Programme Area: Energy Storage and Distribution

Project: Consumers, Vehicles and Energy Integration (CVEI)

Title: D1.1. Summary of approach, conceptual design and key research questions

Abstract:

This report represents Deliverable D1.1, Summary of Approach, Conceptual Design and Key Research Questions. The purpose of this report is to set out the analytical approach being taken to the identification and assessment of system options, and the tool set being used.

This report should be read in conjunction with report D4.1, “Initial Analysis of Technology, Commercial and Market Building Blocks of Energy Infrastructure”, which sets out the detailed components of the framework.

It should be noted that both of these reports (D1.1 and D4.1) were written for the purpose of facilitating agreement regarding the details of the approach and consequently they are quite complex. Other reports later in the project will present the information in a more accessible manner for people not closely involved with the work; those later reports are commended to the general reader as a more suitable starting point. Nevertheless, D1.1 and D4.1 are made available for completeness.

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.

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Executive summary

Background

The Energy Technologies Institute's (**ETI**) Consumers, Vehicles and Energy Integration Project (**CVEI**) has been established to examine how to deliver mass deployment and use of ultra-low emissions vehicles (ULEVs) in the UK, and address the challenges and opportunities of integration with the full energy system (including plug-in hybrid and battery electric vehicles, and hydrogen fuel-cell vehicles).

This report represents deliverable D1.1 (TR1006_D1.1) Summary of approach, conceptual design and key research questions, submitted as part of Work Package 1 within Stage 1. It should be read in conjunction with Deliverable D4.1 (TR1006_D4.1) Initial Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure.

Purpose of Work Packages 1/4

The overall purpose of Work Packages 1 and 4 is to provide a holistic, Multi Criteria Assessment (MCA) of what "good looks like" for successful mass deployment and use of ULEVs, and to help understand how effectively the choices fit together across the 4 overarching Dimensions that are being considered:

- **A) Customer Proposition (CP)** – what the customer sees at the point interacting with a ULEV e.g. is the customer buying or leasing the vehicle
- **B) Physical Supply Chain (PSC)** – the technologies and infrastructure required to deliver the vehicles and their energy requirements
- **C) Commercial Value Chain (CVC)** – 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
- **D) Market and Policy Framework (MPF)** – Government intervention in the form of setting the overarching market framework for commercial entities (e.g. regulated monopolies for network infrastructure) or more direct policy intervention (e.g. in terms of taxes or subsidies on commercial entities or directly 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 1.

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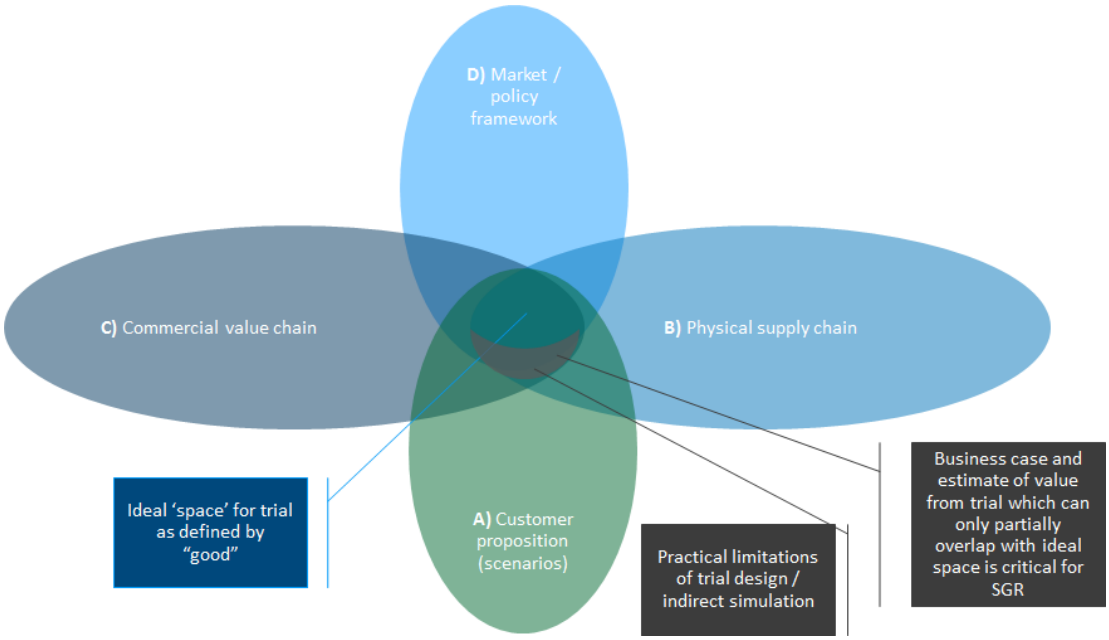
Figure 1 Purpose of Analytical Framework



The scope of the analysis covers:

- The pathway from now to 2050, with consideration given to the requirements in the middle of the pathway to facilitate the overall transition required by 2050
- Cars, vans and the full set of ULEVs (electric vehicles, hydrogen and liquid fuels) for individual consumers and fleets (see section 7.1 for a more detailed definition), but not HGVs (Heavy Goods Vehicles)

Overview of work undertaken within D1.1

The specific purpose of this Deliverable D1.1 is to consolidate early activity across different parts of the project, during the scoping phase, to ensure the structure of the Analytical Framework produced for D1.2 and its subsequent use is able to inform the key questions in the most appropriate manner, given the available resources for the project.

To deliver this the Project Team has:

- Undertaken a first principles assessment of the individual components or Building Blocks that could influence ULEV uptake and use (drawing on existing literature, Project Team expertise and discussions with the ETI) that could be important within each dimension under consideration:
  - Customer Proposition
  - Physical Supply Chain
  - Commercial Value Chain
  - Market and Policy Framework
- Proposed a range of Narratives that explores a broad space of future strategies for ULEV deployment (supported by sensitivities to understand how resilient these strategies are)

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and the key questions they are trying to explore, and a detailed mapping of how the individual BBs are included within these.
    - The Narratives have been framed in close discussion with ETI and the Project Team
- Outlined in detail an Analytical Framework for undertaking a holistic quantitative and qualitative assessment of each Narrative and Sensitivity, which includes the integration of a number of pre-existing and new modelling tools
- Described how this Analytical Framework can be applied both in a standalone manner and to help inform the Stage 2 trial design

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 the four key dimensions ***holistically***. 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 wide-spread PIV charging or hydrogen refuelling infrastructure dependent on commercial models that can viably invest in these).

As a result, the Narratives under consideration must 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.

Summary of Narratives and key questions posed

The Narratives that will be assessed using the Analytical Framework and the key questions that these are aiming to explore are summarised as follows:

- **OEM innovation** *(organic action / mobility as an asset)*: vehicle OEMs make ULEVs attractive to consumers, by increasing vehicle range, performance and 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[1]). Proprietary motorway charging networks complement the dominant mode of home charging.
    - *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 this complicate the delivery of new large-scale supporting infrastructure, in particular with respect to the role of hydrogen?*
- **City led** *(organic action / 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 in depots.
    - *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)?*

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

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- **ULEV enabled** *(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** *(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 ICEs and liquid refuelling infrastructure?*
  - *Is this route materially more expensive compared to other Narratives (such as City-led and Transport on demand) 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?*
- **Transport on demand** *(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-led 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)?*

Each narrative is constructed around a ***'ULEV strategy'*** that can be delivered by the various actors involved (Government, Industry, or indirectly by consumers). Exogenous conditions that are outside of the control of these actors such as international fossil fuel prices or the development of cost-competitive and low carbon synthetic liquid fuels are proposed to be tested by sensitivity rather than drive differences in the Narratives themselves. These sensitivities will be used to explore how resilient a given ULEV strategy is to these changing external conditions (away from a "central view") and where some Narratives are more sensitive to these changes than others. Sensitivities to be explored include:

- A higher degree of decarbonisation required in transport given difficulty decarbonising elsewhere in the energy system
- Higher transport consumer service demands (in vkm)
- Failure to achieve significant further reductions in battery costs and performance

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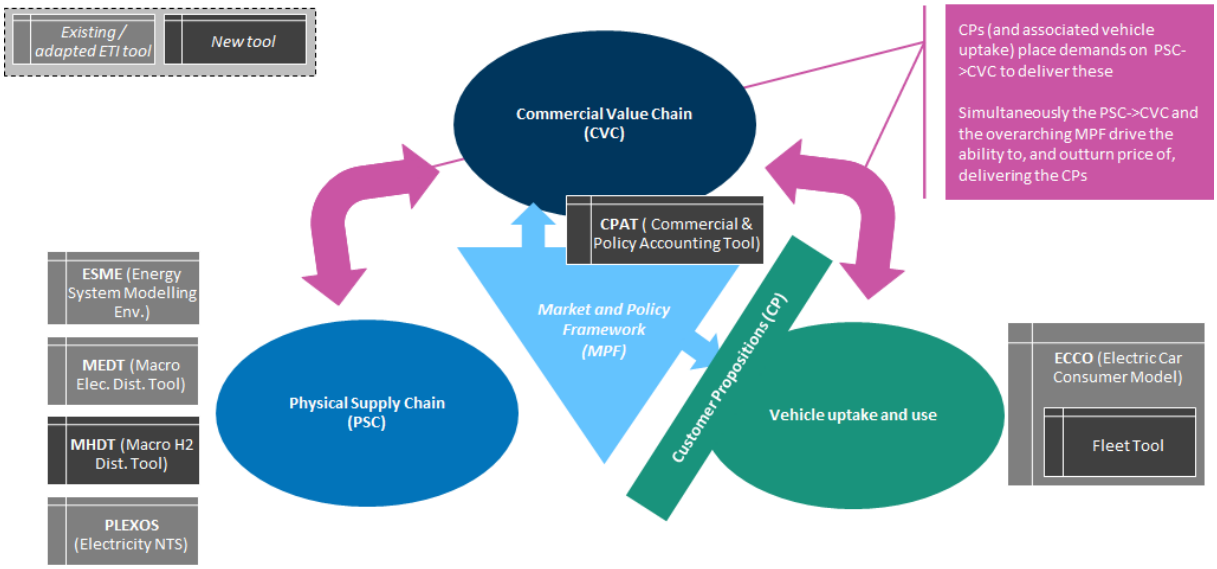
- Liquid fuel options with different carbon intensity / price to understand the point at which this compete with ULEV deployment whilst maintaining the same degree of decarbonisation

Overview of tools in Analytical Framework

To enable a quantitative assessment of key elements of the Narratives a combined set of analytical tools has been proposed as outlined in Figure 2. It is important to highlight that the aim is *not* to create a fully-integrated 'uber-model', but *to use these tools in tandem to enable meaningful quantification, to an appropriate level of detail, in an internally consistent manner.*

Figure 2 Overview of analytical tools



The proposed tools comprise a mix of pre-existing tools (which will be adapted to varying degrees as required to enhance or integrate them as part of this framework) and new tools reflecting standalone development. The analytical tools align with the overarching Dimensions and broadly divide into 3 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 whole energy system model **ESME**, which will provide a consistent picture of how the UK can meet its GHG targets in a feasible manner (in line with the quantitative Success Metrics for the PSC) for both the transport and the wider system.
  - By considering the whole system, ESME is naturally less detailed on a sector by sector basis and it is proposed to supplement the understanding of the costs of infrastructure investment for electricity (via the **MEDT** tool) and hydrogen distribution (via a new **MHDT** tool)
  - In a similar manner, **PLEXOS** will be used as a means to explore the feasibility of the electricity system in more detail. It is *not envisaged* that PLEXOS will be 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

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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.

- Tools used to understand the response of consumers and fleets to different **Customer Propositions** (price and other aspects) on the uptake and utilisation of ULEVs in line with the proposed quantitative Success Metric. For this it is proposed to use the existing **ECCo** model, but with significant improvements to the way that fleets are represented.
- A new tool – **CPAT** - to represent the flows across the **Commercial Value Chain** (CVC) as this acts as *2-way* interface between the demands placed on the Physical Supply Chain by the uptake of ULEVs and the prices seen by the end ULEV-consumers as part of the customer proposition. The CPAT tool calculates the cashflows for (and between) each of the entities who exist on the CVC (e.g. to recover the investment in developing and operating the infrastructure and energy supply to provide various ULEV-related goods and services). From this it constructs an estimate of the prices that need to be charged to ensure these entities are commercially viable - in line with the quantitative Success Metrics - and thus the prices seen by the consumer at the end of the CVC[2].
  - The **Market and Policy Framework** is also included within CPAT, both to track various Government revenue streams (taxes, subsidies, wider investments) for the quantitative Success Metric, 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. VAT)

It should be noted that the final design specifics may vary during the more detailed implementation phase for deliverable D1.2.

In addition, the Stage 2 trial is likely to provide quantitative insights that could be fed directly into the Analytical Framework to refresh the analysis at the end Stage 2. This clearly depends on the trial design, but could include e.g. the impact on different charging profiles as a result of simulated electricity tariffs or managed charging requirements, or the result of choice experiments on the factors that influence ULEV uptake (as the ECCo tool already captures parameterised elements of this).

Next steps for Work Packages 1 and 4

The key next steps for the project related to Work Packages 1 and 4 are:

- Develop and soft-link the Analytical Tools necessary for the Analytical Framework - and corresponding dataset - for deliverable D1.2
- Apply the Analytical Framework to the Narratives and sensitivities and assess implications for successful mass-market deployment and use of ULEVs, and high-level design requirements for the Stage 2 trial, as part of deliverable D1.3
- Finalise the BBs in deliverable D4.2. It is envisaged that this is expansion of the information related to R&D gaps on the Physical Supply Chain, for example, incorporating insights from Work Package 3 on battery technologies

[2] 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.

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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, and address the challenges and opportunities of integration with the full energy system (including plug-in hybrid and battery electric vehicles, and hydrogen fuel-cell vehicles).

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 four Work Packages (WP)

- **WP1:** Market Design and System Integration
- **WP2:** Consumer and gleet usage behaviours and attitudes to adoption
- **WP3:** Vehicle energy supply management systems and technologies
- **WP4:** Energy infrastructure management systems and technologies

This report represents deliverable *D1.1 (TR1006_D1.1) Summary of approach, conceptual design and key research questions*, submitted as part of *WP1* within *Stage 1.*

The purpose of this deliverable is to consolidate early activity across different parts of the project, during the scoping phase, to ensure the structure of the Analytical Framework produced for D1.2 and its subsequent use is able to inform the key questions in the most appropriate manner, given the available resources for the project.

This document should be read in conjunction with Deliverable *D4.1 (TR1006_D4.1) Initial Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure.*

1.2 Overarching project objectives and approach

The key scope, or 'exam questions', from the original project scope have been summarised in Figure 3, along with a brief summary of how they are addressed through the proposed approach in Work Package 1. In subsequent sections, where relevant, further information is provided on how the proposed approach maps back to the core project objectives.

