115] 8600 forecourts supporting 33mn diesel and petrol ICEVs and PHEVs.
[116] Subject to differences such as refuelling time and range.

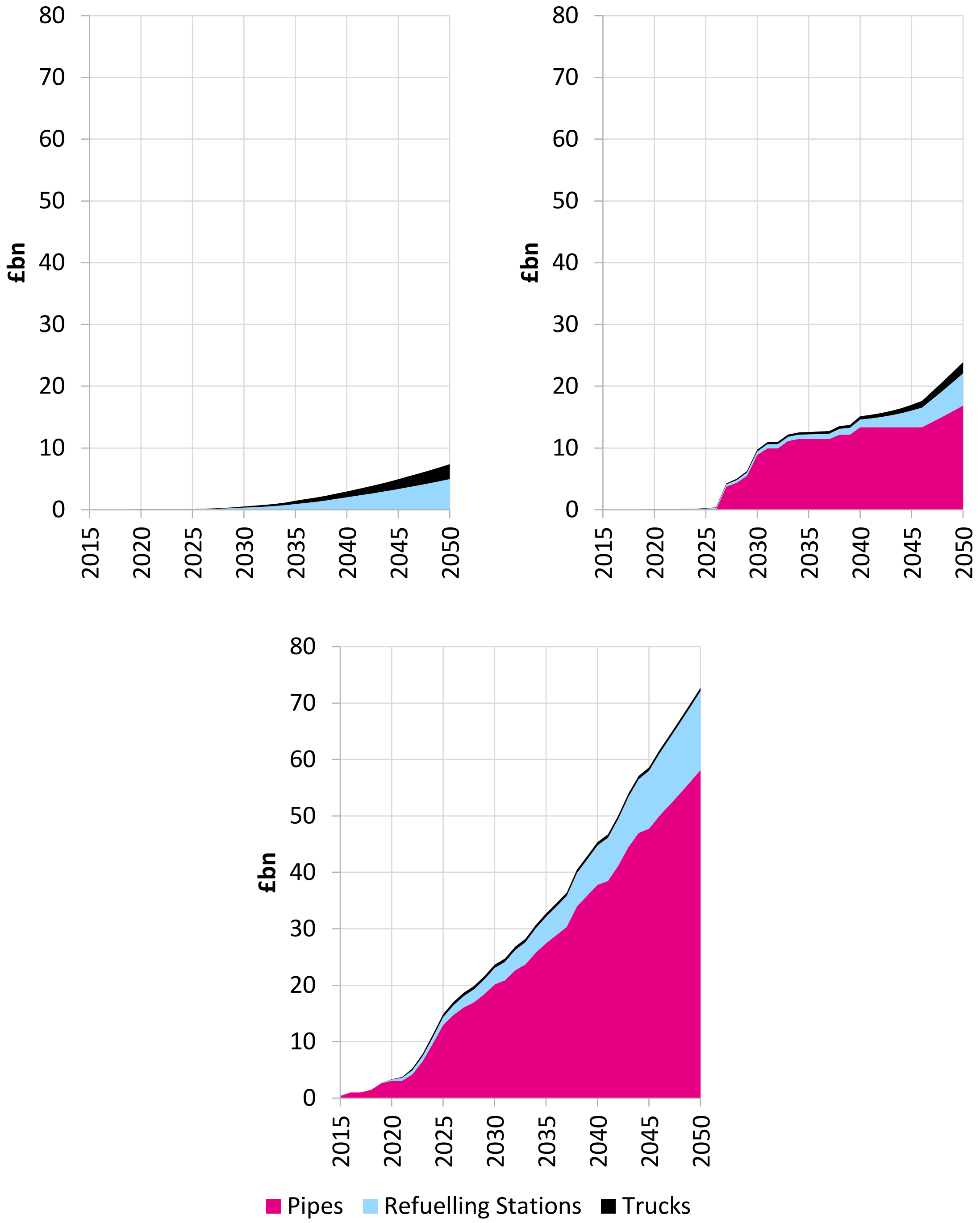
Figure 65 Total installed hydrogen refuelling stations in all Narratives



Tanker distribution

In the majority of Narratives, hydrogen tankers are used to distribute the fuel to the refuelling stations, generally from centralised hydrogen production facilities. The cost of doing so is materially lower than building a new pipeline network as shown in Figure 66 – note that H2P include transmission and pipeline distribution networks whereas ULEV includes only a transmission network. This also leads to less subsidy requirement to support the infrastructure in the Commercial Value Chain.

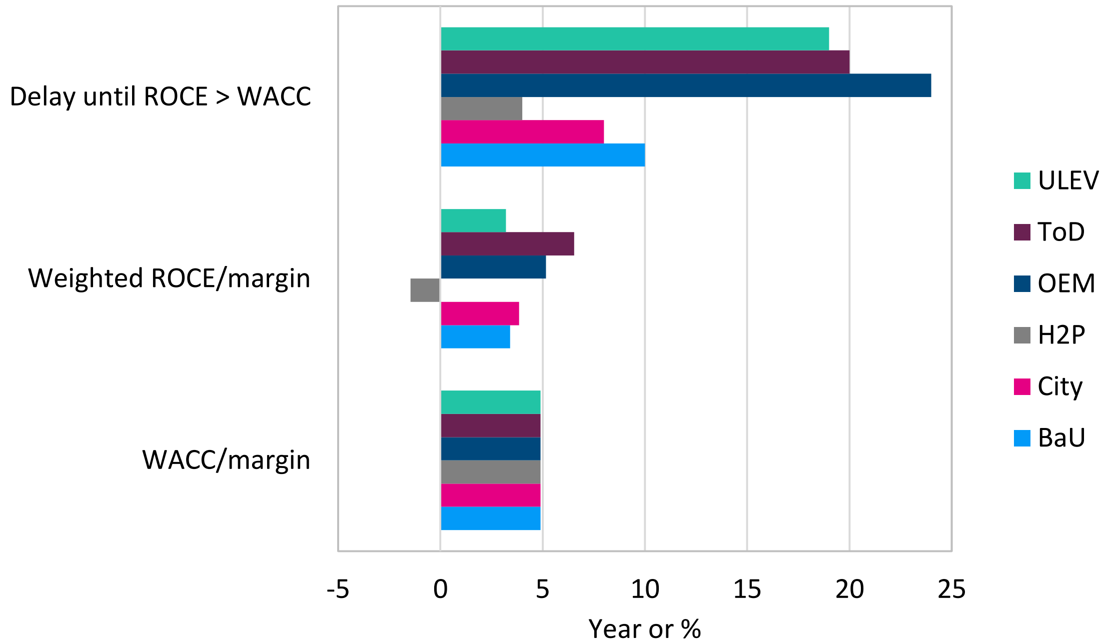
Figure 66 Cumulative CapEx for hydrogen infrastructure in OEM (left) and ULEV (right) and H2P (bottom, central)



Hydrogen tankers are assumed to operate to meet demand from the HRS and as such, in the Narratives in which trucks are used as the primary distribution method, the operation of a truck distributor appears to makes commercial sense.

In H2P the weighted return of the truck distributor is slightly negative over the modelled pathway because the trucks quickly become redundant once the threshold of hydrogen volume required to build a pipeline network is reached. Trucks are used to meet 100% of the demand in the short-medium-term but their use quickly drops off in subsequent years leading to some effective stranding of truck assets. The effect of this is more evident in H2P, which incorporates both a transmission and high pressure distribution pipeline network, but can also be seen in ULEV in which the weighted return is lower than the cost of capital for investing in the infrastructure (illustrated in Figure 67).

Figure 67 Profitability of the hydrogen truck distributor across all Narratives



Pipeline transmission and distribution

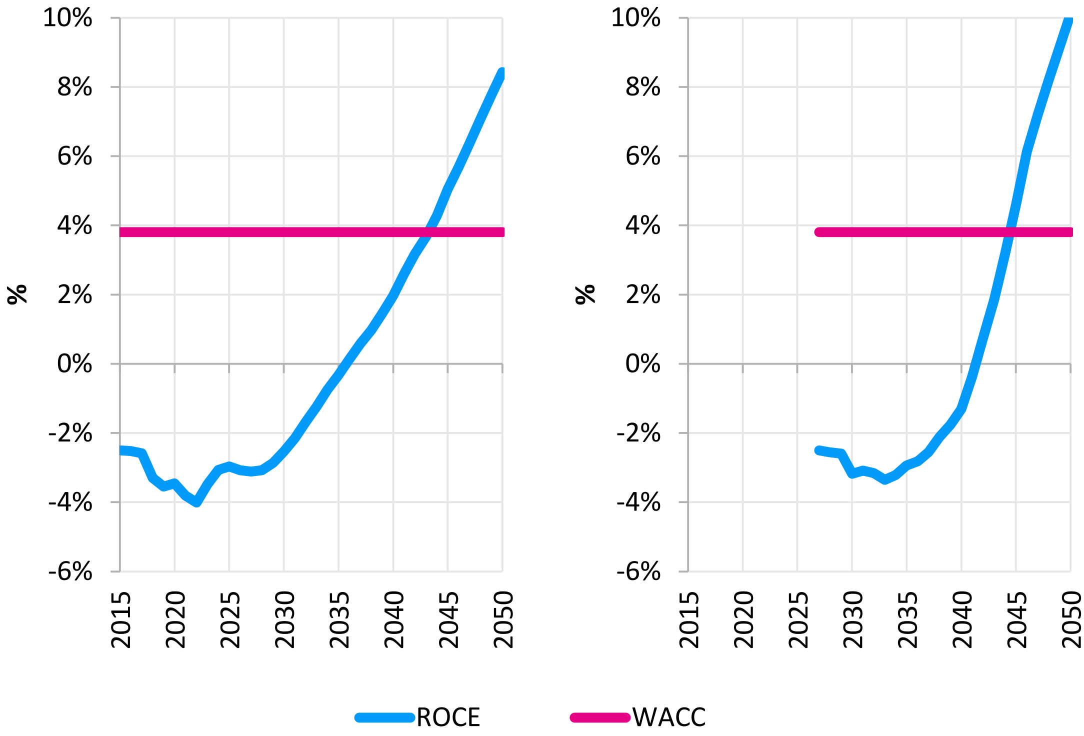
During the pathway modelled, the pipeline businesses do not achieve the returns required to cover their cost of capital, but both the transmission pipeline distributor in ULEV and the combined transmission and local distribution pipeline operators in H2P appear profitable in the longer term.

Both Narratives show that the return on capital has become positive before 2050 (Figure 68), beyond which the assets still have many years of operation before the end of their technical life. Although the hydrogen pipelines might be difficult to invest in on a commercial basis, they may still be affordable with some support, particularly in the case of the transmission pipeline, given the potential for coordination with hydrogen use in the wider energy system. The H_2 pipeline distributor is somewhat de-risked through its treatment as a regulated entity, with the same WACC as the electricity DNO. The pipeline distributors do under-recover across the pathway and this is shown in the present value of the upfront subsidy required for the CVC in Table 12.

Of this, £3.4bn is needed for the transmission pipeline operator in ULEV and £7.5bn for the combined transmission and distribution pipeline operator in H2P. However, the magnitude of the subsidy required is small relative to the level of vehicle subsidy and foregone tax revenue shown by the Government revenue gap.

The high pressure local distribution network pipeline is assumed to deliver hydrogen directly to the refuelling stations and as such almost three times the amount of pipeline is built[117]. The high pressure pipes are around 60% of the cost of the transmission pipes on a per km basis but the need for a more extensive network offsets this, leading to an overall cost of around £16bn for the transmission network and around £42bn for the high pressure distribution network[118].

Figure 68 ROCE and WACC for the transmission and distribution pipeline operators combined (H2P, on the left) and for the transmission pipeline operator only (ULEV, on the right)



The pipeline operator becomes profitable more quickly in ULEV (Figure 69) following initial investment, as it is assumed that other industries also access the transmission network, reducing the per unit cost. In ULEV there is no investment in pipelines until at least 2030 and not unless a certain minimum threshold of hydrogen is met. With deferred investment, the business model Success Metrics are still positive. In the H2P Narrative there is some initial investment early in the pathway, but a more substantial roll-out does not begin in earnest until the mid-2020s as shown in Figure 70.

117 In H2P around 12,700 km of high pressure distribution pipeline is built, similar to the current gas network, whereas around 4,500 km of transmission pipeline is built.
118 In H2P by 2050, pipes only - excluding compressors/ pressure reduction stations.

Figure 69 Profitability of the hydrogen pipeline distributor in all Narratives

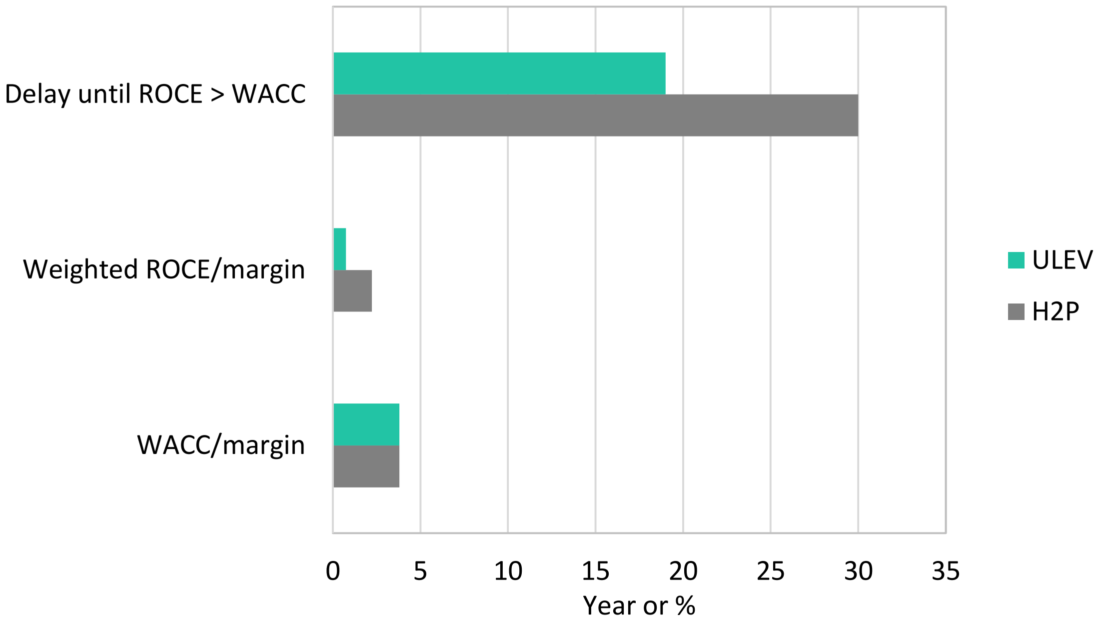
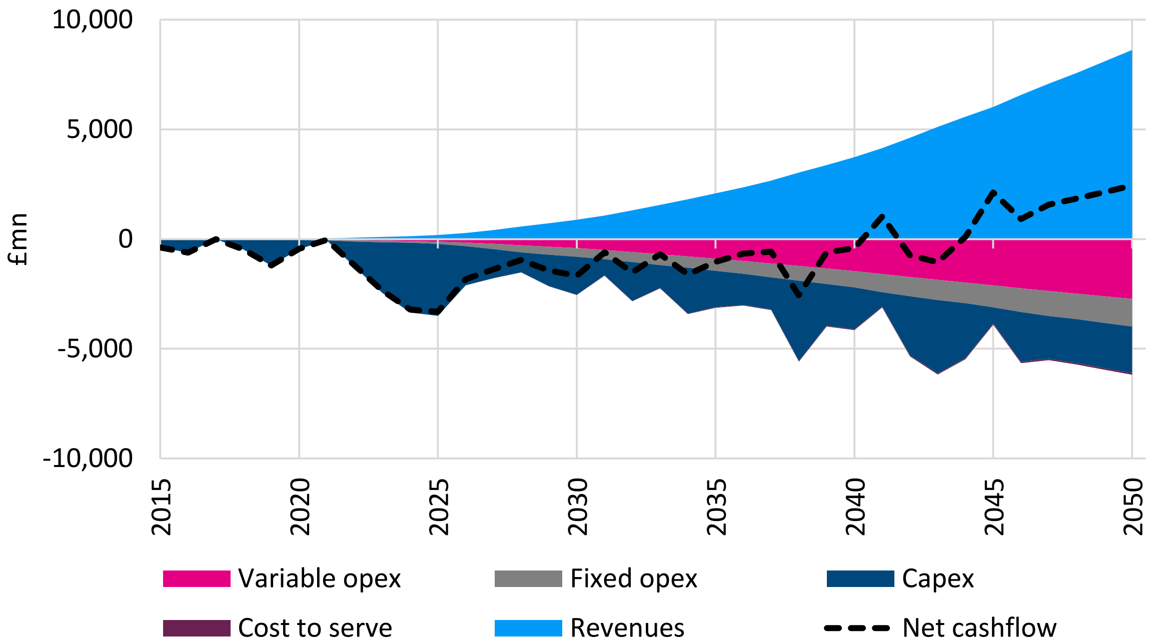


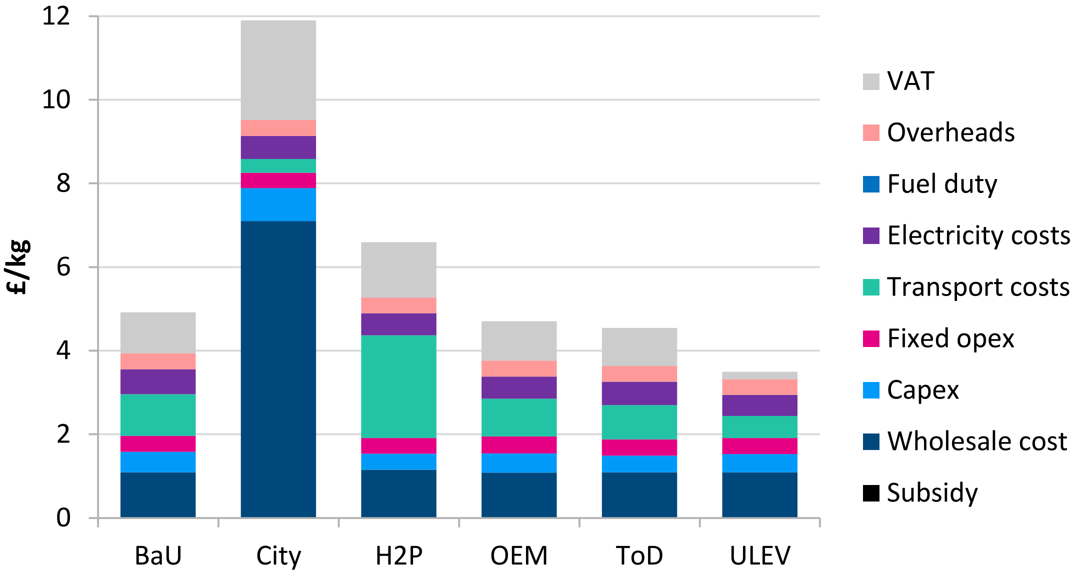
Figure 70 Hydrogen pipeline operator cash flows in H2P (NTS + LDN)



Retail hydrogen prices

The long-run hydrogen prices in each Narrative are shown in Figure 71, illustrating the relative impact of wholesale prices versus transport costs (including electricity for compression) and any policy levers.

Figure 71 Retail hydrogen prices at the forecourt in 2040



Note: For City the costs of electricity to run the electrolyser are included in the wholesale price. The electricity costs component covers electricity for compression at various points in the distribution network.

In City, an increasing proportion of the hydrogen demand is met through on-site localised production at the forecourts using water electrolysis. This is expensive compared with centralised SMR and results in hydrogen being expensive, in order that the producers can recover their costs.

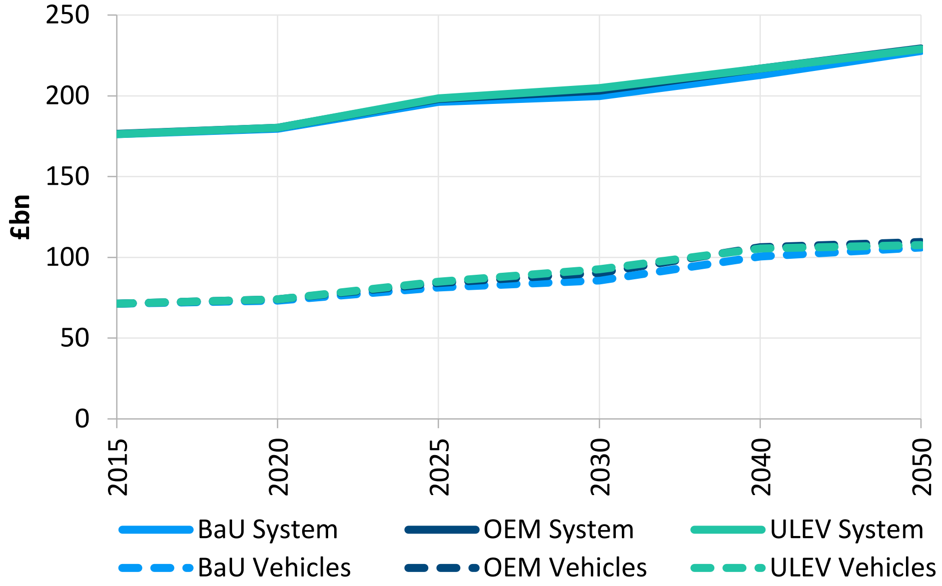
6.2.4 Wider system and vehicles

To add some context around the scale of the key metrics, the cost of delivering the wider energy system[119], including the contribution of vehicle costs to this, is shown in Figure 72[120]. This ranges from around £176bn /year in 2015 to around £227–228bn /year in 2050[121]. For comparison, the residual carbon cost in 2050 has a range of £5–9bn /year across the Narratives and the gap in Government cashflows has a range of £15–57bn /year.

The vehicle costs account for a large component of the total wider energy system costs, starting at around 40% in 2015 and reaching nearly 50% by 2050 as there is a general increase in the number of vehicles sold.

[119] The total energy system cost is the capital cost, fixed cost, variable cost of new and retrofit capacity, storage, the transmission system and resource costs.
[120] These vehicle costs relate to the number of vehicles sold, which for BaU is 2.9mn in 2015 and 3.5mn in 2050.
[121] There are some small system differences between the Narratives, however, the narrow spread is expected given that the Narratives are optimised (via the ESME model) and there are many combinations of system choices in which the overall costs will be similar.

Figure 72 Illustration of vehicle cost[122] and system costs (including vehicles) for BaU, OEM and ULEV



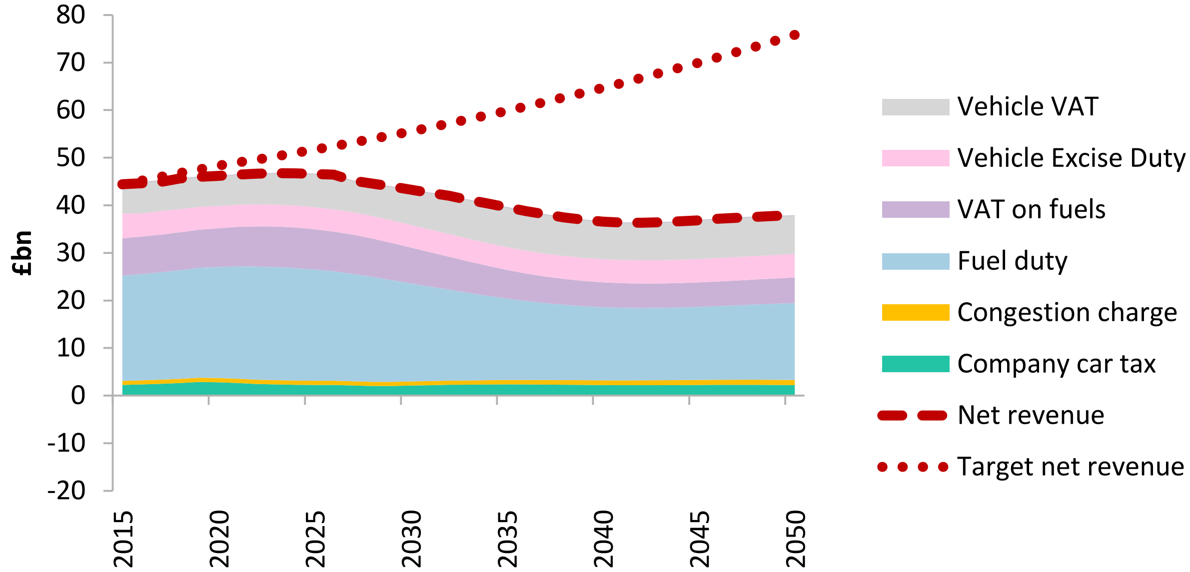
6.3 Effectiveness of Government intervention

6.3.1 Overview

The analysis tracks the key Government revenues and subsidies directly associated with the car and van fleet as shown in Figure 73. It also contrasts the current net revenue position with an assumption that this would be expected to grow in line with real GDP / capita in future. That is, as individuals become better off the net share of their income that goes to Government revenue from transport is broadly maintained[123]. The difference between the calculated net revenue position and the target net revenue would therefore need to be recovered from additional policy measures.

[122] Vehicle cost is the annualised CapEx spend on cars and vans plus maintenance costs.
[123] It should be noted that specific revenue sources are not generally hypothecated in the UK (i.e. using transport revenue purely for transport-related expenditure) and hence this is a key part of the wider Government revenue base.

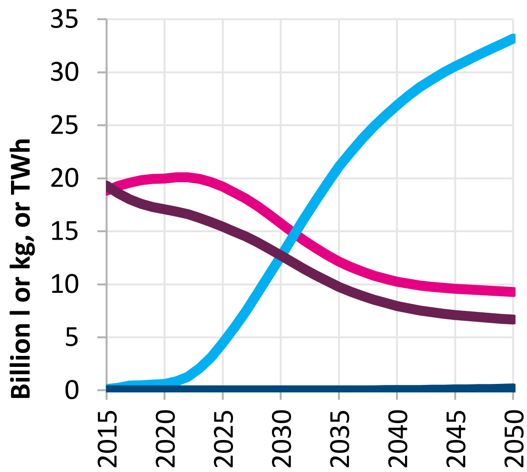
Figure 73 BaU Government tax and spend

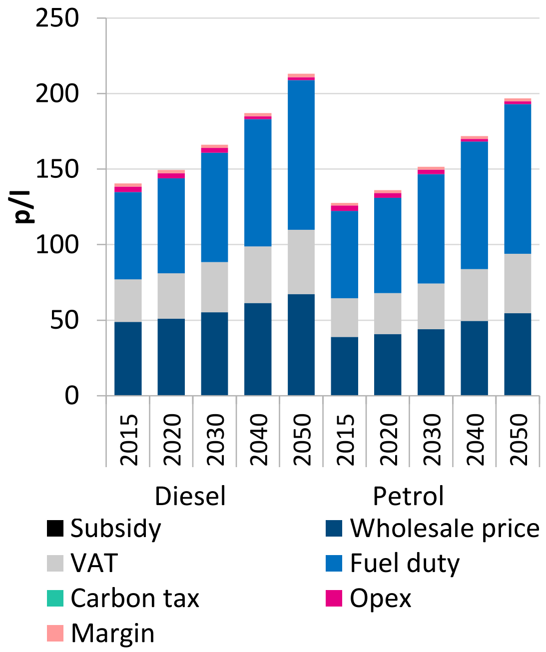


Note: The PiV grant (to 2017) is not shown on the chart as the cashflow is comparatively minor.

In the BaU Narrative the most significant determinant of revenue is fuel duty followed by VAT on vehicles purchased, VAT on fuels and VED (vehicle grants beyond current schemes, subsidies on fuels, and a CO_2 tax are not included in this Narrative). Over the pathway to 2050 one of the major issues is managing the decline in fuel duty revenues. As illustrated in Figure 74, even though fuel duty is increasing over time in line with projected real GDP / capita (i.e. consistent with the revenue target), this is more than offset by the substantial decline in volumes of liquid fuels.

Figure 74 Vehicle fuel consumption and retail price stack for liquid fuels in BaU





A key challenge is trying to balance the competing requirements of driving ULEV uptake and use in a cost-effective manner whilst minimising any gap in revenue. Applying substantial taxes on electricity and hydrogen used in vehicle transport would act to slow the penetration of ULEVs, whilst more aggressive taxation of liquid volumes (e.g. by higher fuel duty or carbon tax) would speed the decline of the underlying volumes, offsetting the benefit of higher taxation. The other Narratives contain a mix of different policy measures and their impact on driving ULEV uptake versus Government net tax and spend is explored in the sections below.

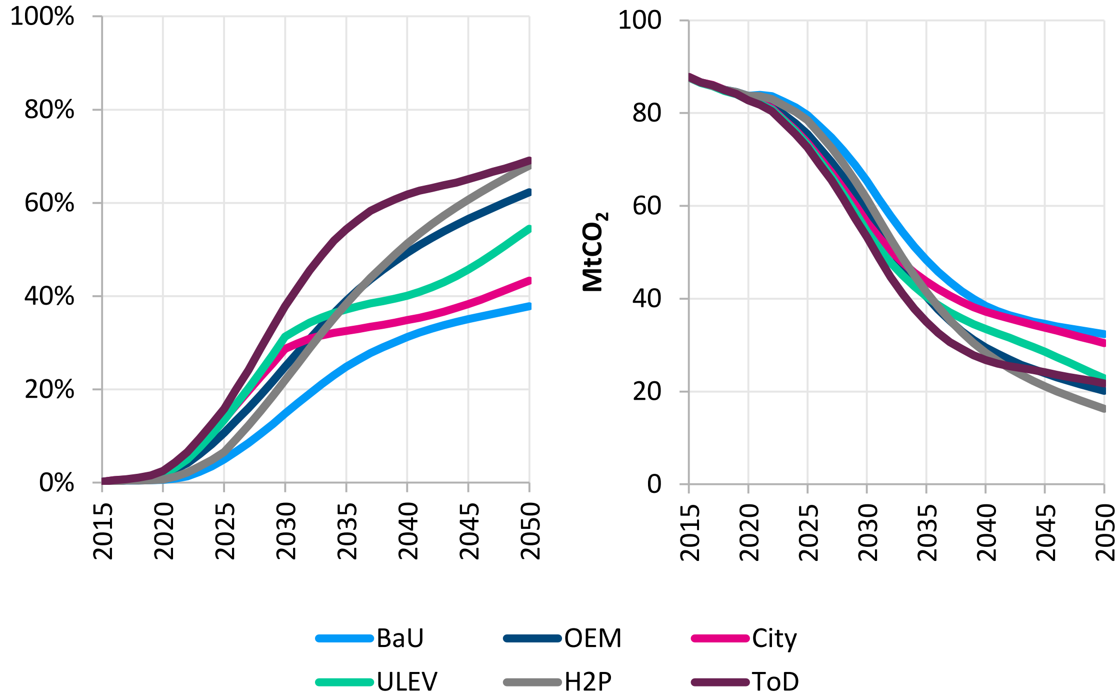
6.3.2 Further spending to encourage low carbon vkm

As described in section 3.4 the application of policy measures across the Narratives splits into three broad groups:

- **No ongoing measures** (BaU): current measures expire by 2018 and are not replaced.
- **Ongoing subsidy over the pathway** (OEM, ToD and H2P): receive ULEV differentiated tax and subsidy benefits across the pathway (increasing in absolute value from OEM at the lowest end to H2P at the higher end).
  - Whilst OEM is technology neutral, ToD and H2P are tailored towards PiVs and FCVs, respectively.
  - ToD also contains subsidised electricity at non-home charging locations to 2030, which is then gradually phased out.
- **Transition from subsidy to CO_2 price driver** (City and ULEV): provide technology neutral VAT differentiation and subsidies for ULEVs (higher in the case of the ULEV Narrative) until 2030 before removing these and transitioning to a CO_2 tax on liquid fuels as the main driver of the transition to ULEVs. In addition City introduces an extended congestion charging scheme to cities other than London. These initially exempt ULEVs based on defined gCO_2/vkm, but this is gradually tightened over time as the proportion of ULEVs in the vehicle fleet increases.

The trends in share of low carbon vkm and the associated residual CO_2 emissions across the different Narratives are shown in Figure 75. There is a clear long-term difference in decarbonisation between the three Narratives that are subsidised continuously across the pathway (OEM, H2P, ToD) and the others, which are not or shift towards a carbon tax from the 2030s. In the case of the ULEV and City Narratives there is a clear inflection point around 2030, with a slower increase in decarbonisation after this point.

Figure 75 Share of car and van low carbon[124] vkm (left) and CO_2 emissions (right)

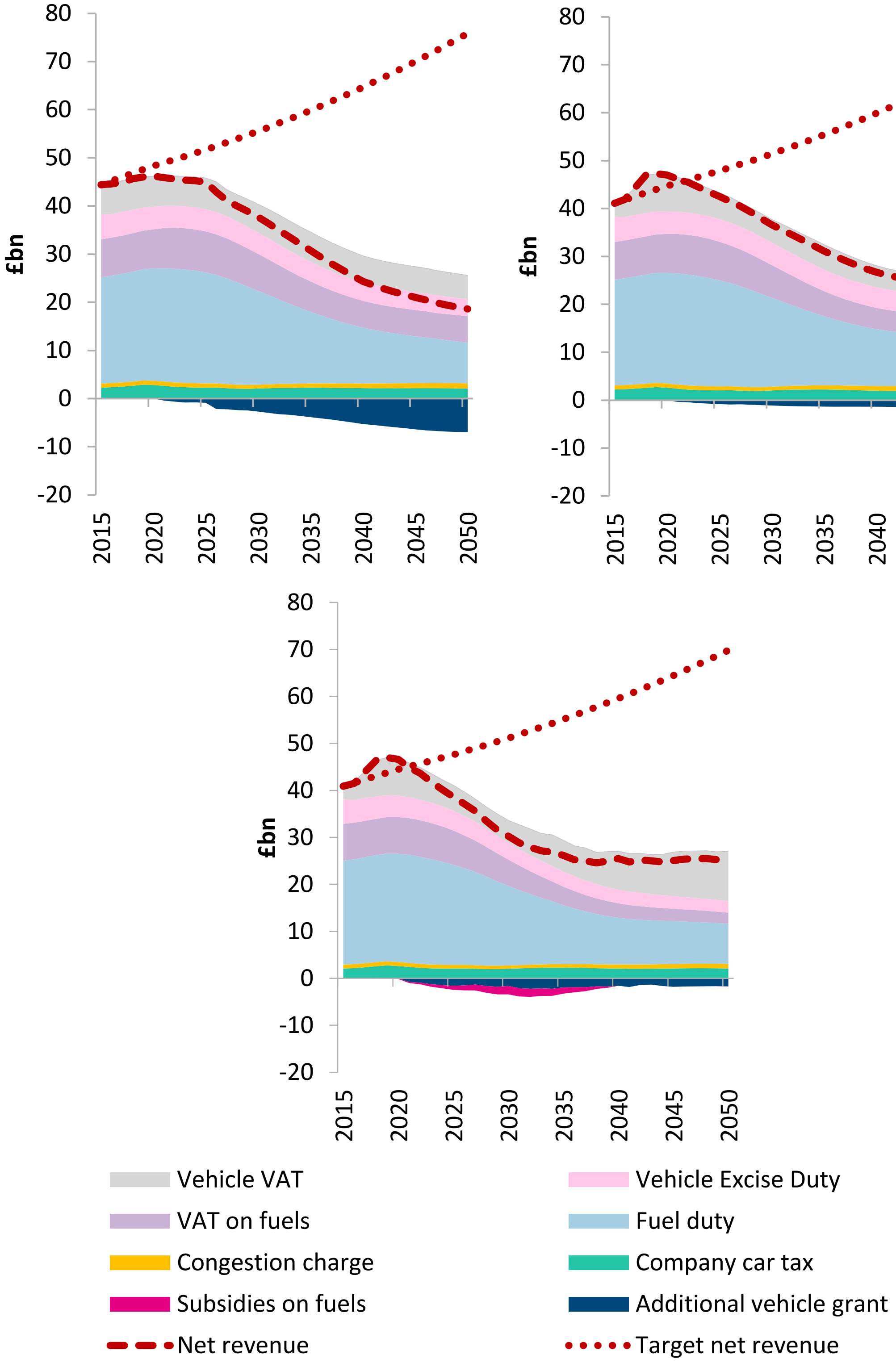


As shown previously in Figure 30, over the longer term the UK economy-wide carbon price (necessary to drive decarbonisation in line with UK targets) tends to increase slowly to 2030 and then sharply from 2030 to around £100 /tCO_2 by 2040 and over £250 /tCO_2 by 2050 in both City and ULEV. In the latter Narrative the increasing strength of this signal to move away from liquid fossil fuels tends to help accelerate ULEV deployment again in the later stages of the pathway, particularly for FCVs (see section 5.1). This is not seen in the case of the City Narrative due to the significantly more expensive cost of hydrogen production from small-scale localised electrolysers.

The level of direct subsidies in the Narratives where they extend over the full pathway has been refined to try to find the lowest level that still drives a comparable level of long-term abatement. The comparison of Government tax and spend under the H2P versus the OEM in Figure 76 highlights the substantial additional cost of incentivising a hydrogen solution only compared to a modest, but technology neutral grant, under OEM.

[124] Electricity and hydrogen

Figure 76 Government tax and spend for H2P (left), OEM (right) and ToD (bottom)

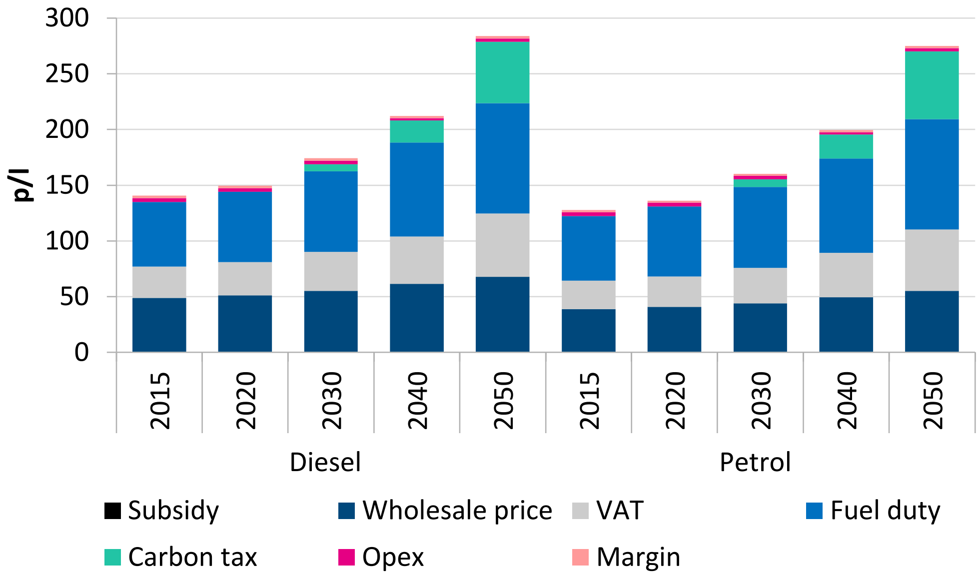


Note: The PiV grant (to 2017) is not shown on the charts as the cashflow is comparatively minor.

The OEM Narrative still leads to a strong mix of BEV, PHEV and FCV vehicles by 2050 at the lowest level of absolute subsidy[125], but this still equates to around £1.7bn /year of direct grants in 2050. However, when comparing across the Narratives, ULEV is likely to be the most representative in terms of showing an efficient long-term level of decarbonisation by 2050 in transport relative to the wider energy system. This is because the primary signal to differentiate ULEVs from conventional vehicles is via a CO_2 tax on liquid fuels, with relatively limited distortion due to other policy measures. The scale of the CO_2 tax within liquid fuels for the ULEV Narrative is shown in Figure 77.

The low carbon price in the early part of the pathway also indicates that it is not cost effective from a whole system perspective to spend significantly to accelerate ULEV uptake in the near term; either by direct subsidies on vehicle costs, VAT differentiation, or indirectly though electricity price subsidies in the case of ToD.

Figure 77 Retail price stack for liquid fuels in ULEV Narrative



There has been substantial discussion to date over the extent to which measures such as fuel duty already cover a range of externalities, including those from climate change. However, a report by the Sustainable Development Commission[126] (incorporating evidence from previous Transport Select Committee reports) concluded that the overall revenue obtained from motorists is likely to be substantially lower than the combination of direct expenditure on transport (such as maintaining roads) and the wider externalities (congestion, accidents, air quality, health, noise and climate change) that motoring imposes. This appears to hold even if climate change externalities are excluded from the list, hence it is reasonable to assume that the full value of any CO_2 tax should be passed through into liquid fuels without any double counting of this externality via other policy measures such as fuel duty.

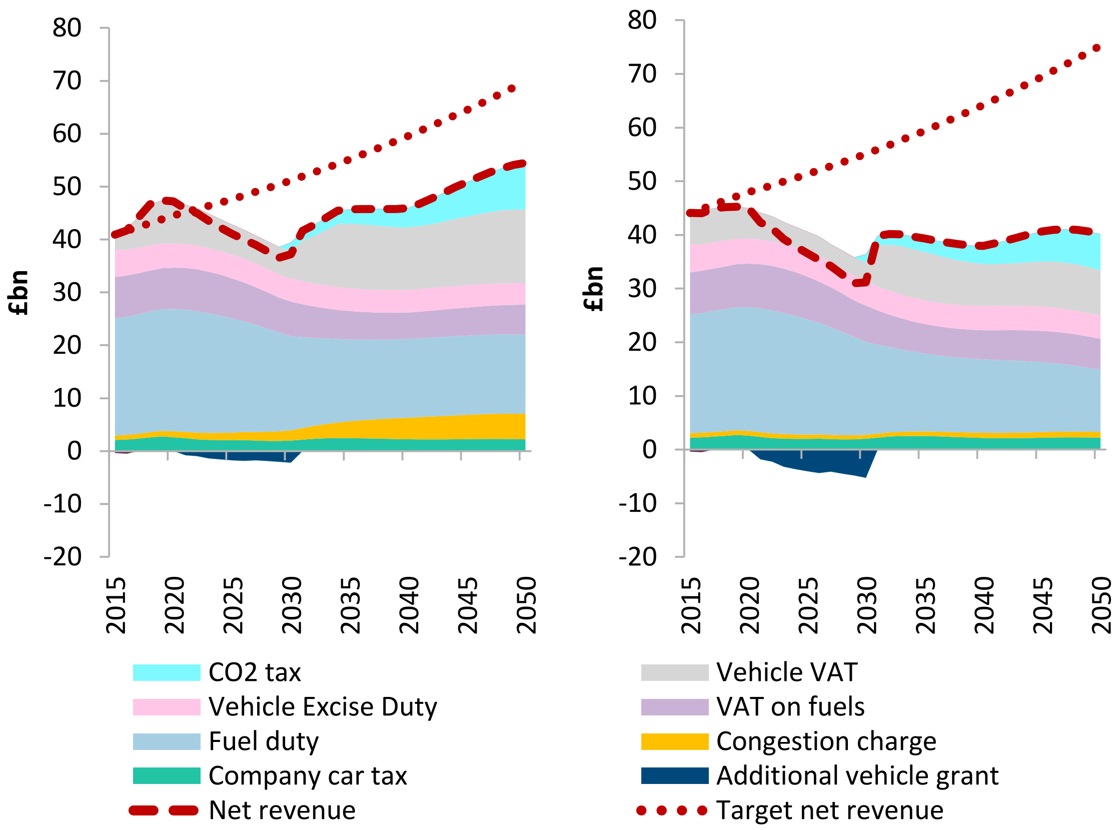
[125] Aside from BaU and City which have a significantly lower level of low carbon vkm.
[126] http://www.sd-commission.org.uk/data/files/publications/fairness_car_dependant.pdf

6.3.3 Filling the revenue gap

The transition from subsidy / VAT differentiation to a CO_2 tax on liquid fuels in the City and ULEV Narrative is an attempt to help fill part of the revenue gap whilst not unduly limiting the revenue base on which the tax is applied. The impact on Government cash flows for these Narratives is shown in Figure 78. Whilst the CO_2 tax leads to a sizeable amount of revenue by 2050 this is not by itself sufficient to offset the decline in liquid fuel duties and a substantial revenue gap still emerges in the ULEV Narrative over the longer term.

The revenue gap in the City Narrative is significantly smaller compared to ULEV because in addition to the CO_2 tax revenue the extended congestion charge also provides a sizeable source of new revenue. In addition, the shift towards vehicle sharing in urban areas has the effect of increasing the rate of sales of new vehicles due to the higher mileage per year. Even after accounting for the fact that this leads to a smaller vehicle parc in total by 2050 compared to the ULEV Narrative, the VAT payments on new vehicles in City are significantly higher given this faster stock turnover[127].

Figure 78 City (left) and ULEV (right) Government tax and spend



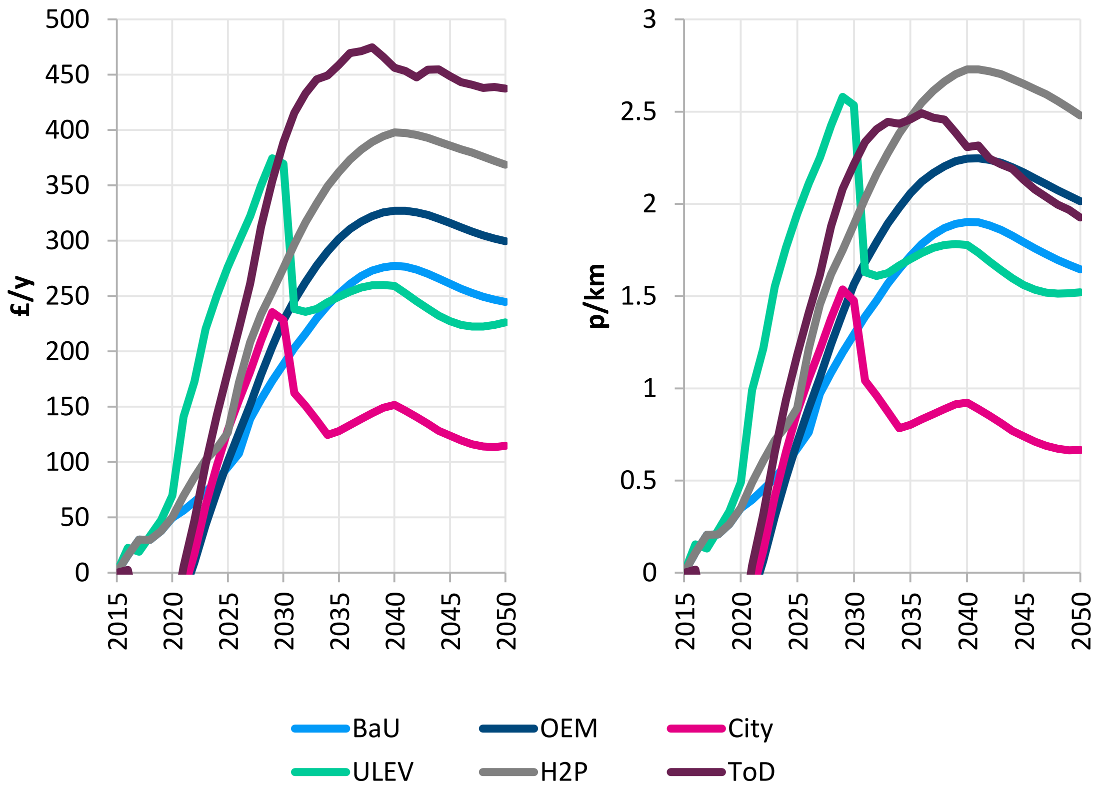
Note: The PiV grant (to 2017) is not shown on the charts as the cashflow is comparatively minor.

[127] Note that the VAT on vehicles and fuel sales associated with car sharing vehicles shown in the figure is a proxy for what is ultimately passed through to consumers and Government in the final price for hiring the car sharing vehicle, as the leasing/car sharing entities themselves do not pay VAT at the point of purchase.

City provides the smallest revenue gap of all the Narratives (noting that its degree of transport decarbonisation is only marginally higher than BaU), but even here a substantial gap remains by 2050. There appears to be relatively limited further scope to apply measures which actively differentiate between ULEVs and conventional vehicles without increasing the level of subsidy or lost tax revenue.

As a result, technology neutral policies such as an additional vehicle tax (£/vehicle/year) on top of VED or a vehicle utilisation policy such as road pricing (e.g. applied in terms of p/km) are likely to be necessary. Figure 79 provides an illustration of the scale of these measures for each Narrative. For comparison the current ongoing rate of VED from 2017 (i.e. separate to the CO_2 differentiated rates applicable in the first year of registration) is £140 /year.

Figure 79 Value of illustrative technology neutral measures (fixed per vehicle on left, road pricing on right) to fill the residual revenue gap – all Narratives



6.3.4 Effectiveness of policy measures

Support for commercial entities versus consumers

The discussion in the previous sections has emphasised the difficulty in maintaining adequate revenue, given the potential costs of promoting early, or significantly higher, long-term uptake of ULEVs from the user perspective.

The revenue gap is based on support to users and excludes any potential additional subsidy to entities in the Commercial Value Chain that might be necessary to help 'de-risk' their investments. The CVC subsidy is focused on what might be needed to support new infrastructure operators (e.g.

charging point or hydrogen distribution), primarily due to the need to invest ahead of likely widespread demand.

The present value of the upfront subsidy necessary to ensure these entities meet their required return on investment (or margin) was summarised as part of the key quantitative Success Metrics in Table 12.

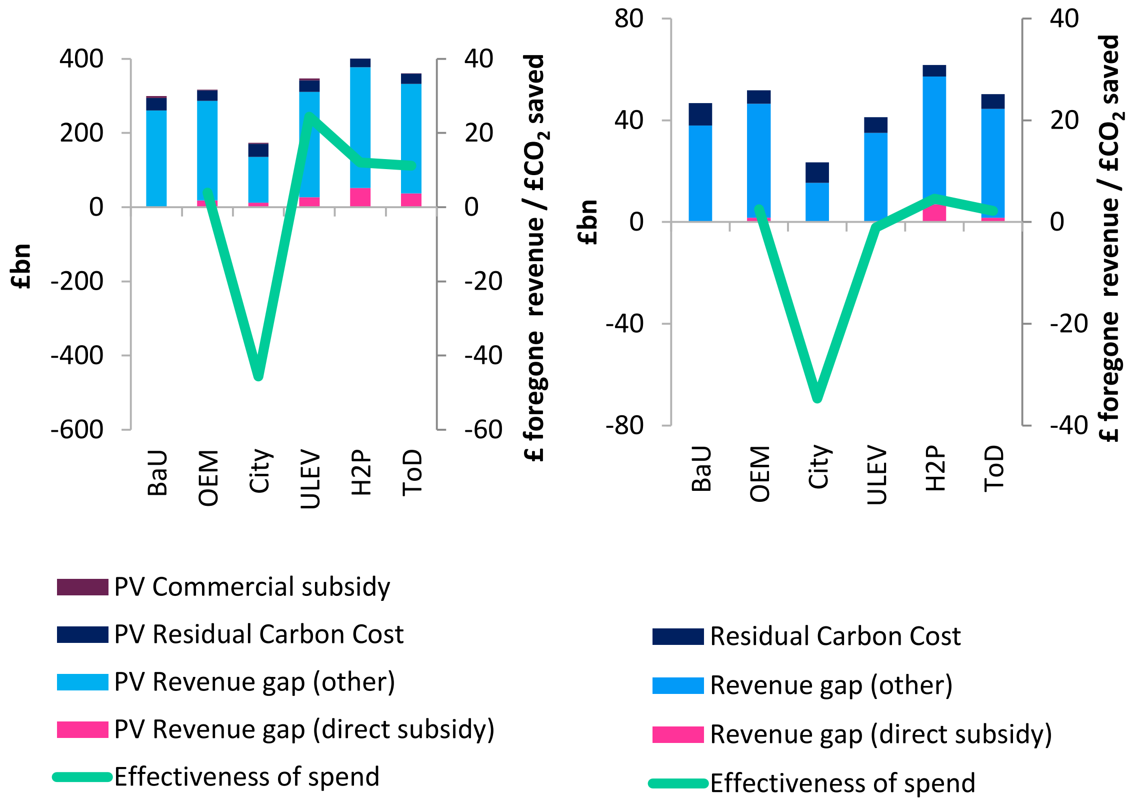
The scale of the subsidy that might be needed for the CVC entities is significantly smaller than that for the consumer. The absolute scale of the CVC subsidy ranges from a present value of £1.2bn under the ToD Narrative to £11.5bn in the H2P Narrative, which reflects a national-scale build out of hydrogen transmission and high-pressure pipeline infrastructure. The Narratives which only require support for charging infrastructure tend to have significantly lower subsidy requirements (of the order of a few £100 mn) compared to those with hydrogen infrastructure.

In comparison to the direct (e.g. subsidy) or indirect (e.g. lost tax revenue) support needed on the consumer side, the support needed for the CVC is always less than a tenth of this, which emphasises that the focus of the overall challenge in facilitating mass-market uptake is sufficient incentives to pull consumers towards ULEVs or push them away from ICEVs.

Effectiveness of combined spend on reducing CO_2 emissions

To help compare the effectiveness of the Narratives in reducing CO_2 emissions, a proxy for this has been outlined in Figure 80.

Figure 80 Proxy for effectiveness of Government spend in reducing emissions over pathway (left) and in 2050 (right)



- This first shows the total combined 'costs' to Government including the revenue gap (split out into direct subsidy and the gap driven by other measures such as reduced VAT on ULEVs), the commercial subsidy and the residual cost of carbon (tonnes of CO_2 multiplied by the carbon price).
- It then shows the implied effectiveness of the incremental changes in net revenue driven by Government policy differences across the Narratives *relative* to BaU in terms of driving additional CO_2 savings – i.e. what is the cost to Government in £ to achieve £1 equivalent carbon benefit. For example, in the OEM Narrative, Government is effectively spending (or forgoing) around £4 in revenue for every £1 of additional benefit from the monetised reduction in carbon emissions. Ideally the ratio would be less than or equal to £1 spent for every £1 saved.

The results are presented in present value terms[128] for the pathway as a whole and for 2050[129], as it is important to distinguish the role of expenditure over the pathway versus the position the system is left in at the 2050 point, given that the cost of residual carbon emissions is significantly higher.

When viewed over the pathway it is clear that there are significant costs to driving higher levels of abatement beyond BaU in the ULEV, H2P and ToD Narratives. The ULEV Narrative in particular looks poor in terms of its effectiveness, given that it has high levels of subsidy in the near term which tend to accelerate uptake of ULEVs ahead of what is necessary in terms of broader decarbonisation.

OEM has modest levels of subsidy, which when maintained over the full pathway drive a significant level of decarbonisation, but still at a ratio of ~£4 spent for every £1 of avoided carbon costs.

City looks highly effective (shown by the negative value in Figure 80) given that fairly modest subsidies are applied over a limited timeframe and additional revenue raising measures are levied in the form of a CO_2 tax and an extended congestion charge. Over the pathway, the residual carbon cost in City is lower than BaU (£28bn compared to £33bn) and this is achieved at a lower present value of the revenue gap in Government cashflows for direct subsidy, commercial subsidy and other (£135bn in City compared to £261bn in BaU).

However, the level of longer term abatement is only slightly higher than BaU. In addition, given that the congestion charge is achieving benefits outside of CO_2 emissions (e.g. time saving) over the pathway it is not necessarily appropriate to assign the full value of the additional revenue to the CO_2 saving alone, which would reduce the implied effectiveness of this Narrative, when viewed purely through a carbon savings lens.

The position in 2050, as a representation of the longer term costs going forward, provides an interesting counterpoint in the case of the ULEV Narrative, as there is now a modest benefit compared to BaU, even though the level of carbon abatement is significantly higher (albeit not as high as OEM, H2P and ToD). This reinforces the view that it is not warranted to spend significant amounts of money to incentivise uptake too early in the pathway given the corresponding CO_2 benefits, although clearly there may be other benefits to this such as improved air quality, reduced noise pollution, etc.

[128] Discounted at the Treasury Green Book Social Discount Rate of 3.5% for carbon costs and Government expenditure, and accounting for the WACC / required margin in the case of the commercial entities.
[129] For this metric it is assumed that any commercial subsidy is negligible when considering 2050 only.

In further fine tuning of the mix of policy measures it appears that combining elements of OEM, City and ULEV Narratives is a promising way to help balance the desire to drive long-term transport abatement towards the ULEV Narrative levels, whilst minimising the expenditure necessary to do this. Given that the CVC subsidy requirements are modest across these Narratives (a breakdown of these by entity is provided in Figure 81) a combination of the following adjustments to consumer incentives is suggested:

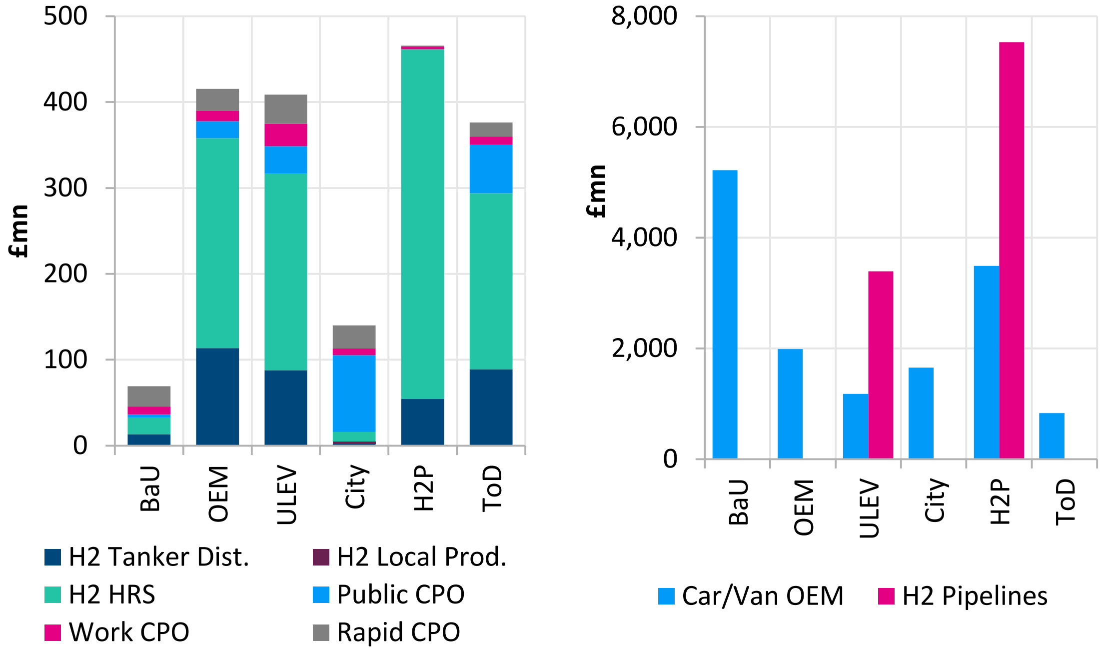
- Applying vehicle subsidies at the level of the OEM Narrative, but delaying their introduction until the late 2020s and transitioning to a carbon tax in the late 2030s. This would appear to be sufficient to maintain the sharpest point of the increasing trend in low carbon vkm and CO_2 reductions seen in the BaU Narrative in the early 2030s such that the position by 2050 intersects with the ULEV Narrative.
- Applying an extended congestion charge, in the manner of the City Narrative, for both revenue raising and congestion objectives. (There are also likely to be smaller indirect benefits for CO_2 emissions from more efficient use of vehicles with reduced congestion).
- Even with these adjustments there is still likely to be a need for further technology-neutral revenue raising measures.

The above still holds true in the high and low uptake Sensitivities, but with some fine tuning of the absolute level of subsidy needed to strike the balance between cost of abatement and the residual cost of unabated carbon, which will differ depending on a) how difficult it is to decarbonise the wider energy system, and b) the underlying fuel prices pushing away from conventional vehicles in conjunction with the CO_2 tax.

Breakdown of estimated Commercial Value Chain subsidy

The primary Success Metric estimating the present value of the subsidy that would be required for the different modelled commercial entities (to ensure they meet their required WACC / margin over the modelled pathway) is disaggregated in Figure 81. It is split into the entities requiring more modest subsidy requirements (charging point operators and hydrogen distribution, excluding pipelines) versus the potentially more significant requirements involving large scale hydrogen pipeline investment and penalties incurred by the OEMs.

Figure 81 Present value over pathway to 2050 of CVC subsidy requirements (note scales)



The CVC subsidy for new infrastructure is greatest for the H_2 pipelines with a present value of around £3.5bn in the ULEV Narrative (transmission only) and £7.5bn in H2P (transmission and distribution), whereas the subsidy for other infrastructure commercial entities is of the order of 10's to 100's of millions. In general it is the hydrogen infrastructure that requires more subsidy support across the pathway, whereas the support needed by the entities building and operating the charging infrastructure is small in comparison. City and ToD have more expensive and faster public charging points, which increases the cost and subsidy requirements. In City, most of the production is localised and thus there are far fewer trucks and less associated subsidy required.

For OEMs, the penalties are an estimate of what they would have to pay due to non-compliance with the EU carbon targets on new vehicle sales (the mechanism for this is explained further in Appendix B.8). Although the OEM penalties are large in absolute terms compared to some of the other components, they represent less than 0.5% of the present value of the OEMs' estimated revenues over the pathway even in the BaU Narrative, with negligible Government support beyond 2017 to support consumer uptake of ULEVs.

However, this does highlight the fine balance between a tightening CO_2 target for new vehicles which helps provide a suitable ceiling to drive transport decarbonisation (and innovation more broadly) versus one which tightens too quickly and leads to substantial additional costs on the part of OEMs.

The OEM penalties paid can be further differentiated into those for cars and vans with examples shown in Figure 82 and Figure 83.

Figure 82 Average new car tank-to-wheel emissions versus target and penalty payments

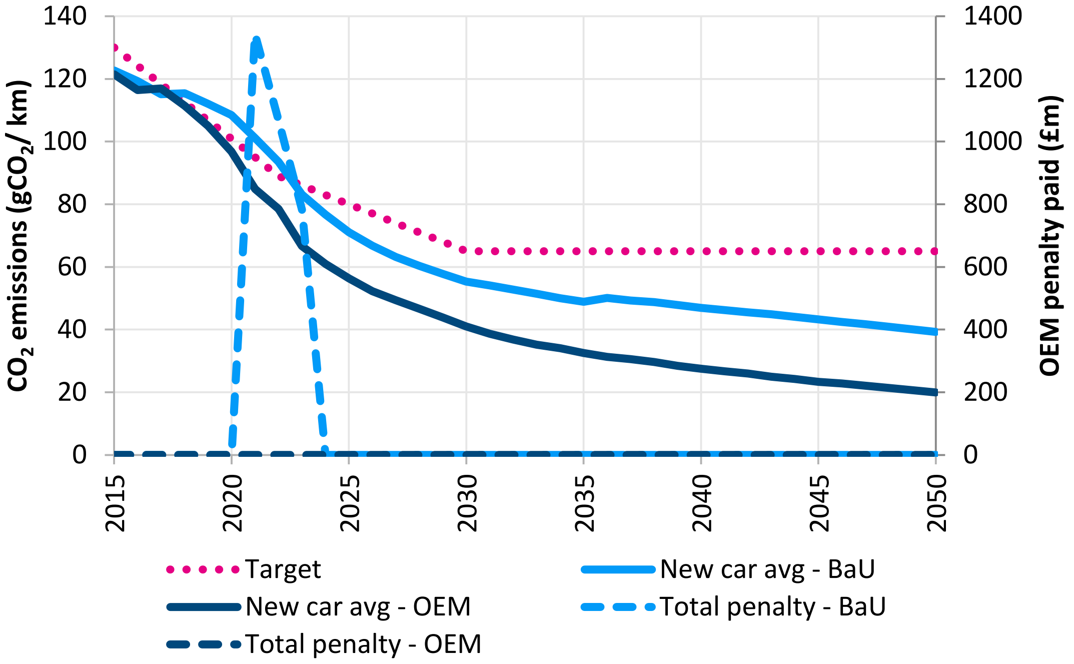
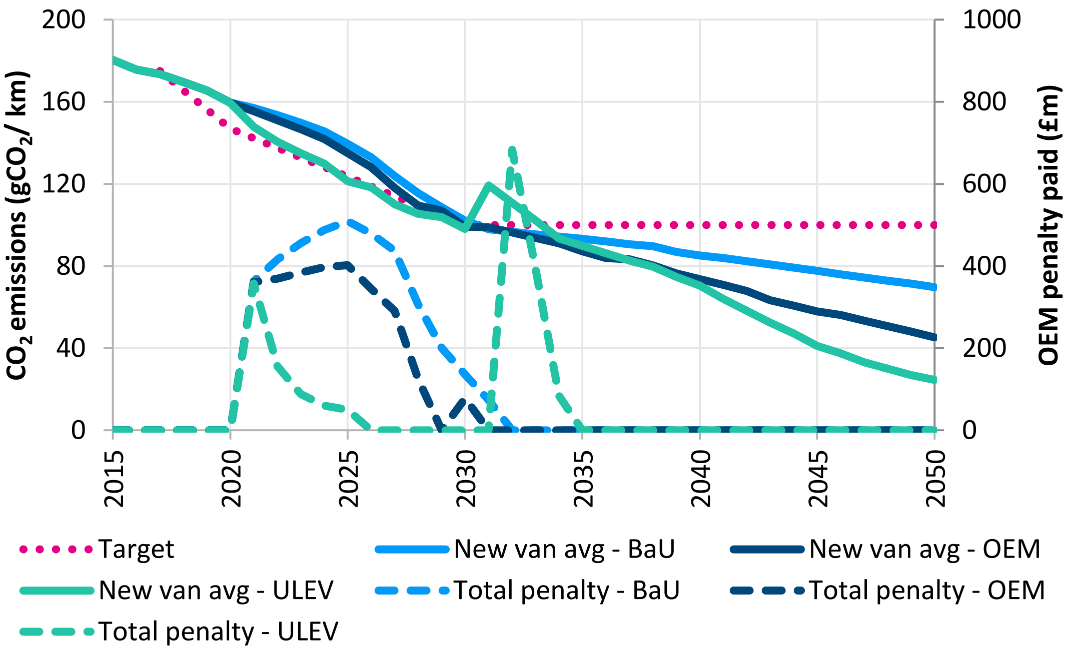


Figure 83 Average new van tank-to-wheel emissions versus target and penalty payments



For cars within the BaU Narrative, the penalty mechanism is activated in the early years but not beyond 2025 as shown in Figure 82, suggesting that setting a constant target from 2030 onwards[130]

[130] Current EU targets are set to 2020/21 and further improvements to 2030 are aligned with the indicative ranges proposed, however, future targets are not yet confirmed.

(as set across the Narratives) has limited further effect. In the case of the OEM Narrative, the modest additional subsidy on the consumer side (£500 /vehicle) pushes the new car sales significantly below the target and penalty mechanism is not triggered.

For vans in the BaU Narrative the target is consistently missed in the 2020-30 period, and to a marginally lesser extent in the OEM Narrative. As a result, this mechanism continues to be triggered into the early-2030s as shown in Figure 83. In the ULEV Narrative the additional van subsidy (£4000 /vehicle) accelerates the decline in the average gCO_2/vkm, broadly in line with the van standard with a lower overall level of penalty. The spike in 2030 reflects the withdrawal of subsidies to be replaced by a CO_2 tax on liquid fuels, which temporarily leads to a shift back to higher emitting vehicles.

However, in all three of the Narratives shown, new van emissions drop below the target by the mid-2030s, indicating that a more gradual tightening of the van target to 2030 is potentially preferable, compared to that for cars. In the nearer term this is due to the greater differential in conventional versus ULEV costs and additional restrictions from duty cycles, which prevents BEVs from being deployed more widely until improvements in battery ranges are available.

Lifecycle CO_2 emissions and air quality

The role of road transport decarbonisation as part of reducing the UK's 'production-based' emissions of CO_2 - i.e. from combustion of fossil fuels or industrial processes that produce CO_2 – to meet its climate change targets is the key underlying driver for ULEV uptake and use within the context of this study.

It is considered as a key measurement of success in the Physical Supply Chain, to align with the need for low carbon vkm. However, it is important to acknowledge that lifecycle carbon and air quality issues will also need to be taken into account as part of a 'good' solution.

- Lifecycle carbon relates to the carbon emissions associated with the end-to-end process of manufacturing and using a particular good or service - e.g. from sourcing the raw materials for a vehicle through manufacture, distribution, use through to the end of life.
- Air quality relates to the production of air pollutants (such as SO_2, NO_x and fine particulates) which cause damage to human health, agriculture, forestry and buildings.

The OEM penalties that have been accounted for in the Analytical Framework are due to OEMs exceeding the carbon emissions limits only, as defined by the European Commission, and are not related to lifecycle carbon emissions or air quality.

The primary portion of transport-related emissions captured within this work are effectively within the use phase – i.e. from direct combustion of fossil fuels and or indirectly through those used to produce electricity or hydrogen.

It should be noted that some portion of UK car manufacturing emissions are captured in the ESME model as energy-based emissions from industry – i.e. those arising from producing the vehicle but not the full lifecycle emissions. Importantly, this does not cover 'imported emissions' associated with the manufacture and import of goods from outside of the UK. Although these emissions are not technically counted within the UK's climate targets they clearly represent an important source of emissions considering the scale of vehicle imports into the UK.

The Low CVP Life-Cycle Assessment of Low Carbon Cars 2020-30 report shows the breakdown of emissions in production and use (i.e. emissions associated with using electricity or hydrogen compared with fossil fuels). In 2020, the production emissions for BEVs are estimated to be around 10 tCO_2e compared to around 6 tCO_2e for ICEVs, with the BEV emissions reducing over time. However, the emissions in the use phase are around 21 tCO_2e over the lifetime of an ICEV, compared with 11 tCO_2e for a BEV, resulting in lower total lifecycle emissions.

In future, lifecycle emissions may need further consideration - the report argues that "as the contribution to lifecycle CO_2e impacts from the use phase decreases in future, so the embodied impacts of the vehicles themselves will become more of a focus for further decarbonisation", particularly the vehicle assembly phase, battery production and recycling and choice of materials. Thus, it may be important that the Government, in setting policy, continues to encourage measures such as battery recycling[131], potentially operating refund schemes.

Pollutants in vehicle emissions other than carbon are regulated through EU legislation governing air quality, such that all new cars sold must meet Euro 6 standards[132], for exhaust emissions of NOx and other pollutants, such as CO, hydrocarbons and particulates. These are being progressively reduced (e.g. for diesel cars the permitted NOx has been reduced to 80mg/km compared with the previous 180mg/km limit under Euro 5) and new testing procedures have been developed (e.g. to test 'real world driving' emissions on the road instead of simulated in a testing facility). Penalties for breaching these regulations are not set per unit of emission – instead if a Member State which has granted an EC type-approval finds that new vehicles do not conform to the type it has approved, it shall take the necessary measures, including, where necessary, the withdrawal of type-approval, to ensure that production vehicles are brought into conformity with the approved type.

In addition, Member States are required to determine the penalties and to take all necessary measures for their implementation. These could be costly, for example, Volkswagen fitted cars with defeat devices to cheat on the emissions tests and as a consequence agreed to set aside up to $10bn to buy back or fix almost half a million cars, pay a $2.7bn fine to environmental authorities for excess pollution and invest $2bn in green vehicle technology and offer $603mn to 44 US states and two other territories to resolve legal claims[133].

There are clearly potential synergies between the introduction of ULEVs and the reduction of air pollutant emissions from transport. However, as per CO_2 emissions care needs to be taken to ensure emissions at the point of vehicle use are not simply displaced to elsewhere in the system - e.g. in the production of electricity or hydrogen. This is further complicated by the fact that the direct damage from air pollutant emissions is localised.

[131] Under EU regulations, Member States are already obliged to set up battery collection schemes http://ec.europa.eu/environment/waste/batteries/pdf/faq.pdf

[132] http://europa.eu/rapid/press-release_MEMO-15-5705_en.htm

[133] https://www.ft.com/content/956928ba-3d49-11e6-9f2c-36b487ebd80a

6.4 Shift towards mobility as a service

6.4.1 Vehicle parc

In the analysis, the introduction of a move to mobility delivered as a service, via car sharing, is considered to varying degrees within the City and ToD Narratives. The former envisages a long-term roll-out targeted primarily at urban areas whereas the latter is extended significantly to the wider consumer vehicle parc.

The decision to shift towards car sharing is an exogenous assumption and is embedded explicitly within the Narratives, rather than being a behavioural choice within the modelling, with the rationale to understand the potential implications for consumer costs and the wider system. (The impact on wider system electricity demand is explored in section 6.1.) A better understanding of the consumer drivers and requirements that would facilitate such a shift in future are a key gap that *could begin to be explored via the Stage 2 trials* (see section 8).

As discussed in section 3.2.1, car sharing is represented by fleets of vehicles that are notionally accessed by consumers hour-by-hour as required, such that vehicles are driven by multiple users throughout the day (i.e. sharing of the underlying asset), as opposed to sharing by multiple users at the same time, which is more akin to a modal shift. The underlying journey patterns and requirements of the users are maintained (i.e. no modal shifting is assumed); however, there is accounting for 'dead mileage'[134] to reflect that the vehicles may need to cover more miles to enable access by multiple users. The total vehicle service demands under car sharing Narratives compared with BaU are shown in Figure 23. The proportion of dead miles is expected to reduce over time as a higher penetration of car sharing enables more efficient use of the vehicles, but this is highly uncertain and fairly conservative values have been used for this work[135].

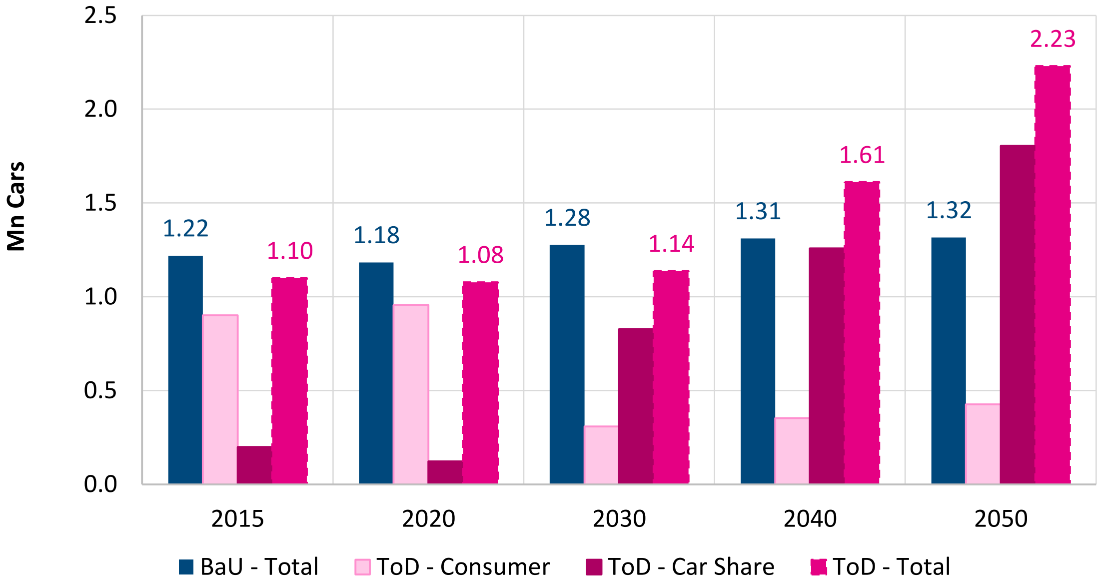
A potential benefit of the widespread roll-out of vehicle sharing is that even though the vehicle service demands are higher versus BaU due to dead miles, the overall vehicle parc needed is smaller due to better utilisation of the vehicles over their lifetime, as shown previously in section 5.1. In the analysis the long-term effect of wide-spread urban car sharing in the City Narrative is that the overall car (and van) parc increases only marginally over time, whereas under BaU it increases by around a third by 2050. In the ToD Narrative, where vehicle sharing spreads beyond urban areas, the absolute size of the fleet declines compared to today and by almost a third compared to BaU in 2050.

This reduction in parc size and more efficient use of the capital intensive stock can lead to lower costs of driving for the end consumer compared to private ownership (which are discussed further below), although these are offset to some degree by the potential impact of 'dead miles' and the higher turnover of the vehicles – thus higher CapEx spend – together with significantly increased costs for maintenance and insurance (reflecting the more intensive use of shared cars). Figure 84 shows that although fewer cars are needed overall in the car sharing Narratives, the higher scrappage rate - due to higher utilisation - means that more cars are sold than in BaU to replace the

[134] Miles driven which are not directly related to the consumer's underlying service demand, e.g. driving from or returning to a base not fully aligned with the consumer's desired start or end destinations.
[135] A starting estimate of ~30% (based on that for taxis) dropping to around 20%-25% for the City and ToD Narratives. The decline is greater in the former due to the likely more efficient use of vehicles concentrated in urban areas.

scrapped cars. The total of Private Consumer and Fleet Car Sharing cars are higher in ToD than in BaU. The scrappage rules are shown in Appendix B.9.2.

Figure 84 Sales of new cars in ToD compared with BaU



Car sharing vehicles compete with other vehicles for access to charging at public and rapid charging points and consequently extended car sharing could reduce the perception of access for Private Consumers (although some may have private charging networks, e.g. using car club parking bays that can only be used by car club vehicles) – the direct impact could be tested as a potential sensitivity in Stage 2.

Composition of car sharing fleets

The impact on the power train composition of the car sharing fleets compared to those for Private Consumers is outlined in Figure 85 and Figure 86 for the City and ToD Narratives, respectively. A key underlying driver for car sharing fleets is the higher average utilisation and annual vkm, which increases the importance of ongoing operating costs such as fuel. This, coupled with generally shorter trip distances, tends to make electric power trains look more attractive.

In the ToD Narrative the share of FCVs in the car sharing parc grows even more strongly than conventional vehicles due to the presence of 'reasonably' priced hydrogen (relative to electricity and liquid fuels) from large scale centralised production. This is not present in the City Narrative due to the significantly more expensive hydrogen produced by localised, small-scale electrolysers (a significant driver of the cost of production being the underlying rise in electricity prices).

Figure 85 Composition of Private Consumer car parc (left) and Fleet Car Sharing parc (right) in City

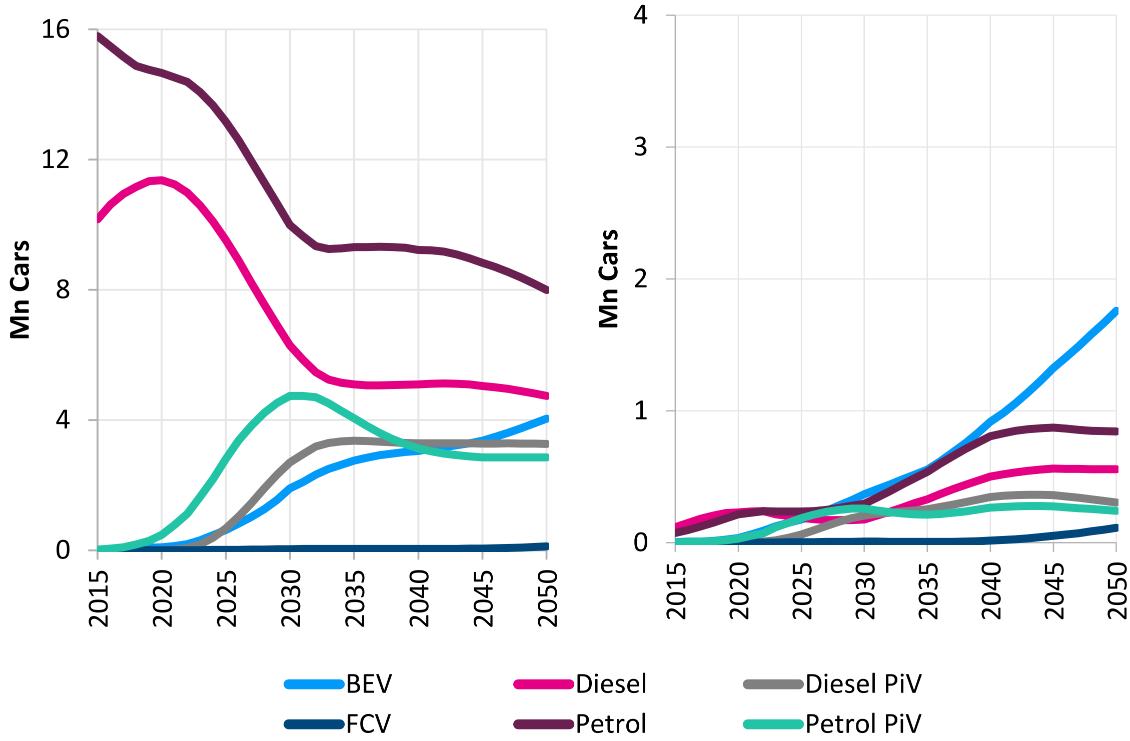
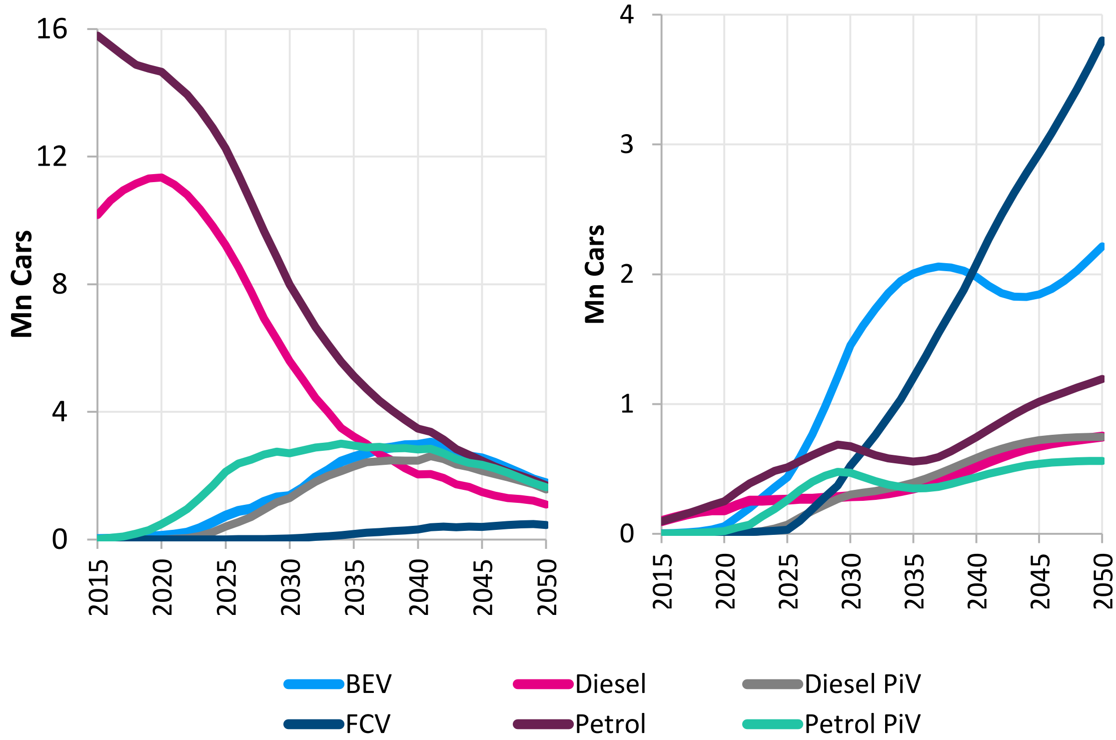


Figure 86 Composition of consumer parc (left) versus car sharing parc (right) in ToD Narrative



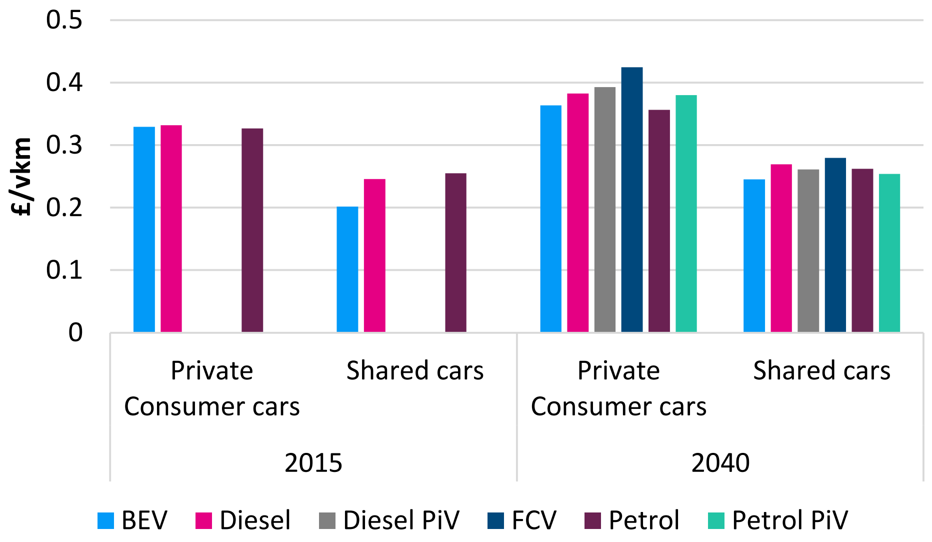
6.4.2 Consumer costs

The majority of the underlying cost components or cost drivers such as the retail price of the vehicle and its efficiency (and therefore fuel costs) are the same or similar, whether the vehicle is for Private Consumer use or Fleet Car Sharing.