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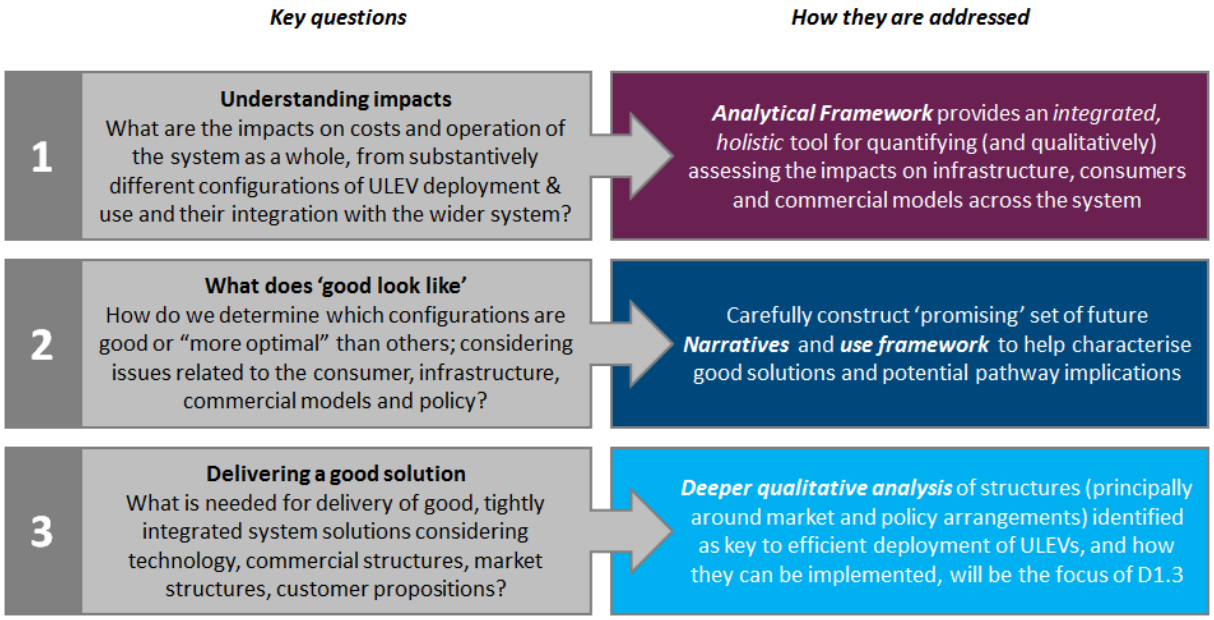
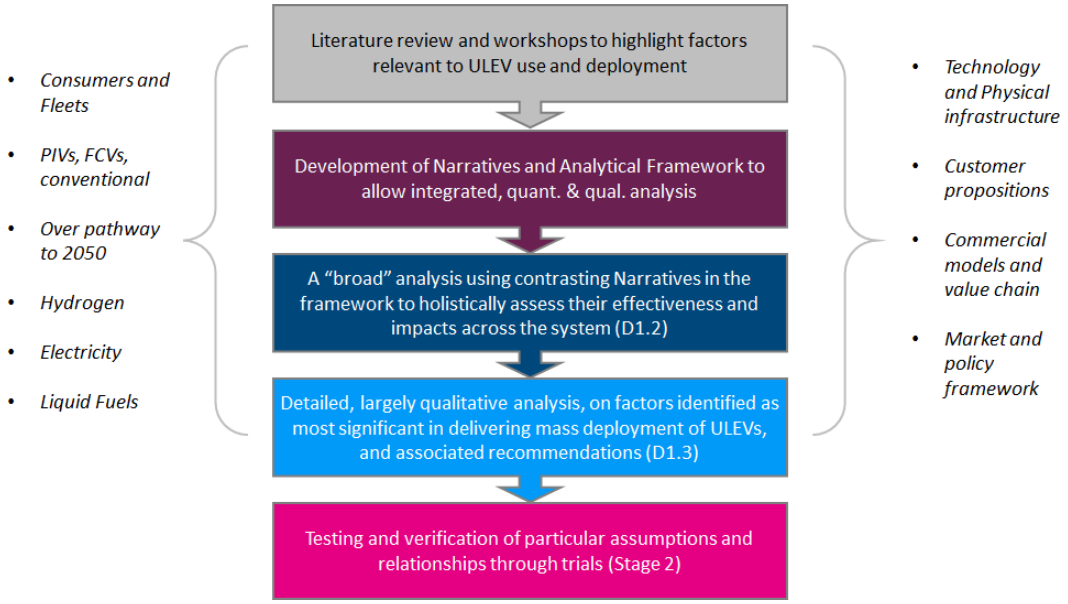
Figure 3 Overview of key project questions



The approach to Work Packages 1 and 4 and an overview of the scope covered by the analysis is summarised in Figure 4.

Figure 4 Overview of Work Packages 1 and 4



1.3 Structure of this document

This document is structured as follows:

- Section 2 describes the purpose of the Analytical Framework and key terminology

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- Section 3 describes the proposed Narratives, which will be assessed via the Analytical Framework
- Section 3.12 summarises the key focus areas for the Analytical Framework (and knowledge gaps) as informed by the analysis of the Building Blocks in deliverable D4.1
- Section 5 provides an overview of the analytical tools used to help quantify key aspects of the Analytical Framework
- Section 5.3 describes the analytical tools related to the Physical Supply Chain in more detail
- Section 7 describes the ECCo vehicle uptake model in more detail
- Section 8 describes the proposed Commercial and Policy Accounting Tool in more detail
- Section 9 provides a more explicit mapping of how the key Building Blocks identified in D4.1 will be assessed within the Analytical Framework
  - It also summarises any development required to each analytical tool required to achieve the above
- Section 10 outlines how the Analytical Framework will be applied in practice and how insights from it will be used to inform the high-level trial design
- Section 11 concludes and outlines next steps for the project

1.4 Glossary and acronyms

A list of key acronyms and glossary of key terms used across the project are provided in Table 1 and Table 2, respectively.

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Table 1 List of acronyms

Item	Description
BB	Building Blocks
BEV	Battery Electric Vehicle
CP	Customer Proposition
CPAT	Commercial and Policy Accounting Tool
CVC	Commercial Value Chain
DNO	Distribution Network Operator
DM	Demand Management
ECCO	Electric Car Consumer Model
ESME	Energy System Modelling Environment
ETI	Energy Technologies Institute
EV	Electric Vehicle
FCV	Fuel Cell Vehicle
HRS	Hydrogen Refuelling Station
ICEV	Internal Combustion Engine Vehicle
LDN	Local Distribution Network
MCA	Multi Criteria Analysis
MCDT	Macro Charging Distribution Tool
MEDT	Macro Electricity Distribution Tool
MHDT	Macro Hydrogen Distribution Tool
MLDT	Macro Liquid Distribution Tool
MPF	Market and Policy Framework
PiV	Plug-in Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PSC	Physical Supply Chain
SGR	Stage Gate Review
TCO	Total Cost of Ownership
ToUT	Time of Use Tariffs
ULEV	Ultra-Low Emission Vehicle
WP	Work Package
V2G	Vehicle to Grid

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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	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.
Build year vintage	The characteristics associated with the technology (e.g. vehicle or infrastructure) in the year it is built, as distinct from the time period it is operating in. For example, the vehicle parc in 2020 may contain new EVs built in that year with lower operating costs and higher range compared to EVs built in 2015, but which are still operating in 2020.
Dimensions	4 highest level areas categorising the BBs impact ULEV deployment and use covering: Customer Proposition (CP), Physical Supply Chain (PSC), Commercial Value Chain (CVC), and Market and Policy Framework (MPF)
Narrative	An internally consistent set of Scenarios and their underling Building Blocks covering *all* Dimensions and collectively characterising (qualitatively) a rational and distinctive model for facilitating mass deployment and use of ULEVs in the UK.
Scenarios	An internally consistent sets of BBs *within* each Dimension that are plausible and distinctive for ULEV deployment and use and can be assessed either quantitatively and/or qualitatively within the Analytical Framework.
Social Discount	Application of the Treasury's Green Book Social Discount Rate as part of financial analysis.
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.
Time period	Annual time steps on pathway from now to 2050
Time slice	Within year disaggregation reflecting characteristic days by season and in some cases further within day (or diurnal) disaggregation.

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2 Purpose of Analytical Framework

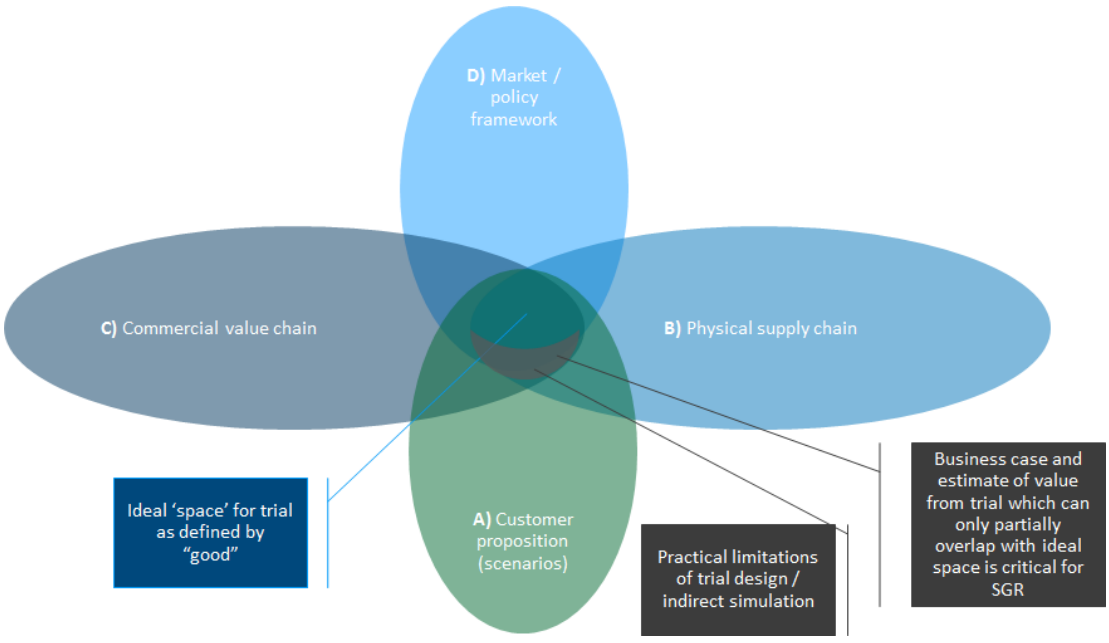
2.1 Purpose

The core purpose of the Analytical Framework is to provide a holistic, Multi Criteria Assessment (MCA) of what "good looks like" for successful mass deployment and use of ULEVs, and to help understand how effectively the choices fit together across the 4 overarching Dimensions that are being considered:

- **A) Customer Proposition (CP)** – what the customer sees at the point interacting with a ULEV e.g. is the customer buying or leasing the vehicle
- **B) Physical Supply Chain (PSC)** – the technologies and infrastructure required to deliver the vehicles and their energy requirements
- **C) Commercial Value Chain (CVC)** – 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
- **D) Market and Policy Framework (MPF)** – Government intervention in the form of setting the overarching market framework for commercial entities (e.g. regulated monopolies for network infrastructure) or more direct policy intervention (e.g. in terms of taxes or subsidies on commercial entities or directly 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. ***The use of the Analytical Framework to inform the trial design is discussed further in section 10.2.*** This is illustrated in Figure 5.

Figure 5 Purpose of Analytical Framework



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The scope of the framework covers:

- The pathway from now to 2050, with consideration given to the requirements in the middle of the pathway to facilitate the overall transition required by 2050
- Cars, Vans and the full set of ULEVs (electric vehicles, hydrogen and liquid fuels) for individual consumers and fleets (see section 7.1 for a more detailed definition), but not HGVs (Heavy Goods Vehicles)

2.2 Concepts and terminology

The Analytical Framework uses a number of key concepts and terminology which are defined below.

- **Dimensions:** the 4 highest level areas categorising all of the issues that could impact ULEV deployment and use covering:
  - Customer Proposition (CP)
  - Physical Supply Chain (PSC)
  - Commercial Value Chain (CVC)
  - Market and Policy Framework (MPF)
- **Building Blocks (BB):** Individual components that influence ULEV deployment and use within each Dimension[3]. A selected subset of BBs and their respective values or states (e.g. technology costs) constitute the tangible components of each narrative.
  - **Categories**: are simply a way to more sensibly group the numerous BBs within each Dimension
  - *Examples of building blocks across each dimension are shown in* Figure 6
- **Scenarios:** internally consistent sets of BBs *within* each Dimension that are plausible and distinctive for ULEV deployment and use
- **Narratives:** An internally consistent set of Scenarios and their underling Building Blocks covering all Dimensions to enable a holistic assessment of ULEV mass-market deployment and use and potential trade-offs.
- **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 qualitatively assessed metrics.

[3] The initial catalogue of BBs is provided as part of Deliverable 4.1.

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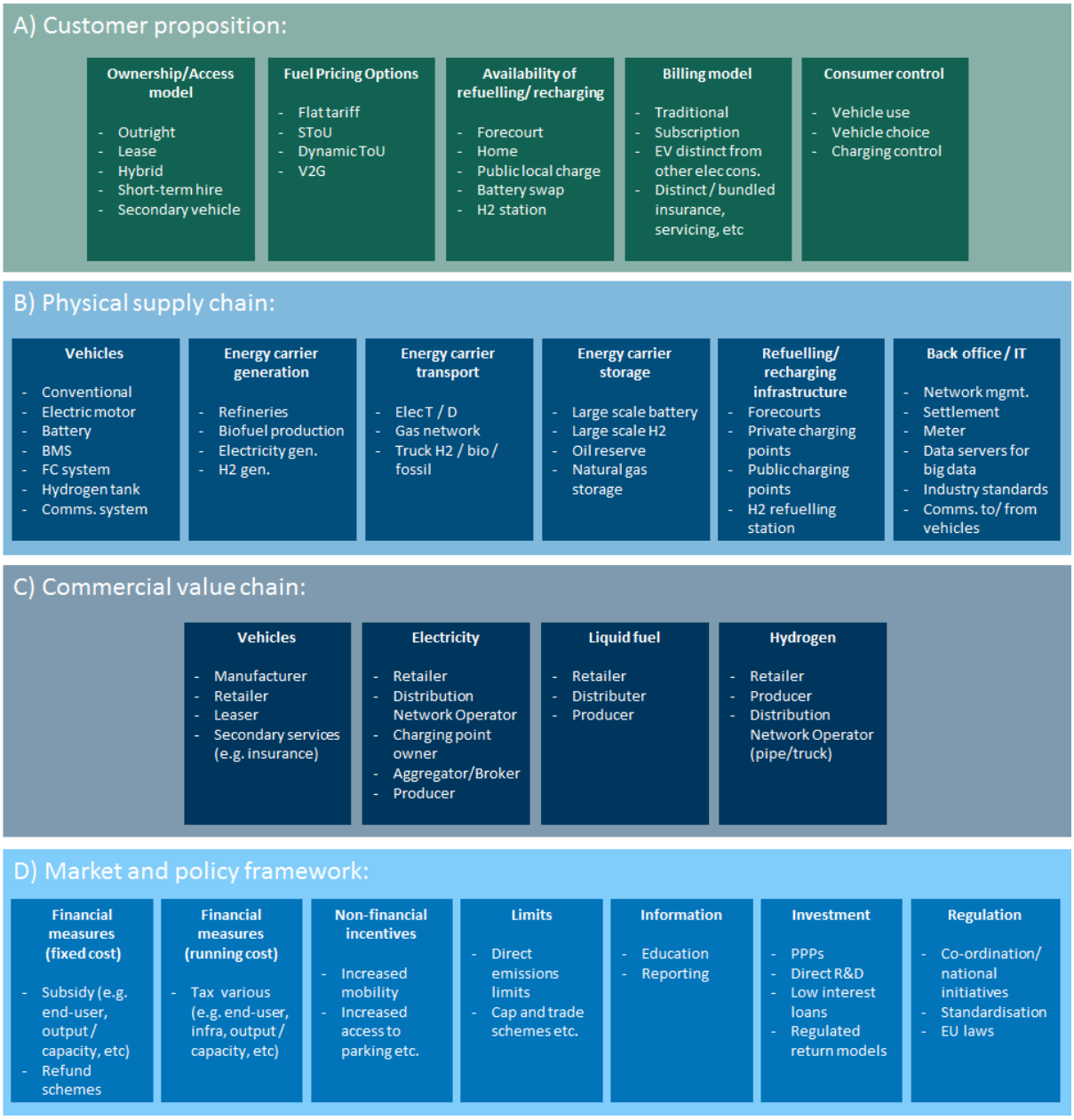
Figure 6 Overview of Dimensions and categories used to define example BBs



These definitions and how they relate to each other are illustrated in Figure 7. Proposed Narratives, Scenarios and Success Metrics are discussed in more detail in section 3.

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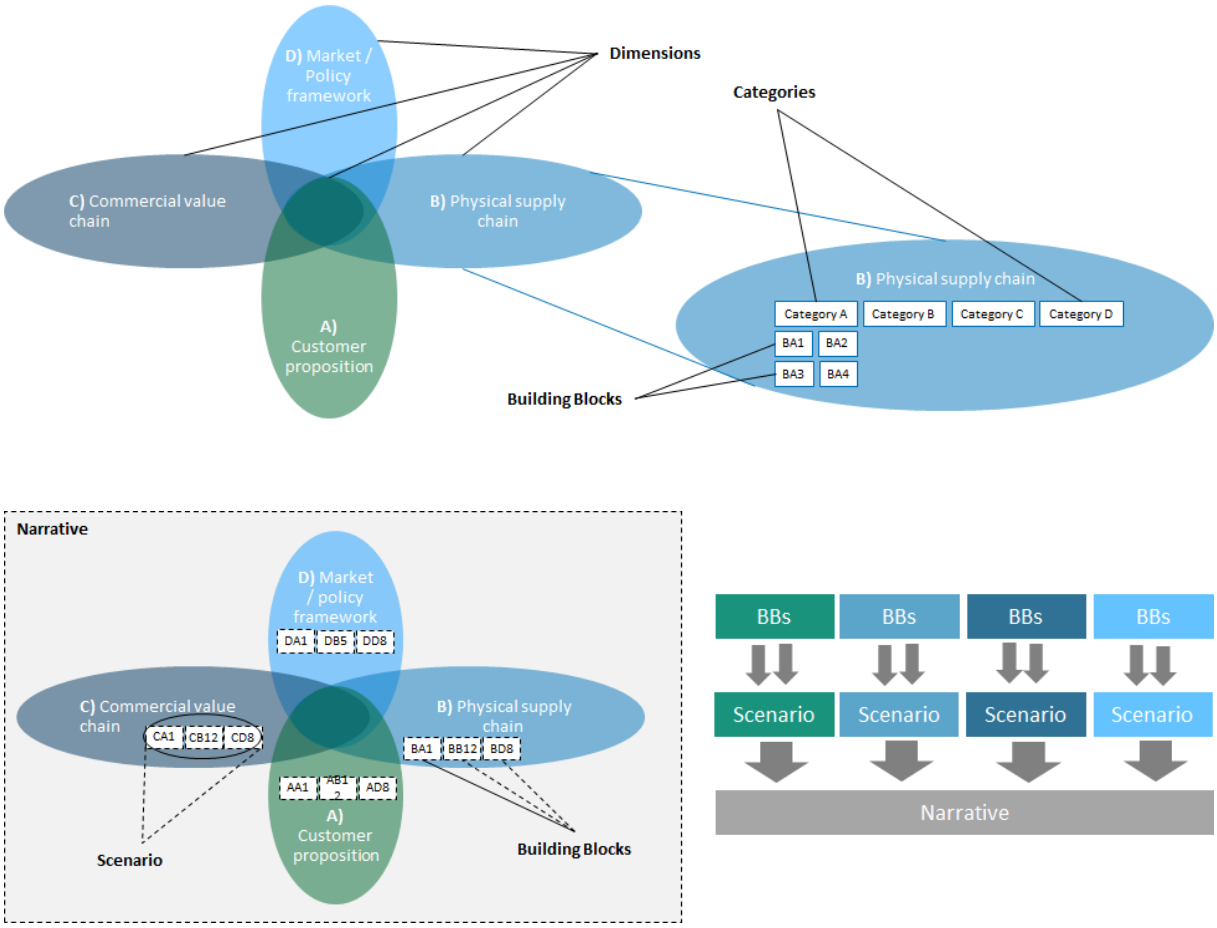
Figure 7 Illustration of concepts



2.3 Multi-Criteria Analysis and Success Metrics

A subset of all possible BBs and their associated states or values (e.g. the cost of a ULEV or the level of subsidy) will be used to define the tangible components of each narrative. The ultimate aim of the Analytical Framework is to compare the proposed Narratives against each other (and in particular against the "Business as Usual" 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).