Key differences for car sharing revolve around significantly higher absolute annual costs for insurance and maintenance (around three times higher). However, the higher overall utilisation of the vehicle over the Total Cost of Ownership horizon of four years leads to a substantially lower cost per km driven as shown in Figure 87. By 2040 the TCO (£/vkm) of new shared cars is around 30% to 40% lower for each vehicle type than the TCO of new Private Consumer cars.

The residual value of shared cars is very low in the TCO calculation (at the end of 4 years) because shared vehicles are assumed to drive further per year and therefore have a shorter economic life and depreciate more quickly (assumed to be 6 years although some will go on a little longer as the scrappage rules applied allow for a maximum technical life of 8 years).

Figure 87 TCO for new cars in City Narrative

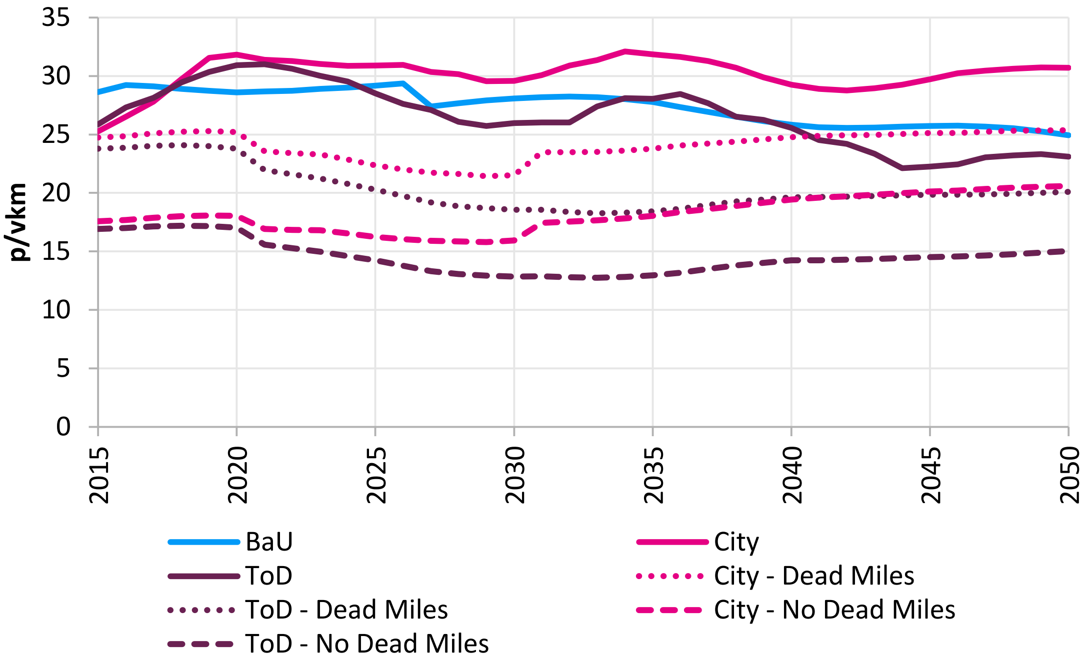


Note: Values of zero reflect no sale of new vehicles in this year

The potential cost reduction is relatively clear on a TCO basis comparing like for like *new* powertrains, but the extent to which this is reflected in the *average* £/vkm based on the rolling stock contained within the Private Consumer and car sharing groups is outlined in Figure 88.

Over the majority of the pathway the average cost per vkm for car sharing is typically lower than the average for the Private Consumer parc. It is important to note that the extent to which the consumer sees a saving from vehicle sharing will depend on the level of 'dead miles' they might have to pay for as part of completing their journey. The closer these are to zero the more the consumer cost will reflect the underlying car sharing costs, average costs per vkm for car sharing with zero and the core assumptions on dead miles are both shown in Figure 88.

Figure 88 Evolution of costs per vkm for shared cars with (dotted) and without (dashed) dead miles versus other cars (solid)



7 Delivering a 'good' solution

7.1 Overview

Section 5.5 provided a number of observations on what characterises a 'good' environment for deployment and use of ULEVs, based on the analysis undertaken. In this section a qualitative analysis of these measures is undertaken, in order to identify what barriers or risks may act to inhibit or prevent the efficient and successful employment of these measures, and to recommend measures and actions to address these. Some of the measures identified, such as vehicle leasing and regulation on CO_2 emissions for new vehicles, already exist in a substantial way and therefore detailed consideration of their implementation has not been considered. For the purposes of this section, those measures representing substantially new actions have been consolidated into five themes:

- **Demand Management**
- **Enabling infrastructure investment,** for hydrogen fuelling and charging networks out of the home (particularly for rapid charging)
- **Mitigation of upfront vehicle costs,** primarily through policy intervention
- **Car sharing**, and
- **Mitigation of declining vehicle tax revenues**, through carbon pricing, congestion charging zones or a broad technology neutral mechanism.

To ensure a comprehensive consideration of the issues that may relate to each theme, the list of BBs has been reviewed in each case. The issues identified are then explored, and insights from the analysis used to make recommendations for successful implementation.

Separate to the barriers or risks to delivering a 'good' solution, it should be noted that some of the factors that would *further encourage* employment of these measures are addressed in the *D1.2 Analytical Framework* for the different Dimensions and in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report.* The subsidy levels required for entities such as a DM aggregator and infrastructure owners to make an appropriate level of return have been identified and the effect of different grant levels on the uptake have been set out.

Outside of direct financial incentives, adoption could be encouraged through the 'qualitative' BBs – in particular those denoted as 'high' and 'medium' materiality or more indirect incentives. For example, to influence consumers to participate in car sharing, incentives such as cheaper exemptions from congestion or toll charges or access to bus lanes could be provided. Government or local authorities could also play a role in active 'education / marketing' of car sharing schemes. To support Demand Management and infrastructure investment, several of the aforementioned BBs could also apply, such as greater 'standardisation' and 'simplification' (e.g. of smart meters or charging infrastructure).

7.2 Demand Management

7.2.1 Potential risks and barriers

Demand Management or Demand Side Response more broadly from PiVs is the shifting of charging to periods when there is an optimum balance of supply and demand, such that the energy costs for the consumer are minimised, leading to more efficient operation of the electricity system and a lower total cost. Full realisation of these savings relies on consumers allowing external management of charging, thus optimising load from the system perspective. However a significant portion of the savings may be achievable by allowing consumers to retain direct control, but incentivising them through price signals to modify their charging behaviour, thereby moderating their impact on the system. Table 19 details the identified risks and barriers to successful deployment of Managed Charging.

Table 19 Potential risks and barriers identified in Demand Management

Dimension / Building Block	Risks or barriers to implementing good solution
Customer Proposition	
CP10: Static ToU (User-Managed Charging)	▸ Uncertainty in degree of consumer response achieved ▸ Uncertainty in reliability of response
CP11: Dynamic ToU (Supplier-Managed Charging)	▸ Uncertainty in consumer willingness to accept loss of control ▸ Uncertainty in effectiveness of consumer interface
CP12: Demand management payment	▸ Uncertainty in compensation required by consumers to provide DM response
CP16: Public charging (rapid) CP17: Public charging (local)	▸ Greater consumer use of rapid and local charging is likely to reduce ability to benefit from demand management
CP30: Charging control	▸ Uncertainty in consumer willingness to accept loss of control
Physical Supply Chain	
PSC2: Battery Management System	▸ Enabling communication of battery state for Managed Charging
PSC7: Comms system	▸ Communications to enable DM
PSC12: Electricity distribution networks	▸ Developing knowledge of asset base to sufficient resolution
PSC25: Industry standards	▸ Enabling mass participation in DM schemes
PSC26: Assets for settlement	▸ Enabling accurate settlement
PSC27: Assets for comms	▸ Communications to enable DM
PSC28: Data servers	▸ Communications to enable DM
PSC29: Assets for comms from and to vehicles	▸ Communications to enable DM
Commercial Value Chain	
CVC7: Electricity supplier CVC9: DNO CVC12: Charge point operator CVC15: DM aggregator	▸ The desired DM actions of different players may conflict. Similarly they may overlap, but lack of coordination may prevent realisation of maximum value for the system as a whole, and by extension final electricity consumers.
Market and Policy Framework	
MPF33: Adequate access to infrastructure	▸ Ensuring regulatory framework enables demand management ▸ Providing price signals that reflect resource costs and incentivise efficient behaviour

7.2.2 Risks and barriers in the Customer Proposition

The main risk to effective implementation of Demand Management from the Customer Proposition perspective regards uncertainty over the extent of consumer adoption, given that it requires some degree of additional effort and potentially inconvenience versus Unmanaged Charging.

The analysis considers two options representing different levels of intervention to manage demand. The first is a representation of User-Managed Charging in response to a static ToU tariff, using a predetermined price structure to signal to PiV users the benefit of shifting the times at which they charge their vehicles, indirectly reducing the costs of managing the electricity system and the cost to the consumer. Although responding to these signals would reduce the cost of charging, the extent to which consumers will modify their behaviour in these circumstances is uncertain. It is likely to depend on the complexity of the proposition, and in general it might be considered that consumers as a whole will have a limited appetite to actively engage with more complex and dynamic structures. In any case, a convenient and accessible means of setting charging instructions is likely to be a prerequisite to achieving response, such as a charging timer on the vehicle (already available in a number of PiV models).

Proposals for the trials to be undertaken as part of Stage 2 of the CVEI project include providing evidence on consumer reaction to a User-Managed tariff using a block series of prices throughout the day. Consumers will have visibility of the price shape and can actively make the decision to charge their vehicle at times when the tariff is cheaper, resulting in cost savings for the individual[136]. The resulting charging behaviour will be compared to a control group with no User-Managed Charging incentives embedded in their tariff.

Some evidence already exists for PiV user response to static ToU pricing in home charging. Participants in a 2014 study by San Diego Gas & Electric[137] had their home charging points metered separately and charged based on a fixed structure with peak, off peak and super off peak prices, with no variation by day of week or time of year. The participants were randomly assigned to one of three groups with different ratios of peak to super off peak charges. The study concluded that participants used timers to complete most of their charging in the super off peak period. Additionally, it found that participants responded to price signals, such that the groups with higher peak to super off peak price ratios exhibited a greater share of super off peak charging and lower share of peak charging. The US Department of Energy, in a review of six projects investigating charging behaviour and impact on the grid[138], also found that 'time-based rates were successful in encouraging greater off-peak charging'. The value of enabling consumers to use a timer device to pre-programme charging start times was also cited. It should be noted that all of these studies were conducted with ULEV 'Innovators' of BEVs and hence a core rationale for the Stage 2 trial is to understand better the behaviour of mass-market consumers with respect to uptake and use of both BEVs and PHEVs.

The second arrangement modelled is representative of Supplier-Managed Charging, where demand for charging is controlled to provide complete load shifting (i.e. further reducing the system costs through better optimisation against the supply and demand balance of the system). This is consistent with a model where the consumer determines a desired end state and devolves the decision on charging profile to an external party, responsible for optimising charging, potentially subject to constraints on the end state. This exposes the consumer to some degree of uncertainty regarding the state of charge prior to the specified end-state time. The willingness of consumers to accept this uncertainty, and the amount of compensation they would require for doing so, is uncertain.

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[136] As for practical and ethical reasons it is not acceptable to engage consumers in a trial where they could be financially worse off than if they had not participated.
[137] Final Evaluation for San Diego Gas & Electric's Plug-in Electric Vehicle TOU Pricing and Technology Study, February 2014.
[138] Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviours – Experiences from Six Smart Grid Investment Grant Projects, US DoE December 2014.

Some qualitative evidence is available from surveys completed in the *D2.1 Consumer Attitudes and Behaviours Report*, which found that approximately two thirds of consumers interviewed suggested they would prefer to retain full control over charging via a static ToU tariff, rather than accept external control under Supplier-Managed Charging. The trials to be undertaken as part of Stage 2 of the project will provide some quantitative evidence in this regard. Under the Supplier-Managed tariff the user will plug-in and specify the desired minimum state of charge and departure time. The 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 can be minimised. A group of participants will be given a tariff that provides rewards that relate to the system benefits realised through the use of flexibility in the charging profile. A control group using a tariff without Managed Charging is also included to provide a basis for comparison. The full details of the proposed trial design are outlined in the separate *D1.4 Trial Design, Methodology and Business Case Report*.

7.2.3 Risks and barriers in the Physical Supply Chain

The majority of barriers to implementing Demand Management in the Physical Supply Chain concern the flow and processing of data and instructions. Many of the existing physical barriers to implementing Managed Charging should be overcome through the roll-out of smart metering. This will enable half hourly metering at domestic and small business locations, and allow prices to better reflect the state of the electricity system[139]. This will allow consumers to control their charging behaviour using timers in response to tariffs with a ToU element. However, the design of a User-Managed Charging system that uses timers should take into account the risk that widespread use of timers may exacerbate the problem if it results in a significant shift in demand at once. The design might usefully incorporate a feedback loop whereby the block price series that form a ToU tariff reflect the system costs close to real-time, rather than being set at the start of the year, for example, and then remaining unchanged. An alternative could be that the supplier sets certain tolerances, such that the charging will be shifted to start *around* the time specified by the user (perhaps half an hour before or after) giving the supplier flexibility to spread the load, though the user has to accept the potential cost implications – in this case, this would be a '*Majority* User-Managed Charging' regime. Another option would be to allow the user freedom to select the charging start time, without then adjusting this ex-post, and instead seeking as much advance notice of the intended start time as possible – for instance through incentive or penalty mechanisms put in place to adhere to the pre-stated start time.

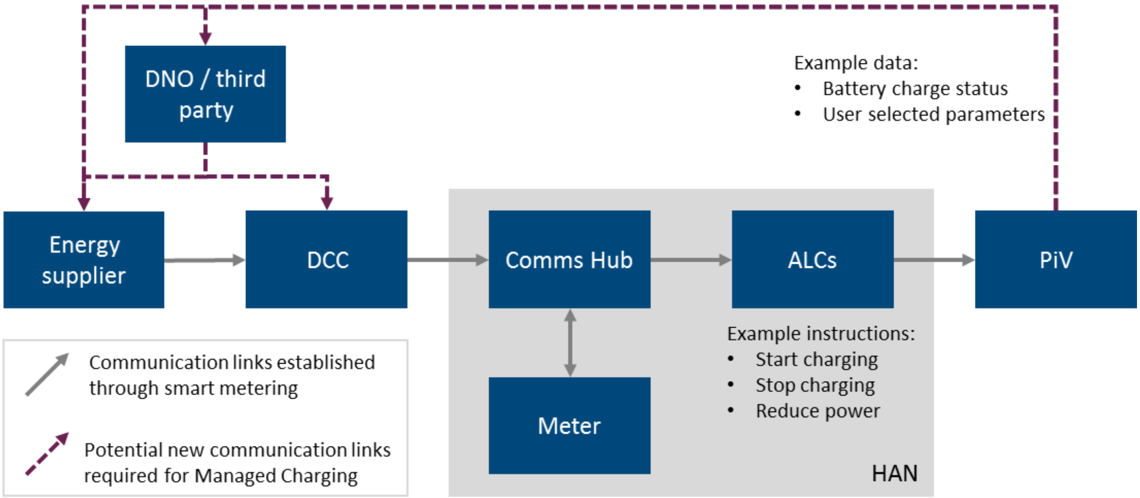
Smart metering will also assist with the implementation of externally Managed Charging using the Auxiliary Load Control Switch (ALCS) functionality, allowing remote control of load on devices connected to the Home Area Network (HAN), though additional communications infrastructure may also be required. Under the Smart Energy Code (SEC), only registered suppliers are able to send commands to ALCs, via the Data Communications Company (DCC)[140].

If PiV charging is to be Managed to respond to signals from the DNO or an independent operator, the ability to pass instructions from these parties to the energy supplier or DCC directly (and potentially pass information back the other way) would need to be established. This scenario has though been identified in the development of smart meter protocols. More sophisticated charging products offering greater flexibility, for example a tariff that guaranteed the battery would be 90% charged by

[139] Assuming associated implementation of half hourly settlement, and that time differentiation exists in underlying costs, which is not currently the case for network charges for mainstream consumers.
[140] https://www.ofgem.gov.uk/sites/default/files/docs/2014/04/decc_smart_metering_slide.pdf

7am, would additionally require communications from the vehicle's Battery Management System to the charging manager. Figure 89 provides a schematic representation of the information flows required.

Figure 89   Information flows required for Managed Charging



It should be noted that uncertainty exists around the programme to implement the Government's ambition to roll-out smart meters to nearly all homes and businesses by 2020, and the effectiveness of the scheme once implemented. The Energy and Climate Change Parliamentary Committee declared in its 2015 report[141] on the programme's progress that it did not believe the target would be met, and also highlighted risks to the expected benefits. Risks identified with the potential to affect roll-out arise from a shortage of installation engineers, the difficulty of successful installation in multi-occupancy buildings, and a delay in the establishment of the communications framework (operated by the DCC). Risks to the effectiveness of the completed programme arise from potential lack of interoperability between meters installed by different suppliers, and meters installed earlier and later in the programme with different technical standards. Clearly, to the extent the programme is delayed or does not operate in the manner expected, the ability of consumers and the system to enjoy the benefits arising from responsive charging of PiVs will be compromised.

7.2.4 Risks and barriers in the Commercial Value Chain

No major barriers were identified that would act to prevent the Commercial Value Chain from delivering Time of Use tariffs presenting more accurate price signals to PiV users, incentivising them to time their charging to periods of lower demand.

Suppliers should be incentivised to offer these tariffs in order to reduce their wholesale costs, and in order to maintain competitive consumer offerings. DNOs would also benefit from setting tariffs in a manner that reduces peak growth and defers the need to invest in network reinforcement, at least within the duration of a price control period (this is discussed further in section 7.2.5).

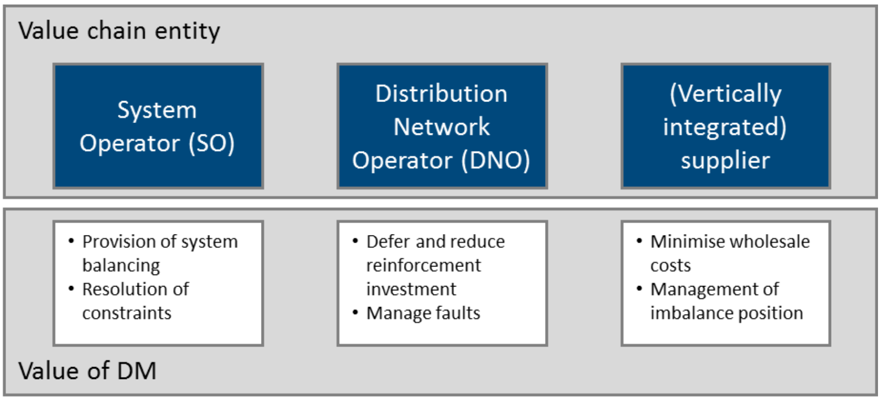
However, it is likely that not all of the potential system benefits of demand management can be achieved through demand response via User-Managed Charging. Achieving a greater proportion

[141] House of Commons Energy and Climate Change Committee, Smart Meters: progress or delay?

requires response in a shorter timescale and on a more reliable and predictable basis, through Supplier-Managed Charging enacted primarily by a third party.

Enabling consumers to devolve control of their vehicle charging to external parties would require an appropriate contractual basis. DM provided by Managed Charging of PiVs in this way could benefit the electricity system in multiple ways, and hence has value to a number of business entities in the electricity value chain, as summarised in Figure 90.

Figure 90 Value of DM for different commercial entities



DM's impact on multiple separate businesses in the electricity value chain presents barriers to the efficient use and procurement of DM sources, and poses a question as to what commercial structure would allow the most efficient use of DM. For example, in some scenarios a DM action may be simultaneously beneficial to one party and detrimental to another, and could lead to an overall increase in the cost of operating the system. Example scenarios are described below.

- After Gate Closure, a DM aggregator calls on contracted PiVs to reduce their rate of charging due to a sudden drop in wind generation. In settlement, the consumers' suppliers will be subject to imbalance charges.
- A surge in wind generation leads the SO to call on a contracted DM Aggregator to increase demand from domestic PiV chargers and immersion heaters. A number of these are clustered in a particular part of a DNO's network, causing a local peak in demand and accelerating the requirement for reinforcement.

There will also be instances when a DM action has value to more than one entity at the same time. In such cases the full value of DM cannot be realised through contracting with a single party, and a less than optimal volume of response will be forthcoming as a result. Example scenarios are described below:

- Peak national demand may coincide with peak demand on a distribution network. In this period, reducing demand from PiVs may mean a generator does not need to dispatch high variable cost peaking plant, and the DNO reduces peak demand, deferring the need for investment in network reinforcement.
- A DNO faces network capacity issues because of high embedded wind generation, and simultaneously the TSO faces a constrained ability to export power from the same district to load centres elsewhere in the country. The same issue is relieved by a DM action to increase demand from PiVs in the DNO's network.

There is also scope for contractual inefficiencies. Typically, contracts for DM services will be struck bilaterally and endure for a period of time. This may prevent the resource being used by other parties, and prevents sharing of costs. A particular example is the case of DNOs, who need to dispatch DSR services relatively infrequently (for example, in response to faults), which risks removing a valuable DM resource from the wider market which could be more valuable if employed elsewhere.

These issues of coordination have previously been identified and are the focus of thinking and analysis by many stakeholders in the sector including DECC, Ofgem, the Smart Grid Forum[142], the Energy Networks Association (ENA), ELEXON[143], and the DNOs as part of the Low Carbon Networks Fund innovation scheme. Ofgem has identified the need to establish an overarching market framework to enable DSR and is taking this forward through the Flexibility Project[144].

An associated question is which entity should play the role of aggregating the individually small DM potentials of PiV users into a significant resource. Entities which could play this role include the suppliers, independent aggregators and Charging Point Operators. Suppliers have the benefit of having existing contractual relationships with consumers, through which Supplier-Managed Charging propositions could be made and associated cash flows channelled. Additionally, under the Smart Energy Code, only suppliers are able to send commands to load switches (controlling supply to the home) and Auxiliary Load Control Switches (controlling specific loads), minimising the communications infrastructure required to implement Managed Charging. As a result, suppliers appear to face the lowest barriers to aggregating private PiV users into a useful DM resource.

The analysis also demonstrated that the greatest proportion of savings available to consumers from Demand Management arises from reducing the cost of energy balancing. Suppliers are directly exposed to these costs, and so may wish to have direct control of measures to manage them. Fleet users, operating many vehicles, may already constitute a significant DM resource. As commercial entities they may also be more focussed on the commercial opportunities demand management presents, and to tailoring provision to match the usage patterns of their vehicles. In this context, independent aggregators focussed on providing demand management services may be better able to offer a bespoke and competitive product. Charging Point Operators would clearly be well positioned to offer DM from PiVs connected to their network, though their ability to provide it may be limited if it conflicts with the way the charging points are used by PiV drivers.

In summary, all these entities may be in a position to provide DM based on Managed Charging of PiVs, though suppliers are perhaps best suited to aggregating domestic charging, where the greatest opportunity lies.

7.2.5 Risks and barriers in the Market and Policy Framework

The main market and policy issues identified that may inhibit the delivery of Demand Management regard the regulatory framework for electricity distribution networks. These are firstly the establishment of prices for use of the network that accurately signal constrained capacity, and

[142] The customer-focused smart grid: Next steps for regulatory policy and commercial issues in GB Report of Workstream Six of the Smart Grid Forum, 2015

[143] Maximising the value from Demand Side Response

[144] Making the electricity system more flexible and delivering the benefits for consumers, 30 September 2015

secondly the ability of the regulatory framework to incentivise the optimal level of DM. This section investigates these issues in that order.

Network price signals

Time of Use price signals already exist for larger consumers in the charges DNOs make for their services (DUoS, Distribution Use of System charges), which are set so as to recover the allowed revenues determined through the price control mechanism. DUoS charges are based on four components:

- A fixed charge (per metering point)
- A capacity charge (per available kW)
- A reactive power consumption charge (per kVArh), and
- A unit charge (per kWh).

A time dependent component may be included in the last of these, with rates varying between three time bands[145]:

- Red, typically weekdays 16:00 to 19:30
- Amber, typically weekdays 07:30 to 16:00 and 19:30 to 22:00, and
- Green, typically weekdays 00:00 to 07:30 and 22:00 to 00:00 and all day at weekends.

All DNOs use a similar structure, and charges are determined through the Common Distribution Charging Methodology (CDCM) for all consumers connected at low voltage and most at high voltage[146]. CDCM charges reflect the average costs imposed on the system by generic types of consumer, and are not location specific within a single DNO (though charges vary between DNOs). The temporal variation reflects estimated long-term costs of reinforcement to meet demand at peak time. However, only half-hourly metered consumers (typically industrial and commercial consumers with maximum demand exceeding 100 kW) who opt for DUoS charges to be 'passed through' are currently exposed to this variation. These consumers therefore have some incentive to modify their electricity use in a manner sympathetic to the distribution grid. In contrast, smaller consumers (such as domestic customers) are not exposed to this price signal to shift demand out of periods of high demand on the network. However, roll-out of smart metering[147] should provide the capability for domestic prices to include time variation of distribution network charges too. Price signals regarding use of the transmission network could also be passed through by suppliers using smart metering, although transmission network charges operate in a different and less predictable way (via the Triad system[148]).

DNO red band periods typically cover a continuous period of three hours or more, arguably providing a fairly crude signal about the period of maximum stress on the network. Furthermore, periods of

145 Exact timings vary by DNO
146 Charges for consumers connected at Extra High Voltage (EHV) are determined through the EHV Distribution Charging Methodology, which produces site specific charges.
147 Including associated changes to the Balancing and Settlement Code and Distribution Connection and Use of System Agreement.
148 For further details see http://www2.nationalgrid.com/UK/Industry-information/System-charges/Electricity-transmission/Transmission-network-use-of-system-charges/

low capacity margin at the national level, and peak wholesale prices, may not align with peak demand in localised parts of distribution networks, or indeed distribution networks as a whole. A signal in wholesale prices to increase consumption may swamp a signal of scarce distribution network capacity, increasing strain in the latter. Additionally, the physical properties and investment requirements on a distribution network vary considerably between different locations. This variation could be exacerbated by clustered uptake of low carbon technologies. The charges calculated through CDCM do not vary by location and disguise this more localised picture.

More precise network price signals may then be required to enable demand response to provide greater benefits to DNOs. Developing a system for setting prices may however be a substantial task. Agreement would be required on how costs should be shared between consumers, and the balance between recovering existing costs and signalling the cost of reinforcements. The equitability of introducing locational prices is also likely to be contentious. The barriers to consumers altering behaviour to adapt to time signals in electricity prices are relatively low (e.g. shifting discretionary load), but the barriers to adapting to locational signals are very high (e.g. moving home), and it may be that introducing them is unacceptable from a social and political perspective. The administrative burden would also increase as charges became more granular. Furthermore, monitoring and knowledge of DNO assets below the primary substation level is typically limited (though this may change as DNOs look to increase adoption of DSR and Active Network Management). This may dictate the greatest level of locational resolution achievable in prices.

DNO price control regime

The analysis demonstrated that significant value arises from Demand Management from both savings in system balancing costs and in network reinforcement. With regards balancing costs, there are well established competitive markets for the SO to procure balancing services from demand reduction and generation. The Balancing Services Incentive Scheme incentivises the System Operator (SO) to minimise the cost it incurs in doing so, and so should support adoption of services provided by management of PiV charging demand if this is cost effective. This section therefore focusses on the suitability of the regulatory framework applied to DNOs, where operational management of loads is less established, to support development of demand management in PiVs.

In 2014, the existing price control framework for the DNOs (known as RPI-X) was replaced with a new scheme called RIIO (Revenue = Incentives + Innovation + Outputs). The overriding objective of the new framework was to encourage DNOs to enable the transition to a sustainable energy sector in as cost effective manner as possible. In the latter regard a significant component of the redesign was to remove a perceived bias towards 'capital expenditure solutions' (i.e., conventional reinforcement) and encourage increased use of 'smart' operational solutions, such as DSR.

Under the RIIO regime, Ofgem sets an allowed revenue that each DNO can recover from consumers. The basis of the calculation is the determination of an efficient expenditure over the life of the price control framework, in total expenditure terms. Four main elements comprise the determination of efficient expenditure.

- First a comparative cost assessment is undertaken, combining on a weighted basis outputs from top down modelling based on factors such as consumer numbers, and bottom up analysis based on the expected activities to be undertaken during the period.
- A reduction is applied to reflect savings expected to arise from smart grids, smart meters and innovation. Expected savings in reinforcement costs are based on a 25% saving on

modelled conventional expenditure. Expected savings in other areas (such as managing faults and outages, operational IT and telecoms, asset replacement and refurbishment, and inspection and maintenance) are benchmarked against the best performing DNO in this area. Expected savings arising from smart meters are based on estimates produced by DECC, with an adjustment back to account for potential double counting with other areas.

- Allowed revenue is indexed to RPI, but some costs faced by DNOs are expected to change at rates different from economy wide inflation and an allowance is made for these 'Real Price Effects'. Additionally, DNOs are expected to make productivity improvements over the price control period, and so an ongoing efficiency assumption is included in the calculation of efficient expenditure.
- Finally a mechanism known as the Information Quality Incentive provides rewards to DNOs submitting business plans with expenditure requirements that closely match those calculated by Ofgem, thereby dis-incentivising submission of inflated costs.

With efficient expenditure determined, fixed percentages are set allocating total expenditure between a 'slow' pot and a 'fast' pot, which in turn set the three basic components of the allowed revenue:

- The slow pot expenditure is treated as capital expenditure, and added to the Regulated Asset Value. The first two components of the allowed revenue of the DNO are then:
    - Depreciation of the Regulated Asset Value, and
    - Return on the Regulated Asset Value.
- The fast pot expenditure is treated as operating cost, and is recovered in full in the same period representing the third component of the base allowed revenue.

As the share of total expenditure considered fast and slow is set in advance, there should be no inadvertent incentive for DNOs to pursue capital expenditure solutions over operating cost solutions where the structure of the price control mechanisms provides greater returns to the former.

After the commencement of the price control period, an efficiency incentive mechanism rewards DNOs who deliver the required outcomes whilst incurring expenditure below the predetermined efficient level. DNOs retain a fixed proportion of savings arising this way (typically 50% to 60%), and the rest is shared with consumers. In this way DNOs are incentivised to seek the most efficient solutions to expenditure requirements, although the mechanism works both ways in that DNOs must cover the same proportion of costs themselves should expenditure overrun. A similar set of rewards and penalties incentivises outperformance (and disincentivises underperformance) versus output based objectives in fields such as reliability, environmental performance, new connections and consumer satisfaction.

The existing structure effectively requires DNOs to use 'smart' approaches, such as Demand Management, to reduce their expenditure. Furthermore, beyond this baseline, they are incentivised to seek such solutions where they reduce costs through the efficiency incentive. Indeed it appears that DNOs have been making use of Demand Management already to reduce costs. For example, in the business plan submitted to Ofgem, UKPN states that it plans '*to replace 14 traditional reinforcement schemes in our Business Plan with interim solutions which we expect to fulfil through Demand Side Response (DSR). We expect DSR to play a role in managing complex construction timelines within a further six reinforcement schemes. This will provide a saving of £43 million* *compared with the original planned schemes*'[149]. Trials undertaken by UKPN have taken a number of forms, including:

- Contracting with DM aggregators supplying a portfolio of industrial and commercial DSR 'building turn-down' and responsive generation services
- Using Active Network Management systems to monitor and control the output of generators embedded in the distribution network
- Deploying smart meters and time varying electricity tariffs to test the responsiveness of residential and Small and Medium-sized Enterprise demand, and
- Exploring the opportunities for and effectiveness of PiVs in providing DM services – including commercial and technical solutions.

In summary, RIIO enables and incentivises adoption of DM solutions to network constraints by DNOs. However, it is difficult to judge whether it will drive uptake at the most efficient level. Setting allowed revenues (through assuming a baseline level of savings can be achieved versus a counterfactual of conventional reinforcement) entails some risk because the availability and cost of DM may not be known in advance and could evolve significantly over the eight-year period of the price control. If the required savings are too large the settlement will pose a commercial risk to DNOs; if too low potential benefits to consumers will be lost. Additionally, there may in some circumstances be a disincentive to DNOs adopting additional DM, despite being able to retain a significant proportion of the benefits, if the savings arising are then 'locked in' to the baseline of the subsequent price control period.

It should be noted that establishment of the RIIO framework for DNOs is not solely driven by anticipation of PiV deployment. Rather, the adoption by DNOs of 'smart' solutions is occurring in response to increasing penetration of distribution connected generation, as well as in anticipation of increasing adoption of electrified technologies, and is often discussed in the context of the transition of DNOs to DSOs. This concerns the move by DNOs away from simple provision of infrastructure sufficient to accommodate demand, and towards actively managing networks to efficiently accommodate multiple sources of generation and demand.

7.2.6 Conclusions and recommendations

Currently available evidence suggests that PiV users adapt their charging behaviour in response to price signals, delivering lower price charging and significant efficiency savings in the operation of the electricity system. Enabling these price signals to be established and consumers to respond to them would appear to be a low regret option. Once the roll-out of smart metering has occurred, the barriers to delivery of ToU tariffs are low (though the efficiency of price signals in DUoS tariffs may be limited). Requiring PiVs or their charging points to have a simple device to time the start of charging should be sufficient to enable consumer response.

Actively Managed Charging would offer additional benefits to consumers and the electricity system. However, there is no evidence base currently available regarding mass-market consumers' willingness to adopt such a measure (though the trials to be undertaken as part of Stage 2 of the CVEI project will help address this). If the evidence establishes that consumers will engage in Managed

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[149] http://library.ukpowernetworks.co.uk/library/en/RIIO/Main_Business_Plan_Documents_and_Annexes/UKPN_Overall_Executive_Summary.pdf

Charging at a price that makes the proposition viable, barriers to implementation exist but are not insurmountable.

In the Physical Supply Chain, some additional communications infrastructure, beyond that established by smart metering roll-out, may be necessary to enable flow of data and instructions between different entities and the PiV to enable actively Managed Charging, particularly to dynamically understand the state of charge of each PiV under the external agent's control. This is unlikely to be technically difficult, but may require the establishment of industry standards[150], possibly through the extension of the Smart Energy Code.

Barriers in the Commercial Value Chain chiefly concern the coordination of DM activity across multiple entities in the electricity supply chain, so as to manage conflicts and realise value. Establishing the means of achieving this coordination may be necessary regardless of whether Managed Charging becomes prevalent for PiVs, as the ability to control load such as electrified heating becomes important. However, PiVs may precede electrified heating as a source of large scale and potentially low cost DM, and so may be the trigger. As discussed in section 7.2.4, the need for coordination has been identified and discussed by a number of industry participants. In broad terms, proposals for its achievement can be distilled into three stages, each accommodating an increasing role of DM, and representing increasing degrees of intervention and market redesign.

- **Stage 1** - initially, a shared services framework setting out how non-domestic DM resource could be shared between DNOs and the SO. The ENA has proposed a concept to deliver this[151], envisaging a hierarchy of dispatch giving DNOs precedence in using DM resources for local issues. This would allow greater realisation of value and reduction of conflicts in the non-domestic sector, where initial development of the DM market is occurring owing to the greater ease of achieving scale.
- **Stage 2** - an approach building on a similar principle but potentially allowing for greater coordination would involve one party (such as the SO) contracting for DM services and then selling them on to other parties (such as the DNOs) when they need them or place a higher value on them. Such a model would represent a more substantial change to the market framework, requiring for example reconsideration of price control frameworks.
- **Stage 3** - the ultimate level of coordination in use and procurement would be through establishment of a central market platform, allowing resource to be optimised across all sellers of DM services and buyers for all purposes. The market would need a locational element to its design to recognise the localised requirements of DNOs. Developing, operating and regulating such a platform would be complex and costly task. This step would be justified only once DM becomes a significant activity, and the inefficiencies of preceding arrangements exceed the costs of a formalised, structured market.

Issues identified in the Market and Policy Framework concerned price signals for network usage, and the ability of the price control mechanism for regulated networks to incentivise DM. Regarding the first issue, time of use differentiation already exists in network charges, and adoption of smart metering should enable these to be more widely passed through in consumer tariffs. This will

[150] BEAMA, A guide to electric vehicle infrastructure, states that work is under way to develop European standards for PiVs, and join these with standards for smart grids, in response to EC Mandates 468 and 490.
[151] ENA Demand Side Response Shared Services Working Group: Demand Side Response Shared Services Framework Concept Paper

increase the incentive for PiV users to charge at times of lower use of the network's capacity. These time based signals could potentially be sharpened by refining the time bands on which they are based, and potentially made dynamic. The potential benefits of Demand Management to DNOs are likely to be strongly location dependent however, and the potential for prices to contain accurate locational signals is limited. Therefore, the proportion of potential benefits of demand management to DNOs that can be achieved by consumer controlled response to ToU tariffs may be relatively low.

With regards to network regulation, the RIIO mechanism has been designed to deliver DM. Whilst challenges are likely to be inevitable to some extent, it is not possible to replicate here the significant consultation and effort that has been expended in designing the scheme, and it is reasonable to assume it is fit for purpose. RIIO is still at the early stages of its implementation, and the sensible course of action will be to monitor and review its success in bringing forward DM, benchmarking networks against each other and international examples where possible, and adapting where necessary parameters such as the required savings, sharing factors and the length of the price control period.

7.3 Infrastructure investment

7.3.1 Potential risks and barriers

In its modelling of the vehicle choices, ECCo assumes that adequate access to charging or fuelling infrastructure is a key driver in the decision for end users adopting ULEVs. In the case of PiVs, access to dedicated home charging is a substantial component in this adequacy, but may not be sufficient alone, and is not available to all potential users. In the case of FCVs, adequacy of access is much more likely to rely on infrastructure outside of the home. Table 20 considers the risks and barriers regarding infrastructure provision.

Table 20 Potential risks and barriers identified in infrastructure investment

Dimension / Building Block	Risks or barriers to implementing good solution
Customer Proposition	
CP16: Public charging (rapid)	▶ Providing consumers with perception of adequate access to charging / fuelling infrastructure ▶ Incompatible standards or inability to 'roam' across networks reducing perceived level of access
CP17: Public charging (local)	
CP18: Workplace charging	
CP19: Hydrogen refuelling stations	
Physical Supply Chain	
	▶ No barriers identified
Commercial Value Chain	
CVC12: Charging point operator	▶ Investing in new infrastructure in face of demand risk
CVC19: Hydrogen forecourt operator	
CVC20: Localised hydrogen producer	
CVC22: Hydrogen network operator	
CVC23: Hydrogen road distributer	
Market and Policy Framework	
MPF28: Government funding / investment	▶ Structuring efficient support for new infrastructure where necessary
MPF29: Leveraging private investment	
MPF32: Government guarantees	
MPF33: Adequate access to infrastructure	▶ Providing consumers with access to charging infrastructure on reasonable terms
MPF36: Role of local authorities	▶ Permitting new infrastructure
MPF37: Standardisation	▶ Risk of multiple incompatible standards for charging infrastructure
MPF39: Planning regulations	▶ Permitting new infrastructure

7.3.2 Risks and barriers in the Customer Proposition

Adequate access to infrastructure for refuelling or charging vehicles is generally assumed to be a prerequisite for a consumer to consider choosing a ULEV. What is considered adequate will vary between different users, and depend on their vehicle usage patterns. Providing access to hydrogen refuelling infrastructure that will be perceived by consumers as adequate is likely to be more challenging than charging infrastructure, where simple-to-implement home charging provides significant access. Nevertheless, many consumers will require dependable access to charging at locations away from home. Perception of adequacy may extend to the length of time it takes to charge, and will be compromised by competing, incompatible standards for charging infrastructure. Access will be diminished to the extent that infrastructure featuring incompatible standards proliferates, or rival networks with prejudicial roaming tariffs are established.

A challenge for providers of fuelling and charging infrastructure is that it is likely that they will initially need to operate on low volumes. To recover fixed and capital costs, the Customer Proposition would then need to be one of high prices, which may in turn deter increased volumes. In practice, the developers of new infrastructure may need to endure a period of loss making operation (in the absence of a subsidy regime of some description) in order to achieve volume growth and profitability at a later date. This issue will be particularly acute where investment is more 'lumpy', and investment occurs further ahead of need.

7.3.3 Risks and barriers in the Physical Supply Chain

The technology to produce, distribute and embark hydrogen and electricity to vehicles exists, and no significant barriers to provision of infrastructure have been identified from a Physical Supply Chain perspective. There may however be risks that lead to deployment at greater cost or reduced rate. The quantitative analysis assumes that learning effects lead to a substantial reduction in the costs of hydrogen refuelling stations and localised producers over the pathway. These may not be achieved at the rate envisaged, leading to increased costs. There is also a risk that if deployment of charging infrastructure tends to be densely clustered in small areas, greater network reinforcement costs will be incurred. These risks however will tend to manifest themselves as barriers in the Commercial Value Chain.

7.3.4 Risks and barriers in the Commercial Value Chain

The most significant issue for the Commercial Value Chain with regards to providing infrastructure is demand risk. This section considers the issue from the perspective of public charging, fast charging, work charging, and hydrogen refuelling infrastructure.

Public charging infrastructure

In common with all new infrastructure considered in this analysis, public charging potentially faces a challenge of demand risk, specifically the timing and level of PiV uptake. As public charging points are generally considered unlikely to be a core location for charging, with the possible exception of helping to facilitate wider spread use of car sharing, there are also additional components of demand risk. As the range of PiVs increases, users may experience less need or inclination to charge at public locations and pay a premium over home charging. There is also a risk that public charging points may become obsolete before the end of their life, for example through deployment of faster charging points (which are likely to be required over the longer term to facilitate longer distance journeys), preventing owners from recovering their investment. Probably as a result of this risk, much of the investment in new public charging infrastructure in the UK has to date been supported by public funds (especially the Plugged in Places scheme).

Nevertheless, the investment in public charging is relatively granular in nature, as each individual public charging location represents a comparatively small investment and incremental deployment can be fine-tuned relative to demand. Additionally, the dependency on provision of supporting infrastructure, as it already exists and is widely accessible, will be limited to instances where concentrated installation of charging points necessitates reinforcement of the distribution grid[152].

Investment in public charging on commercial terms therefore can be envisaged where skilfully executed. Investors will need to carefully select locations that will attract maximum utilisation of the charging points. Host locations are likely to be places where PiV users will park vehicles for some time, such as shopping and leisure venues. However charging infrastructure is not the core focus of

[152] In these circumstances, the Common Connections Charging Methodology (CCCM) requires the connecting consumer to pay for the cost of the minimum works required up to one voltage level above the point of connection.

these businesses, and so in general they are unlikely to be willing to commit capital to their installation. Instead ownership by an infrastructure provider is more likely. Securing a favourable benefit sharing agreement between the infrastructure owner and the host, who is likely to benefit indirectly from the presence of the charging point, is likely to be important to a business case. Another component of a successful business model may be employing a pricing structure that succeeds in monetising the reassurance and convenience public charging points provide PiV users, beyond the commodity value of the energy they provide.

Rapid charging infrastructure

The role of (public) 'rapid' charging (i.e. 50kW and greater) is mainly to allow longer distance journeys, and as with (standard) 'public' charging (i.e. up to 22kW) investment is exposed to uncertainty in the timing and level of uptake of PiVs. Additionally, compatibility with fast charging is currently an optional extra for many PiV models. As with standard public charging, improving battery technology may undermine the business model in the longer term, especially in a location such as the UK where distances travelled will be relatively short. However, there is generally greater confidence in the durability of fast charging versus public charging. Obsolescence because of evolving technology, or stranding due to competing standards is also a risk. The latter risk is illustrated by the current competition between fast charging standards (CHAdeMO, CCS, and Tesla's supercharger). The risks are magnified for investors in rapid charging relative to public charging owing to the greater cost of procuring, installing and operating fast charging points.

However, given the significant utility it provides, and the cost and inconvenience of alternatives for BEV users in particular, consumers may be willing to pay a premium to access rapid charging. As with public charging, an ability to implement tariff structures that recover from consumers the full value of rapid charging above the commodity value of the charge embarked may be important for the commercial success of rapid charging. It is noteworthy that rapid charging networks have already attracted private capital from PiV manufacturers, who presumably consider the existence of a network as an enabler of PiV sales.

Work charging infrastructure

Analysis undertaken as part of this project has indicated that work place charging for fleets (i.e., depots) will be critical to facilitating their duty cycles, which typically do not allow time to stop and use public charging (or even rapid charging in many cases) during the day. In these circumstances provision of dedicated charging infrastructure will be an integral part of the business case for switching a fleet to PiVs. The utility of work place charging for use of employees commuting by car is less certain, as users would be able to undertake price arbitrage with the home charging alternative, assuming adequate battery capacity. Nevertheless, given the captive market and with knowledge of charging behaviour, it should be possible to predict demand with relative confidence, and to plan incremental infrastructure deployment (to the extent it is required) accordingly. The risk entailed in work place charging investment therefore is at the low end of the range associated with the new infrastructure types considered. Given the relatively long periods for which vehicles may be plugged in at work locations, accessing benefits from DM provision is also likely to be possible.

Hydrogen infrastructure

Unlike for electricity, there is no (or at least extremely limited) pre-existing infrastructure, and new investment would be required. Hydrogen fuelling infrastructure built on a commercial basis would be likely to be loss making, at least during the initial years of operation, whilst numbers of hydrogen vehicles and volume of throughput increased. Later investors in a more established market might be profitable more quickly, and with the benefit of learning and without the burden of earlier losses, be in a position to undercut early comers[153]. Uncertainty in the rate and ultimate size of FCV uptake, and hence hydrogen demand, therefore creates a strong dis-incentive to being a first investor. This dis-incentive is strongest for larger, lumpier investments which entail placing greater capital at risk and earlier anticipation of demand.

Linked to this demand uncertainty is uncertainty as to the availability and price of wholesale hydrogen produced in a low-carbon manner. The analysis indicates that local electrolysis is an expensive option in this regard (approximately twice that of centralised production, even accounting for avoided distribution costs), primarily due to the rising price trajectory of electricity.

Initial public intervention to underwrite this demand risk in some way may be necessary if this disincentive is to be overcome, and hydrogen fuelling infrastructure is to be deployed. This issue was identified in reports by UK H_2 Mobility[154] and the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)[155], a public / private partnership between the European Commission, the fuel cell and hydrogen industry and a number of research bodies.

A factor in helping to mitigate to some extent the demand risk for potential hydrogen infrastructure investors would be the involvement of vehicle manufacturers. Vehicle OEMs are the parties most able to manage and promote FCV uptake, as they have the ability to develop and bring to market new FCVs that will be attractive to consumers. If they have a meaningful exposure to the success of hydrogen infrastructure, they will be incentivised to develop a vibrant market for FCVs generating demand for that infrastructure. However, infrastructure is capital intensive and not the core business of manufacturers, and so achieving this may be challenging. Furthermore, the price and availability of low carbon hydrogen is likely to be outside the control of both OEMs and infrastructure investors. It will depend on the availability of CCS or large volumes of cheap off-peak electricity, most probably from new nuclear.

7.3.5 Risks and barriers in the Market and Policy Framework

This section considers how the Market and Policy Framework may be structured to efficiently deliver infrastructure deployment, considering first charging infrastructure and then hydrogen infrastructure.

Charging infrastructure

To date, Government has supported deployment of charging infrastructure through the Plugged in Places grant scheme. However in the longer term, it expects investment on a purely commercial basis, and does not foresee support through a Regulated Asset Base (RAB) system of underwritten returns[156]. As discussed in section 7.3.4, the granular nature of investment in charging infrastructure, and in contrast to hydrogen the absence of dependence on new infrastructure upstream, should

[153] The costs of early investors at this point would be sunk, and they may be in a position to price their product low to deter new entrants. However this strategy would further prolong losses.
[154] UK H_2 Mobility, Phase 1 Results, April 2013
[155] A roadmap for financing hydrogen refuelling networks – Creating prerequisites for H_2-based mobility, December 2013
[156] Making the Connection, The Plug-In Vehicle Infrastructure Strategy, Office for Low Emissions Vehicles

make this viable. However, investment on a commercial basis alone will lead to deployment in areas of concentrated demand, and may leave more rural or less prosperous areas without adequate access to infrastructure. In these circumstances, targeted public support may be considered for social reasons.

Depending on the commercial structures that arise around rapid, public or work charging infrastructure, there may be a need to regulate tariffs to protect consumers, should this not be achieved by competition. In the event that industry failed to deliver technology standards and interoperability itself, intervention to assure this would need to be considered[157] (though it would be more effectively coordinated at a supra-national level).

A more specific regulatory barrier to deployment of charging infrastructure has been removed by Ofgem's exemption of charging points from restrictions on the maximum resale price of electricity[158].

Hydrogen infrastructure

As discussed in section 7.3.4, the demand risk associated with hydrogen infrastructure may be such that for investment to occur, a degree of public support would initially be required. Assuming private capital would be sought, two broad types of strategy can be envisaged, and are outlined below.

The first would be for the public to directly absorb, in whole or part, the demand risk for investors, which could be achieved through a number of means. This could be through a Public Finance Initiative type structure, where Government runs a tender for contracts to provide Hydrogen Refuelling Stations, with payments based on availability. These could be possibly be funded by a levy on sales of conventional road fuels. Other approaches might be to support financing through grants, loans or guaranteeing debt. Government would probably seek to implement such a strategy in parallel with other measures to stimulate FCV uptake, such as vehicle grant programmes. This strategy may make sense as part of a larger, more coordinated push towards hydrogen as a vehicle fuel.

The second type of strategy would be to create concentrated use of FCVs, and hence demand for hydrogen that could underpin investment in refuelling infrastructure. This would be achieved through promoting conversion to hydrogen of high mileage vehicle fleets that operate within a restricted area (such as taxis), return to a base at the end of the working day (such as utility vans), or perhaps have relatively fixed hub-to-hub routes (for example logistics vehicles). In this way, high volumes of hydrogen demand will be concentrated in known locations. Implementation could be via competition for grants to complete conversion, with winners obliged to develop an HRS or to offer a contract with guaranteed minimum annual volume of hydrogen offtake, enabling investment by a third party. By selecting winners in different locations a skeleton network of HRS could be established.

A risk under either approach is of crowding out private investment, postponing the point at which investment can occur on commercial terms and delaying roll-out of infrastructure. A further challenge may be generating meaningful competition for the contracts offered under the

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[157] Currently there are three significant groupings using incompatible rapid charging standards: Supercharger (Tesla); CCS (Audi, BMW, Daimler, Ford, GM, Porsche, VW); and CHAdeMO (Kia, Citroen, Mitsubishi, Nissan, Peugeot, Renault).

[158] Decision on the application of the Maximum Resale Price to the resale of electricity for charging electric vehicles, Ofgem, March 2014.

intervention schemes. This would especially be so where involvement of a vehicle manufacturer was required, a stipulation government might make to mitigate the demand risk. The UK H_2 Mobility report also made the case for cooperation of industry and government at different levels during the early stages of HRS deployment to ensure they are built in the right locations to form a usable skeleton network.

Hydrogen pipelines present a special case, and would require a greater level of intervention. The licensing and planning hurdles of a significant pipeline network would likely necessitate substantial government involvement from the offset. Pipelines represent very large commitments with significant economies of scale and limited ability to invest in increments matched to demand. As such the barriers to investment are very significant. Once built however, they are likely to enjoy a monopoly. As such a RAB approach, as employed for electricity and gas networks, would be required, both in order to de-risk the initial investment and to protect consumers during operation.

7.3.6 Conclusions

Providing users adequate access to infrastructure is essential for uptake of ULEVs, and the most significant barrier to deployment is the demand risk facing the Commercial Value Chain. This will be most severe in the early years of the pathway when the ULEV parc is small, but the risk will diminish as numbers increase. In some cases Government intervention may be required to stimulate initial investment, but as observed in section 6.3 the money required is relatively small in comparison to the cost of mitigating the upfront cost differential of ULEVs to ICEVs for consumers. To the extent then that better infrastructure provision can reduce consumers' requirement for vehicle subsidies, it would probably lead to lower costs overall.

Where investment can be made granular and more closely demand-following, capital exposed to the demand risk can be limited, making investment by the Commercial Value Chain more achievable. Charging infrastructure away from the home can be implemented in small increments, and it is reasonable to expect that investment will occur independent of Government support. As PiV uptake grows; however, and consumers come to regard reliance on ICEVs as disadvantageous, Government may consider that for social reasons support is required to ensure availability of infrastructure in locations where the commercial case is weak.

Leaving aside Government support, a degree of regulatory intervention may be required. In the early stages of PiV deployment, these would be to ensure standards and interoperability in the event that industry does not deliver this itself. In the latter stages, if the development of the charging sector leads to circumstances that may allow consumer exploitation (for example emergence of a small number of dominant networks), regulation may be required to prevent this. It should be noted however that the threat of regulatory intervention may increase required returns in the sectors in question.

The requirement for supporting infrastructure makes investment in new hydrogen facilities less granular and correspondingly more challenging to achieve on a commercial basis. Initial deployment may require the Government to absorb some demand risk, which may in turn look to vehicle OEMs to participate in order to mitigate this. However, from the analysis in sections 5 and 6 it appears that a lower risk route is to delay potential infrastructure investment, or at least any Government support for this, for a period until FCV cost trends are better understood. Until the point that FCVs begin to approach cost competitiveness relative to alternative vehicle technologies, the lack of such infrastructure availability will not provide a significant constraint on consumer choice.

7.4 Mitigation of upfront vehicle costs

7.4.1 Identifying potential risks and barriers

The analysis has illustrated that, in the near and medium-term of the pathway in particular, reduction of the upfront cost premium of ULEVs over ICEVs is important in driving uptake. Table 21 summarises the review of barriers and risks to employment of this measure.

Table 21 Potential risks and barriers identified in mitigation of upfront vehicle costs

Dimension / Building Block	Risks or barriers to implementing good solution
Customer Proposition	
CP1: Outright purchase CP2: Contract purchase CP3: Hybrid (battery lease) CP4: Contract hire CP5: Short-term hire	▶ Effectiveness of upfront measures when vehicle not purchased outright (may be unnecessary where short-term hire costs are low) ▶ Inhibit more innovative models like separate battery leasing
Physical Supply Chain	
	▶ No barriers identified
Commercial Value Chain	
CVC1: Vehicle manufacturer CVC3: Vehicle leaser	▶ Risk of dampening incentive to innovate ▶ May raise prices to gain extra profit
Market and Policy Framework	
MPF1: Government grants MPF3: VAT in assets MPF5: Refund schemes	▶ Multiple options for structuring support ▶ Risk of subsidy dead weight ▶ Risk of unintended incentives

7.4.2 Risks and barriers in the Customer Proposition

Any step to reduce the cost of ULEVs must enhance the proposition they offer to consumers. This could be structured in different ways, for example through a grant or a reduction in VAT, but if the manner in which they are accessed is comparable, it is not clear that consumers would prefer any one approach to any other. More caveated schemes, for example providing a grant towards a ULEV in exchange for scrappage of an ICEV, may drive additional benefits but presents a more complicated Customer Proposition. The positive impact of cost reduction measures on the Customer Proposition may be reduced where consumers avoid exposure to the full upfront cost through use of a financing scheme.

7.4.3 Risks and barriers in the Physical Supply Chain

There are no barriers to implementation of upfront cost mitigation in the physical value chain.

7.4.4 Risks and barriers in the Commercial Value Chain

Measures to reduce the upfront cost of ULEVs should not present a barrier to the Commercial Value Chain's ability to play its role in delivering ULEV uptake. Indeed the risk to these entities is on the upside. In a market with limited competition, intervention to reduce the price point of vehicles may dampen vehicle manufacturer's incentive to innovate and reduce costs, and encourage them to take additional profits. However, the market for ULEVs appears increasingly competitive, with a growing number of manufacturers and models. Assuming this competitive context is sustained, a well-structured cost support scheme with a reasonable length of commitment from Government should drive increased uptake of ULEVs, potentially promoting investment in innovation and new models by manufacturers, and in mitigating demand risk for infrastructure investors. Even in a competitive environment however, there is a risk that intervention could distort manufacturers' product offerings, if for example they sought to make the minimum concessions necessary to qualify for grant support.

7.4.5 Risks and barriers in the Market and Policy Framework

Depending on the spending priorities of the Government at the time, the perceived affordability of a programme of upfront cost mitigation may be a barrier to implementation. This may be especially the case in the context of declining Government income from road transport fuel taxes and levies. The distributional aspects of such a scheme may also present a barrier of political acceptability. Although benefits of reduced air pollution and carbon emissions would be widely enjoyed, the scheme could be perceived as favouring certain sectors of society over others, for example, the well-off, to the extent ULEVs still tend to be more expensive than comparable ICEVs; urban versus rural dwellers; or niche interest groups for whom cost is a secondary consideration. Cost mitigation schemes may also be seen as promoting car ownership over public transport or modal shift in transport service provision, and may also be at odds with pursuing the potential benefits of transport as a service through shared access to vehicles. A scheme could however be structured to reduce these potential criticisms to some extent. For example, support could be focussed on lower priced models, and support for the second hand market for ULEVs considered, making them accessible to a greater cross section of society.

There is a risk that the scheme may underachieve the targets established, by setting support levels too low and failing to spur sufficient uptake. Similarly there is a risk that a scheme may set the level of support unnecessarily high, incurring unnecessary costs and overachieving targets or achieving them too early. Over-subsidisation of the value chain may promote cost inflation[159] and breed an industry dependent on government support, unable to become self-sustaining. Even if not the case at the outset, a poorly designed programme may fail to adapt to evolving market conditions.

However, a well-structured scheme may indirectly support other associated policy objectives, as well as directly driving ULEV uptake. A scheme with sufficient commitment and visibility may mitigate demand risk perceived by investors, lowering the cost of new infrastructure. It may also encourage investment in innovation by manufacturers and in the value chain, and help secure more domestic content. A scheme could also be structured as a scrappage bonus, helping to remove the most

[159] Anecdotal evidence has identified this as an issue with respect to early grant funding of home charging points.

polluting vehicles from the road, and potentially addressing some of the distributional concerns by directing support towards those with the lowest value assets.

7.4.6 Conclusions

The quantitative analysis identified the importance of upfront cost reduction in driving ULEV uptake, and such a measure is likely to be an important ingredient of the overall environment for ULEV deployment through to the medium-term of the pathway. Barriers to implementation of a support scheme are not practical ones, but rather concern political questions of spending priorities. As with any policy intervention there are also risks of inefficiencies.

The quantitative analysis indicates that a well-designed cost support scheme would have the objective of establishing a competitive position for ULEVs in the vehicle market around the middle of the pathway (around the 2030s), when the emphasis of policy intervention would switch more to disincentivising ICEVs. The scheme would require careful design and calibration, and ongoing monitoring to mitigate the risks of inefficiency.

Over that period, the level of support offered for each vehicle would be expected to taper as the difference between ULEV and ICEV prices reduces. In the analytical framework this is achieved through setting the grant as the difference in price between a ULEV and an equivalent ICEV, subject to a cap. In practice this may be difficult to implement, as identifying an equivalent ICEV would be a subjective exercise and administratively complex. An approach similar to the current Plug-in Vehicle grant based on a percentage of purchase price up to a cap may be more practicable. Similarly, the support available could be structured to discriminate between vehicles according to factors such as carbon emissions per km driven and or zero emission range.

A ‘degression’ mechanism, as used for example in Feed-in Tariffs for small scale renewables could provide a model for adjusting the value of support offered under the scheme. Under this model, a budget available for grants is established in advance. Exhaustion of the budget available in a given period would trigger a step down (degression) in the support offered per vehicle in following periods. In this way the support offered is stepped down over time in response to deployment and costs, helping the scheme to maintain efficiency and track targets. Furthermore, by making this stepping down mechanistic and forecastable, a signal is provided to industry on the need to innovate and reduce costs. Periodic checkpoints would provide a chance to review the functioning of the scheme, and recalibrate it as necessary.

The merits of adding a scrappage bonus to the scheme around the point of policy intervention transitioning from incentivising ULEVs to disincentivising ICEVs should also be considered. In addition to removing the most polluting vehicles from the parc, this would help address the risk of a sector of society becoming stranded with increasingly expensive-to-run ICEVs and being unable to afford switch to ULEVs.

7.5 Car sharing

7.5.1 Identifying potential risks and barriers

Car sharing on a large scale holds out the prospect of a smaller parc of more intensively used vehicles. The analysis indicates that more intensive use appears to favour the economics of ULEVs, typified by higher capital costs but lower operating costs when compared to ICEVs, and so reduce the cost of transition. Less directly, putting vehicle purchase decisions to a greater extent on a commercial footing within a car sharing company, may lead to more rational decisions which could also favour ULEVs in the right circumstances. There could also be wider benefits of a smaller vehicle parc, such as freeing up land currently used for road transport for other purposes. Table 22 summarises the barriers and risks facing the greater deployment of car sharing schemes.

Table 22 Potential risks and barriers identified in car sharing

Dimension / Building Block	Risks or barriers to implementing good solution
Customer Proposition	
CP5: Short-term hire	▶ Ability to provide an adequate service that minimises inconvenience
CP29: Sole vs shared use	▶ Symbolic value of car ownership
Physical Supply Chain	
PSC22: Public charging	▶ Reliance on public charging points
Commercial Value Chain	
CVC1: Vehicle manufacturer	▶ Threat posed by increased sharing
CVC6: Vehicle sharing	▶ Commercial challenges of large scale car sharing
Market and Policy Framework	
MPF33: Adequate access to infrastructure	▶ Producing sufficient competition to protect consumers whilst recognising benefits of scale

7.5.2 Risks and barriers in the Customer Proposition

Car sharing schemes may enhance the Customer Proposition by reducing the capital and fixed costs of having access to a car relative to ownership, as well as reducing the potential liability for maintenance costs. It also reduces the hassle of responsibility for maintaining, licensing and taxing a vehicle. However, car sharing is likely to require travelling or waiting to access a vehicle, and may be limited to journeys between dedicated 'docking stations', especially where schemes are BEV based[160]. In this instance, the state of charge of a vehicle when a new user arrives, and the consequent ability to complete desired journeys, will also impact on the Customer Proposition. It may also be a perception of consumers that reliance on a car sharing scheme limits their ability to undertake more occasional longer trips, such as holidays away from home.

Car sharing must therefore overcome a barrier of reduced convenience versus having dedicated and unrestricted use of a vehicle if it is to be regarded as an alternative to ownership, or at least reduce these sufficiently such that any residual inconvenience is more than offset by the lower cost of driving from car sharing. The barriers to providing a service with the required level of convenience are likely to be higher in less densely populated locations. Car ownership may also have a symbolic value to some consumers, which may be difficult to overcome.

[160] Although schemes featuring BEVs do exist without this requirement, such as BMW's DriveNow.

7.5.3 Risks and barriers in the Physical Supply Chain

Vehicle sharing is already in operation in different forms, and there are no technological barriers to its implementation. Wider deployment of PiV, or particularly BEV, based sharing schemes however would be likely to require increased provision of public charging infrastructure, with dedicated parking associated with it, to enable guaranteed use. Additionally, vehicles in use for a greater proportion of the time have less opportunity to charge, which suggests that the charging points supporting car sharing schemes need to have higher power ratings than those for dedicated user vehicles.

Technological advancement, specifically the advent of autonomous vehicles could significantly enhance the prospects of car sharing. From a car sharing business's perspective, autonomy would enable more efficient and intensive use of vehicles and reduce or eliminate the impact of incautious use on vehicle wear and tear. From a consumer's perspective, it could enable vehicles to be delivered and deposited to locations of maximum convenience, rather than being tied to docking stations. In this way, the technology could be a key enabler of large scale uptake of BEV delivered car sharing services specifically.

7.5.4 Risks and barriers in the Commercial Value Chain

As previously noted, mobility-as-a-service type businesses already exist in different forms and on different scales[161]. The analysis undertaken indicates that wide spread use of vehicle sharing could potentially lead to a significantly lower cost per vkm for the consumer.

However providing sufficient capacity to meet peak demand for vehicles and the level of access required by consumers may mean businesses need a greater asset base, diminishing the efficiency of their operation (though this may be mitigated through peak pricing structures). It is estimated that around 75% of the remaining vehicle parc in the ToD Narrative is needed to provide current peak morning and evening travel patterns, but it is possible that such patterns may change in future in response to wide spread use of car sharing. In addition, a competitive market place with multiple operators, whilst desirable to protect and serve consumers, may lead to inefficiencies and redundancies.

The implications for vehicle manufacturers are unclear. Although the vehicle parc may be smaller in a scenario of large scale car sharing, they would probably be replaced more frequently. Less tangibly but perhaps more insidiously, greater acceptance of sharing may lead to consumers regarding vehicles as interchangeable, commoditised providers of a service, rather than objects of aspiration or personal expression. It is notable that a number of manufacturers are exploring car sharing services (such as BMW's DriveNow, GM's Maven and Ford's GoDrive), presumably in part as a hedge to the impact that future large scale adoption of car sharing may have on their business models. If manufacturers are in a position to benefit from car sharing, they may be more incentivised to develop more robust, longer lived vehicles better adapted to car sharing, in turn making large scale car sharing more economically viable.

[161] Uber is a large scale and often-cited example of such a business. It aggregates the services of private individuals offering access to their vehicles, in effect operating as an umbrella organisation for a large number of individual businesses. The observations made about the operation of a car sharing system are valid though, regardless of how that system may be commercially structured.

The role of 'challenger' OEMs in general

As vehicle manufacturers and associated entities vary their offerings to compete in a ULEV market in which the vehicles are more 'connected' and / or autonomous, which is likely to act as a key facilitator of car sharing, the manufacturer business model is likely to evolve from the traditional model[162]. For example, these entities could be:

- **Investing in the technology required for electric, connected and / or autonomous vehicles and / or only in the vehicles themselves**
  - Nissan and BMW have developed electric cars without a focus on autonomy – perhaps as they were early market entrants. Nissan's first BEV was developed from a petrol version, with the conventional engine replaced with an all-electric drivetrain. Similarly BMW developed its Mini-E (a test vehicle used for trials only) from a converted Mini but then designed the i3 (its first BEV) as a PiV from the ground-up.
  - Apple is rumoured to be developing an autonomous driving system and deprioritizing the car itself, although other rumours suggest it is a 'challenger' OEM to the traditional OEMs, developing an electric iCar – potentially bringing its iPhone experience, and perhaps even digital license plates, to the BMW i3 vehicle.
  - Google has developed a self-driving system, to be used mainly with electric cars.
  - Tesla has focused on a 'high-end' electric car, with the unique selling point of longer range (promising 215 miles in its latest model). The new models have features such as the 'autopilot' function which will steer the car within a lane, change lanes automatically, and manage speed by using active, traffic-aware cruise control.
  - Microsoft aims to provide OEMs with technological assistance, helping Toyota in the development of its self-driving car.
  - Nokia has developed a mapping service, then bought by several of the OEMs.
- **Leading the way with hydrogen vehicles**
  - Manufacturers investing in FCV should be less threatened by 'challenger OEMs' because connectivity is less important for these vehicles. However, the OEMs may still take different approaches to manufacture; adapting an existing vehicle to become a FCV (in the case of Hyundai) or purposefully designing a FCV from the outset (as with Toyota, Honda). New manufacturers coming into the FCV market may take the latter approach, though existing manufacturers could save on development costs by taking the former. Currently it is the 'traditional' manufacturers that are in the process of developing FCVs – including BMW, Audi and Mercedes.

7.5.5 Risks and barriers in the Market and Policy Framework

The barriers to greater adoption of car sharing from a Market and Policy Framework appear to be minor. On a local scale, implementation may require local authorities to provide a supportive planning environment to enable sufficient deployment of public charging infrastructure.

[162] The vehicle manufacturer business model is described in section 5.2.2 of the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*.

There are likely to be benefits of scale in operating a car sharing business, leading in the long run, if unchecked, to a small number of dominant players wielding market power. There may be a case, therefore for market supervision and if necessary price regulation.

The analysis suggests that Government revenue may be largely unaffected or even positively impacted despite a smaller overall vehicle parc. The total number of vkm driven is likely to be the same or greater than under private ownership (due to 'dead miles') which leads to similar levels of fuel duty. As a result of higher utilisation the vehicles are generally retired more quickly, leading to a more rapid stock turnover and higher associated levels of VAT on new sales.

7.5.6 Conclusions

Car sharing may offer direct benefits of reduced cost of transport and indirectly from a smaller vehicle parc. However the ability of the business model to offer a product at a price that will result in large scale substitution of car ownership is unclear at this stage, primarily due to capital costs of more frequent vehicle replacement. Vehicle manufacturers may be in a position to improve the economics through producing more durable vehicle designs, and may be incentivised to participate in car sharing in order to hedge the risk to their business models. The advent of autonomous vehicle technology could have a significant positive impact on the Customer Proposition car sharing presents, and could be an enabler of large scale adoption.

The benefits of car sharing are greatest, and the barriers to providing an adequate service lowest, for urban consumers. The indirect benefits of a smaller vehicle parc are also greatest in space constrained urban areas. Efforts to establish car sharing should therefore be concentrated in these areas. To enable ULEVs to be the basis of these services, local authorities should facilitate deployment of charging infrastructure, with associated dedicated parking as necessary.

In the longer term if evidence of the benefits of car sharing becomes clearer, or for example autonomous technology significantly changes its prospects, central government may consider limited intervention to support its uptake. This could, for example be through tax relief for businesses providing the service or consumers using it. As a business that benefits from scale, market supervision may be necessary in the longer term to protect consumers from exploitation.

7.6 Mitigating a decline in tax revenue

7.6.1 Identifying potential risks and barriers

The increasing penetration of ULEVs is expected to lead to tax revenues to the Government from the light vehicle sector declining significantly as a percentage of GDP, particularly in relation to fuel duty on liquid fuels which is currently the largest component. This effect will be compounded by the increasing efficiency of ICEVs. To address this, increased taxation on ICEVs may be expected to play some role, which will also have the effect of incentivising a conversion to ULEVs. Such a tax would therefore be raised on a declining base, and it is likely that a technology neutral tax on the sector, such as road pricing, will be required to achieve substantial restoration of tax revenues. Table 23 reviews the barriers and risks that may apply to raising new tax revenues to replace those lost through declining liquid fuel use.

Table 23 Potential risks and barriers identified in mitigating declining tax revenues

Dimension / Building Block	Risks or barriers to implementing good solution
Customer Proposition	
	▶ Consumer proposition impact is driven by MPF measures
Physical Supply Chain	
	▶ No risks or barriers identified
Commercial Value Chain	
	▶ No risks or barriers identified
Market and Policy Framework	
MPF8: Vehicle excise duty MPF16: Road, congestion, carbon pricing MPF17: Weight tax	▶ Sustainability in face of decreasing liquid fuel use ▶ Public acceptance

7.6.2 Risks and barriers in the Customer Proposition

The impact on the Customer Proposition of new taxation on ULEV uptake and use will be positive to the extent that it discriminates between ULEVs and ICEVs, in a manner favourable to the former. New taxes that are technology neutral should not impact ULEV uptake and use relative to ICEVs, though they may impact vehicle use as a whole.

7.6.3 Risks and barriers in the Physical Supply Chain

The ways in which taxes can be raised in the sector are limited to some extent by the current state of the Physical Supply Chain. For example, fuel use can conveniently be measured and taxed at the pump, but wide spread taxation of road usage would require significant new infrastructure. However, new technology is expected to become prevalent in the future, especially increased data telemetry capability in vehicles, which may make implementation of such taxes practicable within the timeframes being considered.

7.6.4 Risks and barriers in the Commercial Value Chain

New taxation in the light vehicle sector should not impede the Commercial Value Chain's ability to contribute to the uptake and use of ULEVs.

7.6.5 Risks and barriers in the Market and Policy Framework

The analysis identifies passing the price of carbon through to liquid fuels as an effective means of providing a continuing signal to vehicle users to switch to ULEVs, as the programme of upfront cost mitigation measures winds down. This signal would become increasingly strong as the marginal cost of carbon abatement increases towards 2050, in line with tightening UK GHG targets. Assuming an effective and well-functioning market for carbon exists, the approach of passing through a carbon price also avoids the need to determine a level for tax in the road sector in isolation, with associated risks of this being set above or below an efficient level. The measure would provide a limited boost to tax revenues, though not on a sustainable basis however, as it will itself incentivise further reduction in fossil fuel use. It also faces the political barrier of making mobility increasingly expensive for those unable to switch away from liquid fuels.

More widespread adoption of congestion zone charging with exemption for ULEVs, as currently employed in London, also has some merit. It provides a further pull towards ULEV adoption, and new telemetry technology may make implementation easier. It simultaneously addresses issues of congestion and urban air quality. It can provide a limited source of additional tax revenues, though likely to be similarly unsustainable as ULEV penetration increases, and as such any exemption for low emission vehicles would need to be tightened and ultimately removed over time.

A technology-neutral form of taxation is likely to be necessary to produce a sustainable and substantial source of tax revenue from the road sector. Road pricing is a candidate mechanism, whereby drivers would pay per-distance travelled. Charges could be differentiated by type of road travelled or type of road user, for example making travel in rural areas cheaper. By including a ToU element to encourage off peak use it also has significant potential to address congestion. Primarily in this context, it has been the subject of considerable public debate. A pricing structure could potentially incorporate favourable treatment of ULEVs during a transition phase if considered desirable. Comprehensive road charging has commonly been viewed as politically difficult to implement, due to expected public resistance to paying for a service that has previously been free at point of use, and concerns of loss of privacy. The most recent evidence suggests opposition may have reduced however[163]. Nevertheless, a report by the Institute of Fiscal Studies in 2012[164] found the economic case for road pricing to be compelling. It warned against implementing barriers that could compromise government's ability to introduce a policy of widespread road pricing, specifically awarding long-term leases for roads with the private sector.

An annual per-vehicle tax, rather than a per-distance travelled road tax, is an alternative structure for technology neutral tax. This could be structured to incorporate further signals, for example differentiation by weight to drive transition to smaller lighter vehicles, be simple to implement, and avoid privacy concerns. It may also drive change in how consumers access mobility, for example encouraging a shift to car sharing and public transport. The inability to simultaneously tackle congestion and apportion costs to use makes this a less appealing option from a policy effectiveness perspective.

7.6.6 Conclusions

There is forecast to be a significant decline in taxes raised from light vehicles as a proportion of GDP relative to today. In the medium-term, technology discriminating taxes can help sustain ULEV take up and restore some revenue. However in the longer term, a technology neutral tax appears essential to maintain tax revenue. The most attractive means of doing this is likely to be a comprehensive system of road pricing, due to the ability of such a mechanism to simultaneously address the issue of congestion. The primary barrier to implementation of road pricing is likely to be public acceptance.

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[163] A poll by Ipsos MORI in 2010 found 65% of British adults opposed in principle to the introduction of a 'pay as you go' system on motorways and major roads. However a survey by the Independent Transport Commission in 2016 found there to be 'significant support for new forms of charging'.
[164] Fuel for Thought, The what, why and how of motoring taxation, May 2012.

7.7 Summary of recommendations and roadmap

This section presents a summary of the recommendations arising from the analysis detailed in this report, setting them out in order and approximate timing so as to provide a road map for efficient ULEV uptake and use in the UK. This is illustrated in Figure 91.

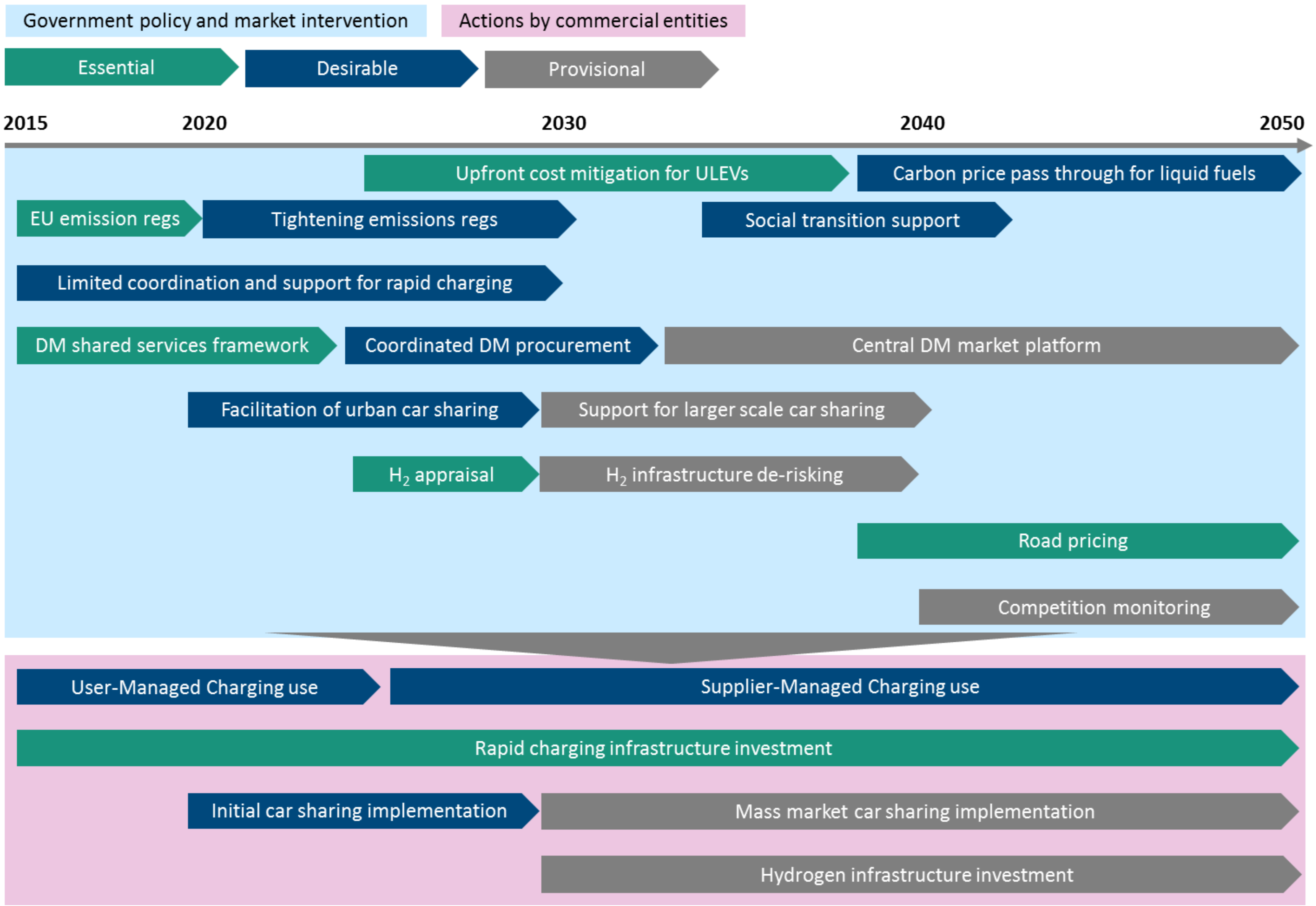
The blue area in the diagram represents enabling actions in the Market and Policy Framework Dimension, undertaken by different levels of government and the appropriate regulators. The pink area represents actions in the Commercial Value Chain, in some cases associated with or prompted by those in the MPF. The combined effect of these actions is to deliver a Physical Supply Chain and Customer Proposition conducive to an effective pathway for ULEV uptake and use. Only new actions, representing a departure from the current state, are included. Actions are categorised as follows:

- **Essential** – these actions have been clearly identified as good, and found to be robust to different circumstances explored through the Sensitivity analysis. They are considered to be no or low regret actions.
- **Desirable** – actions for which a strong case exists and which are likely to have a positive impact under most circumstances. However, a failure to employ these actions is unlikely, by itself, to lead to a failure to achieve mass uptake and use of ULEVs. Additional evidence or reduced uncertainty may also be desired by individual actors before a decision to implement them.
- **Provisional** – an additional categorisation implying actions for which a positive case may exist, but for which the extent or timing of deployment is likely to depend on reduction of uncertainty in the basis of analysis. This may be occur through the passing of time and, for example, realisation of outturn costs. It may alternatively occur through obtainment of additional or expanded evidence from trials or initial pilot scale deployment.

A brief description of each action is provided and more detail is given on the specific items and both the qualitative and quantitative evidence that supports these in section 5.5. The roadmap is also described in the separate *D1.3 Market Design and System Integration Report Summary* document.

Whilst the roadmap is forward looking, it does assume the current market and policy landscape that exists today as a starting point. As noted in section 3.1.1, a review of the literature was carried out at the start of the project in order to develop an understanding of the types of market and policy measures that could be used in the future to incentivise ULEV uptake, or that have been used in the past or elsewhere. Until now policies have primarily been centred on reducing the upfront cost through implementation of PiV grants (Plug-in Car, Van, Motorcycle Grants), incentivising the installation of charging points, for example with match funding through the Plugged in Places scheme, and funding a range of innovative projects to support uptake in cities via the Go Ultra Low Cities scheme. The results of the literature review are captured in detail in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* and the supporting *D4.2 Building Blocks Catalogue* spreadsheet, the latter describing for each measure whether it has been used in the UK or elsewhere and, where possible, how effective it has been.

Figure 91 Roadmap for efficient ULEV deployment and use



Vehicle incentives and regulations

- Consistent with the BaU Narrative, the existing PiV grant scheme continues to 2017, in tandem with the EU emissions regulations.
- In the 2020s, it is assumed a continuation and tightening of the existing emissions regulation scheme, as currently envisaged, continues to help drive ULEV uptake. But in the absence of such regulation, renewal of the grant scheme would be required earlier on.
- In the late 2020s through to the late 2030s, once the emissions regulation regime plateaus, a programme to reduce upfront cost of ULEVs is introduced, as per the OEM Narrative, comprising VAT reduction and a modest level of subsidy.
- From the late 2030s onwards, the price of carbon is sufficient that, when passed through to liquid road fuels, the differential in operating costs between ICEVs and ULEVs drives continued uptake of the latter.
- Around the point of transition from upfront incentives for ULEVs to ongoing disincentives for ICEVs, a programme to prevent vulnerable sectors of society from being left stranded with increasingly expensive to run fossil fuel vehicles would be desirable. This may be in the form of a scrappage bonus for the oldest ICEVs.

Support for charging infrastructure

- The long-term case for lower power public or work charging is uncertain, and deployment should occur on a commercial basis where it is considered viable. A rapid charging network however appears to have long-term value in enabling PiV uptake and use. Some initial government intervention to ensure standardisation (in the absence of this being delivered by industry) and potentially support for delivery by the Commercial Value Chain of a geographically comprehensive network may be desirable.

Enabling regulatory framework for Demand Side Response / Demand Management

- The role of DM in the operation of the electricity system is likely to grow even in the absence of PiV deployment. Nevertheless, PiV charging offers considerable scope for load shifting and management, and may be a spur for growth. Potential stages of development in the regulatory framework for DM are mapped in Figure 91.Figure 1
- The timing in this instance is indicative only, and development would occur as efficient operation of the market required it. Co-ordinated DM procurement is shown from the early-mid 2020s as this is when there is the greatest opportunity for savings, as shown in Figure 42 to Figure 44.
  - The first step is to set up and implement a 'DM shared services framework', which would aim to establish coordination between the entities across the Commercial Value Chain that have an active interest in DM. A shared services framework would set out how non-domestic DM resource could be shared between DNOs and the SO.