Our assessment is, however, complicated by two issues

- Even within an individual Narrative the underlying Dimensions are sufficiently different that they cannot be assessed using a *common* metric or currency

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- 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 a 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 3.12.

Further discussion of how these success metrics are considered collectively to assess different Narratives against each other is discussed further in section 10.1.

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Table 3 Quantitative metrics

Dimension	Metric(s)	Description	Unit	Rationale
Customer Proposition	ULEV use	– Maximises proportion of total vkm (of consumers and fleets covered by scope of this study[4]) that is undertaken with an ULEV	%	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
Physical Supply Chain	CO2 consistent	– Meets overarching UK GHG targets (carbon budget and 2050) and is technically feasible[5]	MtCO2/year	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
Commercial Value Chain	Commercially viable	– Net undiscounted cashflows *over the pathway* for all commercial entities sufficient to provide required profit margin – And net undiscounted cashflow in *the final period of pathway* for all commercial entities sufficient to provide a required profit margin in the absence of Government support	£bn	Commercial entities must be viable over the pathway to 2050 (potentially with Government support) to deliver the required Customer Propositions and supporting infrastructure (e.g. given risks of asset stranding). They must also be ideally be self-sustaining over the remainder of their investment cycle beyond 2050 without the need for ongoing Government support In consideration with the qualitative metrics, a view will be formed as to whether incentives are likely to be

[4] I.e. does not include HGVs.
[5] I.e. reflects availability of technology across the pathway and maximum resource or deployment constraints.

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					sufficient to enable entities to invest
Market and policy framework	'UK Plc' appropriate spending	–	Net 'socially discounted' Government cashflows over the pathway (for tax, subsidy and investment measures) associated with the consumer/fleet vehicle parc are consistent with those seen today, normalised as a % of GDP, subject to: ▪ Incremental spend on transport CO_2 abatement which is deemed cost-effective from a societal resource cost perspective ▪ Reduction in other societal costs where these can be easily monetised e.g. AQ damage costs[6]	% of GDP	Government cashflows directly associated with transport are harder to separate from wider government objectives as not all revenue is hypothecated. This metric reflects a simple proxy for the broad maintenance of existing revenues, subject to increases where there is a demonstrable and monetisable societal benefit driven by ULEV uptake. It also aims to capture issues such as how to replace liquid fuel taxation with alternative sources

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 and of charging and fuelling times) as a result of mass deployment and use of ULEVs (e.g. for either ULEV or non-ULEV owners, or urban versus rural)
	Consumer protection	The market for transport services should protect consumers from exploitation

[6] As per Treasury Green Book guidance https://www.gov.uk/guidance/air-quality-economic-analysis

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Physical Supply Chain	Security of transport supply	The energy / transport system must be able to reliably deliver energy transport service when required by consumers
Commercial Value Chain	No un-investable risks	Even where a business model produces a profit margin, it must not entail risks which a reasonable investor would be unwilling to accept
	No insurmountable barriers to entry/exit	Any new business model assumed must not entail barriers (capital, organisational or operational) which are insurmountable
Market and policy framework	Wider impact on UK economy	Potential impact on e.g. jobs, innovation, competitiveness, developing domestic supply chain
	Consistent policy signals	The policy framework does not incentivise behaviour which is counterproductive with respect to other policy objectives or risk of unintended consequences (e.g. increased congestion or asset stranding) and ensures that the linkages between transport and the wider energy system are appropriate to facilitate deployment and use (e.g. price signals)

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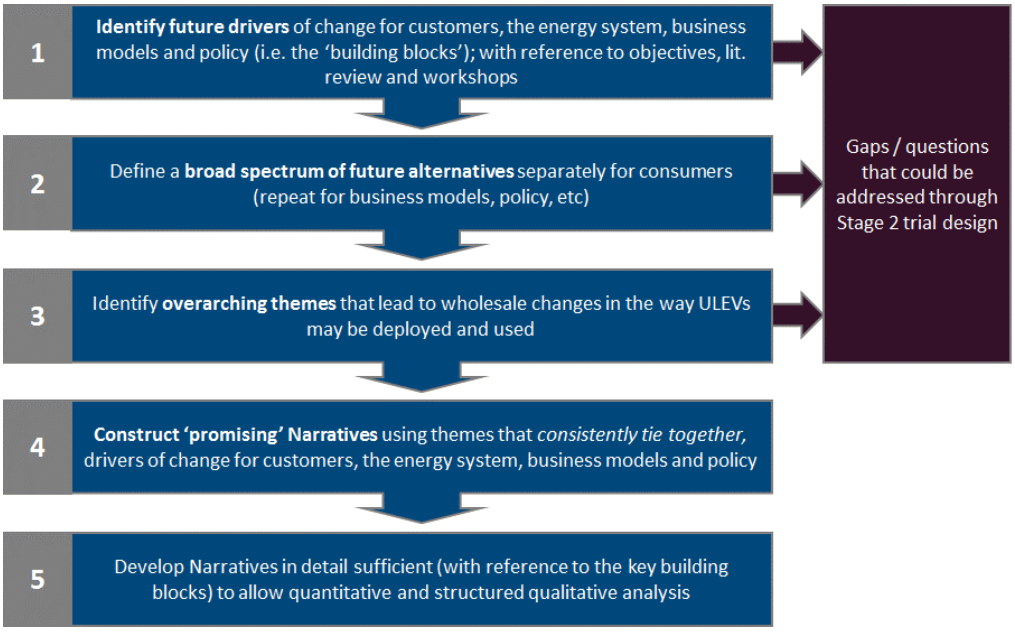
3 Narrative design

3.1 Approach to structuring

In general terms, the Narratives define alternative environments, encompassing physical, commercial, policy and customer factors, in which ULEV deployment and use takes place. In more specific terms, they are internally consistent sets of scenarios, themselves internally consistent sets of building blocks, collectively providing the assumptions necessary to undertake an analysis of ULEV deployment and use. For practical purposes, the narratives will provide structure to the analysis to be undertaken, and facilitate interpretation of the evidence and results arising.

The approach to developing the Narratives is outlined in Figure 8.

Figure 8 Approach to development of Narratives



This section documents the approach described, and describes the Narratives resulting. During the development of the Narratives (and supporting Building Blocks in D4.1) three workshops were held to help draw on insights from the wider 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.

*Note that this section should be read in conjunction with **Deliverable D4.1 section 7** which provides a more detailed mapping of individual Building Blocks to both Scenarios and Narratives; to provide a more complete picture of what is each Narrative represents.*

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3.1.1 Insights from literature to frame Narratives

The review of literature as part of this deliverable and D4.1 has provided a significant volume of information targeted around specific groups of Building Blocks, such as the development of particular technologies (PIVs versus FCVs), the economics of different vehicle types, and consumer surveys / trials. The results of the review are summarised for each of the Dimensions in Section 3.12, and captured in detail in D4.1 and its supporting 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 wide-spread 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 must 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" is the default Government position?*
  - *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 fuel cell vehicles?*
  - *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 capex of the vehicles)?*
  - *Is this more viable in some areas than others (e.g. urban)?*

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- *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)?*

3.2 Scenarios

Scenarios represent a set of Building Blocks with particular values combined to create an internally consistent and distinctive environment for ULEV deployment and use within a Dimension. A Narrative is a set of four Scenarios, one within each Dimension, chosen to be consistent with each other and the overarching themes of the Narrative.

To develop Scenarios, within each Dimension a set of thematic pairs were identified with the potential to describe different environments for ULEV deployment and use. Where appropriate, these pairs were grouped according to the Categories in each Dimension. Scenarios were then outlined by combining different states across these pairs. The pairs identified in each Dimension are set out in Figure 9 to Figure 12.

Figure 9 Customer Proposition scenario thematic pairs

BB category	Customer proposition scenario 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

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Figure 10 Physical Supply Chain scenario thematic pairs

BB category	Physical supply chain scenario 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 11 Commercial Value Chain scenario thematic pairs

Commercial value chain scenario 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

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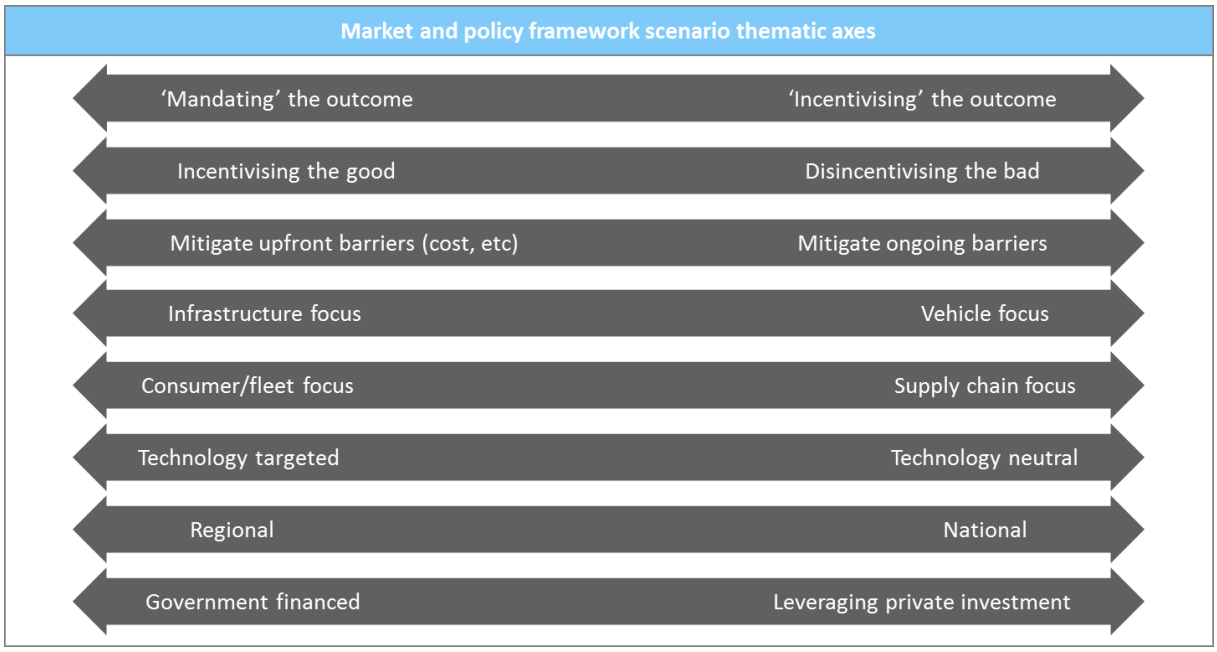
Figure 12 Market and Policy Framework scenario thematic pairs



Using this approach, a number of Scenarios were outlined in each dimension, including in all Dimensions a Business as Usual (BaU) Scenario and a radically different "On demand" Scenario, based on short term rental of vehicles. These are summarised in Figure 13, and have only been developed in more detail where selected to form part of a Narrative, as outlined in sections 3.5 to 3.10.

Figure 13 Scenarios summary

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

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3.3 Narrative development

3.3.1 Framework development

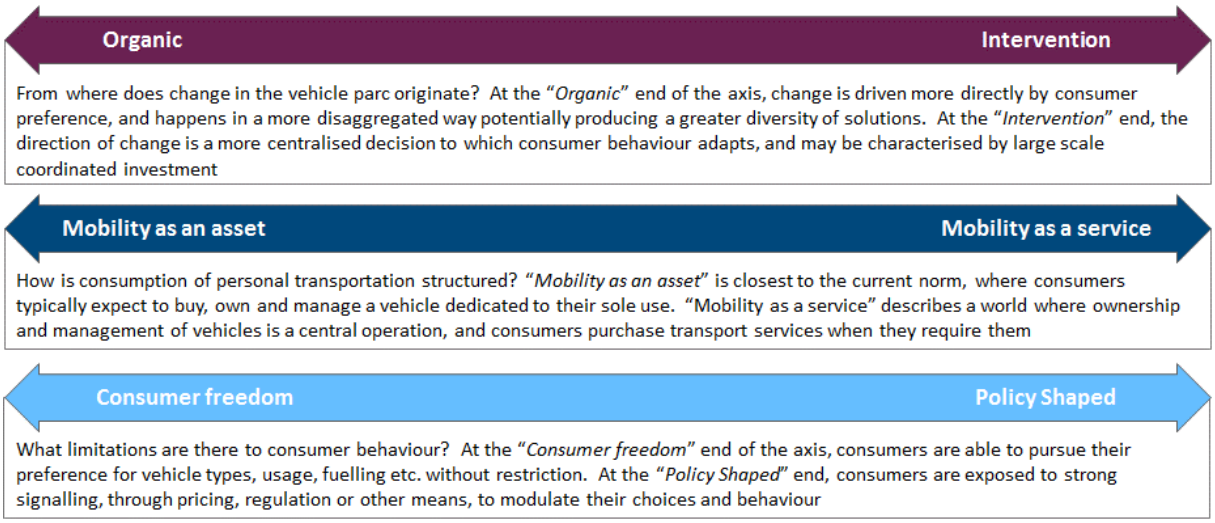
Approach to shaping the Narratives during the scoping phase

Narratives describe the overarching environment for ULEV deployment and use, and imply within each Dimension a Scenario consistent both with the scenarios in the other dimensions, and with the overall themes of the Narrative. Our 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 Building Blocks and the Scenarios then provide a clear and systematic structure to define what is contained within each Narrative given the breadth of issues under consideration across each of the dimensions.

These axes were developed within the Project Team through workshops, informed by the Building Block analysis and then refined through consultation with the ETI and their affiliates. 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 overarching thematic axes are illustrated in Figure 14*, followed by the process for refining this initial set to create the final themes used to define the Narratives in* Figure 15.

Figure 14 Initial Narrative overarching thematic axes



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

- **Mobility as an asset <> Mobility as a service:** 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

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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*

- **Organic <> Intervention:** this axis directly drives distinctive narratives from a policy and market 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*
- **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*

Final narrative themes

The thematic axes as defined for further development are illustrated in Figure 15. Also listed here are ***example characteristics*** of the Scenarios in each Dimension that would be consistent with the themes at each end of the axis.

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Figure 15 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 as broad a space as possible. As discussed, this is important to enable a holistic assessment, using contrasting alternative Scenarios making use of different BBs. This will then enable comparisons to be made and identification of those BB's that characterise efficient environments for ULEV uptake and use.

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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.

3.3.2 Principles

A set of principles will be adopted in the development of the Narratives, as set out below, to ensure they are consistent and useful tools to aid analysis of strategies for promoting ULEV deployment and use.

1. Narratives should be plausible and internally consistent, such that all the underlying Scenarios could plausibly exist simultaneously
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 (see next section)
5. Narratives should represent different strategies by policy makers and / or industry participants to influence ULEV uptake, rather than different market conditions outside their influence (such as international commodity prices)
6. Narratives should assume that significant technology development and availability is driven at a global level[7], and is common across narratives – with variations tested as sensitivities
7. Narratives should meet UK targets for CO_2 reduction
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. transport 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 constructed 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 proposed to be tested by sensitivity rather than drive differences in the narratives themselves. This will be used to explore how resilient a given ULEV strategy is to these changing external conditions and where some narratives are more sensitive to these changes than others.