The ENA has proposed a concept to deliver this[165], envisaging a hierarchy of dispatch giving DNOs precedence in using DM resources for local issues.

- The second step, ‘co-ordinated DM procurement’ would further increase coordination of procurement and operation of DM, with a party such as the SO responsible for contracting services, and then selling them on to other parties, such as the DNOs, when they need them or place a higher value on them. Such a model would represent a more substantial change to the market framework, requiring for example reconsideration of price control frameworks.
- The ultimate step, ‘central DM market platform’, would be a creation of a central market platform allowing resource to be optimised across all sellers of DM services and buyers for all purposes, including those with specific locational needs. Developing, operating and regulating such a platform would be complex and costly, and would be provisional on the size and sophistication of the DM market justifying it.
- This approach and the key risks and barriers of implementing DM, from the perspective of the Physical Supply Chain, Commercial Value Chain, Customer Proposition and Market and Policy Framework, are discussed in more detail in section 7.2.6.

Car sharing

- The value of car sharing is greatest in urban areas. Consequently, as the use of ULEVs for car sharing becomes more economic in the 2020s, city authorities may wish to enable establishment of such schemes, through easing planning for docking stations with dedicated parking and charging points.
- In the longer term, if the case for car sharing and its ability to displace ownership increases, perhaps as a result of autonomous vehicle technology, central government may consider the case for enabling or supporting implementation on a larger scale.

Hydrogen sector

- There is likely to be a need in the early 2020s to conduct a test to establish the need for FCVs in meeting decarbonisation targets. If there is a need, a full appraisal should take place in the mid-2020s. The detail of the ‘H_2 Appraisal’ has not been defined and will depend on the market and policy landscape at the time. At a high level, it is envisaged that the Government and the appropriate regulators would evaluate the need to support a widespread H_2 network, including the use of pipelines as opposed to trucks. There may be an industrial benefit associated with being an early mover (i.e. the vehicle manufacturers might base themselves and invest in those countries leading the way in policy and funding support for hydrogen) – this depends on the strategy employed in other countries which has not been considered as part of this project but could be considered as part of the ‘H_2 Appraisal’. The Commercial Value Chain entities may be able to make a case for more piecemeal private investment before then and if the market for FCVs strengthens significantly in the near term there could be a case for an earlier ‘H_2 Appraisal’.
- The expectation is that a decision on enabling actions will not be required till the later 2020s or early 2030s, due to the greater cost of FCVs compared to other vehicles in this

[165] ENA Demand Side Response Shared Services Working Group: Demand Side Response Shared Services Framework Concept Paper

period. At this time the Government should consider de-risking investment in hydrogen infrastructure if the 'H$_2$ Appraisal' suggests that this would be a low regret decision.

Road pricing

- The decline in the ICEV parc and associated reduction in vehicle tax revenues is a steady trend and action may be justified significantly in advance of the timing. However, the impact becomes more acute by the late 2030s, with ICEV based taxes increasingly unsustainable. At this point a technology neutral mechanism to raise taxes from the sector is necessary. Road use pricing, given the simultaneous potential to address congestion, appears the best option.

Competition monitoring

- Some of the new businesses established as part of the switch to ULEVs benefit from natural economies of scale, such as charging networks or car sharing businesses. As these mature and consolidate later in the modelled pathway, market supervision and price regulation may become necessary to ensure fair treatment of consumers and avoid formation of oligopolies.

Electricity tariffs

- Static ToU tariffs and associated User-Managed Charging can deliver benefits to consumers and the electricity system, and with the roll-out of smart meters there should be few barriers to their adoption.
- The additional value of Supplier-Managed Charging becomes more apparent and desirable from the mid-2020s, when growing PiV deployment might otherwise start to trigger significant investment in LDN reinforcements in some circumstances. Some additional communications infrastructure will be a prerequisite to implementation.

8 Implications for the Stage 2 trial design

8.1 Overview

The WP1a analysis for Stage 1 described in this report has covered a broad, holistic set of issues for cars and vans covering the Customer Proposition, Physical Supply Chain, Commercial Value Chain and Market Policy Framework across multiple energy vectors; electricity, hydrogen and liquid fuels.

The Stage 2 trial itself is described in detail in the separate *D1.4 Trial Design, Methodology and Business Case Report.* Its overarching focus, determined prior to the start of this project, is on the ***Customer Proposition*** Dimension as it aims to gain a better understanding of what will help drive ULEV uptake and use from the perspective of mass-market consumers; as trials to-date have only covered ULEV 'Innovators' who may not be representative of the broader population.

The Stage 2 trial will also centre on the use of Plug-in Vehicles (both PHEVs and BEVs[166]) as these offer the greatest difference in ULEV experience compared to alternatives such as FCVs. There are also various practical reasons (budget, legal, structural, etc.) which mean that it is not possible to explore other energy vectors such as hydrogen, or issues related to the other Dimensions (such as the Commercial Value Chain) in the time available.

A key outcome of the Stage 2 trial is also to provide new quantitative information that can be used to update and refine the analysis in this report.

The WP1a analysis has been used to help inform the high level Stage 2 trial design in two main areas:

- **Key gaps or limited understanding of the quantitative drivers of ULEV uptake and use that could be explored in the trial** which have been identified through scoping and literature reviews across Work Packages 1 and 2. These are summarised in the section below and have been *translated into a set of more specific research questions in WP1b*.
- **Analysis to inform the broad structure and parameterisation of some aspects of the trial design.** For example, the likely value of applying Demand Management at the system level to guide the extent to which this should be explored within any experimental conditions (i.e. some load shifting with User-Managed Charging or more optimal load shifting using Supplier-Managed Charging), along with the use of the estimated range of savings to help anchor the values that might be presented to consumers to obtain their engagement with the scheme.

It should be noted that the Stage 1 analysis does not directly inform all aspects of the trial design as there are more detailed design choices, which are not reflected in the more stylised modelling of the Customer Proposition, given the current lack of understanding of consumer behaviour. For example, whether engagement with a Managed Charging tariff should reflect an opt-in or opt-out approach on the part of consumers by default (i.e. to override or allow charging control by a third party).

[166] With ICEVs as a control group.

8.2 Summary of known gaps for Stage 2 trial

A number of gaps or limitations in the current understanding have been identified that could be investigated in the Stage 2 trial. The is primarily in relation to an understanding of their ***quantitative*** impact on ULEV uptake and use, as opposed to more qualitative insights that exist in the current literature.

The intention, as far as is possible, is to use elements of the Stage 2 trial results to improve the way these factors are currently modelled within the analysis summarised in this report and add them to the modelling framework. For example, one of the trials is aimed at quantification of BEV and PHEV uptake by *mainstream* consumers. The results from this will be used to improve the modelling in Stage 1, which has been based on data from consumers who have little or no direct experience of the vehicles.

To address the 'key gaps', the elements that it would be useful to understand further through the trial are grouped into:

- ***To what extent users engage and how they respond to new electricity charging tariffs*** and what this means for charging behaviour, e.g. via some load shifting in response to ToU tariffs as part of User-Managed Charging, or more optimal load shifting through Supplier-Managed Charging
- ***Indirect factors affecting the decision to purchase a ULEV*** over a conventional vehicle, such as uncertainty over the variability of costs of electricity charging at non-home locations, and other 'components' that were identified in the *four key areas* but not quantified in Stage 1
- An overarching lack of understanding about the ***conditions required to enable a shift towards mobility as a service*** (e.g. what level of financial compensation might be required for any perceived loss of convenience, status and how this varies across different consumer groups)

A further aim of Stage 2 is to deepen the understanding of ***additional factors considered by fleets that are not included in the starting assumption of purely technical suitability and economic TCO-based decision making***, and which are responsible for lower PiV adoption than expected through this approach. This may include the process through which fleets evaluate the risks associated with this novel technology, such as range anxiety, battery degradation and lifetime, access to public and workplace charging, or the potential requirement to re-optimise routes to maximise benefit from adopting PiVs. Alternatively, a misunderstanding of the true costs of PiV ownership may also be a contributing factor.

A summary of the gaps that could be explored and what data might be forthcoming to improve the modelling analysis is outlined in Table 24 below.

Table 24 Summary of gaps that could be explored in Stage 2 trials

Area	Issue	Relevant to	Value to analysis	Potential data / refinements	Relevant Analytical Tools
Mobility as a service	Conditions for significant shift to mobility as a service	Consumer	High	Compensation to overcome perceived inconvenience, loss of status or other issues Refined maximum penetration of car sharing Incorporate reflection of consumer decision making between outright purchase and service as opposed to ex-ante assumption	CPAT, ECCo
Electricity charging	Scale of DM payments and / or tariff structure necessary to engage users	Consumers / fleets	High	Monetised payment values (or avoided penalties) that would be needed to secure engagement with DM schemes Updated charging profiles given consumer choices and response under a specific tariff structure	CPAT, ECCo, ESME, MEDT
	User response to time of use tariff incentives with mainstream consumers[167]	Consumers / fleets	High	Updated charging profiles given consumer choices and response under a specific tariff structure	As above
ULEV uptake decisions	Perception of non-home access to charging on uptake, covering various rapid, public	Consumers	High	Updated calibration of relationship between infrastructure build and impact on uptake and considering e.g. what is required to ensure 'sufficient' access to charging for households without dedicated off-street parking for them to consider a PiV	
	Importance of charging price certainty and implications for billing models (particularly non-home)	Consumers	Medium	Selection of tariffs appropriate to Narratives, varying by charging location and user group Updated assessment of extent to which risk management costs for suppliers can be passed to consumers	
	Differences in perception of support schemes of notionally equivalent value		Medium	For example any difference in the consumer response to a rebate on an ICEV at the end of life compared to an upfront grant of equivalent	ECCo

[167] Many BEV trials have shown a significant response by consumers to shift load off-peak under ToU incentives, given reasonable price differentials and a simple mechanism to allow the consumer to manage this, such as a charging timer on the vehicle. However, these were undertaken with ULEV 'Innovators' and it is not clear what extent this is also true of mass-market consumers. For example, see San Diego Gas and Electric ToU study https://www.sdge.com/sites/default/files/documents/1681437983/SDGE%20EV%20%20Pricing%20%26%20Tech%20Study.pdf

				value	
	Compensation for 'less viable' ULEV journeys	Consumers	Low	Updated monetary penalties for certain types of ULEV to reflect need to use alternative transport services, hire vehicle, etc.	ECCo
	Value attributed to other ULEV perks	Consumers	Low	Monetary values assigned by different consumer groups to e.g. use of bus lanes, free parking, etc. – particularly given the potential for these to decline under conditions of mass-market ULEV uptake	ECCo
Fleet specific uptake decisions	Better understanding of fleet decision making (e.g. rational factors which are ignored or given less prominence, non-rational factors which influence decisions)	Fleets	Medium	Potentially limited new quantitative data given the difficulty in generalising from individual fleets to national level, but potential insights into fleet manager decision making which could potentially be explored indirectly via model Sensitivities	ECCo

Given the broad range of gaps in understanding, the Stage 2 trial has initially been structured into three broad parts which are summarised below

- ***Consumer Uptake Trial***
  - Investigation of PiV uptake of different types of electric vehicle by mainstream consumers (~200 from random stratified sample). Choice experiments and other similar techniques will be used to help quantify consumer responses to a range of the less well understand factors which impact uptake. A short period of direct experience with comparable ICEV, PHEV and BEV vehicles to help close the 'psychological distance' non-mainstream consumers may have in understanding the potential implications of owning and using a PiV.
- ***Consumer Involvement in Charging Trial***
  - Investigation of the impact of alternative energy supplier consumer offerings and tariff structures on PiV charging behaviour and attitudes with mainstream consumers. This will involve a randomised control trial with ~200 participants covering different groups who will use their provided vehicle (BEV, PHEV or ICEVs for the control group) over a period of approximately 2 months.
  - With the available resources and timescales for the trial it is only possible to test two different experimental conditions. Given the potential value of system savings from directly Managed Charging from this analysis it is recommended that at least one of the experimental conditions is focused on an associated tariff design. The value of savings estimated will be used to help anchor a range of potential benefits that might be available to engage consumers.
  - Given the additional complexity of implementing Managed Charging Tariffs, and the strong response seen in early adopters, it is also recommended that the other experimental condition is used to explore the extent to which ToU tariffs can be used to incentivise *mainstream* consumers and avoid the most significant impacts of fully Unmanaged Charging of PiVs.
- ***Fleet case studies***
  - Due to the variation in the types and roles of light duty vehicle fleets it is not possible within the scope of available time and resources to devise an experimental trial that is statistically significant when extrapolated to the national level. Instead this element of the trial is focused around case-studies with a range of different fleet types (including those more closely associated with future provision of mobility as a service) to gain a better understanding of the factors influencing their decision to use a ULEV both now and in the future.

The separate *D1.4 Trial Design, Methodology and Business Case Report* reconciles the long-list of potential options which could be explored with the available time and budget for the Stage 2 trial, and also provides the detailed description of the final design parameters for the trial.

9 Concluding remarks

9.1 Summary

From the review of evidence to date it is clear that there has been limited work undertaken to explore how mass-market roll-out and use of ULEVs can be facilitated when considering a more ***holistic*** assessment across the four key Dimensions of the:

- Customer Proposition
- Physical Supply Chain
- Commercial Value Chain, and
- Market and Policy Framework.

This report, in conjunction with the supporting *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*[168], has helped to fill this gap:

- Undertaken a first principles assessment of the individual components or BBs that could impact on future ULEV uptake and use, drawing on existing literature, Project Team expertise and discussions with the ETI, covering the four key Dimensions above
- Created a range of future Narratives that explores a broad space of possibilities for ULEV deployment (supported by Sensitivities to understand how resilient these strategies are) and assessed these via the creation of a bespoke modelling framework developed for this project. The assessment has been used to compare a series of key quantitative Success Metrics across the different Narratives, with further thematic analysis around the:
  - Role of Demand Management
  - Deployment of new infrastructure and the implications for energy prices
  - Effectiveness of Government intervention, and
  - Shift towards mobility as a service.
- Extracted insights from the quantitative analysis used to help categorise elements of what constitutes a 'good' solution for ULEVs moving forward into those likely to be Essential, Desirable and Provisional, as well as a number that are considered ineffective or unnecessary.
- Undertaken further qualitative analysis to explore what might be needed to *deliver* a 'good' solution in practice thinking about the potential risks and barriers and what may be needed to overcome these as part of a roadmap, in a number of key areas:
  - Implementing Demand Management
  - Ensuring necessary infrastructure investment
  - Mitigating upfront vehicle costs
  - A transition to car sharing and mobility as a service, and
  - Mitigating a potential long-term decline in Government transport revenue.

[168] *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*

- Supported the development of the Stage 2 *mainstream* consumer trial design in two main areas:
  - Key gaps or limited understanding of the quantitative drivers of ULEV uptake and use that could be explored in the trial which have been identified through scoping and literature reviews within this analysis and the parallel work packages, and
  - Analysis to inform the broad structure and parameterisation of some aspects of the trial design.

9.2 Next steps

The learnings from this analysis for the Stage 2 trial have been incorporated in the separate Deliverable on the detailed trial design *D1.4 Trial Design, Methodology and Business Case Report.* The three broad parts of the trial which have initially been proposed are designed both to answer the key research questions and to directly yield additional quantitative data / insights that will be used to update the modelling analysis undertaken in this report towards the end of Stage 2:

- **Consumer Uptake Trial** – will help refine the way ULEV uptake decisions are represented endogenously in the modelling framework
- **Consumer Involvement in Charging** – will provide a better understanding of actual charging behaviour under different types of future tariffs (e.g. static ToU and Supplier-Managed Charging) and what the effective 'costs' or requirements are for engaging mainstream consumers in Managed Charging schemes, with implications for the viability of the aggregator business model (whether this is a standalone entity or e.g. part of a wider supplier or DNO business model), and
- **Fleet case studies –** will help to inform the further Sensitivity testing within the modelling framework[169].

In addition, further work is anticipated during Stage 2 to apply the current modelling framework to a wider range of new Narratives and / or Sensitivities. Potential examples 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
- Understanding what it would take to get closer to 100% ULEV uptake, i.e. to meet the Government's ambition for all cars and vans to be effectively zero emission by 2050
- 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, and

[169] However, given the wide variation in types of fleet and limited number of case studies possible it may be difficult to generalise the findings.

- 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.
- Different assumptions on the resale/ residual value of the vehicles and how this could vary by Narrative.

The next steps are also described in the separate *D1.3 Market Design and System Integration Report Summary* document.

Appendix A Analytical Tools

A.1 Scope and 'resolution' for analysis

The purpose of the Analytical Tools is to quantify the impact of different Narratives at the **UK-level** – i.e. reflect the uptake and use of ULEVs within the overall national vehicle parc, along with the infrastructure requirements and corresponding financial and physical flows. The breadth of the factors to be quantified, the need to look over a pathway from now to 2050, and the complexity involved in hard-linking a diverse set of Analytical Tools mean that the resolution of analysis needs to be targeted appropriately to ensure effort is focused on the most material factors.

The following describes the base level of resolution across the tool; however, in some cases this may require interpolation or adjustment of the relevant tool inputs / outputs:

- Annual time periods to 2050 starting from 2015.
  - ESME has a maximum resolution of 5-year steps and its results are interpolated where required.
- Seasonal and diurnal timeslicing for electricity and hydrogen to understand the impact on costs of supply and peak demands on infrastructure under different ULEV uptakes and charging profiles.
  - For understanding peak electricity demands hourly profiles are used across the tools with the exception of ESME, which only contains 5 diurnal timeslices. ESME provides the wider system electricity demands outside of PiVs and its demand profiles (including its aggregate peak winter day[170]) are shaped to provide the more granular hourly profile with further disaggregation to reflect the difference between weekday and weekend profiles.
  - To understand peak hydrogen demands (outside of those for hydrogen for power generation) the daily average load for each characteristic day is deemed sufficient[171]. This is the current representation in ESME as input vehicle 'load factors' are flat across the day.
- An implicit representation of geography only where it is required in specific tools to better understand materiality.
  - ESME considers the high level regional implications of resource / generation / storage availability and transmission costs on the national level costs of electricity and hydrogen.
  - A representative mix of rural, semi-rural, semi-urban and urban electricity networks is considered, along with where charging occurs (home, on-street, workplace, public car park) within MEDT.

[170] ESME currently reflects a 1-in-20 year cold weather event which is important to understand e.g. the combined impact of heat-based electrification along with PiV uptake on distribution network reinforcements.
[171] This is because peak capacity from transport hydrogen demand is not driven by instantaneous load due to several points of disconnection between production and final use; in particular the final stage of distribution (potentially by tube trailers to forecourts) and various options for 'storage' along the chain (large scale, pipeline linepack, local on-site storage).

- Cost implications for technical options such as distribution of hydrogen are considered in MHDT (e.g. higher costs per km in urban areas).
- ECCo has an implicit representation of the distribution of journey lengths between different types of consumers (e.g. the proportion of short versus longer distance journeys) as this is important for decision making in range-limited vehicles such as BEVs.

A.1.1 Common conventions

To maintain consistency across the Analytical Tools a common set of conventions has been used:

- Price basis – all Analytical Tools produce results in real 2014 prices
- Calorific value basis – all Analytical Tools are on a net calorific value basis

Appendix B ECCo

B.1 Overview of Electric Car Consumer Model (ECCo)

ECCo was initially developed for the ETI in 2011 as part of ETI's Plug-in Vehicles Economics and Infrastructure Project. Multiple updates have been conducted since, and the latest version of ECCo has been integrated into the model deliverable of this project.

B.1.1 Key functional requirements

The core requirement for the ECCo tool is to provide the levels of ULEV uptake and their parc size up to 2050, for cars and vans. The model uses a consumer-centric approach to calculate the market shares of the different powertrains based on policy inputs, vehicles' attributes, consumer purchase attitudes (fundamentally different between consumers and fleets), refuelling / recharging availability and economic and grid inputs. At its core is a rational consumer choice model, populated with behaviour coefficients taken from an extensive consumer survey of attitudes to PiVs that has been updated in 2015 for the Department for Transport.

In addition, ECCo contains a stock model to track parc dynamics such as energy consumption and tax revenues. In each year, features of the parc are fed back into the choice model to influence vehicle purchase decisions. For example, the price of electricity perceived by car buyers is based on the actual annual cost of electricity for cars in the stock.

B.1.2 Definition of consumers, fleets and vehicles covered

In terms of vehicle segmentation, ECCo covers ten car segments (the nine segments defined by the Society of Motor Manufacturers and Traders, SMMT, plus a 'sub-mini' segment) and 10 powertrains within each of them[172]. For vans, there are five segments (from small car derived vans to large panel vans of 3.5t Gross Vehicle Weight) and nine powertrains within each[173].

With regards to consumer segmentations, the market is divided up into 13 consumer segments for car and 7 for vans. These segments are aggregated into four consumer groups, covering both private and company / fleet vehicle purchases. Each consumer has its own set of criteria underpinning their purchase decision.

B.1.3 Key inputs / outputs and interaction with other Analytical Tools

Although most of ECCo inputs are exogenous, to maintain model consistency, some are received directly from the Physical Supply Chain tools and the Commercial and Policy Accounting Tool. The flow of information between the tools is presented in the *D1.2 Analytical Framework Assumptions Book*.

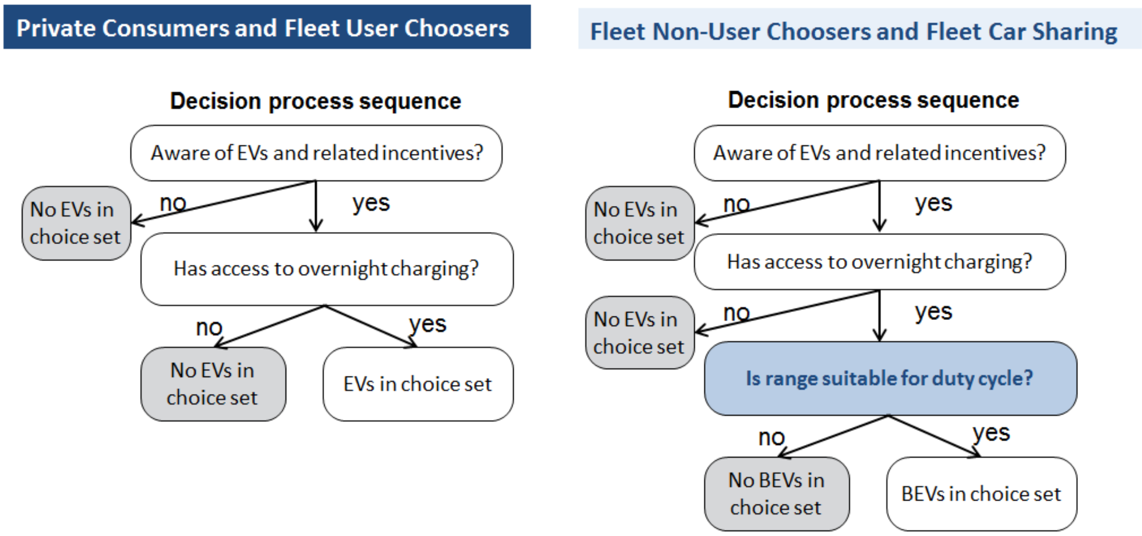
[172] Petrol ICE, Diesel ICE, Petrol Full Hybrid, Diesel Full Hybrid, Petrol PHEV, Diesel PHEV, Petrol RE-EV, Diesel RE-EV, BEV, FCV

[173] Petrol ICE, Diesel ICE, Petrol Full Hybrid, Diesel Full Hybrid, Petrol PHEV, Diesel PHEV, BEV, Fuel Cell

B.2 Segmentation of vehicle buyers in ECCo

ECCo aggregates the consumer segments into four consumer groups: *Private Consumers, Fleet User Choosers, Fleet Non-User Choosers,* and *Fleet Car Sharing*. These define the mechanism used to determine the vehicle choice set and to model the purchase decision. The decision tree through which the choice set is determined is summarised in Figure 92.

Figure 92 Purchase decision tree as implemented in ECCo



Like the choice set, the structure and components of the purchase decision differ by consumer group.

- *Private Consumers* base their decision upon a number of attributes such as cost, state of charging infrastructure, range, and the availability of their preferred model / make. For cars, this consumer group is further divided into six consumer segments (e.g. 'innovators', 'cost-conscious greens') with each placing a different set of weightings on these attributes, as defined by the Consumer Survey carried out for DfT in 2015[174].
- *Fleet User Choosers* are company owned cars where the driver has been given free choice in the purchase decision. The purchase decision therefore resembles that of a *Private Consumer* but with a different set of values placed on each attribute. *Fleet User Choosers* are split into those that pay Benefit in Kind (BIK) tax and those that do not, which affects the vehicle running costs and hence purchase decision.
- *Fleet Non-User Choosers* are also company owned vehicles where the purchase decision lies with the company or Fleet manager. It is assumed that a purely rational decision is made through comparison of the Total Cost of Ownership. The decision of whether to include BEVs in the choice set is based upon the possibility of fulfilling the daily duty cycle on a single charge. Fleet Non-User Choosers are divided further into a number of consumer segments, which are differentiated by the driving requirements and the location

[174] Element Energy for DfT, 2015

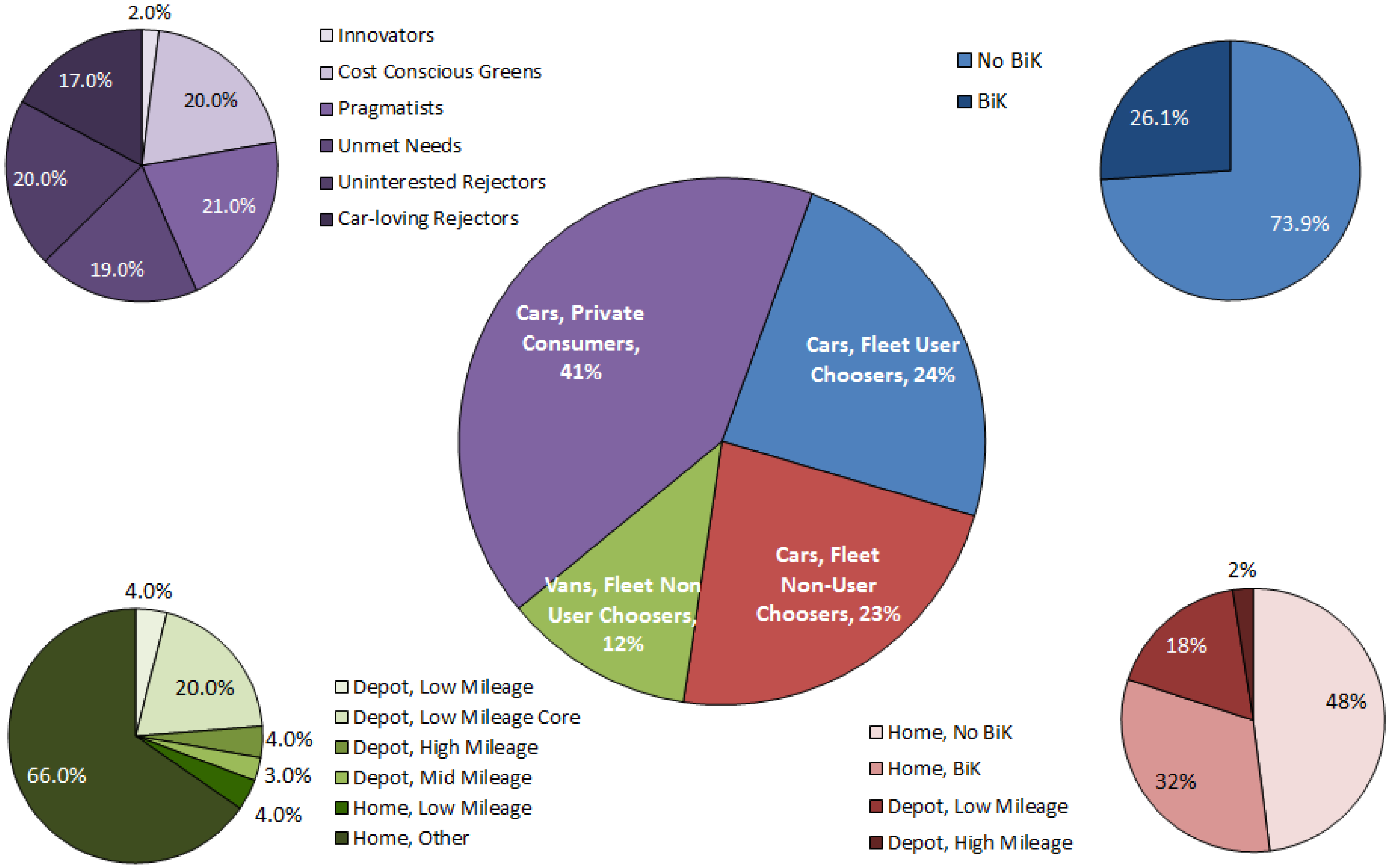
of overnight storage (home or depot). All new van buyers are modelled as Fleet Non-User Choosers.

- A final consumer group, *Fleet Car Sharing*, has been added to model the purchase of cars by car sharing companies. The purchase decision resembles the rational requirements / TCO approach of Fleet Non-User Choosers.

The usage behaviour of each consumer group is incorporated into the vehicle stock in order to more accurately track the parc characteristics. It is assumed that fleet vehicles are sold into Private ownership at the end of their lease contract. This mechanism allows privately owned vans to be considered within ECCo, and results in a realistic private / company split in both the car and van parc.

Segmentation of Fleet Non-User Choosers was carried through analysis of the fleet data provided by RouteMonkey. Figure 93 summarises the overall segmentation of vehicle sales.

Figure 93 Summary of the current buyers' segmentation in ECCo



B.2.1 Purchase decision penalties

The attributes considered by Private Consumers and Fleet User Choosers are:

- Upfront vehicle cost
- Running cost
- Rapid charging performance (km range obtained from 20 minute charge)
- Electric range
- Access to charging infrastructure
- Brand supply
- Familiarity / supply, and
- The alternative specific constant.

The latter three attributes are applied as penalties. Brand supply encompasses the lack of a PiV powertrain from a buyer's preferred manufacturer, and is derived from a forecast of when OEMs are likely to introduce PHEV and BEV powertrains into each segment. The Alternative Specific Constant (ASC) accounts for the individual consumer bias shown towards novel powertrains as observed in the Consumer Survey carried out for DfT in 2015[175]. The magnitude of the ASC is reduced with sales and is zero once cumulative sales of PHEVs, BEVs and FCVs respectively reach four million. This corresponds to approximately 10% of the vehicle parc, in line with research conducted in North America that studied the change in technology acceptance that comes with the 'neighbour effect', i.e. a technology becoming more desirable as its adoption becomes more widespread[176]. The ASC start point is set to reproduce the difference in PHEV, BEV and FCV perception observed between the surveys carried out in 2010 and 2015.

Finally, familiarity accounts for overall market bias shown against novel powertrains, and the existing bias observed towards the currently available diesel powertrains within each segment. For example, in the small car segment, diesel powertrains have a very small market share, whereas the opposite is true in the larger segments. This is likely the result of a lack of choice provided by the OEMs as they favour petrol engines for small cars and diesel engines in large, while also providing little optionality with regards to the PiVs they currently sell. Despite the fact the Fleet Non-User Choosers and Fleet Car Sharing buyers are assumed rational, estimating present day sales through considering just the TCO tends to over-predict the sale of novel powertrains, as well as petrol vehicles in the larger segments. Consequently, it is assumed that this underlying familiarity bias affects all consumers.

Derivation of the familiarity penalty is achieved by calibrating the model uptake with actual sales in the period 2010-15. For cars already available before the start of this calibration period, the starting value is calculated from the 2010 market share:

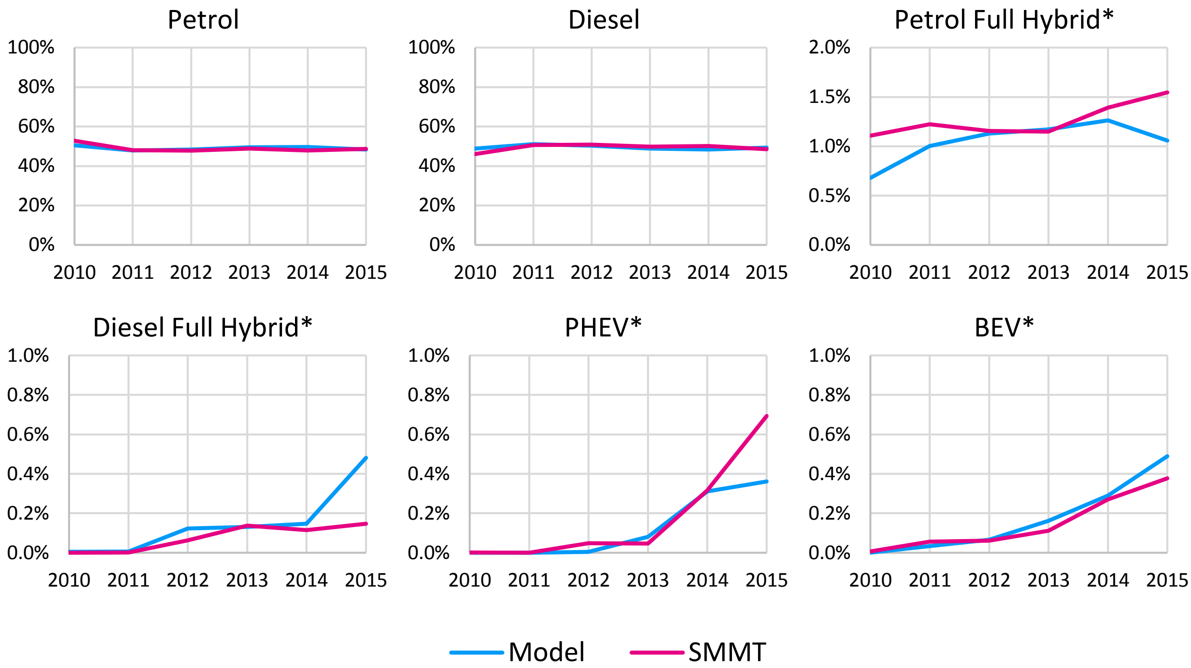
$$F_{i,seg} = k \times ln \frac{sales_{i,seg}}{\sum_{seg} sales}$$

[175] Element Energy for DfT, 2015

[176] Axsen J. et al., 2009, Combining stated and revealed choice research to simulate the neighbour effect: The case of hybrid-electric vehicles Resource and Energy Economics 31 221-238

The future value of the familiarity is made a function of predicted sales and so as the powertrain market share increases, the familiarity penalty is decreased. The coefficient k is used to calibrate predicted sales with observed. This approach results in excellent agreement with observed market trends as shown in Figure 94:

Figure 94 Comparison of actual market shares provided by SMMT with those predicted by ECCo during the calibration period (*note scale).



For cars introduced during the calibration period, both the starting value and coefficient, k, are calibrated against market shares, and for those introduced after the calibration period the starting value is assumed as the strongest existing penalty for that powertrain across all segments in that year. However, to reflect the expected adoption of novel electric powertrains by all major OEMs in the 2020s, and consequent acceptance by drivers, the familiarity penalties are set to reduce by a minimum of 30% from 2020. The result is that the familiarity penalties become negligible by 2030.

The familiarity penalty for FCVs is based not on relative sales but the coverage of the hydrogen refuelling infrastructure. Since usage behaviour of an FCV is broadly similar to that of a conventional internal combustion engine vehicle, it is proposed that the market will require a much shorter acceptance period, and instead market bias will result from availability of refuelling facilities. Under this assumption, the FCV familiarity penalty tends to zero as the number of hydrogen refuelling stations approaches the number of petrol stations currently operating in the UK.

Whilst the existence of a familiarity penalty seems sensible for private buyers, its existence for fleet buyers appears to go against the assumption that they behave completely rationally. Alternatively, it may be that ECCo does not fully account for all aspects of the fleet purchase decision and this has been identified as an area for investigation in Stage 2. For example, this could be due to the difficulty in installing charging posts at employee's home, or the estimated risk of purchasing a powertrain without a proven track record in the more demanding usage patterns of fleet vehicles.

B.3 ECCo vehicle dataset

The original ECCo model (2011) used a dataset provided by the Ricardo 2010 Cost Model. This covered 21 vehicle attributes for 20 powertrains across 10 segments (9 SMMT segments + 'Sub Mini'). In this latest version of ECCo, the format of the dataset has been simplified by removing redundant attributes, such as luggage capacity, top speed, and acceleration, which do not contribute to the vehicle purchase decision – see Table 25.

Table 25 Vehicle attribute lists used in ECCo in 2016 versus 2011

ECCo 2011	
1	Powertrain availability
2	Fuel consumption
3	Electricity consumption
4	Tailpipe emissions
5	Range, fuel mode
6	Range, electric mode
7	Real world electric range
8	Payload
9	Luggage capacity
10	Acceleration
11	Top speed
12	Battery capacity
13	Usable battery capacity
14	Vehicle mass
15	Purchase price
16	Maintenance cost
17	Depreciation
18	Insurance cost
19	Sales and admin margin
20	Production emissions
21	Battery cost

ECCo 2016	
1	Overall margin
2	Fuel consumption
3	Electricity consumption
4	Tailpipe emissions
5	Battery cost
6	Electric range
7	Real world electric range
8	Production emissions
9	Insurance cost
10	Maintenance cost
11	Depreciation
12	Battery capacity
13	Usable battery capacity
14	Vehicle mass
15	Purchase price

Note that production emissions are not used in this model sequence as instead ESME captures the energy-related UK car manufacturing emissions[177], although this does not reflect the powertrain market shares. The impact of this is considered small as only 10 to 15% of the cars bought in the UK are built domestically.[178] The real world electric range is also inputted as a placeholder as this is recalculated in ECCo from the New European Driving Cycle (NEDC) electric range using the real world correction factors (see section B.5).

In addition to simplifying the attribute list, some of the original powertrains were deemed superfluous and were removed, shown in Table 26:

- 'Stop-start' models: 'gasoline' and 'diesel' now includes micro hybridisation, with variations across segments in line with market penetration values.

[177] Emissions from industry – i.e. those arising from producing the vehicle but not the full lifecycle emissions
[178] SMMT Motor Industry Facts 2015

- 'Mild hybrid' models: these are poorly defined and there is not enough differentiation across models offered on the market to warrant two separate hybrid powertrains. Very similar products are not recommended in a choice model.
- Hydrogen ICEV, E85, B100, CNG, LPG, FC RE-EV: not relevant for cars in GB (biofuel blends are however represented through a change in the properties of fuels used in petrol and diesel engines, through inputs received from ESME).

The list of powertrains for vans (left) also contains powertrains not relevant for this analysis (e.g. LPG) or not relevant for all segments (e.g. petrol hybrid). For clarity, the lines for redundant powertrains in the dataset are left empty in the *D1.2 Analytical Framework Assumptions Book*.

Table 26 List of car and van powertrains used in ECCo in 2016

Cars	
1	Petrol ICE
2	*Petrol Stop-Start*
3	*Petrol Mild Hybrid*
4	Petrol Full Hybrid
5	Petrol PHEV
6	Petrol RE-EV
7	Diesel ICE
8	*Diesel Stop-Start*
9	*Diesel Mild Hybrid*
10	Diesel Full Hybrid
11	Diesel PHEV
12	Diesel RE-EV
13	Electric
14	Fuel Cell
15	*Hydrogen ICE*
16	*Fuel Cell RE-EV*
17	*Gasoline E85*
18	*Diesel B100*
19	*Gasoline LPG*
20	*Gasoline CNG*

Vans	
1	Petrol ICE
2	Petrol Full Hybrid
3	Petrol PHEV
4	Diesel ICE
5	Diesel Full Hybrid
6	Diesel PHEV
7	Electric
8	Fuel Cell
9	*Fuel Cell RE-EV*
10	*Gasoline LPG*

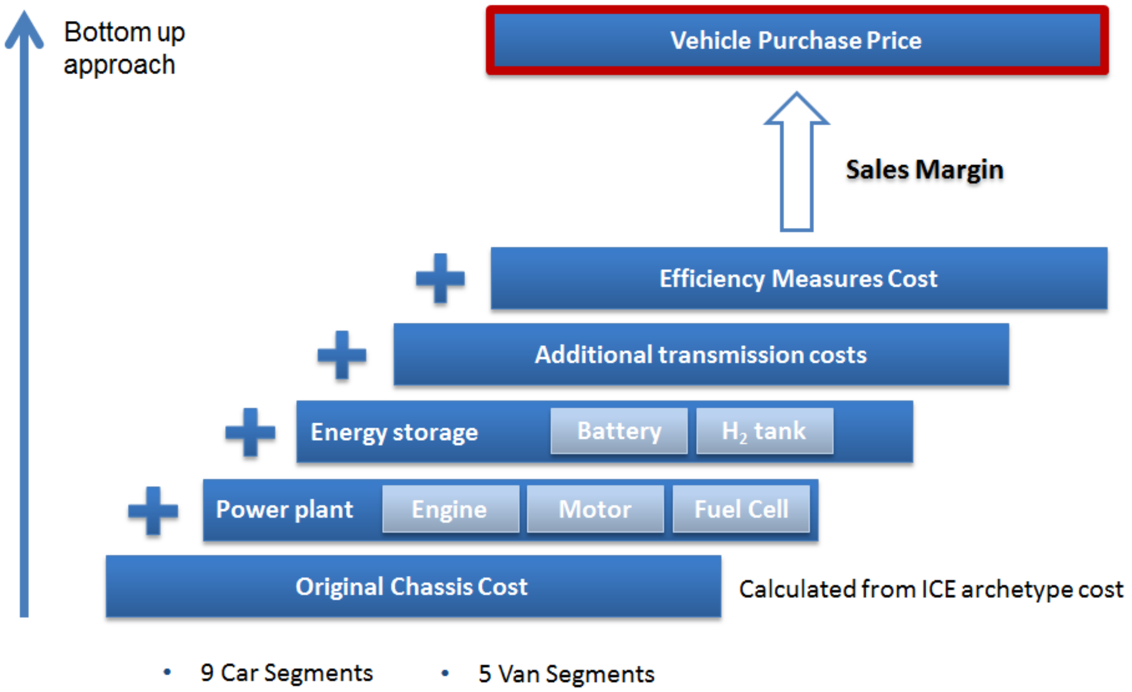
Inputs and outputs passed endogenously between the Analytical Tools of the ETI CVEI Model use a further reduced powertrain list. Petrol and diesel ICEVs and Hybrid Electric Vehicles ('Full Hybrids' / 'HEVs')[179] are combined into 'Petrol' and 'Diesel' respectively, and PHEVs and Range Extender Electric Vehicles (RE-EVs) of both petrol and diesel are combined into 'Petrol PiV' and 'Diesel PiV'.