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

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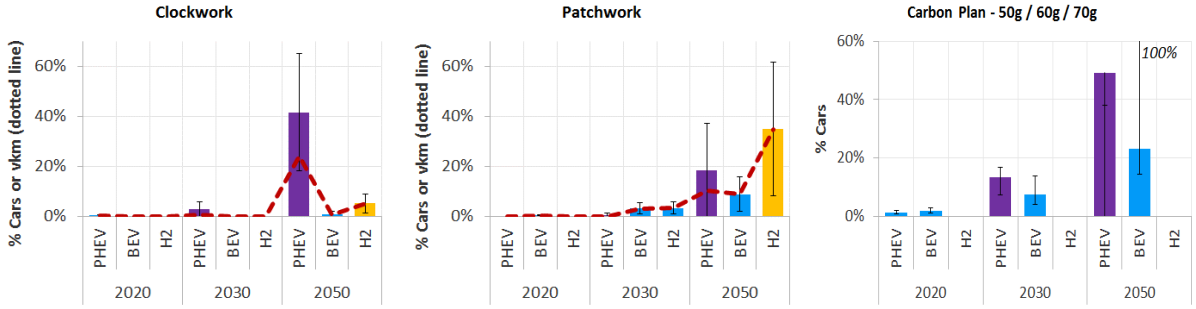
3.3.3 Framing ULEV uptake levels

In order to ensure a common understanding of "mass deployment and use", it is informative to refer to other comparable studies which have considered ULEV deployment and use. Figure 16 illustrates ULEV deployment outputs (in terms of % of the car vehicle parc) for ETI's Clockwork and Patchwork scenarios, and the UK Government's Carbon Plan. 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 shows the share of vkm, scaled to the share of electricity consumption in the case of PHEVs

Figure 16 ULEV deployment and use in comparable studies



Note: The dashed line in the Patchwork / Clockwork scenarios shows the share of vkm, scaled to the share of electricity consumption in the case of PHEVs

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%-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 will help shape expectations within broad ranges, for example:

- BaU is likely to reflect up to ~30% vkm by ULEVs driven primarily by EU regulation on new car/van fleet averages
- Those Narratives or sensitivities exploring the conditions necessary for very high deployment and use are likely to represent >75% vkm ULEVs
- The remainder of the Narratives are likely to be within the range of 30%+ to 75% vkm by ULEVs, but concentrated more around the mid-point of this range

Role of EU car and van CO2 standards in driving ULEV uptake

A significant driver in likely future uptake of ULEVs is the EU regulation for new (fleet average) performance standards for cars and vans. These are currently set to 95 gCO_2/km for cars by 2021 and 147 gCO_2/km for vans. In 2014 the EU parliament approved an indicative target of 68-78 gCO_2/km for cars by 2025, but future targets have not yet been finalised. The car industry's expectation is for a target of around 75 gCO_2/km for cars to be set by 2030 to allow industry more time to adapt, with a potential commensurate improvement for vans.

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As outlined in section 9.1 it is proposed to reflect a linear improvement in the current targets from 2020/21 to 2030, of 75 gCO_2/km for cars and 120gCO_2/km for vans, but hold these constant from 2030 to 2050. From separate modelling work by Element using ECCo this leads to ULEV uptake (in terms of number of vehicles in the parc) of around 30-35% by 2050. These targets would be applied consistently across the BaU and other Narratives described in section 3.4, and hence the Narratives would focus on the impact of domestic policy on top of this.

3.4 Summary of Narratives and high level questions posed

Using the overarching thematic axes developed in section 3.3.1, and the principles in section 3.3.2, a set of Narratives have been developed, as described below. As discussed, by using contrasting Scenarios employing alternative BBs in these Narratives, the results can be compared to draw out conclusions about the role of individual 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:

- **OEM innovation** *(organic action / mobility as an asset)*: vehicle OEMs make ULEVs attractive to consumers, by increasing vehicle range, performance and 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[8]). Proprietary motorway charging networks complement the dominant mode of home charging.
  - *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 this complicate the delivery of new large-scale supporting infrastructure, in particular with respect to the role of hydrogen?*
- **City led** *(organic action / 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 in depots.
  - *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** *(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?*

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

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- *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** *(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 ICEs and liquid refuelling infrastructure?*
  - *Is this route materially more expensive compared to other Narratives (such as City-led and Transport on demand) 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?*

- **Transport on demand** *(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-led 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)?*

This structure is summarised in Figure 17. Suitable scenarios matching the characteristics of these narratives are also identified.

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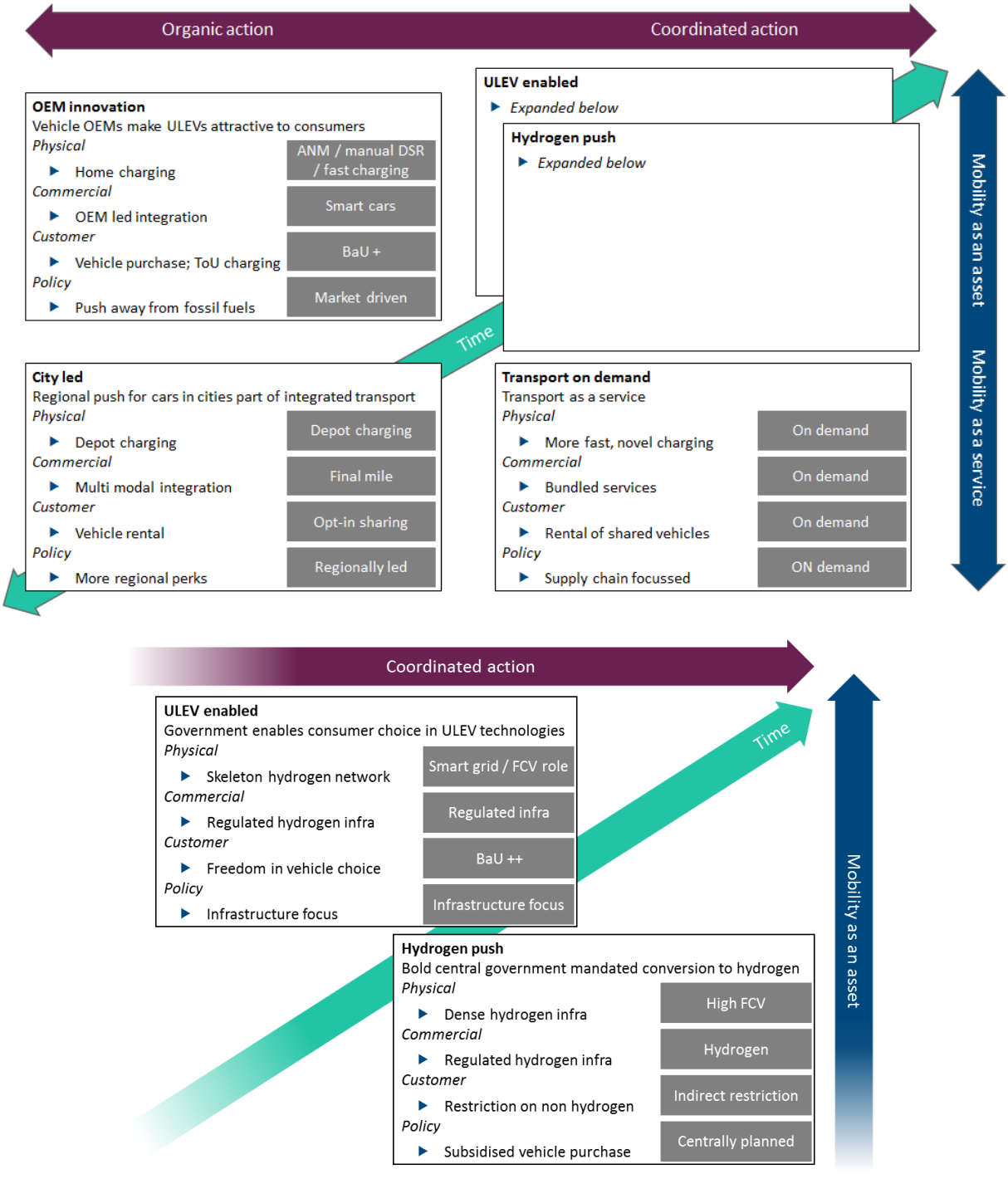
Figure 17 Narrative summary



A number of factors will need to be considered under all the narratives.

- **Time:** the degree to which mass deployment and use of ULEVs is sought in the earlier years of the modelled time horizon.

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- **Fossil fuels:** the evolution of conventional vehicles and the fossil fuel system, interaction with ULEV deployment and use, and the sustainability of business models in this sector as volumes decrease.
- **Urban versus rural:** although this factor does not constitute an axis itself, as discussed in section 3.3.1, clearly transport choices in remoter areas are subject to different drivers from those in dense urban areas. Draw down of the fossil fuel system may also have a disproportionate impact on rural areas.

In addition to these, a Narrative representing continuation of existing conditions (BaU) will be 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 innovation (organic action / 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 Deliverable D4.1 (TR1006_D4.1) Initial Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure. Section 7 of D4.1 provides a detailed mapping of how individual Building Blocks (BB) and scenarios in each dimension are used to provide the foundation of each narrative, as the descriptions below provide a snapshot of each.

The following sections provide further context for the Narratives. It is anticipated that in practice, some details of the narratives will be adjusted in order to provide results which enable meaningful comparison.

3.5 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 to premium and niche sectors of the vehicle market. Lower decarbonisation is achieved in the transport sector relative to other narratives, meaning greater effort would be required in other sectors if targets are met.

In the physical supply chain, change to the energy systems is incremental. Limited deployment of hydrogen filling stations occurs on a commercially led basis, co-located at existing liquid fuel stations. 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 hence consumers have less visibility of price signals and minimal load shifting occurs.

The policy environment is moderately supportive for ULEVs, with limited grants available to support purchase and advantageous 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.

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The Scenarios used to help frame the Narrative, and a summary of the themes driving them, are outlined below, and the specific Building Blocks used within each Narrative are described in Deliverable D4.1 Section 7.

Figure 18 Scenarios used within Narrative

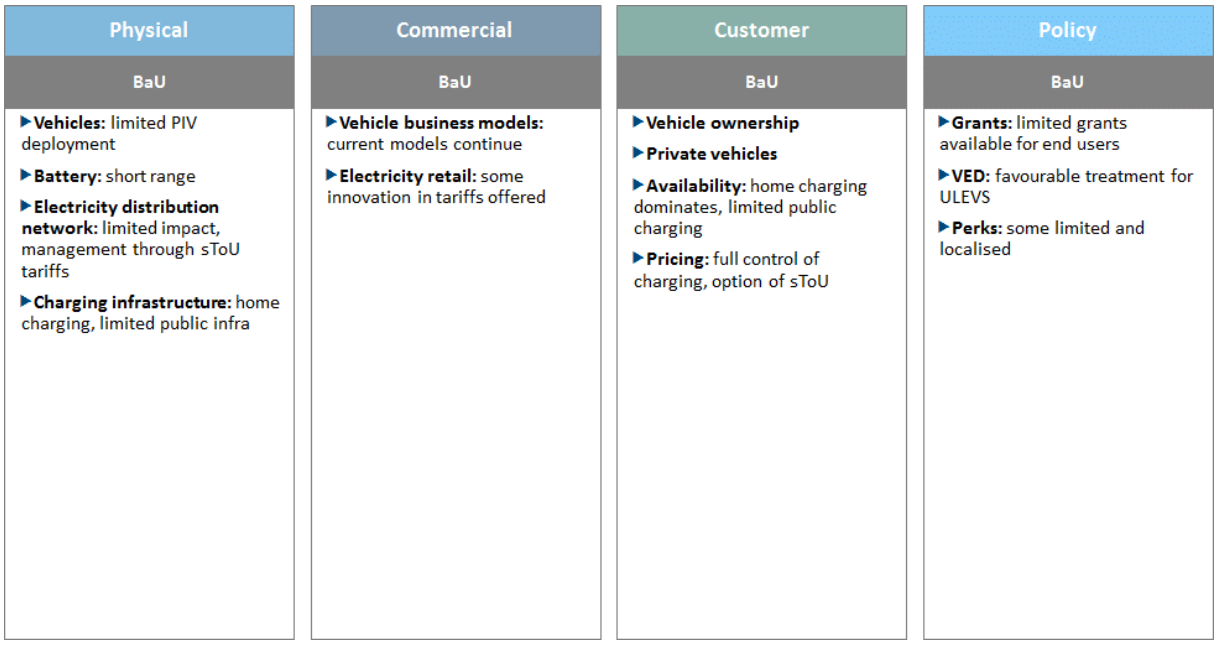
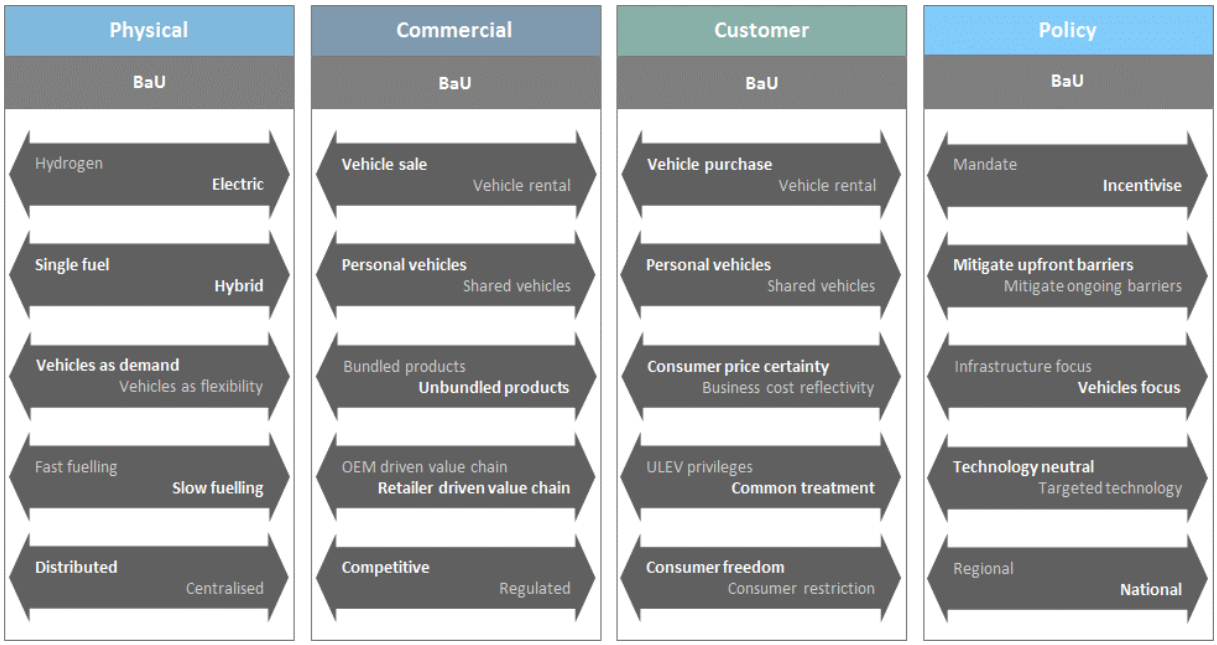


Figure 19 Scenario themes used within Narrative



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3.6 OEM innovation

The OEM innovation narrative is one where manufacturers lead change by producing innovative ULEVs with increased range and performance, 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, 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, although a limited rapid charging network exists. Impact on the electricity system is moderated through widespread adoption of static ToU tariffs, though the disaggregated provision of infrastructure means more advanced options for integration (dynamic ToU and ANM) 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.

Customers 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 charging stations to facilitate longer journeys, though as not all manufacturers' equipment is interoperable most use a traditional pay-per-unit billing model. V2H charging allows consumers to power their homes with their vehicle battery when required.

Policy at a central government level is directed at pushing buyers away from conventional vehicle purchase, for example through differential rates of VAT and fuel duty. Consumers may also receive private grants from OEMs towards the capital cost of their vehicle or charging point, and part exchange schemes for old batteries.

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 EV charging; and bundling services which drivers had previously obtained separately, such as insurance.

The Scenarios used to help frame the Narrative, and a summary of the themes driving them, are outlined below, and the specific Building Blocks used within each Narrative are described in Deliverable D4.1 Section 7.