179 Full Hybrid Electric Vehicles are conventional hybrids with a short electric-only range (<2km) but which cannot be plugged into an external electricity supply. All energy is provided by their liquid fuel source (e.g. Toyota Prius or Auris Hybrid). A Plug-in Hybrid Electric Vehicle (PHEV) has a larger battery, allowing for significantly longer electric range, and can be plugged into an external electricity supply, allowing for it to be powered by both liquid fuel and electricity drawn from the grid (e.g. Mitsubishi Outlander or VW Golf GTE).

B.3.1 The Element Energy Cost and Performance Model

New vehicle price assumptions were developed for ECCo in 2015 for the Department of Transport. DfT commissioned an update of ECCo, with a focus on primary consumer research (the dedicated report is expected to be published in 2016), revision of the car database and addition of vans. To this effect, Element Energy developed dedicated bottom up car and van cost models (Element Energy Cost and Performance Models), building on previous work for LowCVP and DfT, and taking into account latest findings from the literature. Assumptions taken on vehicle components were reviewed in detail by the DfT team over January to July 2015. The approach taken to building this model is illustrated in Figure 95.

Figure 95 Graphical representation of the bottom-up approach taken in the Element Energy Cost and Performance Model



The model was developed according to the following process:

- Cost and performance data for the top five models from each vehicle segment collected for both petrol and diesel. In addition, a PiV review was carried out to capture all currently available vehicles.
- Sales weighted average values for each vehicle feature derived, providing both a petrol and diesel ICEV archetype.
- Trends in the impact and cost of vehicle components and efficiency measures developed for 2010-50. Future deployment of efficiency technologies taken from literature[180,181] and

[180] TNO 2011 -Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars.
[181] Ricardo-AEA for CCC 2012 -A review of the efficiency and cost assumptions for road transport vehicles to 2050.

the costs of which were estimated by employing a learning rate methodology. PiV specific characteristics were estimated from review of the currently available PiV models and reflect the latest OEM announcements.

- Cost and performance values calculated for each powertrain within each segment by adding relevant components and efficiency measures to an original chassis derived from the ICEV archetypes.
- Model outputs calibrated against the real world examples reviewed in the market study and average new car CO_2 emission data.[182]
- The model results were aggregated into 15 vehicle characteristics (such as fuel and electricity consumption, retail price, and electric range) which can then be fed into the ECCo model.

B.3.2 Vehicle segments

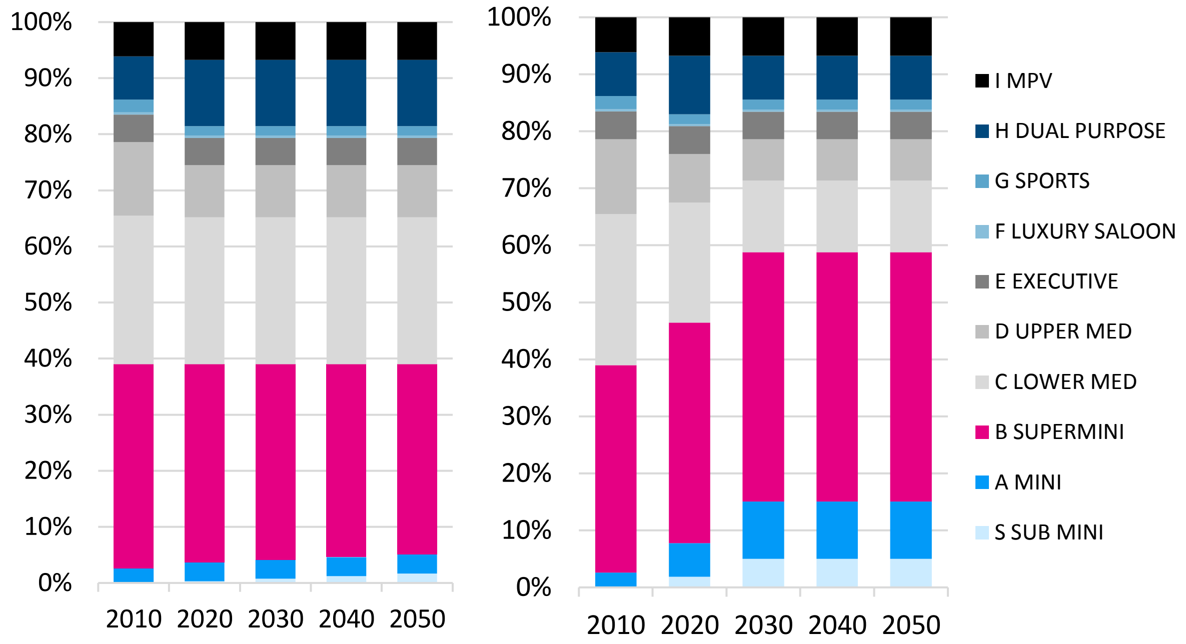
For cars, the original ECCo segments have been preserved (9 SMMT segments + a 'sub-mini' segment). However, not all segments are treated explicitly:

- Sub-mini: original values have not been updated (this is a minor segment, capturing under 2% market share by 2050).
- For niche segments F and G, the assumptions on 2015 vehicle archetype (engine size, power to weight ratio etc.) have not been defined explicitly. Instead their characteristics are mapped into the segment E case and 2015 costs are scaled to reproduce the premium over segment E observed in 2015.
- For all other segments (A, B, C, D, E, H and I), the detailed bottom up approach was taken.

By default, ECCo maintains the 2015 segment shares up to 2050, apart from a slight adjustment to accommodate a 2% share for the sub-mini segment in 2050. An alternative segment share scenario exists whereby there is a gradual shift towards smaller cars. The segment shares are set out in Figure 96.

[182] SMMT New Car CO_2 Report 2014.

Figure 96 Default segment share scenario (left), and shift towards smaller cars (right)



Applying this in the BaU Narrative results in ULEVs comprising 37% of the car parc in 2050 as opposed to 40% when holding the segment shares at their 2015 values. This is a result of the lower availability of Plug-in Hybrids in the showroom of the smaller segments, as well as the reduction in the average new car emissions lessens the need for ULEVs in order to the meet the EU tailpipe emissions target.[183]

B.3.3 Cost and Performance Model outputs: vehicle price trends

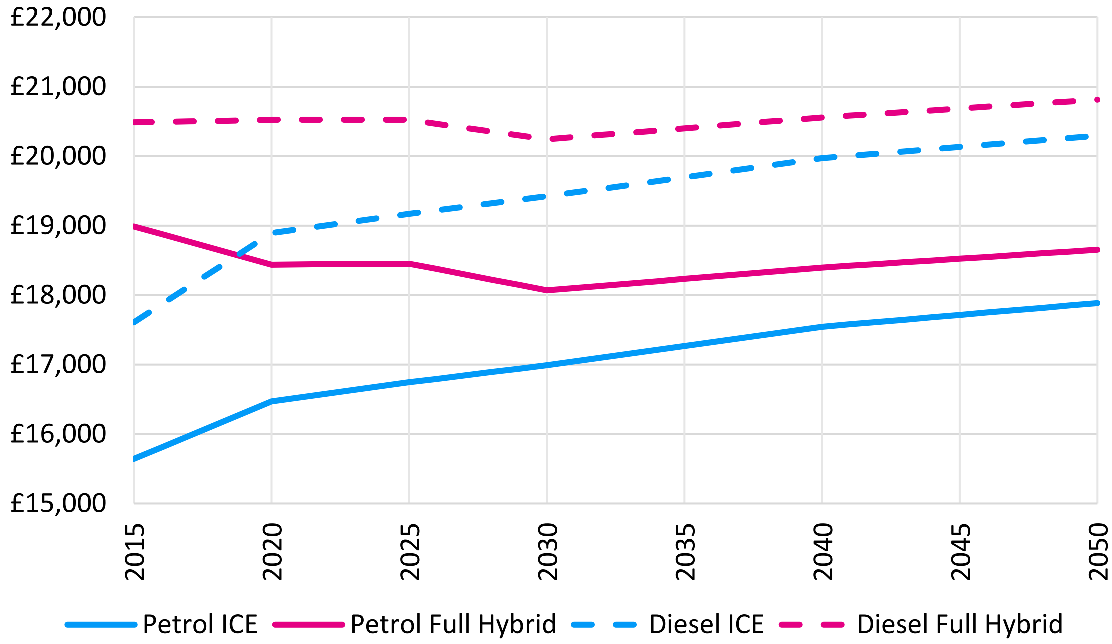
ICEVs and HEVs

ICEVs follow a general upward trend in price over time, driven by the increased deployment of efficiency measures in order to meet EU regulation imposed on tailpipe emissions. This is in line with recent trends that show diesel and petrol ICEVs are increasing in cost. For example, Element Energy's market studies of top selling vehicles in 2010 and 2015 found that segment C (medium-sized) petrol ICEV had increased from £14,855 to £16,796, in 2014 terms. The Ricardo-AEA cost curve model developed for the Committee on Climate Change in 2012 assumes continued deployment of efficiency measures in a manner 'consistent with the goal of progressively reducing new vehicle CO_2 as far as is practicable by 2050'.

In the case of hybrids, the increase in cost due to the addition of efficiency measures is compensated by a decrease in motor and battery costs, resulting in near constant prices (or slightly decreasing) between 2015 and 2030. The assumptions on vehicles costs are shown in Figure 97.

[183] Fewer plug-in hybrids in the showroom so fewer sales of ULEVs, and smaller cars therefore lower CO_2 emissions and less need for ULEVs to meet the target.

Figure 97 Segment C ULEV retail prices (excluding grants and VAT) for 2015 to 2050 from the Element Energy Cost and Performance Model



Some efficiency measures are applicable to petrol (or diesel) engines only, meaning the deployment and cost of efficiency measures differ across diesel and petrol vehicles (both ICEV and HEVs). This results in non-constant price gaps between these technologies.

Ultra-Low Emission Vehicles (PHEVs / RE-EVs / BEVs / FCVs)

The key assumptions underlying ULEV prices are:

- Battery size: derived from driving range assumptions.
- Pricing strategy: what margin is added to the cost and how quickly this is assumed to reach the same level applied to ICEVs.
- Additional deployment of efficiency measures such as improved aerodynamics, low rolling resistance tyres and weight reduction.
- Battery and fuel cell cost: both are assumed to go down with time. Battery costs as per developed in WP3 (see *the D3.1 Battery Cost and Performance and Battery Management System Capability Report and Battery Database*) and fuel cell costs as developed by Element Energy.

For fuel cells the cost decrease over the next five years is quite significant due to the expectation that the technology will graduate from its current pre-commercial stage to mass-market production. Between 2015 and 2020, fuel cell costs for FC-EVs are forecast to decrease by 59% on a £/kW bases, which is consistent with the latest US Department of Energy cost projections[184]. This price reduction is driven by:

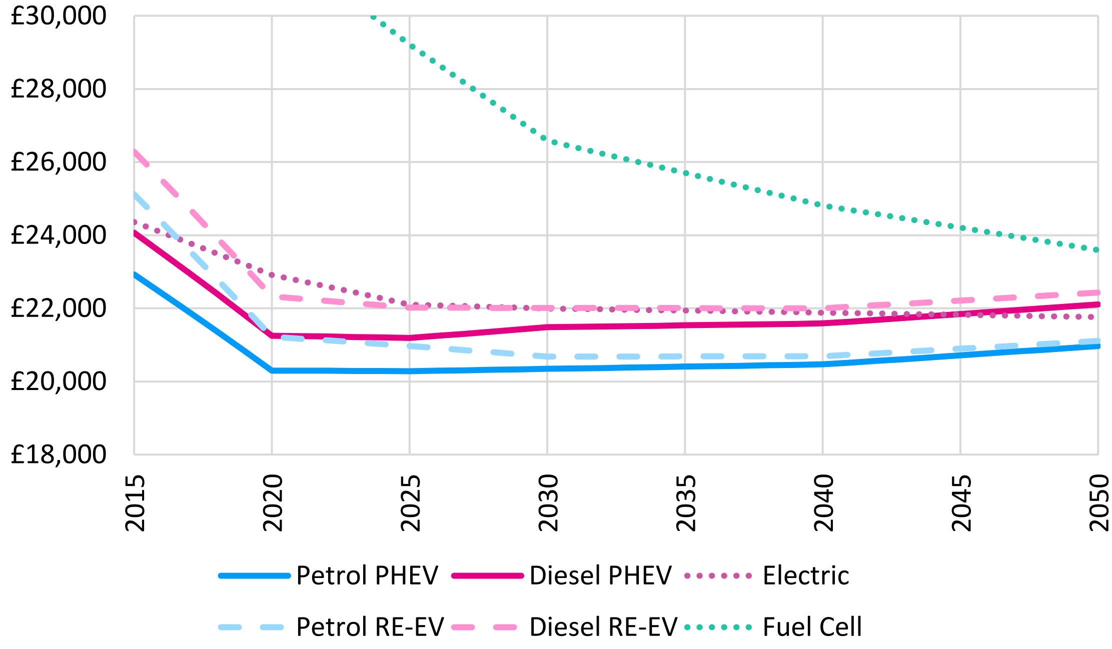
- Next generation stack design - lower platinum loading, increased density, and a possible shift to high speed 'printing' of the membranes. Unlike photovoltaic solar, for which cost reduction is now due mostly to volume, fuel cells will likely undergo new designs, different composition and different ways of manufacturing in the period 2015 to 2020.
- Full mass production - Toyota is currently manufacturing about 700 fuel cell units per year, but are planning 30,000 per year in 2020[185].

The significant gains from these cost drivers are only available over the early years. Once production volumes are high, it takes longer to double the cumulative production, hence the learning curve effect takes longer to show. Consequently, in the period 2020 to 2050, the fuel cost is projected to decrease by only 57% on a £/kW bases.

The electric driving range is assumed to improve over time for BEVs, while is kept constant for PHEVs. The margin applied to BEVs is set to converge towards the 'standard margin' (i.e. for ICEVs) as fast as possible while preventing prices to go up year on year.

The margin trends derived for BEVs are then applied to PHEVs / RE-EVs / FCVs too. This and the fact that cost trends for PHEVs / RE-EVs are different, due to a flat electric range, means the price gap between BEVs and PHEVs / RE-EVs can be oscillating – example shown in Figure 98 for segment C.

Figure 98 Evolution of segment C ULEV retail prices (excluding grant and VAT) from the Element Energy Cost and Performance Model



184 https://www.hydrogen.energy.gov/pdfs/14012_fuel_cell_system_cost_2013.pdf
185 Toyota's announcement: http://www.reuters.com/article/us-toyota-environment-idUSKCN0S80B720151014

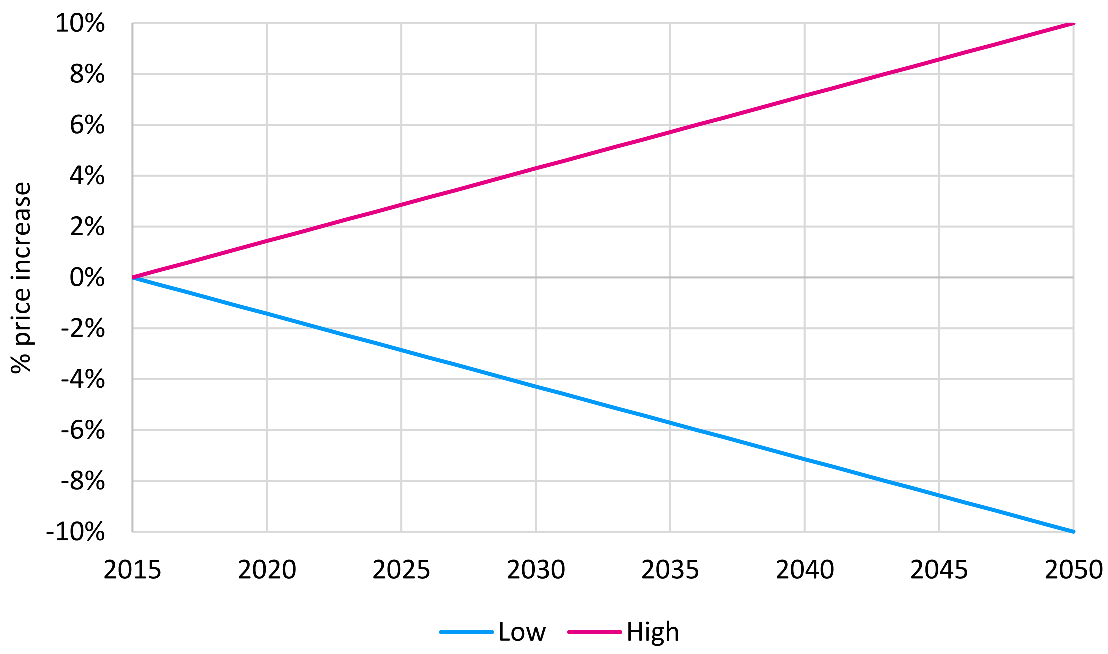
Note: The FCV cost in 2015 and 2020 is £52,800 and £32,100 respectively.

In this example, the BEV range is constant in 2040 to 2050, giving the opportunity to increase the margin (as the battery cost decreases). This margin increases the price of PHEV / RE-EV over 2040 to 2050, as the vehicle cost is not decreasing as much as the cost of BEVs (the cost of the battery being a small proportion of the total cost for PHEVs / RE-EVs).

Price sensitivity

ECCo is very sensitive to vehicle price, particularly in the later years as the prices of PiV and conventional powertrains converge. To illustrate this, ECCo has been run with various different price change scenarios. In each case, the 2050 price of a set of powertrains was changed by a fixed percentage while the 2015 prices were kept the same. The percentage price change applied in the intervening years was an interpolation between 0 and the 2050 value – the values used for the Sensitivity are shown in Figure 99.

Figure 99 Price increases applied in the ICEV and Full Hybrid +/- 10% price Sensitivity

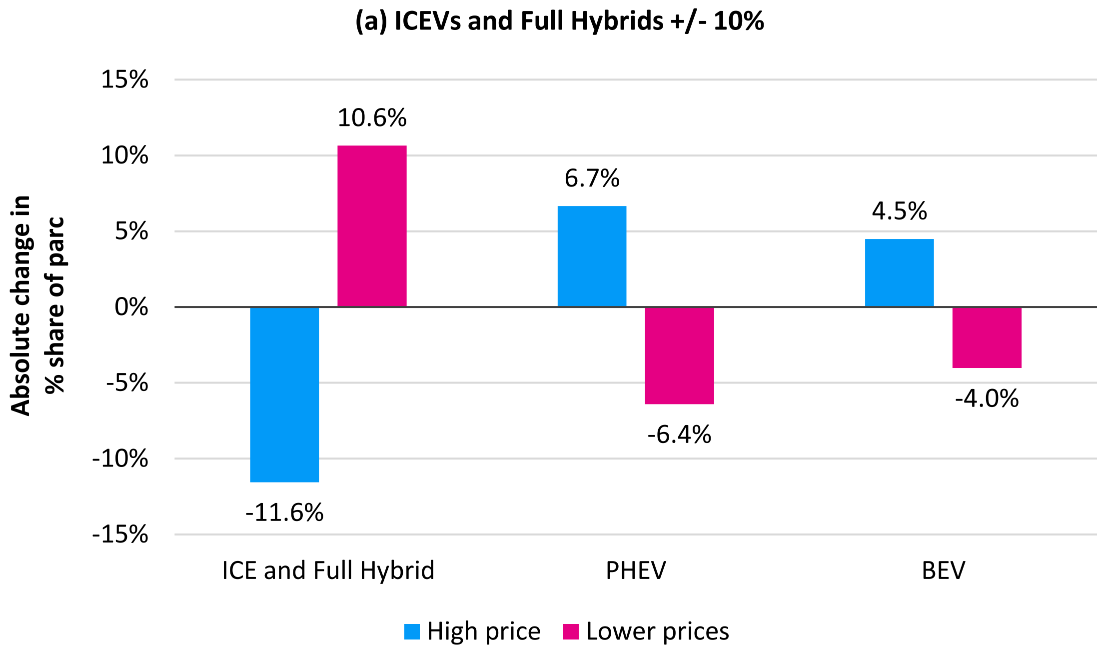


The price change scenarios investigated were:

- ICEV and Full Hybrids: +/- 10%
- BEVs: +/- 20%, and
- PHEV and RE-EVs: +/- 20%.

In each case, the retail prices of all other powertrains was left unchanged from the baseline.

Figure 100 Absolute change in % share of parc for ICEVs and Full Hybrids in 2050 against baseline when changing price of (a) ICEVs and Full Hybrids, (b) PHEVs and (c) BEVs



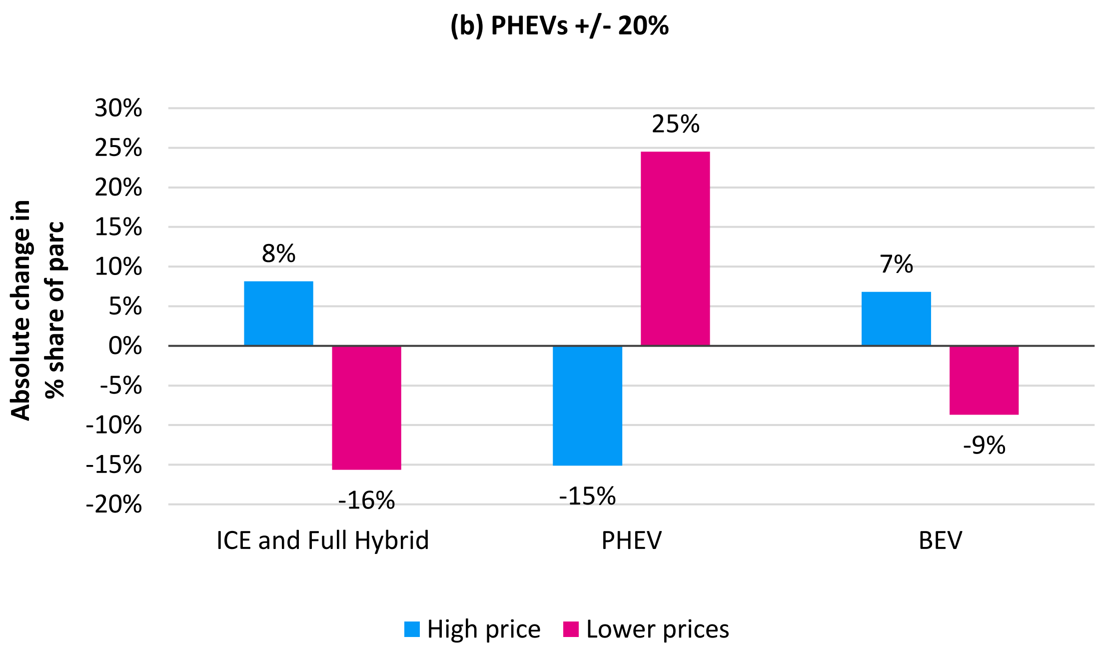
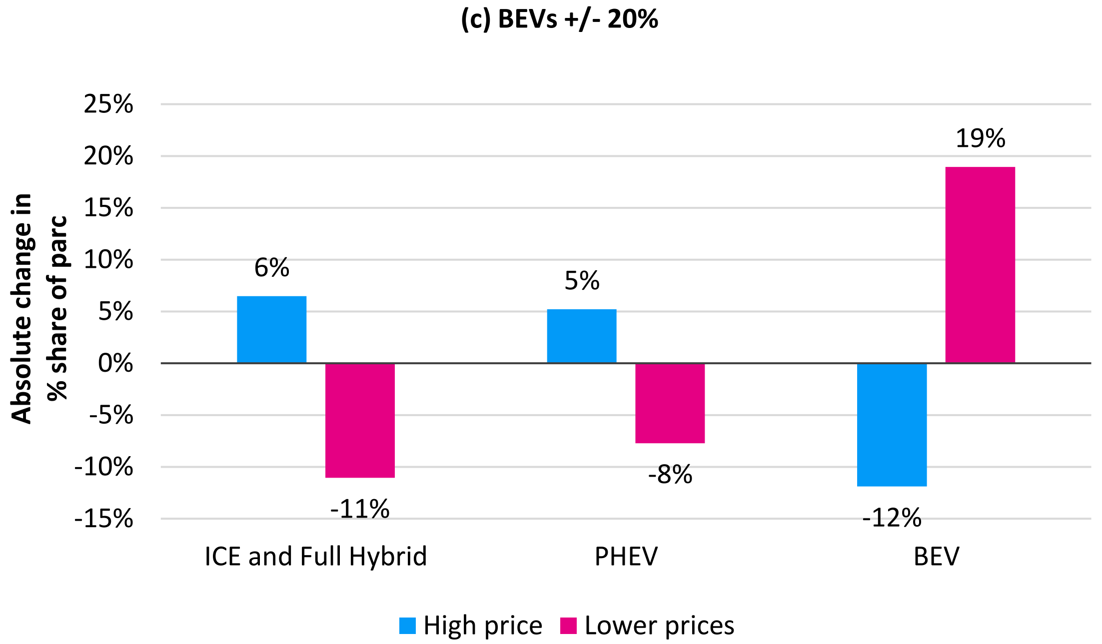


Figure 100 Absolute change in % share of parc for ICEVs and Full Hybrids in 2050 against baseline when changing price of (a) ICEVs and Full Hybrids, (b) PHEVs and (c) BEVs

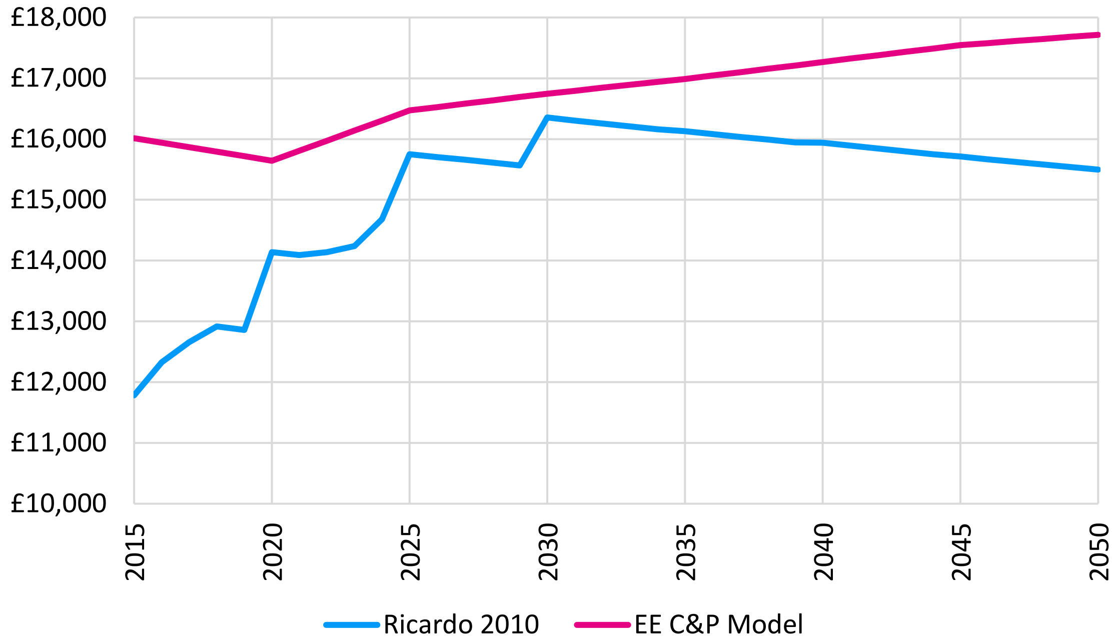


As can be seen in Figure 100, the price changes lead to a significant change in the parc uptake. For example, a 20% increase in the BEV cost in 2050 results in the share of parc made up by BEVs decreasing from 16.6% in the baseline in 2050 to 4.7%.

B.3.4 Comparison with Ricardo 2010 Cost Model

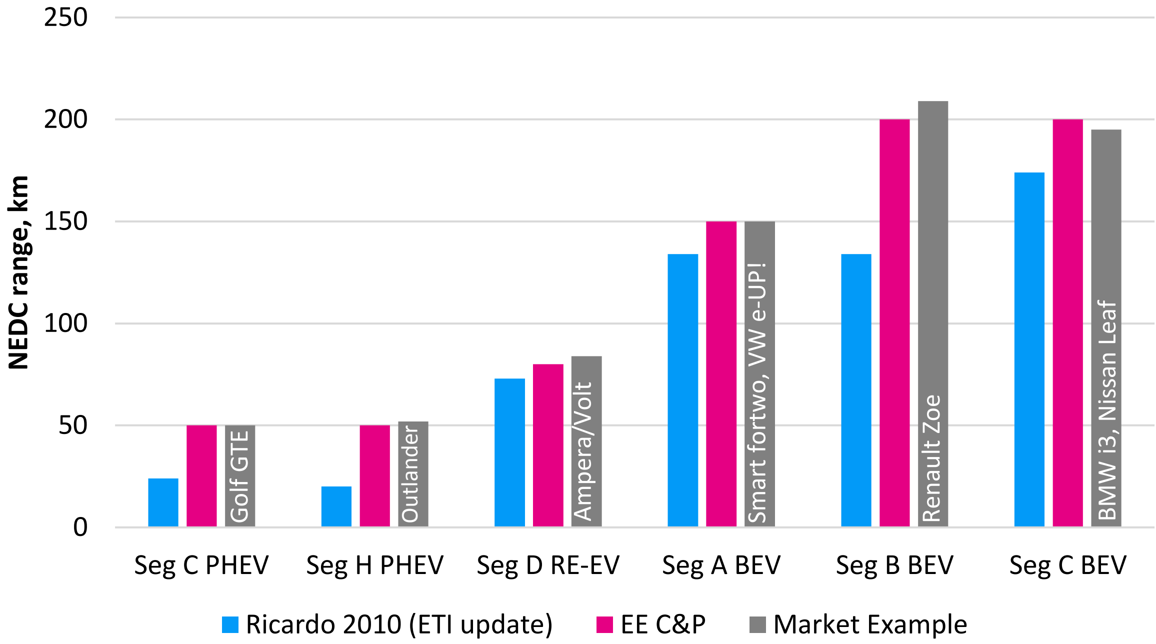
The Element Energy Cost and Performance Model provides several improvements over the original Ricardo 2010 Cost Model. The Ricardo model applies new efficiency technologies to all vehicles from a given year resulting in step changes to the vehicle characteristics, illustrated in Figure 101. This does not well reflect what is observed in reality, in which a new technology is gradually rolled out by multiple OEMs across their vehicle range.

Figure 101 Comparison of the cost of segment C Petrol ICEVs from the Element Energy Cost and Performance Model and the Ricardo Cost Model



Recent progress in PiV technology has exceeded the expectations held in 2010, and this is reflected in the comparison of the Ricardo 2010 Cost Model with what is observed today, shown in Figure 102. Chiefly this is a result of the assumptions on battery size and vehicle range.

Figure 102 NEDC ranges observed in the market today, compared with 2015 data from Element Energy Cost and Performance Model and Ricardo Cost Model 2010[186]



The Element Energy Cost and Performance Model contains range forecasts based on the most recent OEM announcements and market consensus, while also incorporates the findings on battery cost and energy density developed in *WP3* (see the *D3.1 Battery Cost and Performance and Battery Management System Capability Report and Battery Database*).

Finally, the Ricardo 2010 Cost Model was provided for cars only. As the Element Energy Cost and Performance Models were developed for both cars and vans, their use ensures consistency of approach for both vehicle types. Consequently, for the ETI CVEI project, datasets using outputs from the Element Energy Cost and Performance Model 2015 are used, with some updated assumptions (e.g. battery costs as derived from *WP3* research and margins applied to ULEVs).

B.3.5 Comparison with the ETI 2012 Dataset

The ETI have developed their own dataset compatible with ECCo, originally based on the assumptions of the Ricardo 2010 Cost Model, but with a number of revisions:

- Fuel and electricity consumption values increased by 15% to match ESME assumptions
- Proportion of mileage carried out under electric power for PHEVs changed, resulting in a 40% increase in fuel consumption and 40% decrease in electricity consumption
- Electric range, electricity consumption, battery capacity and costs for PHEVs and RE-EVs updated to reflect National Travel Survey Analysis

However, a number of inconsistencies have appeared during this update process:

[186] Including the ETI 2012 update.

- Emissions remained unchanged and so do not match fuel consumption
- Battery costs, on a per kWh basis, are larger for BEVs compared with RE-EVs, despite BEVs carrying a larger battery capacity. This suggests that either battery costs or battery capacities were not fully updated.

This dataset provides an alternative view of vehicle cost forecasts, and incorporates stronger cost reductions for vehicle components than observed in the Element Energy Cost and Performance model. This, therefore, offers a valuable sensitivity scenario for the Analytical Framework's ULEV uptake projections. However, the trends in ULEV characteristics, such as electric range and battery costs, are taken from the 2010 Ricardo Cost Model, and comparison with ULEV models available today reveals many of these forecasts to be out of date. In order to make best use of this alternative dataset it is clearly beneficial to update these assumptions, and include the latest battery cost assumptions developed for this project. However, since the battery costs contained within the dataset appear inconsistent with the battery capacity assumptions, an update is not straightforward. Furthermore, a significant increase in battery capacity to accommodate a larger range adds considerable weight to a ULEV, which in turn increases the electricity consumption.

As a result of the difficulties in updating the ULEV assumptions in this dataset, it was decided, in agreement with the ETI modelling team, that the sensitivity should apply the observed cost trends to the conventional ICEVs and HEVs, while the ULEVs retain the costs outputted by the Element Energy Cost and Performance Model. It is acknowledged that this simplistic approach unfairly penalises ULEVs, as some of the components that experience cost reductions in the ETI dataset, such as aerodynamics packages and weight reduction techniques, will be shared across all powertrains. In addition, this sensitivity includes only changes to cost, and so does not incorporate the trends in energy consumption which are directly linked to the assumed deployment of efficiency technology in the ETI dataset.

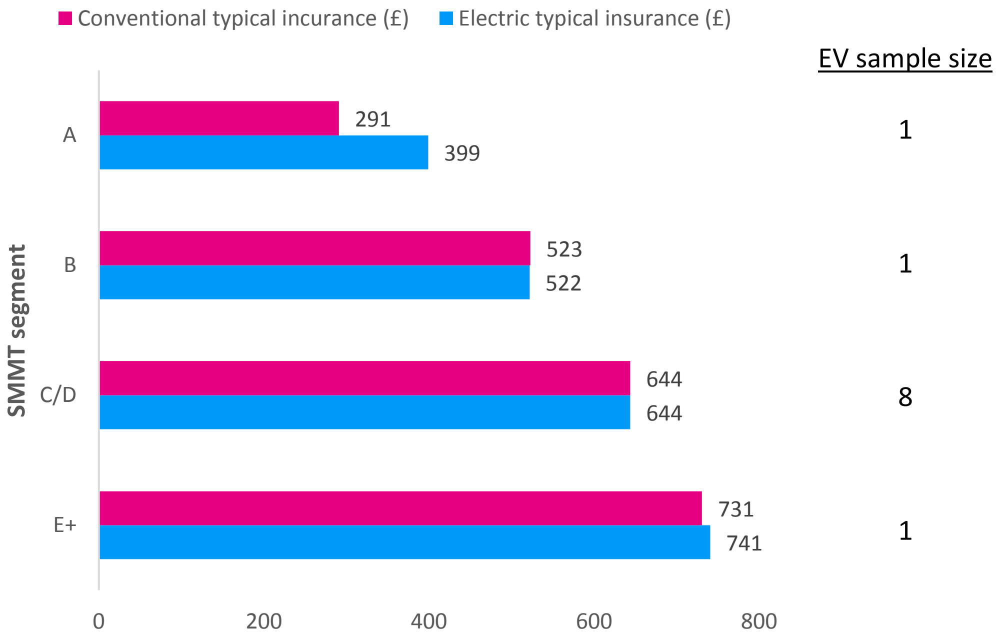
It is proposed that Stage 2 should include an analysis of the model used to generate this alternative dataset, in order that the latest assumptions surrounding ULEVs in the Element Energy Cost and Performance Model can be more realistically integrated.

B.3.6 Insurance and maintenance costs

As part of the update to the ECCo dataset for DfT in 2015, new insurance and maintenance costs were gathered during the market review, summarised in Figure 103. At the time that the original ECCo dataset was prepared in 2011, very little information was available on these costs for PiVs as so few were in circulation.

In this latest review is was found that insurance costs for plug-in cars were comparable with that of conventional powertrains across all segments. As a result, insurance costs for ULEVs are set equal to their ICEV equivalents. This deviates from the Ricardo 2010 Cost Model which applied an insurance cost premium for BEVs of several hundred pounds right up until 2050. For example, for segments A-D this amounted to £450 in 2015 and £350 for 2050.

Figure 103 Insurance costs observed in market study[187]



With regards to servicing costs, it was found that the Mitsubishi Outlander PHEV cost £400 less than the Diesel ICEV version,[188] and so maintenance was set 30% less for PHEVs / RE-EVs versus their ICEV equivalents. Fleet managers report even lower costs for BEVs due to few moving parts, fewer fluids and reduced brake wear owing to regenerative braking, thus a 50% discount was applied to BEV maintenance cost over the ICEVs. The lack of FCVs on the market means data for their maintenance is unavailable. However, because engine maintenance makes up a large portion of the costs incurred by other powertrains, and like BEVs these do not apply to FCVs, fuel cell vehicles take the BEV values.

B.4 Vehicle showroom

In ECCo, the choice of powertrains that buyers can see and choose from is defined by the 'showroom'. This sets when each powertrain becomes available within each segment, and when it is withdrawn from sale by the OEMs. For cars and vans the showroom is based on the most recent OEM announcements as well as some additional assumptions:

- Segment A receives only a limited PHEV / RE-EV offer to reflect the general low cost approach taken in this segment. Diesel full hybrids are never introduced due to the low appetite for diesel vehicles in segment A.
- RE-EVs are limited to segments B-D to reflect feedback from consulted OEMs (February 2015) that no more RE-EVs would be offered, or only a limited number of models.
- In segments dominated by petrol cars (A, F and G), no diesel PHEVs are introduced.
- A petrol ICEV van not introduced in any segment due to lack of interest in the powertrain.

[187] Element Energy for DfT, 2015

[188] Whatcar quotes a 3-year service cost of ca. £1,500 and ca. £1,100 for the ICE and PHEV Outlander models, respectively.

- Petrol PHEVs introduced in smaller van segments, whereas diesel PHEVs are introduced in larger segments.

See 'showroom' tables in the *D1.2 Analytical Framework Assumptions Book*.

B.5 Correction for Real World Driving

ECCo 2010 was originally designed to provide an 'NEDC' view of the car market, and as such made the assumption that purchase decision was based upon only the advertised performance figures and these provided an acceptable representation of real world driving conditions. In recent years it has become widely recognised that this is no longer the case as OEMs have focussed efforts on improving their vehicle's performance in the test cycles, which does not necessarily translate into real world driving. Consequently, ECCo now makes a correction for this 'emissions gap', with correction factors that incorporate recent findings on its existence and the likely future trends as the test cycles are adjusted to reduce the gap.

Introduction of these correction factors has also allowed for adjustments to be made to the real world performance of electric powertrains to take into account, for example, seasonal variation. For Private Consumers and Fleet User Choosers, ECCo maintains the assumption that buyers consider only the advertised official figures (i.e. NEDC). However, for Fleet Non-User Choosers and Fleet Car Sharing, who are more concerned with cost and take the rational Total Cost of Ownership approach, real world correction is included in their purchase decision.

In order to further improve the accuracy of the stock model, real world correction has been applied for all consumers to the energy consumption and associated outputs.

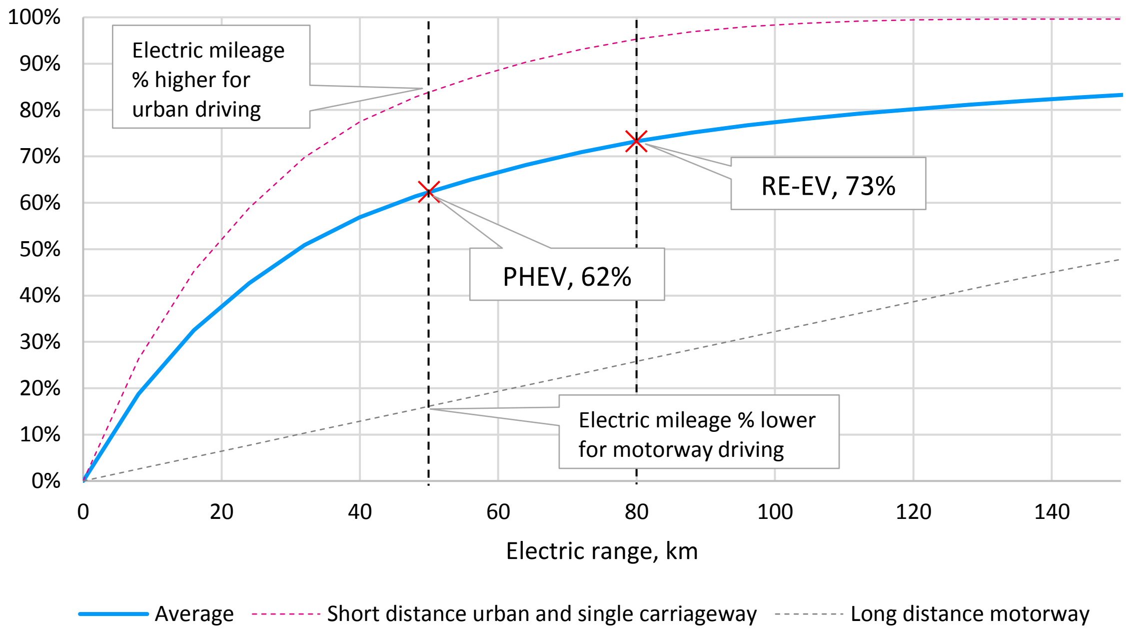
B.6 PHEV / RE-EV Fuel and Electricity Consumption

Unlike all other powertrains, the energy consumption values of PHEVs and RE-EVs depend upon the journey and charging patterns of the user. High mileage without charging will result in fewer kilometres travelled on electricity and consequently higher fuel consumption. The NEDC consumption figures passed to ECCo in the attribute dataset are 'combined' figures, derived from the consumption in "pure" fuel/electricity mode and the % of mileage in electric mode for the average driver. The latter was calculated from a relationship with the electric range, developed through analysis of trip statistics from the National Travel Survey. This analysis grouped trips by distance, and calculated the proportion of each trip group that could be carried out in pure electric mode for a given electric range[189]. Summing the kilometres travelled in electric mode across all the trip groups yielded the required relationship between range and % electric mileage.

The relationship is illustrated in Figure 104.

[189] The DfT Road Traffic Forecasts 2015 show 32% of vehicle kilometres travelled take place on motorways and dual carriageways. A relationship for proportion of electric mileage against range for long distance motorway driving was derived by considering only the longest trips that together encompass 32% of annual mileage. The remaining shorter trips were used to derive a relationship for short distance urban and single carriageway driving.

Figure 104 Relationship between NEDC electric range and % of mileage in electric mode



This relationship provides the "sticker" energy consumption figures used by Private Consumers and Fleet User Choosers in their purchase decision. As this is an overall figure based on average trip distribution, the actual proportion of electric mileage will differ between drivers. On individual trips, the proportion of driving under electric power may be considerably lower, in the case of long distance motorway driving, or higher for short urban trips. However, for the purposes of providing a stock-wide view of consumption, driving at the individual trip level is not considered.

The combined consumption figures used in the stock model and those used in the purchase decision of Fleet Car Share buyers incorporate the real world correction factors for electricity and fuel consumption.

For Fleet Non-User Choosers, their high daily mileage and lack of opportunity to charge mid-duty cycle means that their percentage of electric mileage is considerably higher than that based on average trip statistics. Since their purchase decision is based on a rational total cost of ownership assessment, combined real world fuel and electricity consumption figures are recalculated for each Fleet Non-User Chooser based on their driving behaviour. It is assumed that that the electric range is fully exhausted during the duty cycle and all additional mileage is driven in "pure" fuel mode. The proportion of driving in electric mode is then simply:

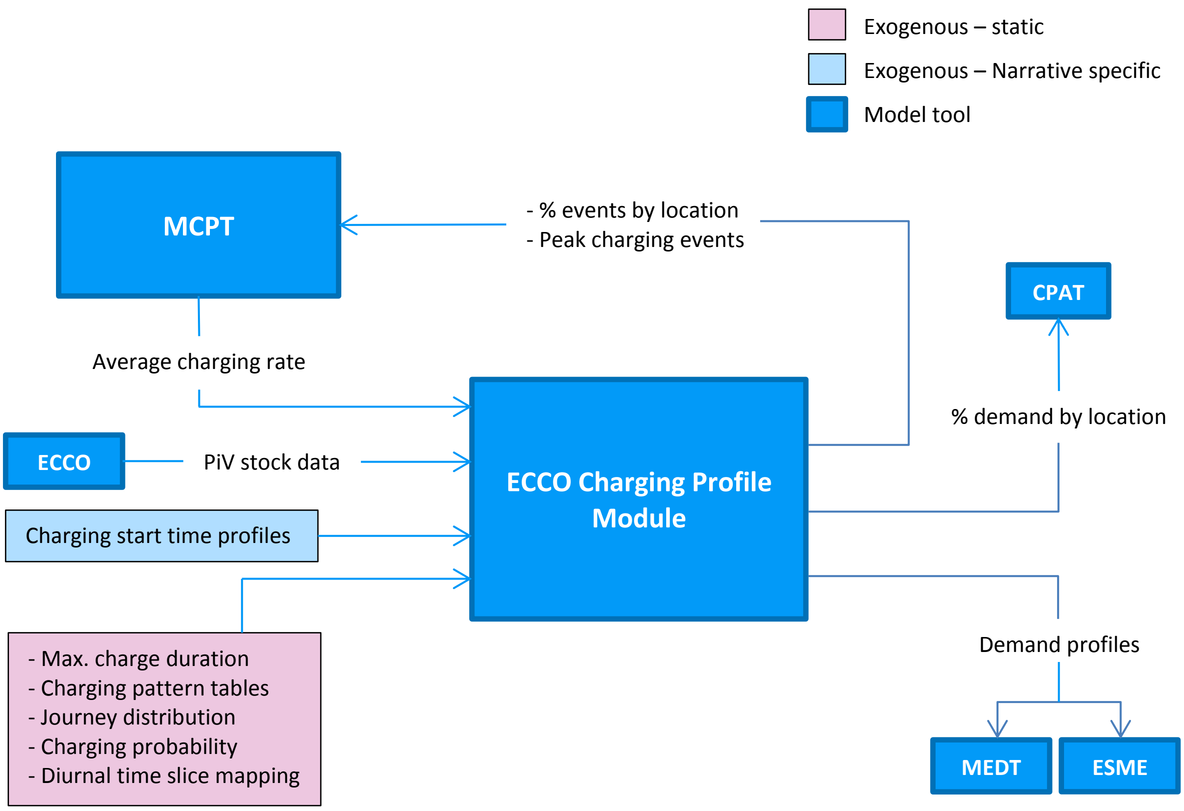
$$\%\ elec\ mileage = \frac{real\ world\ electric\ range}{daily\ mileage}$$

Calculation of the daily mileage assumes a five day working week. Real world electric range is calculated for both Summer and Winter using the relevant correction factors. The purchase decision uses the worst case (i.e. Winter) whereas the average Summer / Winter value is passed to the stock.

B.7 Calculation of charging profiles

ECCo has previously included a mechanism to estimate the likely charging profiles of a given PiV stock. At the time it was developed, this was based almost entirely on travel patterns due to a lack of PiV charging studies. Since then, data on charging behaviour has become more readily available in the literature and consequently a new approach has been implemented in ECCo for the ETI CVEI project. Figure 105 shows the data flow required for the charging profile calculation.

Figure 105 Inputs and outputs of the ECCo Charging Profile Module



ECCo calculates 24 hour charging profiles separately for the stock of PHEVs, RE-EVs and BEVs within each segment and consumer group, and at each of the four charge point locations – home, work, (public) rapid and public (slow). It further differentiates by the 5 seasonally dependent tariffs (peak weekday, Summer weekday, Summer weekend, Winter weekday, and Winter weekend).

The process by which each demand profile is calculated is as follows:

- For the powertrain, segment and consumer group in question the daily electricity usage is calculated from the vehicle's stock average electricity consumption rate (real world) and daily mileage corresponding to the day / season in question. Basing the demand profile on the actual daily usage ensures consistency with the overall electricity usage by the stock. Depot based Fleet Non-User Choosers, are assumed to be used only on weekdays. For all other vehicles, the annual mileage is apportioned to a greater extent to weekday driving as observed in the National Travel Survey.

- Likewise, the number of trips per day is calculated for that specific vehicle. Depot-based Fleet Non-User Choosers are assumed to make only two trips a day (on the days they drive), a trip from and to their overnight location. For the other consumer groups, the number of trips is based on the calculated daily mileage and an assumed average trip length of 17.7 km[190]. Other than having a different mileage, home based Fleet Non-User Choosers are treated like Fleet User Choosers.
- Trips are separated into four groups: homebound, workbound, other and long distance (defined as over 80 km). The distribution of these trip types is taken from the National Travel Survey. Assumptions have been made on the likely charging location that will be used for each trip type. In essence, PiVs on homebound trips will charge at home, those going to work will charge at either work or public depending on whether work charging is available, long distance trips will require rapid charging, and public charging will be used for other trips. The charging behaviour tables are presented in the *D1.2 Analytical Framework Assumptions Book* (sheet 'ECCo_in'). The charging behaviour tables and the journey distributions are combined along with a probability of charging at each destination to give an overall probability of charging at each location. The probability of charging by destination has been based on literature values where available. Where data could not be found to support these, the value was calibrated against the differences observed between literature charge start time profiles (model input) and demand profiles (model output).

$$\begin{aligned} charge\ events\ per\ day_{CP\ location} \\ &= probability\ of\ choosing\ CP\ on\ trip\ type \times trip\ type\ frequency\ (\%) \\ &\times probability\ of\ charging\ on\ trip\ type \times trips\ per\ day \end{aligned}$$

- Those with and without access to work charging are handled separately and their distribution of charge events by location are combined, weighting by the respective numbers in the stock.
- The distribution of charge events by location is multiplied by the number of trips per day to get the average number of charging events per day per location. Fleet Non-User Choosers and Fleet User Choosers are limited to one home / depot charging event per day as they are unlikely to return to base more than once per day in order to charge.
- For all vehicles, it is assumed that only the overnight location is actually relied upon to provide the energy needed to complete the daily mileage. This is known as the 'base' charging location. Charging at the other locations is opportunistic and is dependent on the trip patterns only. The duration of charging events at these locations is therefore exogenously defined, with 1 hour assumed for public and work charging points and 20 minutes for rapid. This defines the time spent at the location; however, the actual time spent charging during any charging event is always limited by the battery capacity:
  - PHEVs: this is the entire usable battery capacity as the vehicle can still operate with a fully depleted battery.

[190] Derived from analysis of the National Travel Survey.

- BEVs: the maximum charge is limited to 75% of the usable battery capacity, to represent BEV owner's unwillingness to allow their batteries to run below a 25% state of charge[191] .

$$demand_{CP\ location} = rate_{CP\ location} \times duration_{CP\ location} \times charge\ events\ per\ day_{CP\ location}$$

- Subtracting the energy provided by the charge events at all non-'base' locations from the total daily electricity requirement provides the amount that must be provided by the 'base' location.

$$demand_{base} = total\ daily\ consumption - demand_{non\ base}$$

The above provides a simple derivation of the likely charging behaviour at each location (charge duration, number of events, total energy supplied) based on trip statistics and the daily electricity requirement. However, additional corrections must be made to take into consideration the cost of charging, impact of Managed Charging, and finally to ensure that the charge events predicted are realistic:

- The overall 'base' charge demand must meet a minimum level, defined as follows:
  - If the 'base' charging location provides the cheapest means of charging then it is likely that a PiV owner will attempt to maximise the level of charging they can do here. It is assumed that a PiV owner will charge purely at 'base' (bar what is needed for long trips at rapid points) if it has the capacity to provide 1.5x their daily mileage. This capacity is what can be supplied by doing a maximum charge (as defined above) every time a 'base' charge is carried out (frequency also defined above). The factor of 1.5 represents a safety margin that PiV owners will employ in case they drive further than their average daily mileage. If the capacity provides 1.5x the daily mileage then a PiV owner will perceive no requirement to charge elsewhere. The more the capacity falls below this limit, the more energy a PiV owner will attribute to non-'base' locations, despite the fact that it may still be possible to charge almost entirely at 'base'. This relationship provides a means to define the minimum energy that will be supplied from the 'base' charge point.
  - If the 'base' charging location is not the cheapest, then for BEVs a *de minimis* 'base' load is set as enough to provide 1.5 x average trip length (17.7km) every time the driver plugs in. For PHEVs in this case, there is no minimum 'base' load as the vehicle still has the means to drive without charging.
  - Should the above result in unrealistic charge durations at the 'base' location, based on the total energy provided and the number of charge events, then the duration and energy of each 'base' charge event is set to the limit defined by battery size. The total energy provided by the 'base' location is adjusted accordingly.
- Introduction of Managed Charging:
  - The default charging start time profiles employed are based on current unrestricted use of charging points. Should Managed Charging be introduced at the 'base' charge point it is expected that there will be less opportunity to charge here and the overall energy demand will decrease. In order to model this decrease it is assumed that no

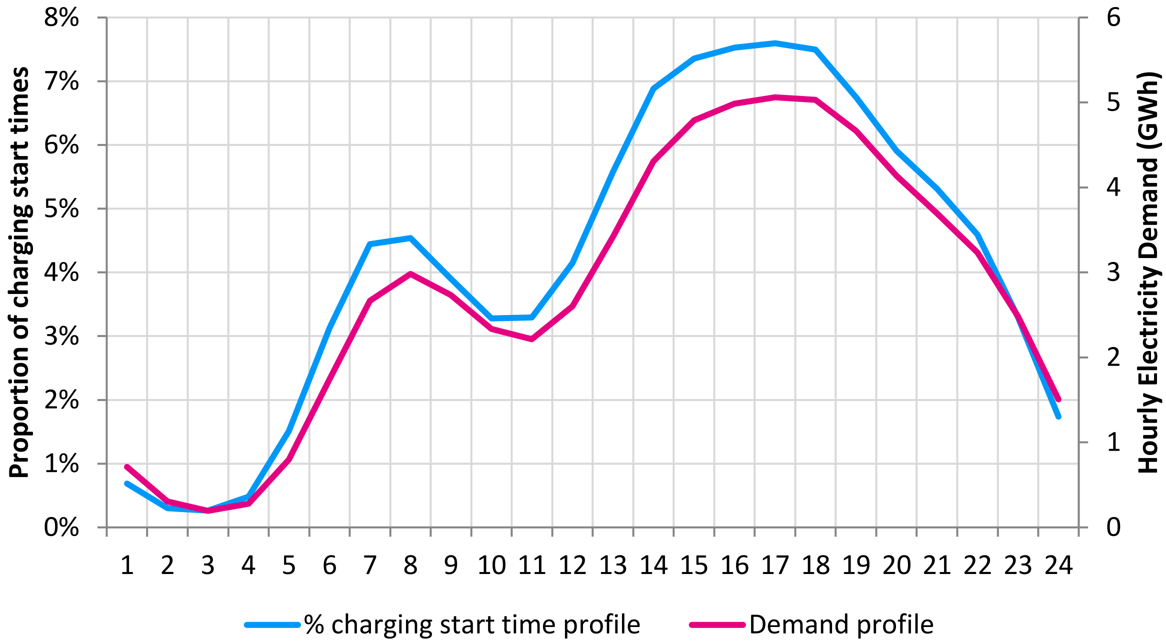
[191] My Electric Avenue (2015) Work Activity 3 'Model Validation and Data Analysis' – Report for Deliverables 3.1, 3.2 ,3.3 and 3.4; p. 9

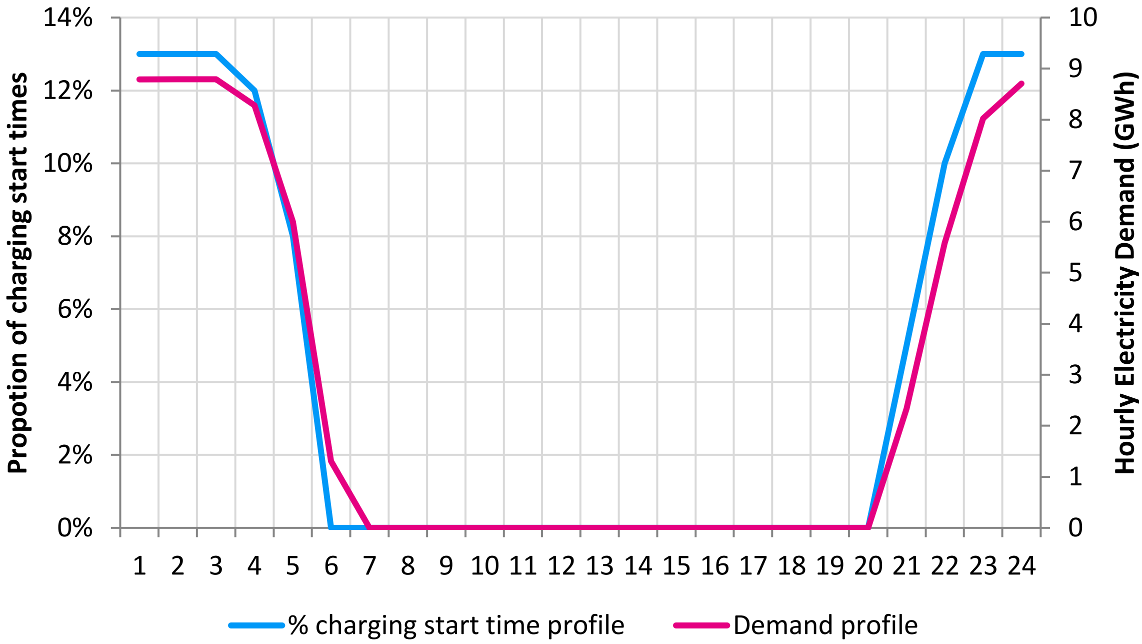
charging will be allowed beyond 6 am. Based on the start time profile, any electricity that would normally be provided after 6 am must be acquired from elsewhere. The average charge duration of 'base' charging is reduced to represent this cut off point.

- Adjustments:
  - Once these requirements have been imposed on the 'base' charging location, the charging behaviour at the other locations is adjusted such that the total daily energy requirement is met.
  - If too much energy is currently being provided, then the number of non-'base' events is scaled downwards (excluding public rapid which is still needed for long journeys).
  - For all but the depot based vehicles, if not enough energy is currently being supplied, then work and slow public charging is increased to compensate. If work provides the cheapest option then the duration of current work events is increased up to the limit set by the battery capacity. It is assumed that additional work charging opportunities are limited as the number is based on travel patterns and charging access. If public is cheapest, or still further energy is required, then the number of public charging events is increased.
  - For depot based vehicles, additional energy is assumed to be provided by extra rapid charge events. Although analysis by RouteMonkey concluded that no time was available during a duty cycle for rapid charging, some vehicles are modelled with a daily energy requirement larger than their battery capacity. This is an unwanted side effect of modelling the duty cycle suitability on a curve (a proportion of users can purchase a BEV with a given range); however, a single average mileage is used to model their energy consumption. This allows some BEVs to be sold with a range less than the daily mileage, although this anomaly decreases over time as BEV ranges increase.

With these adjustments made, the number of charging events per day per location, and the average charging duration at each location has been defined. The charging demand profile is calculated by mapping the events onto the exogenously defined charge start time profile – example given in Figure 106. This process assumes that for each hour, the average event start time is in the middle of the time slice (i.e. half past the hour). The energy supplied by charge event is then apportioned to the hour in which it is delivered. For example, if the charge event is an hour long, then half the energy will be attributed to the hour the event starts in and half to the next hour.

Figure 106 Example charging start time profile and resultant demand profiles at home (Private Consumers, Summer weekday) for Unmanaged (top) and Managed (bottom) charging





In addition to calculating the electricity demand profile, the number of vehicles charging simultaneously is also estimated in order to provide the MCPT with the required minimum number of charging points. The day is first divided up into 20 minute windows. A uniform distribution is applied to the charge event start times within each hour and the number of vehicles that are charging in each 20 minute window is tracked. The window with the most vehicles charging in it is taken as the peak number of vehicles charging simultaneously.

It should be noted that as part of the calculation of the costs and demand associated with vehicle charging there are two rates used in the modelling

- The first used for the capital cost calculation in the Macro Charging Point Tool (see Appendix D.4). This is based on new posts with a step change seen in rate from 3.3 kW to 7 kW / 22 kW in a number of the Narratives
- The one used for charging profiles calculation, which reflects the average rate across the installed stock of charging points and thus varies on a continuous scale from 3.3 to 7+ kW

Variations across Narratives

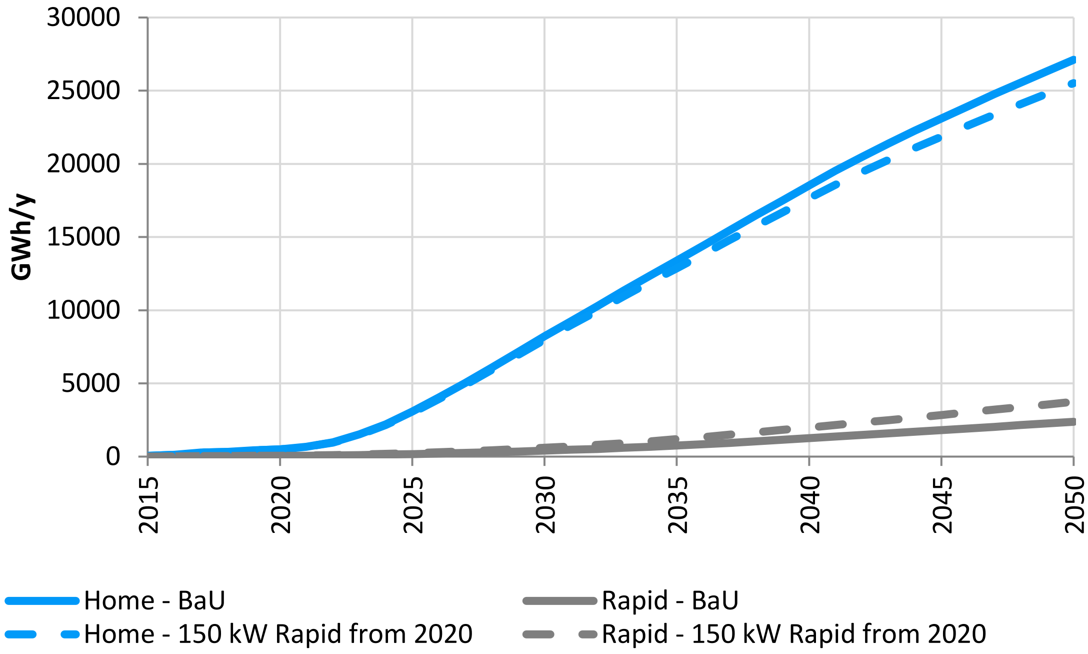
Between Narratives, User or Supplier-Managed Charging is simulated through applying different charge start time profiles, and making the adjustments to overall energy supply described above. However, in all cases ECCo also runs the Charging Profile Module for the BaU start time profile in order to build a counterfactual demand profile. This allows the value of Managed Charging to be assessed, upon which the DM payments are based (for Supplier-Managed Charging).

The behaviour assumptions with regards to probability of charging at a destination do not change across Narratives. These numbers were chosen so that the model replicates the demand split across the four locations that are observed today. For public and rapid charging points no restriction on charging based on competition is imposed. Perceived access is considered in the purchase decision but not in the charging profile logic. The assumption here is that at these two points, PiV drivers will charge as a result of making the journey, not as a result of the charge point being available. This is permissible due to the fact that the MCPT always installs enough charging points to satisfy peak demand. In reality, it may be the case that if the number of public charging points increases relative to the number of PiVs then more PiV drivers will choose to charge here, but no studies were found to support this (whereas there is strong evidence that home charging is a preferred location). However, in Narratives forcing high rollout at certain charge point locations (e.g. slow public in City), the choice model will estimate greater numbers of PiVs, which will offset to some extent the increased number of charging points relative to PiVs. This will dampen any resultant change in competition for public charging points.

B.7.1 Sensitivity: introduction of 150 kW rapid charging

Other than the additional rapid public charges needed for high mileage depot based Fleet Non-User Choosers, the ECCo Charging Profile Module assumes rapid public charging is only needed when completing a long journey (> 80km). As trip patterns are exogenously defined, introducing faster rapid public charging rate has limited effect on the distribution of charging at each location. However, a faster rate will provide more energy to the PiV per charging event, thus slightly less energy will be required from the 'base' charge location in order to meet the total daily energy requirement. The results of introducing 150 kW charging from 2020 is illustrated in Figure 107.

Figure 107 Total annual electricity demand from home and rapid charging points with and without 150 kW rapid charging from 2020



As the rate of rapid charging is included in the purchase decision of Private Consumers and Fleet User Choosers, changing it should change PiV uptake. However, the impact on uptake is negligible (BEVs make up 18.7% of the parc in 2050 compared with 18.8% when using 50 kW rapid charging), as the increased utility of faster charging is offset by the slight increase in average observed cost of electricity.

In reality, access to faster charging may alter a PiV driver's probability of charging at a particular location. If fast rapid charging became widespread then the need for overnight charging may no longer become a limiting factor to PiV purchase. However, because of the current infancy of charging studies, behavioural data of this kind cannot yet be inferred.

B.8 Cross Subsidy Mechanism to meet EU New Vehicles Emissions CO_2 Targets

The European Commission has legislated a mandatory tailpipe emissions reduction target for both new cars and vans. The current target for OEMs is for new cars sold in the EU to emit on average 95 gCO_2/km (NEDC) by 2021, and for new vans 147 gCO_2/km by 2020. In all Narratives, ECCo applies a 2030 target of 65 gCO_2/km for cars and 100 gCO_2/km for vans, and these are held constant from 2030 onwards. Failure to comply with this target results in the contravening OEM having to pay a penalty.

In the CVEI analysis, there is no Mt CO_2 target being enforced for the transport sector. Instead ESME finds the best way to meet overall Mt target, for a given transport Mt (coming out of ECCo) and the wider energy system's emissions. In ECCo, there is a mechanism to enforce the aforementioned EU target on new vehicle gCO_2/km.

ECCo includes a mechanism by which OEMs subsidize vehicles emitting less than the target by raising the price of vehicles emitting more, with the purpose of driving down average emissions to meet the target. From 2022, in a given year if the target is missed the collective OEM entity pays a penalty of £70 x gCO_2/km above target x vehicles sold[192]. To avoid this cost in future, OEMs adjust the price of vehicles according to their emissions in order to encourage the sales of cleaner powertrains:

$$adjustment = 0.1 \times £70 \times (rated\ gCO_2/km - target) + 0.9 \times adjustment\ last\ year$$

If the target is met then the adjustment the following year is reduced to 90% of the adjustment the previous year. This reduces the chance of the average tailpipe emissions rising above the target again which would likely occur if the adjustment were removed as soon as the target is met. The coefficients 0.1 and 0.9 are chosen to avoid large price swings and oscillation of the uptake due to the average emissions continuously falling above and below the target.

B.9 Modelling of car sharing within ECCo

The purchase decision and stock monitoring of car sharing vehicles are new features in this version of ECCo designed for the ETI CVEI Project. The impact of car sharing is investigated in both the City and ToD Narratives.

B.9.1 Calculation of car sharing vehicle service demand input

The extent to which car sharing replaces conventional ownership is defined exogenously through the car sharing vehicle service demand. It is assumed that car sharing displaces only Private Consumer vehicle kilometres travelled, and so increasing the kilometres provided by car sharing does not affect the Fleet User Chooser and Fleet Non-User Chooser parcs. The basis for this assumption is:

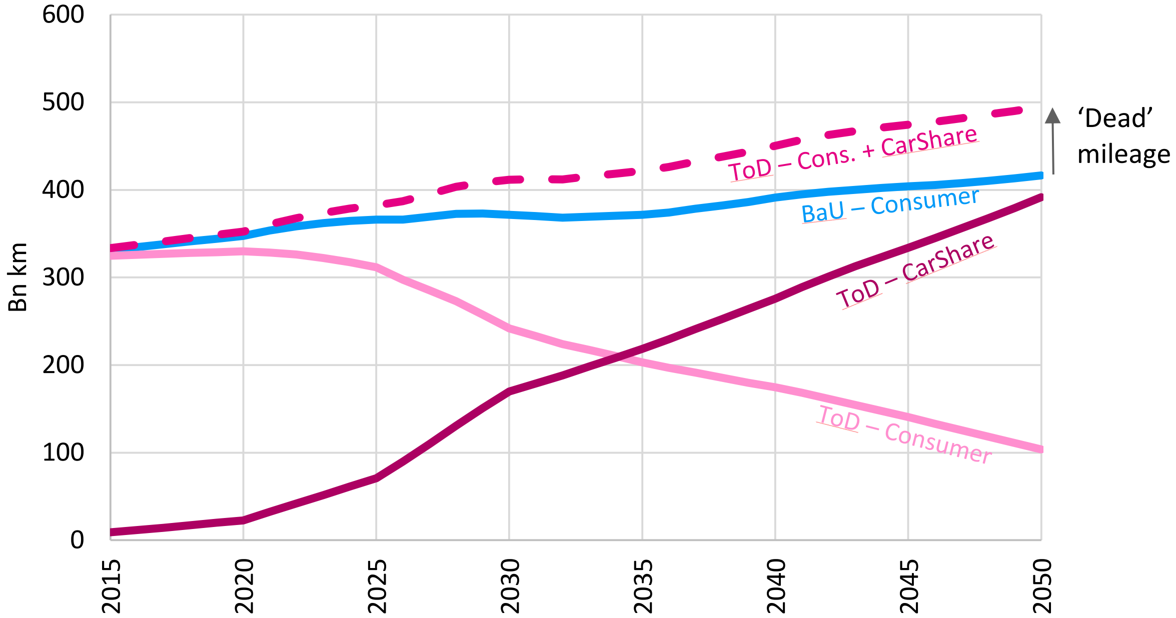
- Companies will continue to incentivise Fleet User Choosers through providing them with a car.
- Fleet Non-User Choosers would see little benefit to car sharing as their usage is already optimized. This devalues the advantage of reducing redundancy in the vehicle fleet, which is provided by car sharing. Fleet managers would also have concerns that transport would not always be available when needed.

As car sharing has no impact on the Fleet User Chooser and Fleet Non-User Chooser parcs, these are set to the values calculated in the BaU Narrative. The car sharing service demand is defined by the % of Private Consumer service demand provided by car sharing, as required for the Narrative. The overall Fleet Car Sharing vehicle kilometres travelled is calculated from Private Consumer service demand it has replaced and an assumed % of dead mileage resulting from car sharing. This occurs due to vehicles having to drive to the point where the requested service is needed, rather than starting their journey from this location. The result is that the overall vehicle kilometres travelled is higher in Narratives with car sharing. The annual mileage of car sharing vehicles is defined exogenously, and consequently the parc of required car sharing vehicles can be calculated.

The annual service demand in ToD, the Narrative with the greatest amount of car sharing is shown in Figure 108, against BaU for comparison.

[192] http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

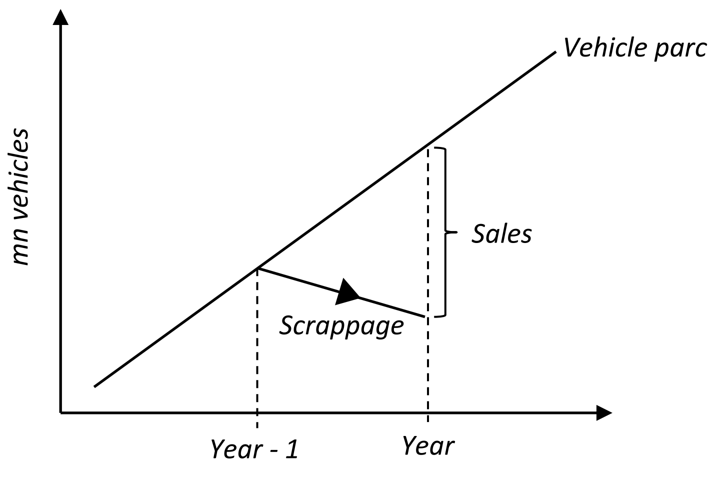
Figure 108 Annual service demand in BaU and ToD



B.9.2 Calculation of sales of car sharing vehicles

As stated in section B.1.2 car sharing companies choose their vehicles using the same Total Cost of Ownership approach as Fleet Non-User Choosers. This defines the market shares of each powertrain, which when applied to the overall annual sales of car sharing vehicles provides the absolute sales for each powertrain within each segment. Overall annual sales are calculated from the difference between the required vehicle parc, set in the service demand input, and number of cars remaining from the previous years as calculated by the stock model – outlined in Figure 109.

Figure 109 Mechanism by which overall sales are calculated



Provision of Fleet User Chooser, Fleet Non-User Chooser, Fleet Car Sharing and overall vehicle parcs allows for the sales of each consumer group to be calculated separately. The sales of Private Consumer cars is what remains in order to meet the overall parc, once the sales of the three fleet groups have been calculated. However, it is possible in some cases that the addition of sales of the three fleet groups to the existing vehicle stock results in number larger than the overall vehicle parc, and consequently negative sales of Private Consumer cars are predicted. This is clearly impossible, and in fact signifies a potential limit to the rate at which car sharing can replace conventional ownership, which is determined by the rate at which Private Consumer cars leave the stock i.e. are scrapped.

In ECCo, the scrappage rate of all vehicles is exogenously defined and is not linked to market forces. The introduction of car sharing will likely lead to a glut in the used car market; however, won't necessarily lead to a change in the scrappage rate. Cars are scrapped when they reach the end of their useful life, which is a function of the car rather than the market. As long as the car still works as a car, its second hand value will compete with car sharing as a seller would prefer to realise some value rather than nothing. Of course, all cars have a scrappage value which may be met sooner should car sharing become prevalent, and government regulation may encourage scrappage through a subsidy, but regardless it is clear that moving transport to a service model can only happen gradually.

In ECCo, in years where Private Consumer sales are predicted to be negative, they are set to zero and the average mileage of Private Consumer cars is reduced to compensate. This ensures that the total vehicle kilometres travelled by the parc meet what was set in the inputs. Furthermore, to reduce the size of the residual Private Consumer parc, the transfer of company cars to private drivers is limited by increasing the lease lengths of Fleet User Choosers and Fleet Non-User Choosers over time. This simulates lease companies responding to the shrinking demand in the second hand car market as car sharing becomes more widely adopted.

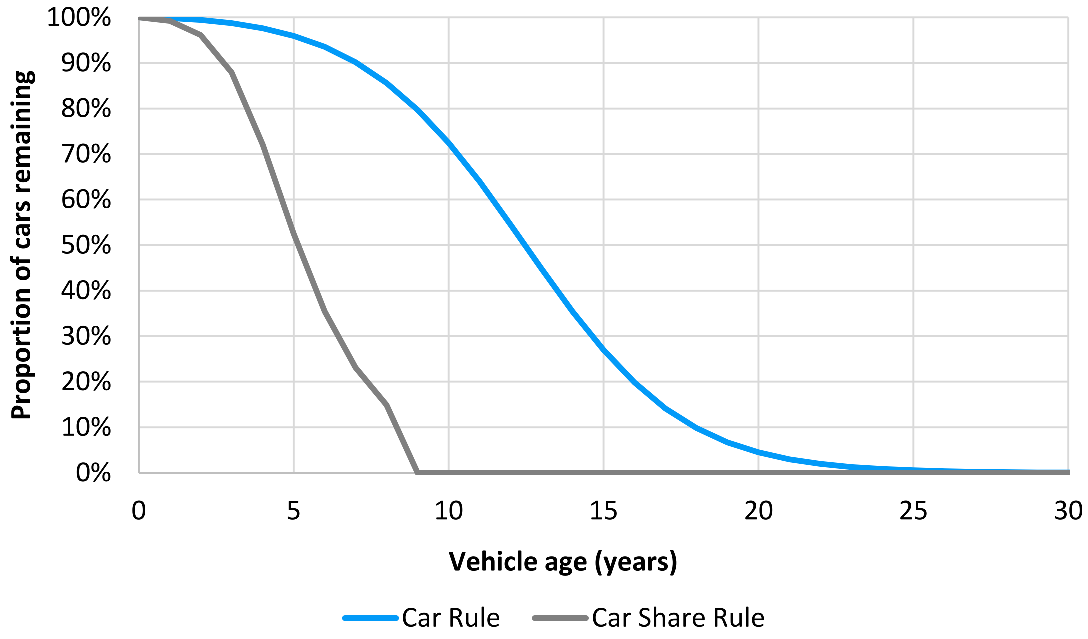
Scrappage rules

Analysis of total real life car sales vs stock data yielded a scrappage rule that was applied to all cars in ECCo. This defines the probability of a car being scrapped in a given year as a function of its age, and resulted in a mean vehicle lifetime of about 13 years. This rule was applied to company cars as well as private cars as, despite their higher mileage, company cars are transferred to the private stock in typically the first 2-3 years of their lifetimes. Under this Analytical Framework it is assumed that car share vehicles remain as such for the duration of their useful lives, and are not transferred to the private stock. This is not necessarily representative of what is observed today, but ensures that the residual Private Consumer parc shrinks over time allowing the car sharing market share to grow at the rates defined in the City and ToD Narratives. Without this assumption, the Private Consumer parc remains dominant and provides very little capacity to accommodate increasing demand for car sharing. In reality, such a situation might occur if rapid growth in demand for car sharing leads to a collapse in demand for used cars, thus providing no market for old car sharing vehicles.

As a result, car share vehicles maintain a high annual mileage for the duration of their useful lives and so an accelerated scrappage rule was developed. This results in car share vehicles being scrapped at a rate which is around 3x faster than the rest of the parc, based on the ratio of annual car share mileage and the average mileage of the remaining parc (44,500km vs 14,000 km). The lifetime of car share cars is also limited to 8 years to avoid them driving more than 350,000 km in a lifetime. Insurance and maintenance costs are also assumed around 3x higher for car sharing vehicles.

The relationship of vehicle age and scrappage is outlined in Figure 110.

Figure 110 Illustration of car scrappage rules – standard and for car sharing schemes



Appendix C CPAT

C.1 Overview

The Commercial Value Chain consists of the entities that exist in the value chain, together with the underlying business models that define how each of these create value. Given the myriad of potential commercial entities across the value chain these have been simplified to focus on generic commercial entities (and variants of these), which are closest to the ULEV consumer or more material in terms of driving ULEV specific investments in either vehicles or supporting infrastructure.

An initial review first identified all entities on the value chain, categorised into a matrix by:

1. **Category**: e.g. transport (Vehicles, Batteries, Fuel Cells) or Fuel & Infrastructure (Electricity & Charging Points, Hydrogen & Pipelines / Trucks / Trailers, Liquid Fuels & Trailers).
2. **Position**: along the value chain, in terms of 'classic' business models (manufacturer, broker / exchange operator, installer, site developer, owner, operator, distributor, retailer, service provider and secondary services).

The short list of commercial entities on the CVC to be modelled more explicitly in CPAT was summarised in Table 7 and can broadly be categorised into:

- **Electricity:** retail suppliers, network operators, aggregators and charging point operators (public, rapid, work)
- **Liquid fossil:** distributers and retailer (to forecourt)
- **Hydrogen**: forecourt retailers, distribution (road, pipeline network), localised H_2 producers, or
- **Vehicles:** retailers, leasers, sharing business models (e.g. car clubs).

C.2 Key functional requirements

The core requirement of CPAT is to provide the point of **translation** between requirements from the Physical Supply Chain and the prices seen by the Customer Proposition (and the subsequent impact of these on ULEV uptake and use).

This is strongly influenced by the Market and Policy Framework through e.g. tax / subsidy flows; either directly on the commercial entities who collectively deliver the elements of the Customer Proposition at the point of the Customer Proposition itself. As a result both the CVC and MPF Dimensions are covered by the tool.

Given the interactions between the price seen by consumers, the uptake and use of ULEVs, and the demands on the CVC to deliver the consumer requirements (which may then affect the price), there is iteration across the suite of Analytical Tools, including CPAT, to achieve a *sensible* supply / demand position consistent with the wider Narrative.

The tool itself is intended to provide an 'accounting framework' to track the **magnitude, direction and timing** of financial cost and revenue flows over the pathway for ULEVs and the wider vehicle parc (scaled to UK-level):

- Across and between the discrete modelled commercial entities on the Commercial Value Chain and at the point this interacts directly with consumer (e.g. retailer).
- Associated with Government policy and relevant transport fiscal flows.

By modelling the flows across the various entities in the CVC the tool is required to:

- Develop **price stacks** seen by the Customer Proposition for both vehicles and fuels (electricity / liquid / H_2).
- Assess the viability of the **quantitative Success Metric for commercial entities**. As outlined in Table 3 this is defined in the case of capital-intensive businesses in terms of the ability of to generate an adequate return on capital employed versus their Weighted Average Cost of Capital[193], where a negative number may imply the requirement for subsidies.
  - Viability is assessed through the Market Value Added of the business, the net present value of the economic profit over the modelled pathway (discounted at the WACC)[194].
  - Further elements of this Success Metric are considered when comparing across Narratives and entities;
    - A single figure for ROCE (return on capital employed) is calculated for the modelled pathway, weighted by the net asset profile, for comparison with the WACC[195].
    - Years till first economic profit (ROCE exceeds WACC) is also assessed to ascertain how quickly different entities become profitable and therefore how 'risky' they might be to investors, especially in the absence of Government support.
  - There is an element of subjectivity in terms of determining the business models 'commercially viable' as each entity consists of many individual projects and no account is made of how the business might perform after the end of the modelled pathway.
- Assess the **quantitative Success Metric associated with Government cash flows**, as outlined in Table 3 – **net socially discounted Government cash flows** over the pathway (for tax, subsidy and investment measures) associated with the consumer / fleet vehicle parc **are consistent with those seen today** subject to acceptable increases in spend (e.g. due to monetisable societal benefits from CO_2 abatement, air quality or congestion)[196].

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[193] In the case of margin businesses it is assumed that they set their prices to recover the required margins

[194] Economic profit = Earnings Before Interest and Tax (EBIT) - (WACC x net assets). Net assets represents cumulative CapEx less cumulative depreciation, and EBIT is comprised of the revenues and costs, excluding CapEx but including depreciation

[195] A straightforward comparison of IRR achieved versus WACC is not possible, because each business entity makes investments in multiple projects producing complex patterns of cash flow, and making an IRR impossible to calculate. Additionally the life of some projects will extend beyond the end of the modelled pathway

[196] The present value (at the Treasury Greenbook Rate) of the gap over the pathway between direct transport related income (revenues less subsidies) and a target share for transport related income. The target transport

Key drivers of the values for the Success Metrics within CPAT are likely to be:

- The **mismatch** in timing of investments versus revenues, either because the latter are delayed and / or there is a mismatch with the size of the market in the near term (e.g. in relation to hydrogen ULEV deployment and use and the requirement for distribution infrastructure). There could also be an analogous problem for existing assets (e.g. liquid fossil forecourts and distribution), or those developed early in the pathway, which may be at risk of becoming stranded.
- **Commercial / consumer responses to price signals** which reduce underlying resource cost of one part of the system (such as reduced network reinforcement). CPAT provides an understanding of how the benefit of these avoided costs are distributed across the value chain.

C.2.1 Focus of the CPAT

As outlined in the separate *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report* there exist a myriad of potential commercial entities across the value chain and these have been simplified to focus on generic modelling entities (and variants of these), which are closest to the consumer or more material in terms of ULEV-specific investments.