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Figure 20 Scenarios used within Narrative

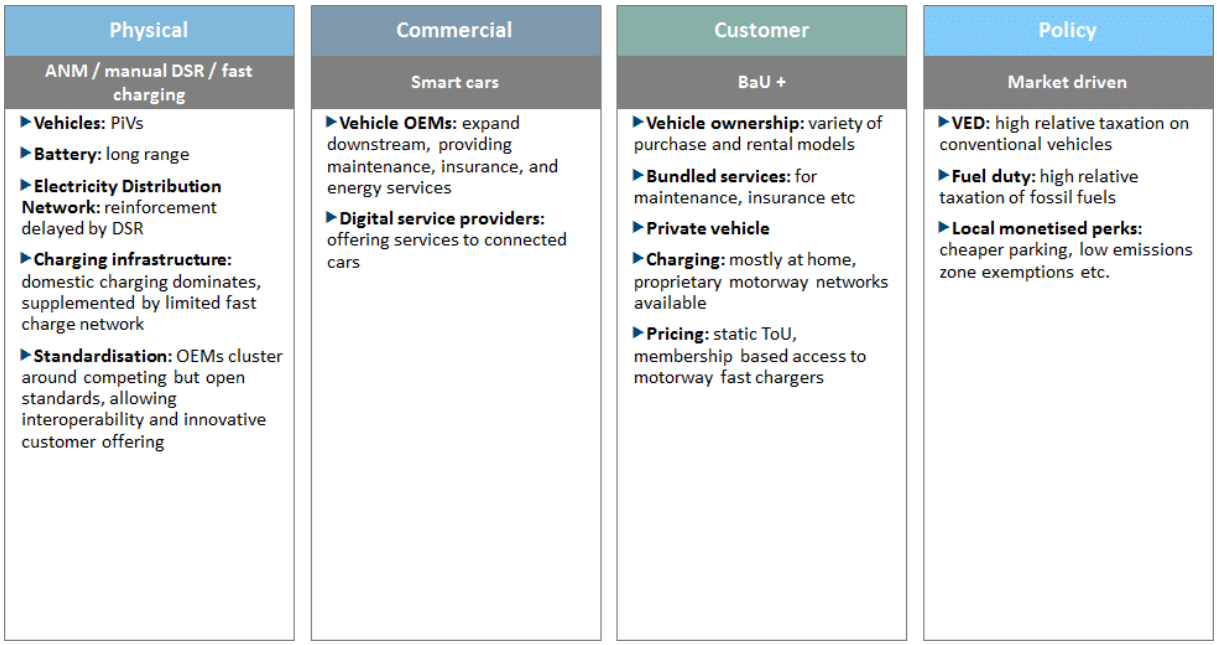
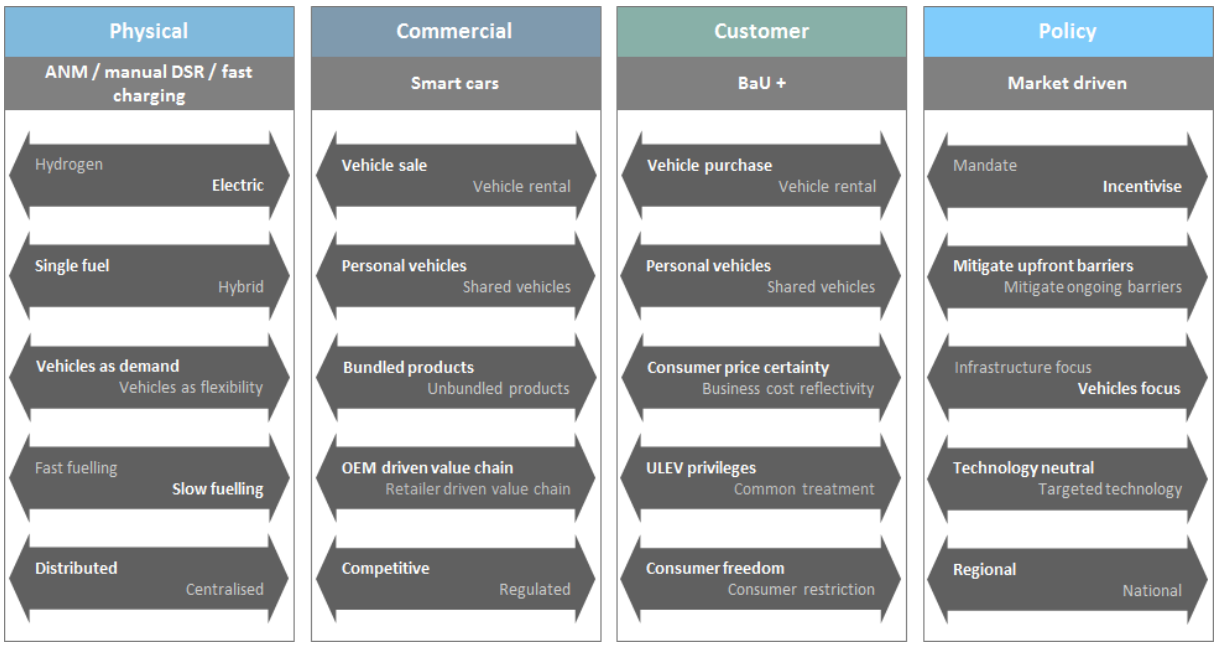


Figure 21 Scenario themes used within Narrative



3.7 City led

The dominant theme of this 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.

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In the physical supply chain, 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 production, and at public hubs. Where fleets are PiV based, the more concentrated nature of charging facilitates dynamic Time of Use (ToU) tariffs[9], demand management of vehicle charging and ANM, though flexibility is somewhat curtailed by the greater utilisation of vehicles. Some modal shift and greater sharing occurs for intercity journeys, and vehicle users in rural areas tend to opt for PHEVs.

Private purchase of vehicles becomes much 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 more, 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 horizon, measures such as preferential access to 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 and fuel duty

From a commercial perspective, the most notable change versus current or Business as Usual 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 Scenarios used to help frame the Narrative, and a summary of the themes driving them, are outlined below, and the specific Building Blocks used within each Narrative are described in Deliverable D4.1 Section 7.

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

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Figure 22 Scenarios used within Narrative

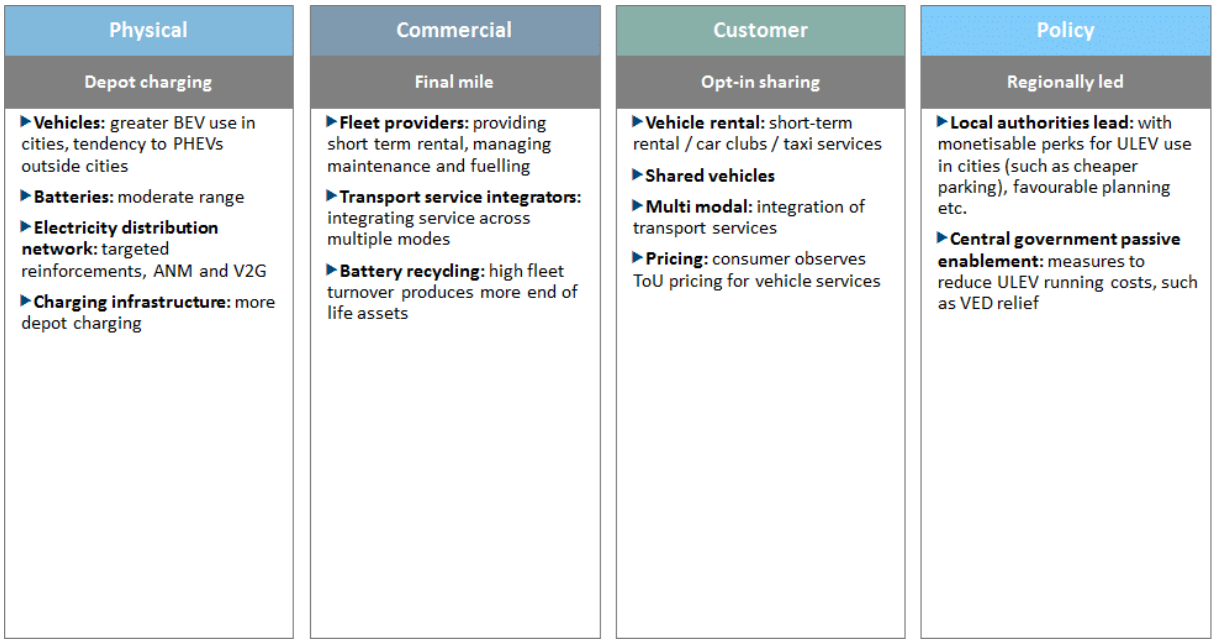
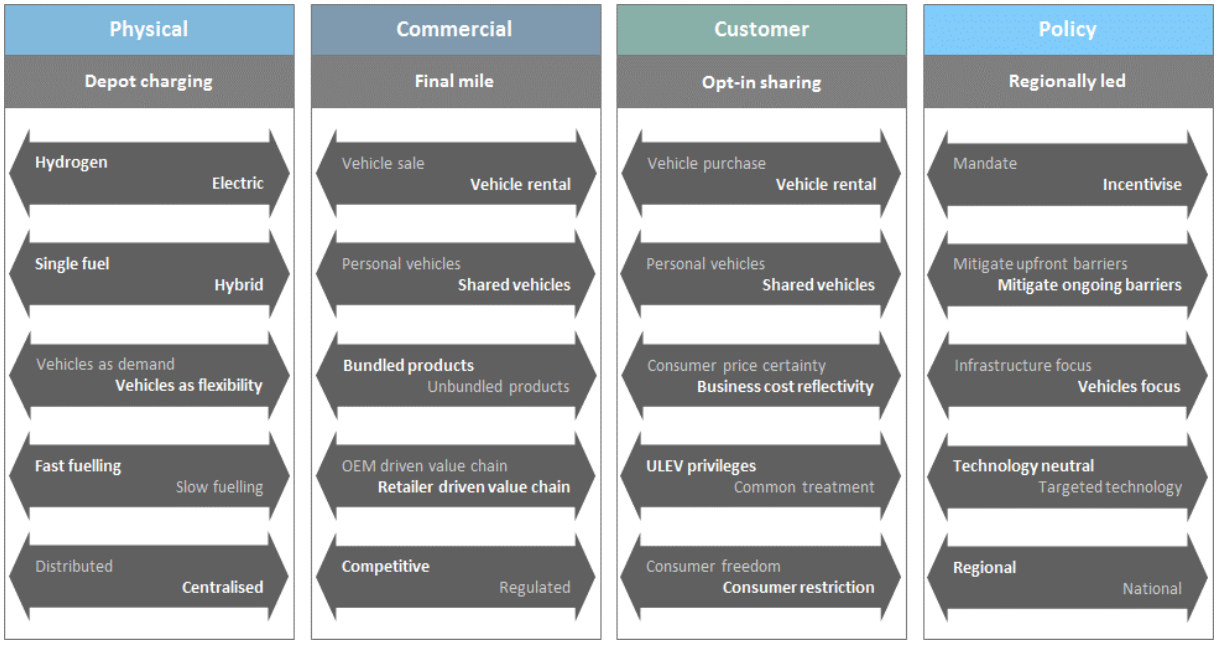


Figure 23 Scenario themes used within Narrative



3.8 ULEV enabled

The ULEV enabled 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.

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In the physical dimension, overnight charging is available to a significant proportion of users. DNOs use ANM to mitigate the impact on their network, 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 filling stations is available, co-located with liquid fuel forecourts, supplied by road tanker distribution in the short-term, transitioning to pipelines to forecourts as demand grows.

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 HFCVs, 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.

Regarding the commercial value chain, regulated business models support deployment of charging infrastructure and hydrogen networks in the longer term.

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Figure 24 Scenarios used within Narrative

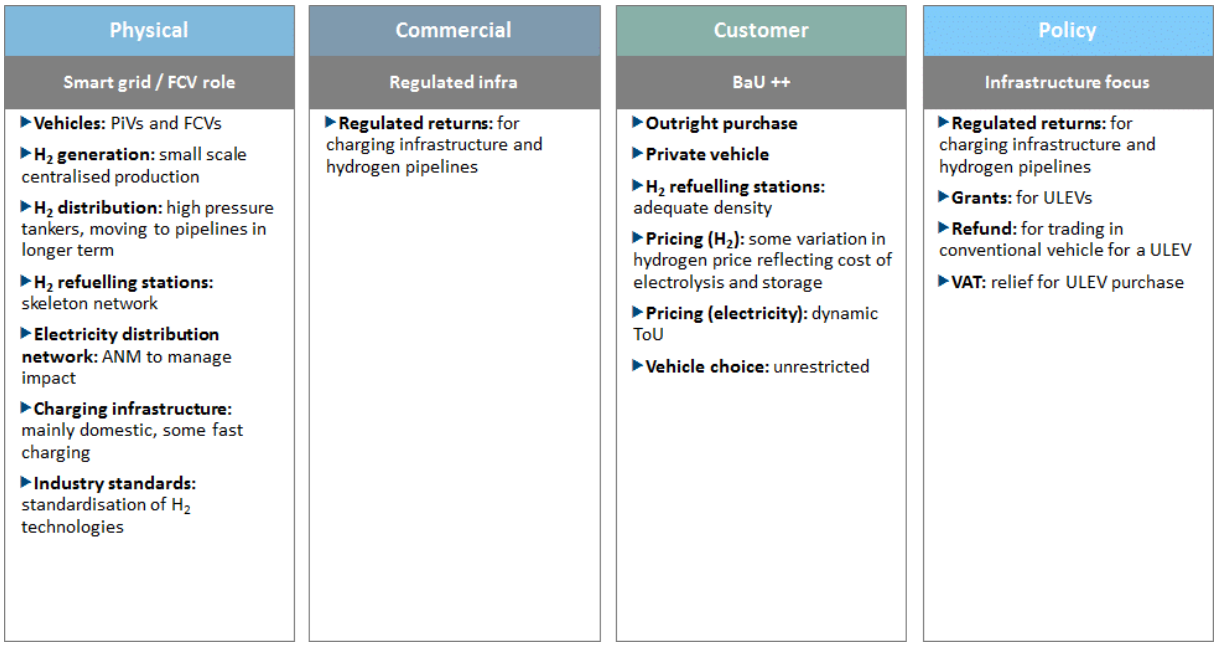
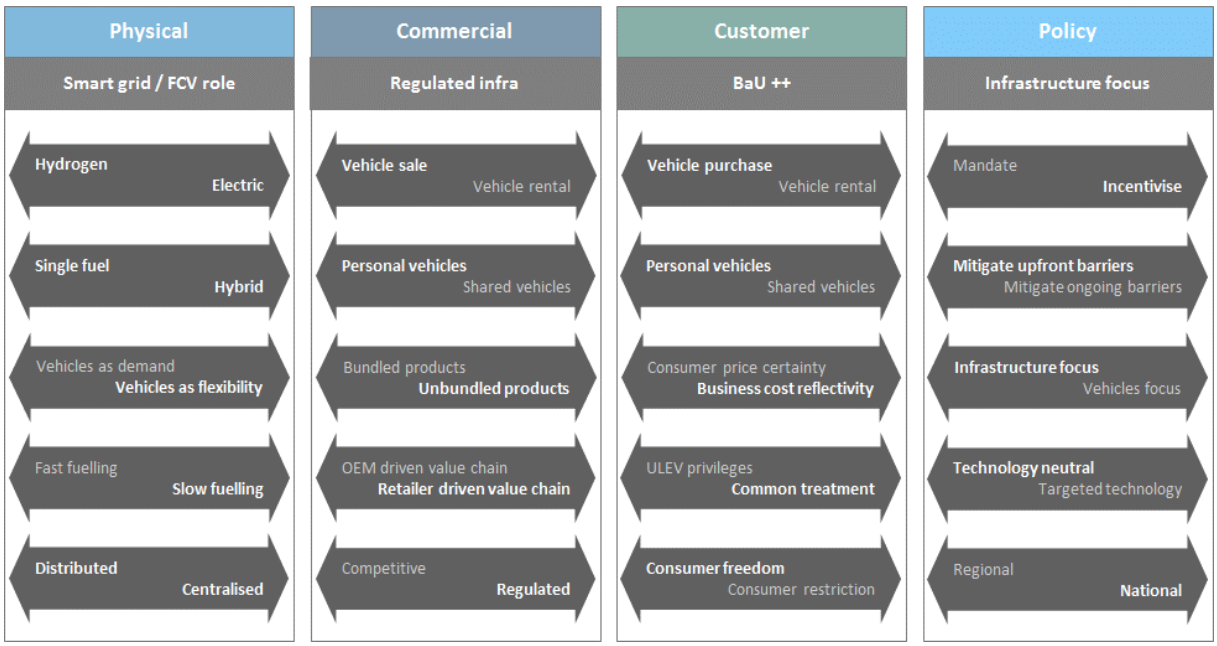


Figure 25 Scenario themes used within Narrative



3.9 Hydrogen push

Hydrogen push 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-enabled

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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, VAT and a scrappage bonus when exchanging a conventional vehicle. 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 Scenarios used to help frame the Narrative, and a summary of the themes driving them, are outlined below, and the specific Building Blocks used within each Narrative are described in Deliverable D4.1 Section 7.

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Figure 26 Scenarios used within Narrative

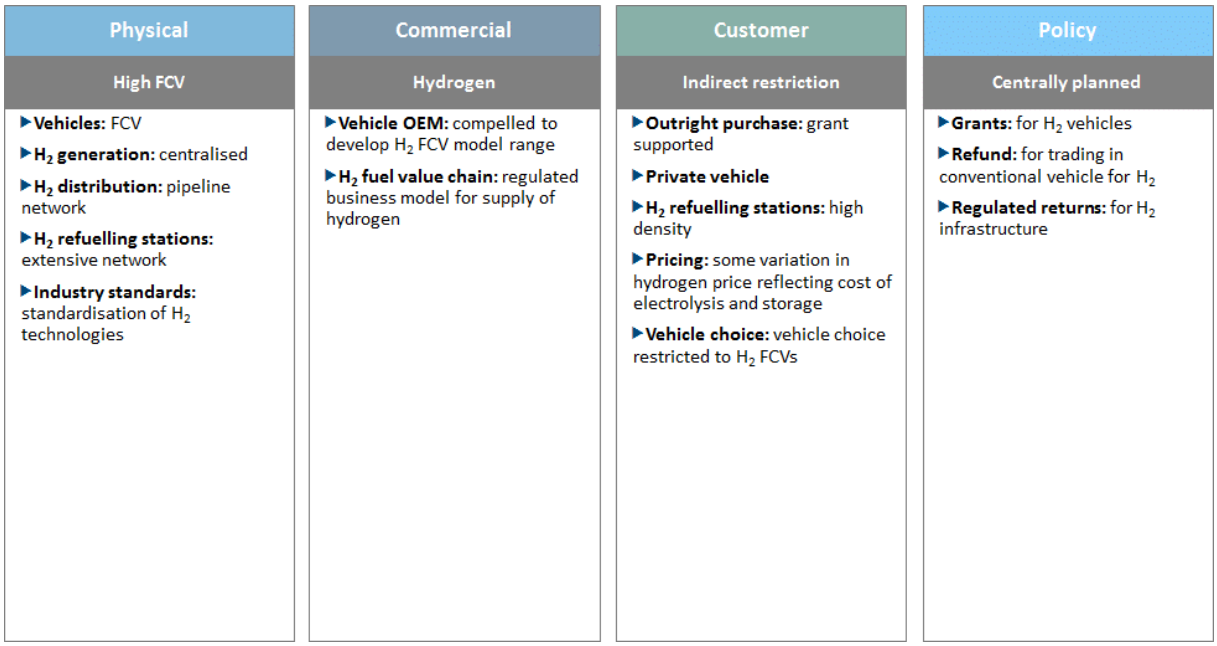
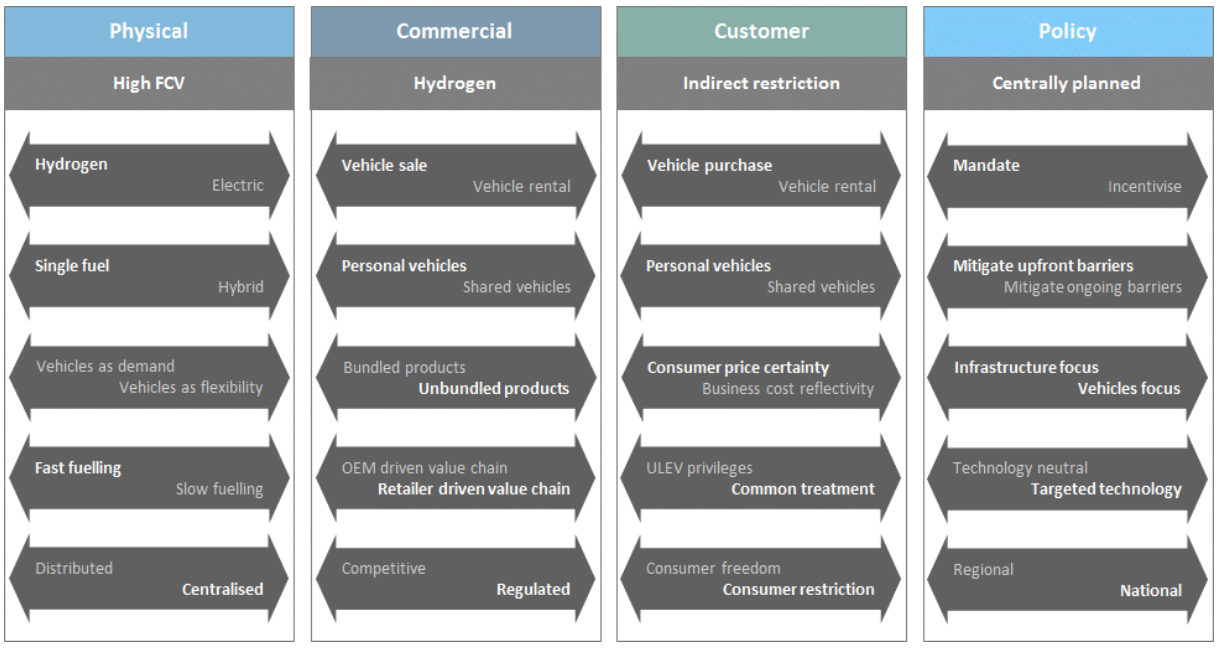


Figure 27 Scenario themes used within Narrative



3.10 Transport on demand

In this narrative, central government identifies that transition to a smaller, more intensively used low emission vehicle fleet offers significant benefits of reduced land use for transport, increased 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

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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 ANM and dynamic ToU charging, helping to moderate impact on the electricity distribution network. Standardisation provides the potential for novel and convenient charging solutions to be deployed (e.g. battery swapping), and for vehicle-to-vehicle communications and ultimately autonomous vehicles.

From the consumer perspective, private purchase of vehicles becomes very 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 at public locations and rapid charging points on the trunk road network rather than at homes.

In the policy dimension, a supportive regulatory framework underwrites creation of a dense national charging network, and subsidises the cost of electricity that it provides for mobility. Incentives focus on ongoing costs using 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 Scenarios used to help frame the Narrative, and a summary of the themes driving them, are outlined below, and the specific Building Blocks used within each Narrative are described in Deliverable D4.1 Section 7.

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Figure 28 Scenarios used within Narrative

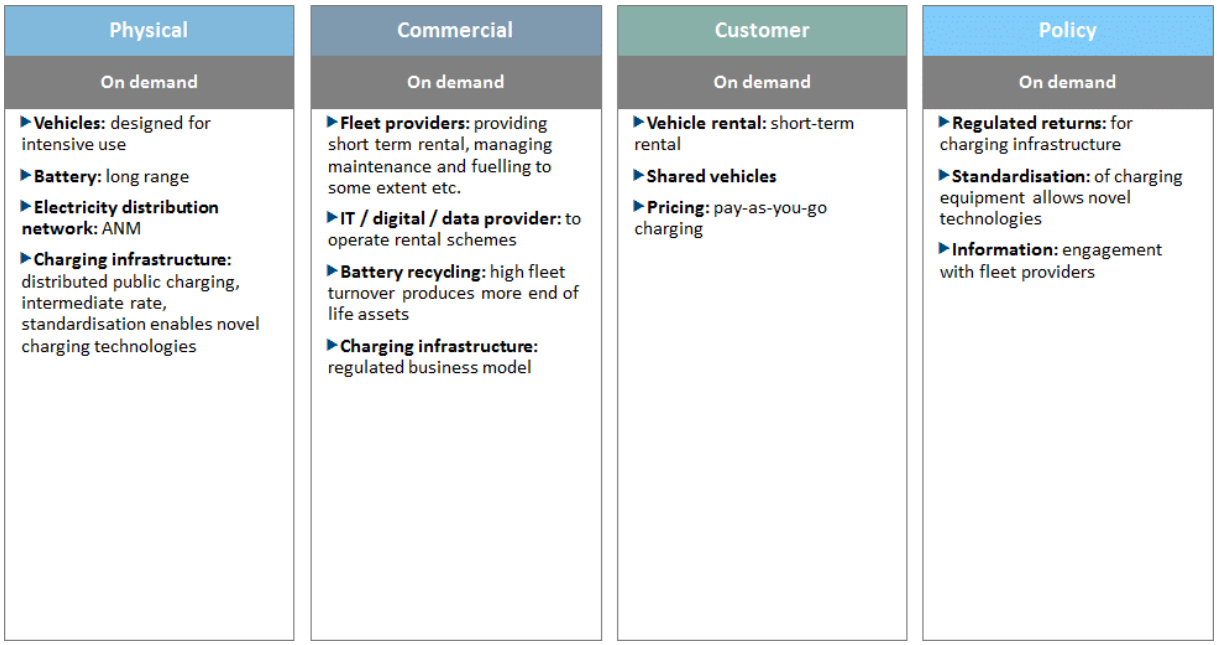
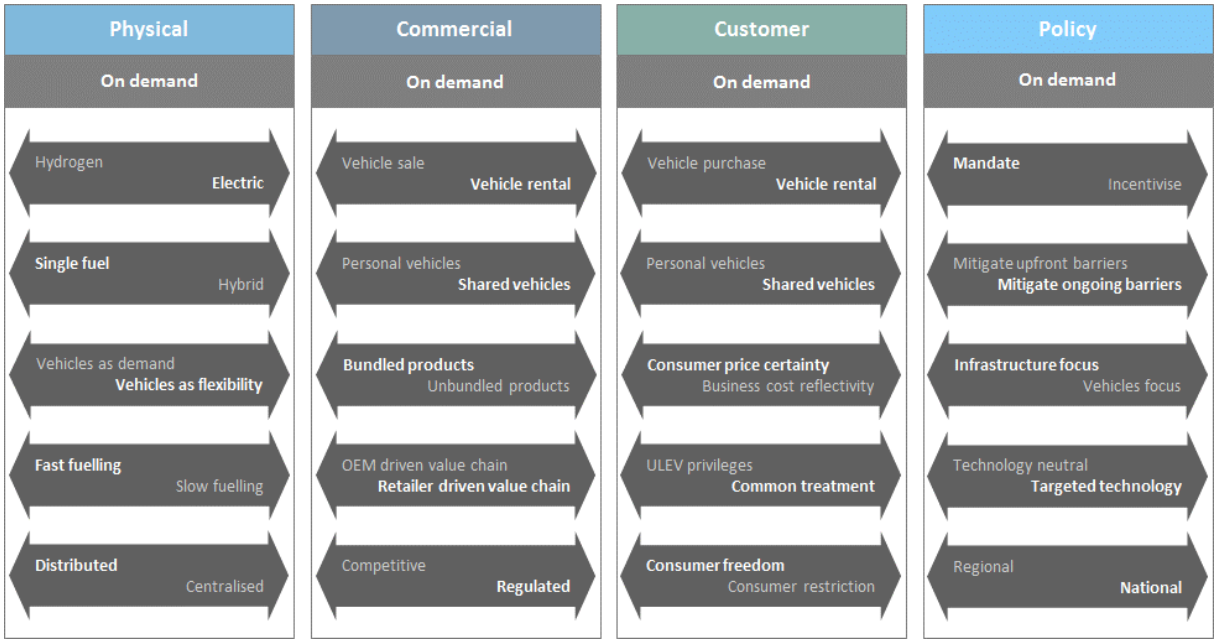


Figure 29 Scenario themes used within Narrative



3.11 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 Government, industry, or indirectly by consumers). Exogenous conditions that are outside of the control of these actors such as international fossil fuel prices or the development of cost-competitive and low carbon synthetic

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liquid fuels are proposed to be tested by sensitivity rather than drive differences in the Narratives themselves.

This will be used to explore how resilient a given ULEV strategy is to these changing external conditions (away from a 'central view') and where some Narratives are more sensitive to these changes than others.

A set of suggested sensitivities has been compiled from both the review panel and Project Team across the scoping phase of the project in Table 5. However, given the large number of potential Narratives/sensitivities it is proposed to target the sensitivities only where they are likely to provide more significant insights. In addition, some sensitivities may require more significant adjustments to the Analytical Framework or need to be included in a bespoke manner. The rationale for including the different sensitivities and for which Narratives is outlined in Table 5.

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Table 5 Proposed sensitivities

Sensitivity	Rationale	Narrative(s) focus	Materiality of impact on Analytical Framework	Complexity of including in Analytical Framework	Include
Degree of transport decarbonisation	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 CO2 target. This could be driven by e.g. a failure of CCS (or lack of availability of biomass in particular to generate negative emissions), or limited progress in decarbonising other sectors such as heat.	BaU H2 Push Transport on-demand	High	Medium	Y
Higher service demand for car vehicle km	Mobility as a service-based Narratives offer the most significant adjustments to the way vkm are delivered (even if overall vkm are similar to BaU). Higher service demand in these Narratives would help understand the extent to which this additional demand significantly complicates the delivery compared to mobility as an asset-based Narratives	Transport on-demand	High	Medium	Y
PiV costs and/or battery performance (range, degradation, etc)	Understand extent to which Narratives with high PiV deployment and use look 'worse' when coupled with no/low reduction in associated vehicle costs/battery range. In addition, for the ULEV enabled world, understanding the extent to which a less rapid improvement in PiVs significantly alters the case for 'hedging' across PiV/liquid, vs PiV/hydrogen outcomes	ULEV enabled Transport on-demand	High	Low	Y

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Sensitivity	Rationale	Narrative(s) focus	Materiality of impact on Analytical Framework	Complexity of including in Analytical Framework	Include
Liquid commodity prices/carbon content sensitivity (e.g. synthetic/bio liquid fuel)	Understand the extent to which lower commodity prices reduce the cost-effective scale of investment in transport abatement, or, the price point at which a "low carbon liquid" fuel would be able to compete with PIV/hydrogen outcomes whilst maintaining the same level of transport decarbonisation Most relevant for Narratives with modest, but not extreme ULEV deployment and use to more realistically explore potential costs (primarily in terms of Government intervention) of 'getting it wrong'.	ULEV enabled	Medium	Low	Y
Hydrogen vehicle costs	Understand extent to which Narratives with high hydrogen deployment look 'worse' when coupled with a slower reduction in associated vehicle costs	H2 Push	High	Low	N
Repurpose gas grid for H2 to buildings	Understand the extent to which this significantly changes the economics of Hydrogen ULEVs given the wider implications for the energy sector and that distribution costs for hydrogen are potentially a smaller component compared to hydrogen production and vehicle costs. Most relevant for high hydrogen Narratives.	H2 Push	Medium	High	N – Value in repurposing gas grid is heavily dependent on choices for providing building and industrial heat and hence it is difficult to provide an effective point of comparison with other Narratives focused primarily on direct ULEV issues.

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Sensitivity	Rationale	Narrative(s) focus	Materiality of impact on Analytical Framework	Complexity of including in Analytical Framework	Include
Consumer attitudes	Understand the impact of more intangible aspects of attitudes to ULEV uptake (e.g. beyond costs, range limitations) More material for Mobility as an Asset-based Narratives.	ULEV enabled	Medium	Low	N – Already considered within ECCO tool and not a material constraint on ULEV uptake from ~medium term onwards. Sensitivity values could be informed by Stage 2 trial data so better to test once these are established
High Distributed Electricity Generation	The link between more distributed electricity generation and uptake of ULEVs appears less direct (than that for localised hydrogen production going only to transport) given the wider demands for electricity.	ULEV Enabled	Low	High	N

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3.12 Summary of Narratives

A pictorial summary of the key themes and components of the Narratives is provided in Figure 30, along with a summary of the higher level thematic questions that the Narratives will help to explore, by tying together insights and conclusions from across the Narratives (see Figure 31).

It is important to note that these questions are *in addition* to the primary assessment of what "good solutions looks like" for each of the Narratives, via the use of the quantitative and qualitative success metrics (see section 2.3). Furthermore, these questions are *separate* to the specific gaps and research questions that have been identified that could potentially be addressed through elements of the Stage 2 Trial. The trial-specific questions are summarised in section **Error! Reference source ot found.** and subject to further development as part of the other Work Packages in Stage 1 of this project.