As a result parts of the CVC have been simplified to be reflected as 'boundary conditions', such as wholesale generation markets for electricity or hydrogen. These are likely to change according to the wider Narrative and are informed by other Analytical Tools on the PSC, but are not modelled as a series of interconnected commercial entities as per the rest of the CVC in CPAT.

The generic 'building block commercial entities' are described in more detail in the *D4.2 Final Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure Report*, but consist of:

- **Electricity:** retail suppliers, network operators (DNO), DM aggregators (and various alternative configurations) and charging point operators (non-home / depot).
  - Large-scale generation and transmission are treated as part of the boundary conditions reflecting a 'wholesale price'.
- **Liquid fossil:** distributers (to forecourt) and retailer (at forecourt).
  - Primary production and supply is treated as part of the boundary conditions reflecting a 'wholesale price'.
- **Hydrogen**: retailers (either forecourt or deport[197]), distribution (road, pipeline network), localised H_2 producers.
  - Large-scale generation and transmission are treated as part of the boundary conditions reflecting a 'wholesale price'.
- **Vehicles:** retailer, leasers, sharing business models (e.g. car clubs).

related income is based on growth of the 2015 net revenue with growth in GDP / capita (on the assumption that the amount of money spent by consumers as share of income broadly remains the same)

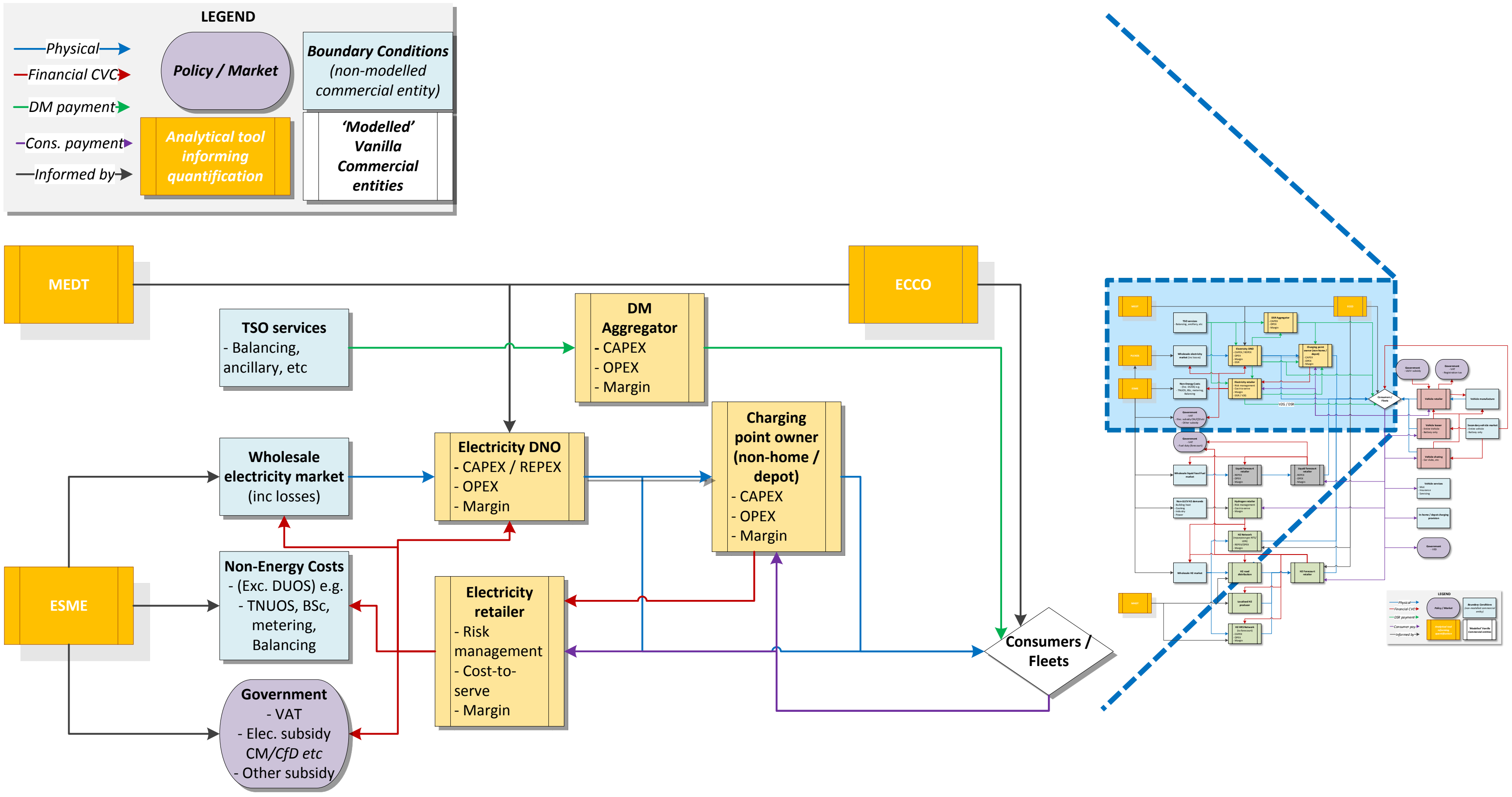
[197] I.e. via pipeline network and potentially separating ownership and operation of the network to sale of the product flowing through it; analogous to the overarching market structure for gas and electricity today.

- Manufacturers and the secondary vehicle market for ULEVs are treated as part of the boundary conditions.

Figure 111 provides a schematic illustration of the CVC, which is represented by CPAT, and shows:

- The generic 'building block commercial entities' that could be modelled (or combinations / variants of these) depending on the Narrative
- The physical and financial flows between the entities up to the point of the consumer; again these flows vary between the Narratives
- The boundary conditions feeding into the different commercial entities and the other Analytical Tools within the *D1.2 Analytical Framework* which inform these, and
- An illustration of potential Market and Policy Framework interventions such as taxes or subsidies, and where these interact with the CVC.

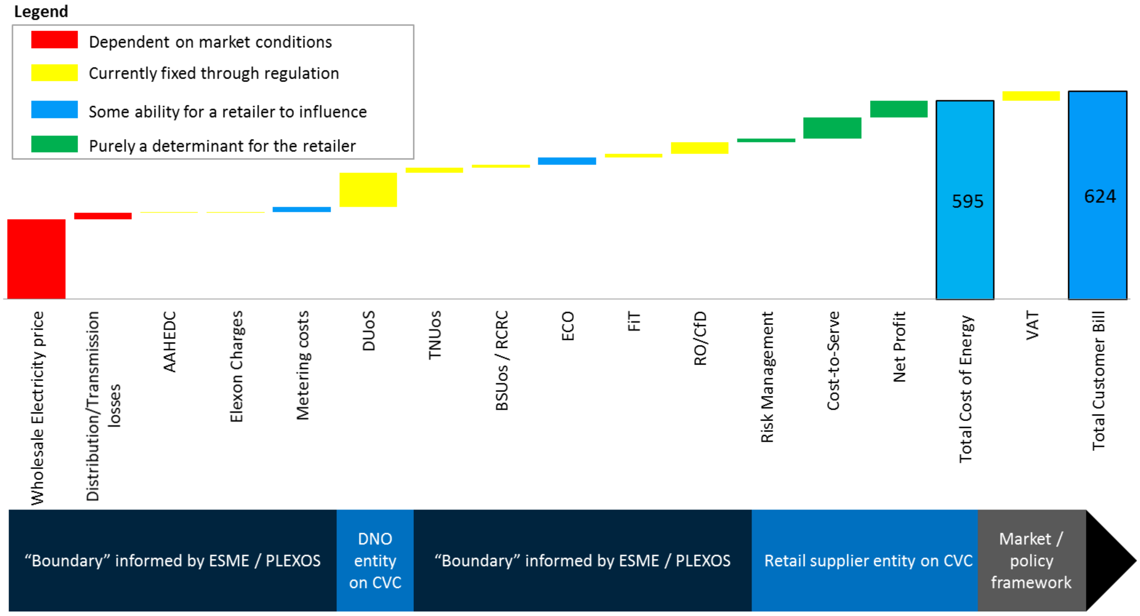
Figure 111 Conceptual structure of CPAT focusing on electricity value chain



Note: Shaded blue area represents subset of CVC used in example of electricity price stack in Figure 120

To demonstrate how CPAT develops the price stack seen by the consumer as part of the Customer Proposition the illustrative example of the electricity price as seen at the point of the electricity retail supplier is shown in Figure 112. This reflects the current stack of components that exist given the regulatory and policy framework. The analysis undertaken has not modelled all of these steps in detail, but focused on those which are more material (the size of the waterfall steps is broadly consistent with the cost components in the average 2013 / 2014 bill).

Figure 112 Illustrative electricity stack price build-up at point of retailer on CVC



The size of the components varies over the pathway (and within year) as the system evolves, consistent with the overarching Narrative. Given the relative importance of some of the steps (and that the commercial models and policies may change in future) the modelling has simplified some of the accordingly. As illustrated at the bottom of Figure 112, the price stack has simplified:

- Estimated wholesale prices, network losses, transmission charges and balancing costs informed by the ESME model on the Physical Supply Chain.
- The charges associated with operating and investing in the distribution network as reflected by a modelled DNO commercial entity who passes the charges for this through to the retail supplier (at least in the current market arrangements). This includes the profit margin required by the entity.
- Estimated subsidies at the wholesale generation-level, which are assumed to be passed through to the consumer from the boundary conditions (i.e. as part of a mark-up on the wholesale price) via the retail supplier and are informed by ESME by estimating what prices would need to be assuming that there is no 'missing money' for the generators (see Appendix D.1.2 for further information).
- The additional operating costs (and profit margin) associated with the retail supplier commercial entity modelled on the CVC.

- The direct Market and Policy Framework interventions that exist in the explicitly modelled section of the CVC e.g. VAT on the retail price of electricity.

C.2.2 Key simplifying assumptions

Modelling the CVC is potentially complex and to ensure that effort is focused appropriately given the aim of understanding the impact on the quantitative Success Metrics, the following key simplifying assumptions have been made (the implications of moving away from these can be assessed qualitatively where relevant as part of the wider framework):

- There exist either **fully competitive or regulated markets** (with no economic / supernormal profits, even in short run). As a result this implies that CPAT:
  - Models **single commercial entities** on the CVC – i.e. one stylised electricity retail supplier, not multiple competing suppliers.
  - The evolution of each entities' long-term price strategy over the pathway aims to be as **reflective of annualised costs** (including profit margin) as possible. This precludes more strategic pricing over the pathway (such as under-recovery in early years over-in later) or within its consumer base (e.g. by cross subsidising). It also requires an initial assumption on the level of expected market demand (i.e. units over which to spread costs to inform pricing) to enable subsequent iteration with ECCo.
  - Any intervention to ensure viability of commercial entity is then dependent on policy intervention (direct or indirect at the point of interaction with the consumer).
- New investments are reflected by vanilla **annualised capital costs** subject to a given hurdle rate (which includes the target rate of return) as the tool is not attempting to model different forms of financing options. The hurdle rate is a key exogenous assumption and could vary by market framework, degree of Government funding, type of technology (novel / mature), etc.
- The cash flows used to assess the viability of the commercial entities do not have an additional **social discount rate** applied to them (in addition to the annualisation of investment costs). The rationale for this is that the social discount rate primarily reflects the time preference of money, but in this case the timing of the investment is not a variable only that the investment is viable when it is required. By contrast the Government Success Metric does have the social discount rate applied to its cash flows as there is a clear preference to prioritise public income sooner and public expenditure later in the pathway.
  - CPAT is effectively modelling a proxy for a simpler pre-tax profit position and not considering e.g. corporation tax, dividend payments etc. As a result, some of the more complicated policy instruments such as capital allowances, which could be used to delay tax, are not explicitly represented.
- No long-term price elasticity is assumed **outside** of the impact on ULEVs, i.e. whilst ULEVs may affect the price of electricity and the demand for ULEVs, due to the change in total cost of ownership, this change in electricity price does not affect wider *energy service demands* for electricity for lighting, industry, space heating, etc. However, the cost effective solution for wider use of electrification to provide these services could potentially change in the ESME model as a result of very different ULEV uptake.

A number of potential second order issues have been identified that are either considered to be less material and / or too complicated to model within the resources available for this project, and have been considered more qualitatively. These include:

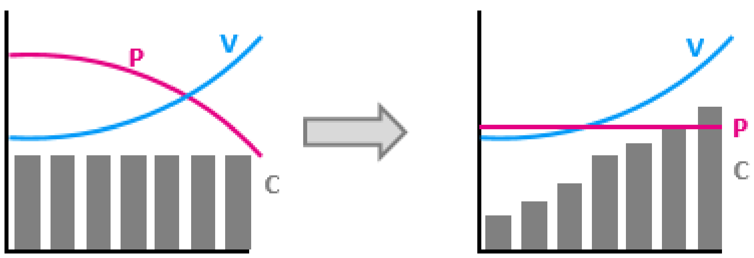
- The distribution or sharing of any **risk premium** across the CVC, e.g. the retail supplier price stack in Figure 112 reflects a component for risk management, which is passed on to the consumers. This reflects the cost of the supplier managing the price / volume / imbalance risks on the consumers' behalf via various hedging strategies. Applying dynamic ToU tariffs could potentially shift some of this risk directly to the consumer reducing the risk management costs the retail supplier. However, the current proportion of this within the overall electricity retail price is very small (~1-2%) and modelling this in detail would require more emphasis to be put on the wholesale market, further away from the consumer.
- **Economies of scale** in relation to either the scale of the investment (in terms of different hurdle rates for the same type of investment) or in relation to cost to serve – e.g. a reduction in administrative costs for smaller versus larger retailer electricity suppliers.

C.2.3 Assessing commercial viability

Figure 113 provides an illustration of how the cash flows across a generic entity have been estimated over the pathway to 2050 as part of assessing the quantitative Success Metrics outlined in section 2.3. In this example there is a clear mismatch between the revenue and cost profile (even accounting for annualisation of CapEx within the pathway[198]) due to the commissioning period and a slow growth in revenues as market demand gradually grows[199].

The effect of this has been somewhat reduced by annuitising the CapEx and weighting it by the demand for electricity or fuel demand each year over the economic life of the asset, such that the CapEx is spread equally across demand, i.e. price charged by the entity to recover CapEx is stable over the economic life of the asset – illustrated in Figure 113. Therefore, costs are under-recovered at the beginning of the asset life and over-recovered at the end, although on a discounted basis the return on capital achieved is that required to meet the defined WACC.

Figure 113 Yearly expenditure shifted from equal cost (left) to volume-weighted cost (right)[200]

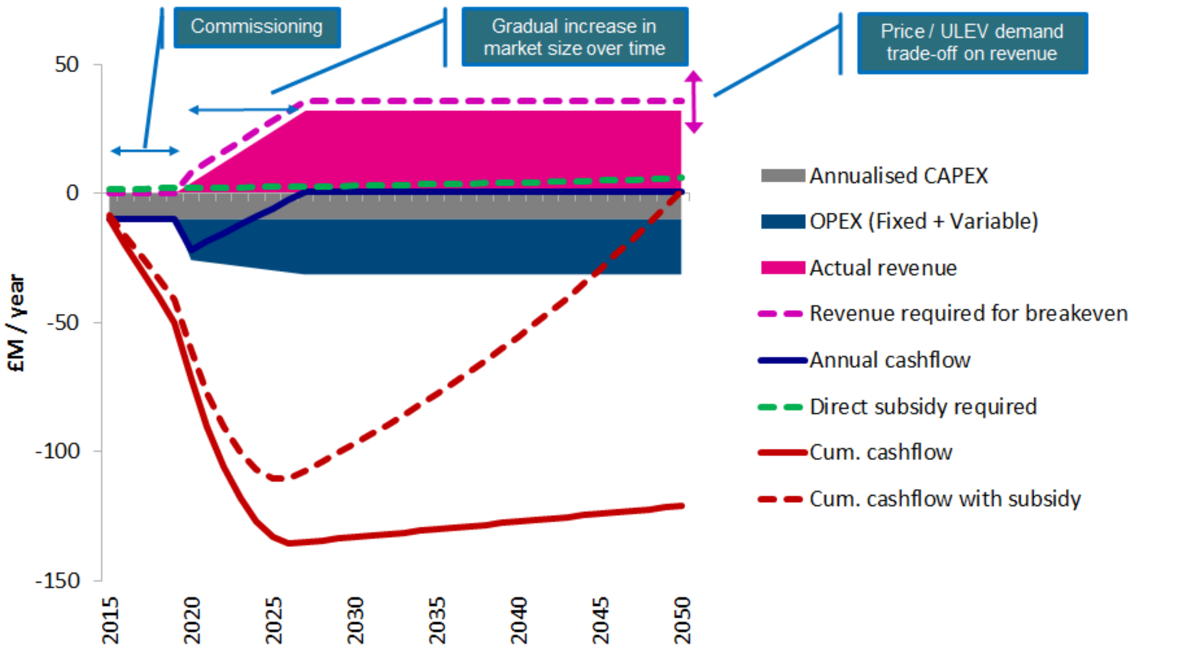


[198] I.e. to avoid having to recover costs where the economic life clearly extends between the 2050 period of analysis as in some cases the full investment life cycle of project is not being modelled.
[199] E.g. in the case of developing a piece of network infrastructure which does not reach required utilisation straight away.
[200] V = volume of electricity or liquid fuel used; C = cost profile; P = resulting price of capital per unit of demand

In the example in Figure 114 the equilibrium price of the good / service means that the revenue is not sufficient to break even over the pathway modelling (as shown by the cumulative cash flow) – i.e. the model is not viable on the basis of the success criteria. The dotted pink line shows the boundary of revenue that would have to be received for the same cost base (i.e. by increasing price), but it is assumed that this is not likely to be possible given that it would adversely affect demand for ULEV uptake; unless Government is providing subsidy support to the consumer which means they do not see the fully impact of the higher price.

The alternative is to provide Government support directly to the commercial entity. An illustration of the subsidy required to break even (green dotted line) and the impact on the cumulative cash flow (red dotted line) is shown in Figure 114. The gradual increase in annual subsidy over time reflects the time Social Discount Rate criteria applied to Government expenditure as there is a preference to backload expenditure and bring forward revenues over the pathway.

Figure 114 Illustration of cash flows and viability assessment for generic commercial entity



The modelling stops in 2050, and the metrics do not incorporate any estimate of value or profitability after that point. In this sense, the metrics may underestimate the value or viability of the business models. In determining prices associated with investments whose life will extend beyond 2050, demand for the commercial entity's product is assumed to remain flat.

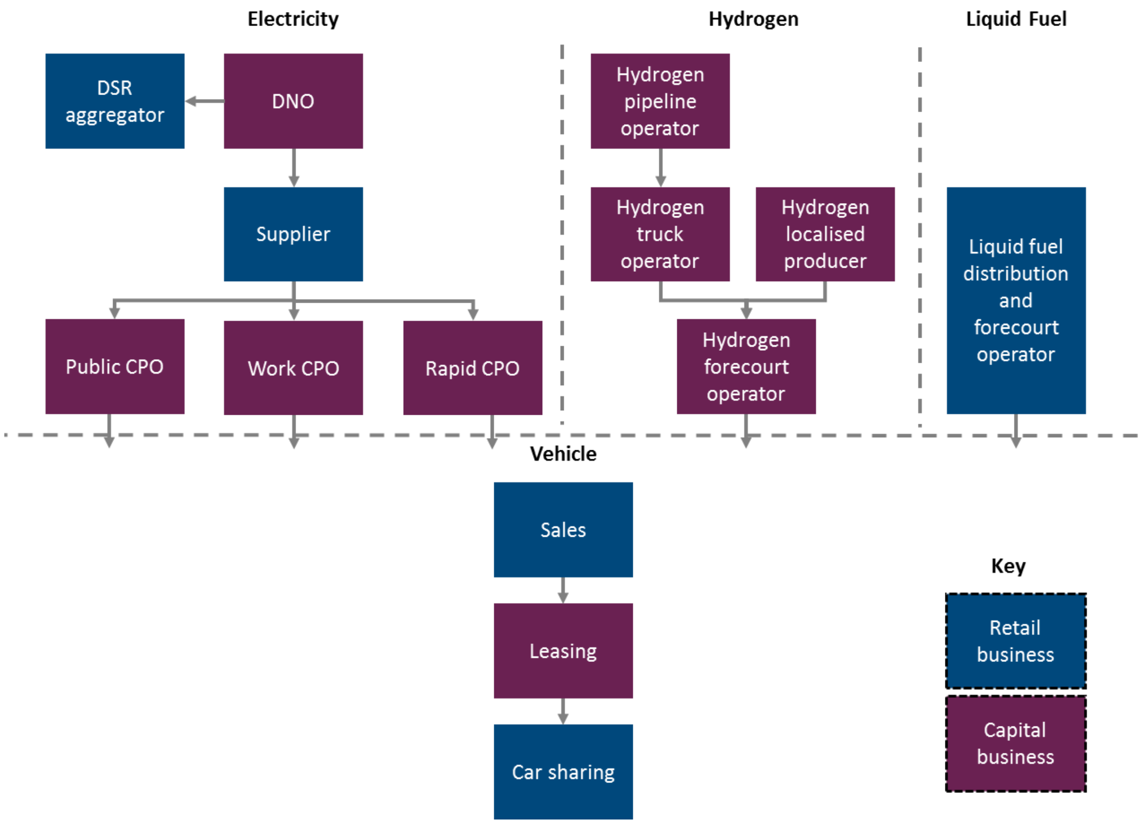
However, for the purposes of the *D1.2 Analytical Framework* all commercial entities are being assessed on the same basis and the overarching metric of viability reflects a position of 'what is needed to make the delivery of the end-state system and supporting infrastructure viable by 2050 at the latest.'

C.2.4 Business models

Thus far Appendix C has focused on how the commercial viability of the entities is assessed, focusing mainly on the **capital-intensive businesses**[201]. These are the public CPO, work CPO, rapid CPO, H_2 tanker (/truck) distributor, pipeline distributor, refuelling station operator, localised producer, for which the subsidy needed in order to recover the cost of capital is assessed through the Success Metrics.

The CPAT also assesses the business models for **margin-led businesses**: the vehicle retailer, leaser, and car sharing provider, the electricity supplier[202], liquid forecourt operator[203], the DNO and the DM aggregator – as outlined in Figure 115. The DNO and DM aggregator are not typical margin business models and are therefore explained in further detail.

Figure 115 Commercial entities assessed in the CPAT



[201] Fixed operating costs and CapEx are calculated in the infrastructure tools – these are volume adjusted and the CapEx is annuitised. Cost to serve, taxes and subsidies for the entities/ fuel are added where relevant to create £/MWh adders to the wholesale electricity price for the CPOs, or £/kg adders to the wholesale hydrogen price for the hydrogen-related entities. In order to avoid high unit costs early on when demand is low and the majority of CapEx is spent and low costs later on in the economic life, the CapEx for the capital-intensive entities is volume adjusted

[202] Costs include the wholesale cost of electricity, system and network costs, cost to serve, to which a margin is added in order to create the retail price

[203] Treated as a margin business as stations close over time as there is less demand for liquid fuel and therefore no new CapEx is spent. The margin is absolute at around 2 p/l rather than a % of the wholesale price

DNO

The DNO business model is driven by a WACC rather than a margin; however, it is treated as a margin business in the sense that the revenues recover the costs and it meets its required regulated return. The DNO earns a return on an existing asset base, which is added to by capital investment and diminished by depreciation, and recovers capital and operating costs through passing on appropriate charges to all electricity users (ULEV and non-ULEV).

The modelling framework uses charging profiles for PiVs that assume modification of behaviour (i.e. shifting demand out of peak periods) in response to incentives from the DM aggregator. Therefore a payment is included in the DNO's costs to compensate the DM aggregator for its services, of a size determined by the costs the DNO avoids. When displacing network capital investment through DM, before paying the DM aggregator the DNO retains from the savings the return on capital it would have made, so that in effect it is indifferent between capital investment and DM.

DM aggregator

The DM aggregator interfaces with both the consumers and system operators and is arguably more complex that the other margin-led business models. An overview of the various cost and revenue flows is shown in Figure 116.

The DM aggregator has as costs payments to consumers (to compensate them for modifying their behaviour), and as revenues payments from the DNO and TNO / TSO (passing on savings they make from reduced investment and expenses on maintaining and operating the networks).

Payments to consumers are set at the change in cost arising from changing their charging profile where that change results in increased costs, plus the cost of the inconvenience they suffer.

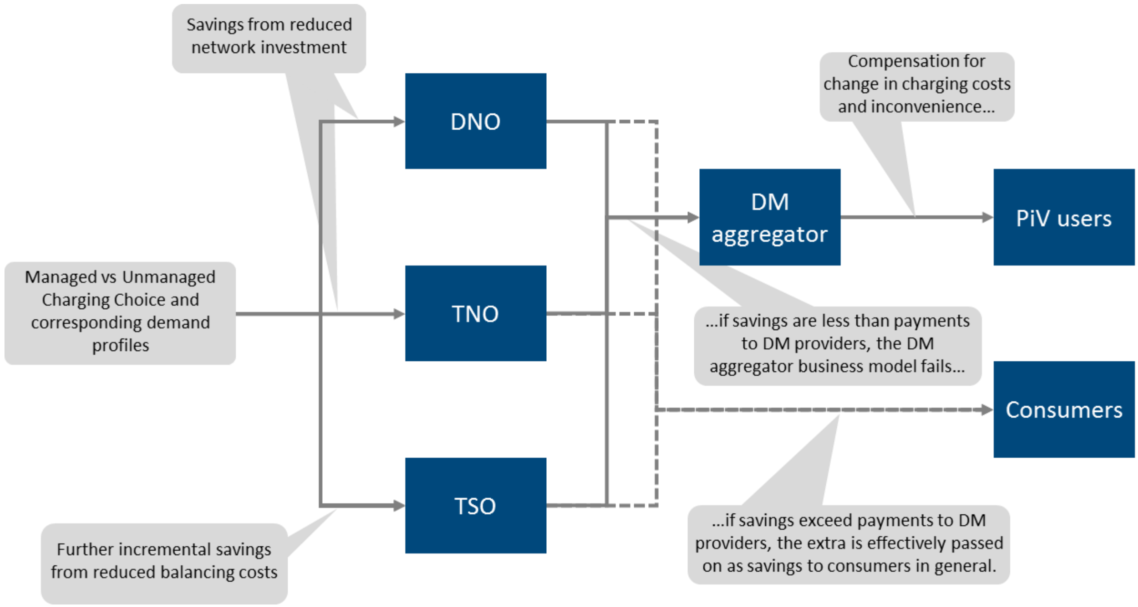
- As the modelling framework assumes modified charging profiles, this payment is in all circumstance.
- If the changed charging profile results in reduced costs to the consumer, they keep the savings.

The income that the DM aggregator receives from the DNO and TNO / TSO has a maximum value set at the savings made by those parties, less any amount they retain themselves.

- If this income is less than the DM aggregator's costs (cost to serve and payments to consumers for inconvenience and changes in charging cost), it will make a loss, or fail to make sufficient margin.
- If this income exceeds the DM aggregator's costs plus margin, the surplus is passed to consumers through a reduction in the charges the DNO and TNO / TSO pass to the supplier.

The DM aggregator is assumed to manage all PiV electricity consumption at home and work locations.

Figure 116 Overview of approach to Demand Management aggregator



Appendix D Physical Supply Chain Tools

D.1 Energy System Modelling Environment (ESME)

D.1.1 Key functional requirements

ESME is required to provide an internally consistent view of how the entire UK energy system can evolve over the pathway from now to 2050 in the most cost-effective manner to meet the UK's GHG targets, whilst ensuring that the energy service demands (for heating, lighting, transport, etc.) are met along with other constraints (on resource availability, security of supply, etc.)[204].

More specifically the tool is required to:

- Help frame the interactions between varying levels of transport decarbonisation (as driven by a more detailed analysis of ULEV uptake and use outside of ESME in ECCo) and wider system decarbonisation.
  - In particular, to understand the scale of infrastructure investment for electricity and hydrogen, where this dependent on other sectors outside of transport (e.g. electrification of heat or hydrogen for HGVs).
- Provide estimates of 'boundary conditions' to feed into the other modelling tools such as an estimated wholesale price of large-scale centralised hydrogen production where these are relevant for specific Narratives.
- Frame the additional level of Government spending it is appropriate to channel towards abatement via ULEVs, e.g. providing a shadow price of carbon consistent with the balance of decarbonisation across the system which could be applied as a carbon tax on ongoing fossil use in vehicles[205].

ESME naturally has a more aggregated representation of technology and temporal resolution to be able to model all energy sectors in parallel. As a result, the other supplementary tools described in Appendix D are used to expand the detail in the ESME outputs in a number of key areas (e.g. investment in electricity distribution upgrades), but with the overall analysis bounded broadly by the ESME results.

D.1.2 Wholesale electricity prices

A core requirement is to help create a more disaggregated (hourly) temporal profile of potential future electricity prices (given the limitation of 5 diurnal timeslices in ESME) to understand the implications for the cost of ULEV ownership under different potential electricity tariff schemes.

It is important to reiterate that the requirement for this project is not to undertake detailed modelling of future electricity prices consistent with a set of defined market arrangements and other features, but to provide more disaggregated shaping of prices based on the underlying system

[204] Further background on the ESME model is available here http://www.eti.co.uk/wp-content/uploads/2014/04/ESME_Modelling_Paper.pdf

[205] This would provide an additional source of revenue which could be recycled to ULEVs via e.g. subsidies or tax reductions

fundamentals. As a result a number of key simplifying assumptions have been made as part of the modelling:

- All interconnectors are assumed to be at float to avoid the need to understand and model the future evolution of markets connected to GB
- Carbon prices reflect those from an economy wide cap and trade system as this is effectively the representation in ESME, and
- Prices are reflective of the Long-Run Marginal Costs of generation.

The last of these is necessary to avoid making complicated assumptions about how the overarching market and policy arrangements for the wholesale electricity system will evolve over time. Generators clearly need to recover their long run costs to make the investments worthwhile and until fairly recently this was achieved predominantly by some generators (primarily peaking plant) bidding in scarcity premiums, setting the price well above the variable cost for both themselves and other generators (i.e. by allowing other generators to capture the additional infra-marginal rent from this).

The dynamics of future electricity systems are starting to change significantly due to the need to bring on low carbon electricity plant (with higher overall investment costs). In addition, some of these plant have very low or zero variable costs, which will start to impact how prices are set in an increasing number of periods. As a result it is becoming more complicated to ensure that the required plants, whether for decarbonisation or peak capacity adequacy purposes, are remunerated appropriately; leading to a proliferation of support mechanisms in GB such as Contracts for Difference and the Capacity Market[206].

By calculating prices on a basis that also recovers fixed and capital costs, there is an implicit assumption that prices are set such that generators recover any 'missing money'- e.g. via a 'generic support scheme' which socialises the missing money. This is reflected within the wholesale price portion of the electricity price stack constructed in the CPAT (see Appendix C) and appears in the price seen by the ULEV consumer (highlighting the link between the Market and Policy Framework for electricity and potential impact on ULEV uptake and use).

The estimated prices from the ESME outputs have been shaped to create a more granular hourly demand profile to create an hourly price series for each characteristic day which reflects the broad trends over time in the ESME diurnal timeslices, both:

- Absolute levels of demand, and
- Overarching changes in shape of demand due to e.g. more electrified heating, use of storage etc.

D.2 PLEXOS

The core requirement for the PLEXOS tool is to help create a more disaggregated (hourly) temporal profile of demand against which to test the feasibility of system operation (given the limitation of 5

[206] And other complexities such as administered scarcity pricing, which has been introduced under Ofgem's recent Energy Balancing Significant Code Review. This ensures that the price of electricity can rise to the assumed Value of Lost Load in times of extreme system stress.

diurnal timeslices in ESME). PLEXOS has not been used within the core suite of Analytical Tools for every Narrative or Sensitivity, but to support the understanding of the feasibility and potential additional costs of system dispatch in the BaU Narrative versus those where there is high PiV uptake and / or less direct control over charging – i.e. where the electricity system is more significantly stressed.

PLEXOS[207] has been used previously by the ETI to explore the feasibility of electricity system solutions produced by ESME. At its core is an optimisation engine which decides how to dispatch plant (and operate storage) under the constraints of their dynamic operating parameters to meet electricity demand in the most cost-effective manner.

Prices used as part of the dispatch optimisation are calculated on the basis of running costs + carbon price + technical uplift[208] only, with no calibrated scarcity uplift during periods of system tightness.

D.3 Macro Hydrogen Distribution Tool (MHDT)

The MHDT's core requirement is to provide a more detailed understanding of the investments required to facilitate distribution of hydrogen for use in ULEVs as the representation within ESME is not sufficiently granular. The focus is on the distribution of hydrogen to the end-use, although the capital and operating costs of localised production are incorporated where relevant (large-scale production is captured in ESME).

The exact structure of distribution options varies by Narrative, and a simple spreadsheet tool is used to enable assessment of the following key areas:

- **Hydrogen Refuelling Station** infrastructure costs and the relationship between ULEV (and non-ULEV) demand and number of HRS required
  - Small / medium / large HRS are built depending on the average demand per station in the preceding year.
  - At a minimum, the number of stations built meets the ULEV (and non-ULEV) H_2 demand[209] and otherwise, depends on the number of FCVs and a network density / redundancy (to reflect that, especially when there are fewer FCVs, a refuelling network will be less than 100% utilised).
- **Localised production** (water electrolysis) infrastructure costs, and the relationship with ULEV (and non-ULEV demand)
  - The proportion of demand that is met by localised production at the refuelling stations, rather than centralised H_2 production and truck / pipeline distribution is used, together with the specification of whether the localised generators are small / medium / large-scale and assumptions on the efficiency and load factor expectation, to determine the number of localised producers required[210].

[207] See http://energyexemplar.com/software/plexos-desktop-edition/ for further information.
[208] To recover start and no-load costs.
[209] Excluding that provided at private depots (for a proportion of the HGVs).
[210] There may be a few HRS served by one localised producer and any additional distribution cost resulting from this is assumed to be small and thus not included.

- **Tanker distribution** (gaseous tube trailer or liquid H2) and the relationship between ULEV (and non-ULEV) demand, form of the HRS network, and scale of distribution[211]
  - The number of tankers required is based on the actual demand at the refuelling stations (less that produced on-site from localised producers), the tanker capacity, whether the tanker serves multiple stations per trip and assumptions on the availability and journey distance etc. from the centralised H_2 production facility.
  - The capital and operating cost of the tankers are assessed, including the costs associated with personnel, driving and compression to the tanker pressure[212].
  - In the Narratives, the 'final mile' deliveries into major population centres are assumed to be met either through additional tanker use or by laying high pressure local distribution pipelines (at a higher cost than the rest of the pipeline network).
- **Pipeline distribution** and the relationship between ULEV (and non-ULEV) demand, form of the HRS network, and scale of the pipe network
  - The NTS pipe network lengths are based on regional H_2 demand, supply and flows from ESME.
  - Pipelines are built once the H_2 flows across the pipeline exceed a certain threshold, which is an estimate of the volume required to make pipelines economic based on the proposed pipe length; below this trucks are used to deliver the H_2 to the HRS.
  - The LDN is sized according to the current gas network and distributed regionally according to population density. The pipes are built in 100 km segments (maximum per region per annum) to reduce the lumpiness of investment and avoid impractical labour requirements.
  - The cost of compression and pressure reduction is included, together with sense checks on the achievable and maximum throughput of the pipes.

In many cases the investment requirements need to consider both that related to ULEV deployment and use and wider transport demand, primarily hydrogen HGVs. The scale of investment is then passed to CPAT and the structure of the commercial network entities within this tool inform how this investment is seen by the end-consumer.

- **Repurposing** of the gas network for H_2 delivered direct to the household / depot is a special case and is *not considered within the scope* of the MHDT as it has significant interdependencies with the wider system e.g. repurposing all heat, cooking and small scale industrial appliances to either hydrogen or electricity. It is not currently considered part of any of the core Narratives.

D.4 Macro Charging Point Tool (MCPT)

The purpose of the MCPT is to assess the need for investment in charging point infrastructure for PiV users at public, rapid and work locations.

The number of charging points built needs to consider the trade-off between:

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[211] Primarily trading off more tube trailers to deliver an given level of hydrogen versus additional costs/losses associated with liquefaction

[212] Around 400 bar H_2 tube trailers assumed

- **the utilisation of the charging points**; i.e. a substantial over-build of charging points will lead to a higher the capital cost component in the retail electricity price stack as the charging point operators have less demand per charging point over which to recover their costs. High electricity prices will lead to lower uptake of BEVs and vice versa, and
- **the perception of access to the charging points**; the level of competition for charging that users perceive there to be at a given charging location at a given time of day.

Lack of apparent access to charging is a major barrier to consumer uptake, and this takes on two forms in its representation within ECCo:

1. Option to buy PiV
   - In order to be offered a PiV in the showroom, the user needs to have access to overnight charging. The location of the overnight charging varies with each user segment:
     - **home access for Private Consumers**; varies from 68% for pragmatists to 100% for innovators based on a survey conducted in Feb 2015 over 2,000 UK car buyers
     - home access for Fleet User Choosers; 78% access[213].
     - **home access for Fleet Non-User Choosers parked at home overnight;** access is assumed to be 78% as for Fleet User Choosers and 50% for vans[214]. Home-based Fleet Non-User Choosers charging at work behave as per Fleet User Choosers at work[215]
     - **work access for Fleet Non-User Choosers parked at depots overnight**; access is assumed to be 80% for cars[216] and 66% for vans[217].
     - **public access for Fleet Car Sharing;** the level of access is calculated based on the degree of competition for charging as survey data is not available.
2. Likelihood of buying PiV
   - For vehicles chosen by Private Consumers and Fleet User Choosers the access to other charging locations improves the probability of purchase
     - Private Consumers also have access to work, public and rapid charging points
     - Fleet User Choosers also have access to work, public and rapid charging points
     - Fleet Non-User Choosers parked at home overnight also have access to work, public and rapid charging points
     - Fleet Non-User Choosers parked at depots overnight do not need access at other locations, and
     - Fleet Car Sharing users that also have access to work and rapid charging points.

[213] The weighted average of Private Consumers
[214] Based on analysis of the Survey of Company Owned Vans
[215] i.e. have the same charging profile
[216] The vast majority of depot based fleet cars are kept at the depot overnight, but 100% is unrealistic as there is likely to be some restriction on where a charge point can be located. Varying access levels for this user segment has a small overall impact because depot based Fleet Non-User Choosers account for only 5% of sales
[217] Based on analysis of the Survey of Company Owned Vans

Aside from the segments and locations for which there is survey data available to indicated perceived access levels, the **access to charging is determined in the MCPT as the number of vehicles competing for a given charging point**:

- The PHEVs and BEVs charge[218] at the different locations at different times of the day according to the profiles for charging event start times[219].
- The perceived level of access is defined as the access in the most competitive hour of the day for each user group and includes vehicles that access a charging point several hours ago and are still plugged-in
  - e.g. at 9am, 100 vehicle users plugged-in their vehicle for 5 hours at a public charging point, and this was repeated around 10am and 11am, so that at 12pm, 100 users wish to plug-in their vehicle and there are already 300 vehicles plugged-in or queueing. There are only 100 public charging points installed, therefore only 25% of the vehicles have access in that hour and the perception of access by all users is 25%.
- The length of time that each vehicle is plugged-in for is fixed and based on data from the Plugged In Places trial; the battery may only be charging for a proportion of the time the vehicle is plugged-in.

The level of access depends on the extent of the charging post network at different locations and this is defined by long-run density factors i.e. number of charging points installed per PiV

- The density factors are exogenous and vary between the Narratives depending on the theme of the Narrative, e.g. ULEV has a relatively high number of charging points per PHEV and BEV at work and public locations.
- Some level of anticipatory investment is assumed for all the Narratives, as per the hydrogen refuelling stations.
- At a minimum, the number of charging points installed must be sufficient to meet demand.
- The capital cost of the charging points differs according to the rate of charging and the production cost specifically decreases as more charging points are manufactured and learning rates are applied.

D.5 Macro Electricity Distribution Tool (MEDT)

The MEDT is based on the 'Macro-Level Model' created as part of the ETI's previous PiV (Plug-in Vehicle) project[220]. Its core requirement is to provide a more detailed understanding of the additional investment required on the electricity distribution network as the representation within ESME is not sufficiently granular.

This needs to cover both investment from the wider energy system evolution (e.g. due to electrified heating) as well as that from ULEV deployment and use. The scale of investment is then passed to CPAT and the structure of the commercial network entities within this tool inform how this investment is seen by the end-consumer (e.g. in the form of DUoS charges).

[218] BEVs only in the case of rapid charging points.
[219] Peak weekday profiles are used.
[220] See SP2/IMP/18_v2.0 (2011) Plug-in Vehicle Economics and Infrastructure Project: Electricity Distribution and Intelligent Infrastructure Contract for further background details of the Macro-Level Model.

D.6 Macro Liquid Distribution Tool (MLDT)

The MLDT is used to assess the operating cost component of the petrol and diesel retail price stack, which in addition to the margin charged by the retailer forms the 'ex-refinery spread'. This constitutes the part of the retail price that is not either the wholesale price or taxes such as fuel duty.

The operating cost (in p/l) depends on the number of forecourts in operation and the throughput of these forecourts:

- As the demand for petrol and diesel falls, fewer liquid forecourts are needed to meet demand and stations are closed based on an economic relationship derived from historic analysis. At a minimum, around 200 forecourts are closed each year, following the trend since around 2010 and a de minimis 2000 stations kept for national coverage[221].
- The fixed operating cost is based on stylised business models and assumed to remain constant at around £170,000 /year for an 'average' forecourt that has a throughput of around 4.2 ml/year[222]. Shop profits are removed from the operating costs such that the remaining costs need to be met by fuel sales.
- Each site is assumed to need a minimum margin of around 2 p/l, on top of the operating cost, in order to avoid triggering closures.

There should be enough liquid fuel demand to support the skeleton network of stations, such that the operating costs can be spread widely and therefore remain a small proportion of the retail price stack, otherwise the potential need for Government subsidy is considered.

[221] Based on the current LPG network of 1800 LPG filling stations in the UK and around 100,000 cars and light-duty vans currently using LPG.
[222] 2015 throughput data for the forecourts in operation; this varies significantly between supermarket, oil company and independent operators.