Figure 30 Summary of Narratives components

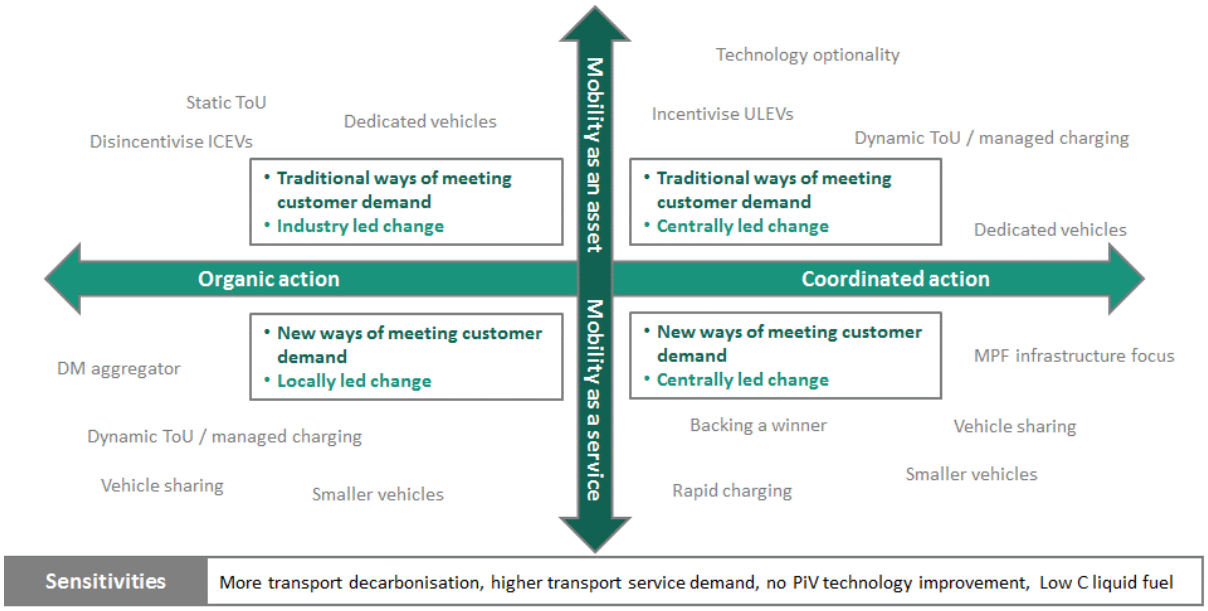

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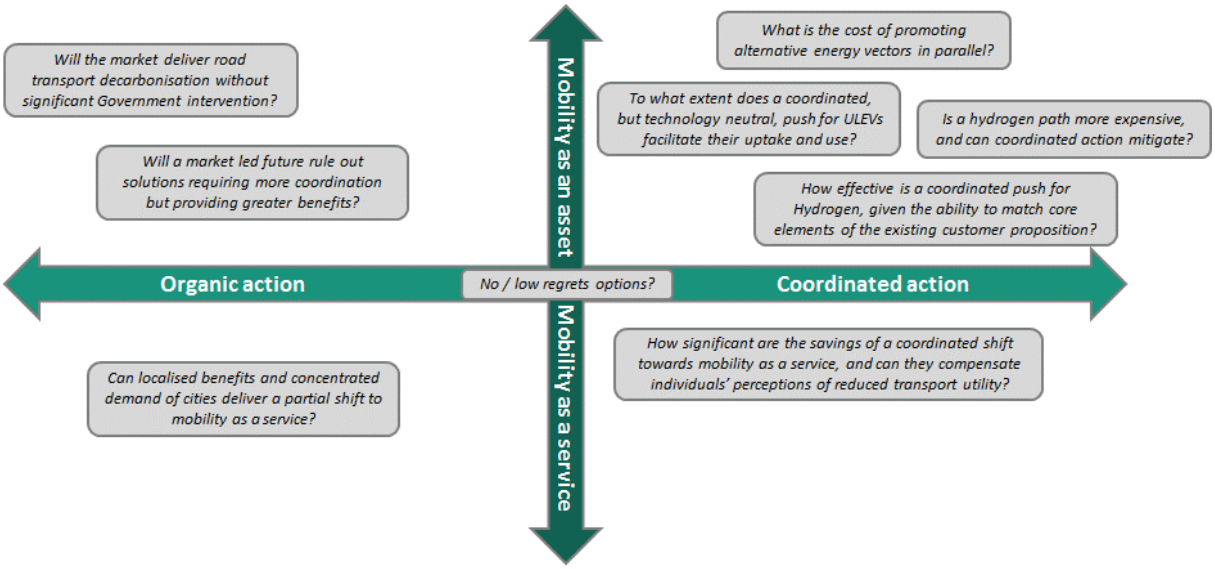
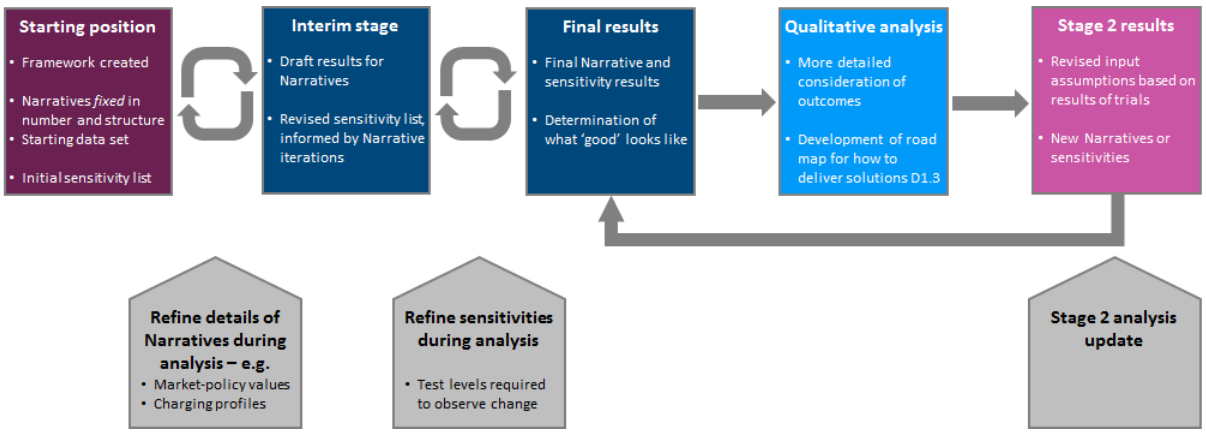
Figure 31 Summary of higher-level questions Narratives will help to explore



Whilst the scoping phase for Stage 1 has fixed the number of Narratives and their broad structure (along with a proposed set of sensitivities) it is important to note that the analysis allows flexibility to refine and adapt elements of the Narratives/sensitivities in response to early findings, within the overarching bounds of the available time and budget for Stage 1. In addition, it is anticipated that the analysis will be updated at the end of the Stage 2 trial given the new data this is likely to generate, and at this point there is a further opportunity to explore new Narratives or sensitivities. The flexibility in the overall analysis process is summarised in Figure 32.

Figure 32 Flexibility to refine Narratives / sensitivities during analysis



3.13 Mapping Narratives back to project objectives

As discussed in section 1.2, one of the key project objectives is to try to determine what "good looks like" for mass-market ULEV deployment and use. I.e. how is it possible to determine which configurations are good or "more optimal" than others; considering issues related to the consumer, infrastructure, commercial models and policy.

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The original project scope contained a number of examples of what might constitute a good solution. Figure 33 provides a summary of these examples and demonstrates how these have been captured via a combination of their inclusion in the Narratives, sensitivities or in terms of the underlying thematic axes/drivers, which have been used to shape the Narratives.

Figure 33 Mapping Narratives and sensitivities back to project objectives

	Example good solutions from contract	Key future drivers	Spectrum of alternatives	How issue is captured
PSC	Robust integration of ULEVs with wider low carbon system	Explore the importance of managed charging alternatives (physical impact)	Flat tariffs, SToU, DtoU	Distribute across Narratives
PSC	Accounting for availability of technology and project developments	Explore the impact of technological development	Higher performance batteries, cheaper batteries	Tested via sensitivity
PSC	Work in harmony with battery management and energy systems			
PSC	Support and facilitate transition to longer term energy system	Explore the contribution of transport to decarbonisation	High transport contribution, low transport contribution, high demand, low demand	Embed in sensitivity
PSC	Provide suggestions for standardisation requirements	Explore the importance of central coordination and planning	Government led change, locally led change, industry led change	Thematic driver (Organic / Coordinated Action)
CP	Meet needs of users (choice, certainty, flexibility, etc) and understand responses	Explore how users' demand for vehicle services may be met	Vehicle sharing, leasing, dedicated vehicles, smaller vehicles, access to charging	Thematic driver (Mobility as asset / service)
CP	Initial evaluation of adoption of vehicle types by different user groups			
CP	Provide choice to users (need for day-to-day interaction with DM should be optional)	Explore the importance of managed charging alternatives (consumer impact)	Flat tariffs, SToU, DtoU	Distribute across Narratives
CP	Provide clarity certainty and simplicity to operators particularly in relation to costs			
CP	Accommodate uncertainty over ULEV vehicle adoption and use	Explore the effectiveness of a technology push versus maintaining optionality	Backing a winner, technology optionality	Distribute across Narratives
MPF	Clear view of appropriate options for facilitating integrated ULEV deployment	Explore the effectiveness of different policy tools	Incentivise ULEVs, disincentivise ICEVs, infrastructure focus, fuel focus	Distribute across Narratives
CVC	Provide sufficient incentives for key actors to make investments and propose business cases	Explore the impact on existing and viability of new business models	DM aggregator, hydrogen pipelines, hydrogen trucks, public charging, rapid charging	Distribute across Narratives

In addition, for each of the above examples further detail has been provided with respect to how the example is tackled via:

- **Quantification:** how the example is captured and quantified in the Analytical Framework
- **Variation:** how variation in the Narratives will explore the space relevant to the example
- **Qualification:** how further qualitative analysis will inform the assessment, particularly with respect to what needs to happen to 'delivering a good solution'
- **Verification:** where issues could be explored further via careful structuring of the Stage 2 trial

*This information is provided in **Appendix B.***

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4 Analysis of Building Blocks in D4.1

4.1 Overview

This section ***replicates*** a significant portion of the analysis of the Building Blocks undertaken within the separate deliverable *D4.1 (TR1006_D4.1) Initial Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure* (further information is provided in D4.1 along with and the underlying detailed spreadsheet which e.g. contains the sources of information). It describes:

- A brief synthesis of the underlying evidence and literature
- Areas for further research or known gaps in the literature
- Building Blocks which are important for the Analytical Framework and why they have been proposed for inclusion or exclusion within the proposed Narratives

It should also be noted that *Section 7 within D4.1* provides a detailed mapping of individual Building Blocks to Narratives, to support the high-level description of each Narrative contained within section 3 of this document (D1.1), only the summary tables are repeated here. In addition, section 9 of this document (D1.1) describes how the Building Blocks are represented as part of the Analytical Framework.

Implications for use of the Building Blocks within the Analytical Framework and Narratives

It is important to note that the purpose of the 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 Building Blocks are used – and indeed required – in at least one Narrative, rather than being excluded completely.

The aim is to capture as many of the identified high / medium blocks quantitatively across the set of Narratives as possible ***and as a result the initial distinction between high / medium materiality is largely indicative*** as the aim is to assess their materiality more directly through analysis of the Narratives.

Some of the low materiality blocks are still captured by virtue of being included in the Analytical Tools, although these tend to be modelled in less detail. The application of the Building Blocks within the Narratives also tends to cover a wide range of states including the ends of the spectrum (e.g. no charging control to DNO managed charging) so that this will drive more meaningful insights from the final analysis, rather than minor variations.

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 of the project
- 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

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- The impact is likely to be very similar to other - already included - Building Blocks, given necessary simplifications required in the approach to modelling, and hence additional insights from including it are likely to be minimal

The specific rationale for exclusion of building blocks is discussed in subsequent sections.

4.2 Customer proposition

4.2.1 Synthesis of evidence and literature

As part of the review of available evidence and literature for the Building Blocks in Deliverable D4.1, early insights from the separate literature review being undertaken for Work Package 2 were also drawn upon, which focuses largely on aspects of the customer proposition for consumers and fleets. The final outputs of the Work Package 2 review will be included in the corresponding Work Package deliverables

The research questions that have been explored are:

- *What is the relative importance of purchase cost, price, maintenance, insurance, depreciation, tax incentives/grants/subsidies on the uptake and use of ULEVs?*
- *What is the relative importance of access to bus lanes, access to High Occupancy Vehicle lanes, parking incentives, road user charging incentives on the uptake of ULEVs?*
- *What is the role of access models on the uptake and use of ULEVs?*
- *What is the relative importance of the availability of different refuelling / charging propositions in the uptake and use of EVs?*
- *What is the relative importance of fuel pricing / payment / demand management options in the uptake and use of EVs?*

The literature review exercise provided evidence on what the most critical parameters for the Customer Proposition are and highlighted those elements of the Customer Proposition in which there is no evidence on their impact on ULEV uptake or use.

- *Costs of ownership*
  - Purchase price is more critical to the Customer Proposition than running costs; recharging and driving range are also important (as these are the two most important 'anti-bias' factors putting-off potential purchasers of buying a PiV)
  - Other incentives, such as parking fee exemptions/rebates, congestion charge, or High Occupancy Vehicle lanes, appear likely to be less important than purchase price incentives and are highly context dependant. However, despite the lower impact on their own, evidence suggests that a package of well-designed financial incentives plus non-financial incentives may be the most effective means of increasing EV uptake.
- *Infrastructure availability*
  - Regarding charging infrastructure, home charging is seen as a pre-requisite of PiV ownership at this stage of the market development, and a combination of home and public charging is more valued than home and work charging infrastructure. Rapid chargers enabling longer trips (e.g. on motorways and A-roads), are highly valued by

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PiV owners, particularly BEVs, and they are regarded as the most efficient way to complement overnight charging and key for mass uptake and use of ULEVs.

- Infrastructure availability or range 'anxiety' remains an important factor for many prospective ULEV drivers who often anticipate higher usage of charging points away from their home than actually transpires. This is compounded in some cases by lack of interoperability between public charging schemes (e.g. via 'roaming billing' models or standardisation of charging connections) which is flagged as a current source of frustration for some PiV owners

- *Charging behaviour*
  - There is no clear evidence in the literature of the impact of electricity pricing structures (i.e. ToUT) and controllability of charging (i.e. direct control) on the uptake of ULEVs, as the focus has been on understanding how those parameters affect ULEV use such as electricity consumption behaviour, and the acceptability of those tariffs.
  - A recent UK survey (sample of 4,000) to measure consumer demand in Great Britain for a range of demand-side response tariffs[10], shows that EV owners are more likely to switch to static ToUT and that a direct load control tariff was the most popular, provided that it does not compromise end-user satisfaction[11] and that overriding facilities are offered.
  - Additionally, *My Electric Avenue*, a two-year demonstration trial, is testing ULEV customer acceptance to direct control propositions, and results will be available in December 2015.

4.2.2 Areas for further research and known gaps

WP2 will inform on the attitudes and behaviours of consumers and fleets towards energy demand management through interviews that could potentially also seek evidence on these points, in particular in relation to **the impact of fuel pricing options** (i.e. Static or Dynamic Time of Use tariffs) **and related charging control options** (e.g. manual, automatic) on the uptake and use of PiVs.

Other gaps identified in the literature include:

- Analysis and demonstrations currently in progress aim to understand the **impact of different billing models (PAYG, subscription)** and how important this is within the Customer Proposition.
- **The relative depreciation of PiVs in comparison with ICEVs** is not well understood and is particularly critical among fleets. Similar aspects include **impact of the battery life and resale value** on the owner experience, the potential impact that the **secondary market** could have on ULEV uptake, and the **potential success of battery leasing** in the UK (which is not well understood).
- The potential penetration of **solutions to provide overnight charging to households without off-street parking** (e.g. socket network / street furniture connections, shared charge points installed in residential areas) needs to be understood further (i.e. do they

[10] Is it time? Consumers and time of use tariffs. Trialling the effect of tariff design and marketing on consumer demand for demand-side response tariffs; UCL Energy Institute for Smart Energy GB, 2015
[11] In terms of maintaining acceptable temperature thresholds

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have the same value / provide as much certainty of access as 'home charging' for consumers).

- There is uncertainty around the **mass take-up potential in cities of car clubs** and other ways consumers could use ULEV mobility as a service.
- The **compensation required by ULEV users to provide Demand Side Response** services, e.g. providing flexibility services to network operators.
- **The monetised value attributed by ULEV customers to perks** (e.g. access to bus lanes, free parking, etc.) is not well understood, particularly in terms of the extent to which customers heavily discount these benefits at the point of purchase, particularly where there is the potential for this value to diminish in future with significant ULEV uptake (e.g. the time saved from bus lane access with many users). This could include consumer attitudes to car ownership and the value of 'status' associated with owning a ULEV.
- **The monetised value attributed to having access to a secondary vehicle** either permanently / temporarily or e.g. via alternative transport services (e.g. longer distance journeys via rail).

4.2.3 Key focus areas for the Analytical Framework

In the CP, those BBs categorised as high *and medium*[12] materiality are:

- **Purchase methods** in the access model are outright purchase, contract purchase, hybrid - battery leasing only, contract hire, short-term hire / car clubs and the secondary market. It is therefore important to attempt to reflect the impact of leasing, such as spreading costs over time for contract purchase, or reducing the cost the customer sees together with the vehicle lifetime in for contract hire, as distinct from outright purchase, in the Analytical Framework.
  - The secondary market for ULEVs is negligible in the UK currently, but is viewed as an important determinant of the economics of ULEV ownership in fleets. The depreciation of ULEVs may be higher than ICEVs particularly when the battery life is less than the vehicle life and especially in the 'Organic' Narratives (as there is less of coordinated push to standardise around ULEVs).
  - *Bundled installation of charging points*, (i.e. provided with the vehicle) is classified as medium materiality. For home and fleet charging points this could be added to the cost of the vehicle; the use of public charging points, together with the bundling of other services such as O&M, insurance and fuel, will be either described qualitatively or as part of the tariffs seen by the consumer in the CVC.
- **Electricity pricing options** such as SToU will be reflected through exogenous charging profile assumptions, adjusted in relation to estimates of consumer response to electricity price shapes from the analytical tools. *Demand Management Payments* should appear in several of the Narratives and under these overall DNO control of charging is assumed and modelled as a payment to consumers. The EV owner benefits indirectly because distribution network reinforcements are not as significant as they would have been without charging control and the EV owner would separately receive a direct payment for

[12] Medium materiality BBs are italicised

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providing the DM services (to a DM Aggregator who provides the consolidated service to the DNO).

- For simplicity, the extent of consumer control will vary depending on whether the customers see flat tariffs, SToU (some load shifting, consumer charges less at peak times but does not transfer power into the grid from the battery), DToU (more load shifting, no transfer to grid), and managed charging (DNO direct load control, including payments for provision of such as service).
- In the 'Co-ordinated' Narratives, it is assumed that a DNO expands its services to become a DSO, or Distribution System Operation (for instance aggregating individual loads and providing balancing services to the TSO). However, for the purposes of analysis this will likely be represented as a DNO and Aggregator for all Narratives in which Demand Management Payments for the use of automated charging control apply[13]. Note that active network management is assumed to be through network automation algorithms, rather than via instructions to individual users as per a traditional system operator role. V2H may appear qualitatively as part of the OEM Innovation Narrative.
- **Hydrogen and liquid fossil fuel pricing** will be variable, although to a lesser degree of granularity than electricity, and charged in a PAYG manner, as per current pricing of liquid fossil fuels

- **Recharging availability** should reflect, in particular, private charging (home), workplace and public charging (rapid). For the latter, the access to charging and the extent of the network is important.
- **The billing models** that the customer sees may vary between Narratives, such as the *subscription model,* and *support for price certainty* (e.g. real time data on current charging costs, at public locations for instance, to allow the consumer to take informed decisions on where it is more economically sensible to charge), may be important. However, there is limited direct evidence on this and it is not practical to model differences directly within the Analytical Framework.
  - The variations in billing models by Narrative will be described qualitatively and could be tested, or simulated, in the Stage 2 Trial.
- The extent of **consumer control:** sole vs. shared, *charging control* (indirectly captured through response to ToU tariffs and V2G provision) and the *vehicle choice.* Shared use is more applicable to the 'Mobility as a Service'-based Narratives and its impact could potentially be captured via the extended use of fleets as opposed to consumer vehicles, assuming that a higher proportion of ULEVs is fleets and consumers hire these hour-by-hour.

Other cost/ subsidy elements that are part of the CP are for instance VED and Company Car Tax. These can be factored-in to the uptake tool and will be discussed further as part of the MPF.

The CP building blocks have been applied in a manner consistent with the description of the Narratives as shown in the summary Table 6, further detail is provided in D4.1 Section 7.

[13] As the DSO model is much broader than PiV charging and considers e.g. connection and management of various types of embedded generation

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Table 6 Summary of BBs to Narrative mapping for the Customer Proposition

✓	Captured quantitatively
✓	Captured qualitatively
✓	Exists as per BaU

Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
1. Outright purchase	✓			✓	✓	
2. Contract Purchase		✓	✓			
3. Hybrid (battery lease)						
4. Contract hire	✓	✓	✓	✓	✓	✓
5. Short-term hire/car club			✓			✓
6. Secondary market	✓	✓	✓	✓	✓	✓
7. Bundled installation of charge points		✓				
8. Maintenance, servicing and insurance	✓	✓	✓	✓	✓	✓
9. Access to other vehicles or forms of transport when ULEV unsuitable						
10. Static ToU		✓	✓			
11. Dynamic ToU			✓	✓		✓
12. Demand Management Payment			✓	✓		✓
13. Flat tariff	✓				✓	
14. Vehicle to Grid/House (V2G/H)						
15. Private charging	✓	✓	✓	✓	✓	
16. Public charging in motorways and A-roads (rapid)	✓	✓		✓	✓	✓
17. Public charging in local points (mid-level)	✓	✓	✓	✓	✓	✓
18. Workplace charging	✓	✓		✓	✓	
19. H_2 refuelling stations	✓	✓	✓	✓	✓	
20. Battery swapping						
21. Electrolyte charge						
22. Dynamic charging						
23. Forecourt	✓	✓	✓	✓	✓	✓
24. Subscription model			✓			✓
25. Support for price certainty		✓		✓		
26. Traditional pay per unit model	✓	✓		✓	✓	
27. Multi-modal			✓			✓
28. Own account						
29. Sole vs shared use	✓	✓	✓	✓	✓	✓
30. Charging control			✓	✓		✓
31. Vehicle choice	✓	✓	✓	✓	✓	✓

In terms of building blocks that are not considered explicitly or tackled more qualitatively across the Narratives the rationale for these is as follows:

- CP3 - Hybrid models - these are unlikely to show sufficient variation compared to the other purchase models which span the range from outright purchase, leasing and 'on-demand/hire'
- CP9 – Access to other vehicles or other forms of transport when ULEVs are considered 'less viable' for particular journeys (e.g. in terms of additional time requirements for recharging) – and there is limited evidence to quantify the monetised value consumers place on this. Qualitatively it is deemed of secondary importance versus access to

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charging infrastructure and the physical sufficiency of the ULEVs to meet the desired driving range in their role as the primary vehicle, both of which factors are considered of explicitly in the Analytical Framework. However, this is an issue that has that can potentially be explored in more detail as part of the Stage 2 trial

- CP14 – Whilst dedicated V2G could be used for flexibility services, such as providing power back to the grid during a shortfall, it is assumed that consumers would not normally enact V2G themselves (i.e. as a reaction to price signals for energy arbitrage) without automated controls to facilitate this process. The focus of the literature is also predominantly around DNO/Aggregator led demand management (CP12/CP29), which is considered in a number of Narratives and would restrict the ability of the consumer to manage their own charging or export back to the grid. V2G/H is also dependent on the level of battery degradation that might be experienced under more extensive charging cycles, which will be explored further as part of WP3.
- CP24-28 – there is limited evidence to understand the extent to which consumers value different forms of billing models (as opposed to the actual costs of the energy or transport service) and hence these BBs are more illustrative examples of what might sensibly exist given the broader Narratives, rather than integral part of the success of the each Narrative
- CP20-22 – more novel forms of PIV charging have been excluded either due to early evidence that they are likely to be less effective (e.g. a move away from attempts to commercialise battery swapping) or a high degree of uncertainty over the long-term prospects for others such as electrolyte or dynamic charging (at least for mass market consumers). Given the number of BB permutations associated with more 'standard' charging infrastructure (availability, locations, pricing, etc) these have been the focus for differentiation across the Narratives

4.3 Physical Supply Chain (PSC)

4.3.1 Synthesis of evidence and literature

The Physical Supply Chain (PSC) Dimension covers all of the supply chain components relevant to the transport sector and ULEVs in particular, including those associated with the energy supply chain.

The research questions for the literature review have focused primarily on:

- *What is the availability of different technology BBs?*
- *How significant are the BBs expected to be in terms of driving ULEV-related costs both now and in the future?*

In contrast to the Customer Proposition dimension, most PSC BBs exist across multiple Narratives, but the extent to which they are used – i.e. their materiality – depends significantly on the uptake and utilisation of different types of vehicles in the analysis of the Narratives. However, key initial insights from the review of literature are:

- *Vehicles*
  - Battery costs will continue to comprise a significant portion of the costs of PIVs in the near term (~40% now ~25-30% in 2020), but they are dropping steadily coupled with

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more gradual improvements in range. A variety of more novel battery chemistries (e.g. Lithium Sulfur) exist, but their likely cost is subject to significant uncertainty. *A more detailed assessment of battery technologies is being undertaken as part of WP3 and costs/performance data will be included within the Analytical Framework.* In contrast to PIVs there is still significantly higher uncertainty over the long-term costs of Fuel Cell systems vehicles

- Continued, but more incremental improvements, are expected in conventional vehicle components through weight reduction and improved energy efficiency, but many of these will benefit ULEVs as well as conventional vehicles

- *Energy carriers*
  - Hydrogen production is well established at small and medium scales via existing industrial processes (e.g. SMR). The key challenge moving forwards is production at larger scale for ULEVs in a manner that has low carbon intensity and at reasonable cost. To reduce carbon intensity sufficiently this is generally dependent on CCS-based production routes (SMR + CCS or coal/biomass gasification + CCS) or large quantities of cheap, low carbon electricity (e.g. from new nuclear). Localised production (e.g. via small scale electrolysers) tends to be more expensive and the value of this route needs to be contrasted with the additional costs of distribution from centralised production
  - Second generation biofuel production routes offer potentially significant CO2 reductions (e.g. 70%+ on a well-to-wheels basis compared to petrol and diesel)
- *Distribution of energy*
  - Management of electrification of vehicles (both scale of supply and balancing) on the wider energy system and associated carbon benefits will benefit from broader activity associated with e.g. integration of increasing levels of intermittent generation and electrification of heat (which are likely to place higher absolute demands on the electricity system than electrification of transport)
  - Individual components of hydrogen distribution technologies are generally already established and the costs of distribution are generally small compared to the overall fuel selling price (potentially <10%). The relative economics of pipeline versus truck distribution depends on the volumes being transported, the former becoming preferable once a critical scale is achieved
- *IT / communications*
  - Technology pre-requisites are required to enable greater management of PIV charging (either by the consumer or more directly by an Aggregator / DNO), such as smart metering and control systems for Active Network Management. But, these are already been driven by other factors of which PIVs are only one aspect (mandated roll-out in the case of smart meters and the requirement for more active management of all supply/demand by DNOs)
  - Interoperability and standards, e.g. with respect to charging infrastructure, are seen as an important enabler of PIVs from the customer perspective and are primarily a matter of coordination as opposed to technology development

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4.3.2 Areas for further research and known gaps

Gaps identified in the literature include:

- More research may be required on the potential role **of low voltage motors for PiVs** and to quantify the impact on the total cost (e.g. there may be a trade-off between cheaper batteries and more expensive motor/electronics controls), however, this is currently considered to be a low materiality BB based on the low R&D impetus vs. improvement of high voltage battery packs.
- **Industry standards:** a more detailed understanding of the impact of different levels of industry standards (e.g. strict standards to guarantee the interoperability of ULEVs with the charging infrastructure)

It should be noted that deliverable D4.1 also includes a summary of identified R&D gaps related to the Physical Supply Chain.

4.3.3 Key focus areas for the Analytical Framework

The high/medium materiality Building Blocks in the PSC are discussed below:

- For the **vehicles** the material components are the battery and battery management system (which will be part of the focus of WP3) and the fuel cell system.
- The electricity generators and H_2 generation plants are an important part of the **energy generation** category and will be accounted for in the system modelling. The price of electricity and H_2 will vary under different Narratives depending on the generation mix (including types and capacities of H_2 generation technology deployed). A distinction will need to be made between localised H_2 generation (e.g. on-site via electrolysis) and centralised generation and the cost differences between these.
- **Energy carrier transport** needs to be considered, in particular the electricity distribution network, *H_2 distribution network* and to a lesser extent the electricity transmission network. The investment requirements for the networks depend on demand for energy vectors which varies by Narrative. In most Narratives it is assumed that H_2 distribution is carried out by trailers as this is generally more cost effective at lower volumes, however, the H_2 Push Narrative may include pipelines in the longer-term (to forecourts)
- The focus of the **recharging / refuelling infrastructure** should be on private charging, public charging, H_2 refuelling stations and *petrol / diesel forecourts* – the demand for infrastructure will vary between the Narratives[14]

The PSC building blocks have been applied in a manner consistent with the description of the Narratives as shown in the summary in Table 7, further detail is provided in D4.1 Section 7.

Table 7 Summary of BBs to Narrative mapping for the Physical Supply Chain

✓	Captured quantitatively

[14] E.g. less demand in Narratives without FCVs due to a lack of H2 stations that would otherwise have been sited at petrol/ diesel forecourts. In this situation fossil forecourt retailers would likely require Government subsidies to remain commercially viable given the same number of overall forecourts.

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✓	Captured qualitatively
✓	Exists as per BaU

Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
1. Battery	✓	✓	✓	✓	✓	✓
2. Battery Management System	✓	✓	✓	✓	✓	✓
3. Fuel Cell System	✓	✓	✓	✓	✓	✓
4. Generic high technology readiness components (e.g. chassis, engine)	✓	✓	✓	✓	✓	✓
5. Electric motor	✓	✓	✓	✓	✓	✓
6. Vehicle H_2 tank	✓	✓	✓	✓	✓	
7. Communication systems						✓
8. Electricity generators	✓	✓	✓	✓	✓	✓
9. H_2 generation plants	✓	✓	✓	✓	✓	
10. Biofuel plants	✓	✓	✓	✓	✓	✓
11. Refineries	✓	✓	✓	✓	✓	✓
12. Electricity distribution network	✓	✓	✓	✓	✓	✓
13. Electricity transmission network	✓	✓	✓	✓	✓	✓
14. H_2 distribution	✓	✓	✓	✓	✓	
15. Trucks for liquid fuels	✓	✓	✓	✓	✓	✓
16. Gas network						
17. Large batteries	✓	✓	✓	✓	✓	✓
18, Large underground H_2 storage	✓	✓	✓	✓	✓	
19. Oil strategic reserves						
20. Natural gas storage						
21. Private charging	✓	✓	✓	✓	✓	
22. Public charging	✓	✓	✓	✓	✓	✓
23. H_2 refuelling stations	✓	✓	✓	✓	✓	
24. Forecourts	✓	✓	✓	✓	✓	✓
25. Industry standards						✓
26. Assets for settlement (e.g. smart meters)	✓	✓	✓	✓	✓	✓
27. Assets for comms.			✓	✓		✓
28. Data servers for Big Data						✓
29. Assets for comms. from/ to vehicles (e.g. autonomous vehicles)						✓

In contrast to the Customer Proposition dimension, most PSC BBs exist across multiple narratives, but it is the extent to which they are used which will depend on the uptake and utilisation of different types of vehicles in the analysis of the Narratives. The rationale for excluding specific BBs or treating them more qualitatively is as follows:

- PSC7/25/26/27/29 - Measures such as industry standards should form a part of the relevant overarching Narrative but their impact cannot be quantified explicitly and hence they can only be explored more qualitatively
- PSC10/11/17 are included in the Analytical Framework as part of the existing tools used, but are modelled only at a relatively high level (e.g. large scale batteries in the ESME model) or treated as a boundary condition (e.g. Refineries via exogenous assumptions for petrol/diesel wholesale costs)

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- PSC16/19/20 are not modelled explicitly as part of the Analytical Framework tools, but their direct impact on ULEV uptake and use is deemed to be very limited (as they have limited impact on the cost of availability of infrastructure from the perspective of the ULEV owner) and hence there is negligible value to including them in the analysis

4.4 Commercial Value Chain (CVC)

4.4.1 Synthesis of evidence and literature

The CVC 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.

The review approach first identified all entities on the value chain, categorised in 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)

This raised several key challenges or research questions that commercial entities might need to meet in order to efficiently achieve high ULEV uptake (aside from the overarching commercially viability of the business model, which will be assessed using the Analytical Framework):

- *How can the impact of plug-in vehicles on electricity distribution networks be managed?*
  - *How can network management be structured? How can efficient reinforcement be incentivised?*
- *How would hydrogen be delivered to the consumer?*
  - *How could a hydrogen network be financed?*
  - *What drives the viability of pipeline versus truck-based distribution?*
- *How might integration of vehicle provision, energy provision and other bundled services be achieved?*
  - *What constructs efficiently achieve this integration?*
- *How can fossil fuel business models be sustained?*
  - *As volumes decline, can a fossil fuel distribution business be made viable?*
- *How will deployment of charging infrastructure be financed?*
  - *Public finance, private businesses, individual installation?*

Targeted research was undertaken by E3 and Baringa, to provide information on how these questions might be answered by the CVC, and to understand the roles of each entity and relevant business models already in existence in the UK and elsewhere internationally (this information has

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been incorporated into the descriptions of the business models in the supporting D4.1 deliverable and spreadsheet), but key insights include:

- *Vehicle-related propositions*
  - Vehicle manufacturers / retailers are already beginning to offer a range of financing / leasing packages to PIV consumers mirroring the Customer Proposition Building Blocks and this is expected to increase in future helping to overcome the barrier of high upfront cost of ownership for ULEVs
  - PIV-based car hire / sharing is still in its relative infancy, particularly in the UK. There are however, more developed examples in other countries, such as Car2Go in the US, which also includes bundling of additional services including energy. This is facilitated via free charging at a number of points in San Diego owned by partner charging point operator ECOtality
- *Charging infrastructure and propositions*
  - A wide range of entities are involved in the development of non-home charging point infrastructure from dedicated charging point providers (e.g. Chargemaster), OEMs such as Tesla to retail suppliers such as Ecotricity in the UK. However, the deployment of such infrastructure is still at relatively small scale and many charging points are either free or heavily cross-subsidised to serve other purposes (e.g. promote customer loyalty, advertising) and a question mark remains of the viability of these approaches at larger levels of infrastructure deployment and use.
  - Other more novel forms of charging infrastructure have proven less successful commercially. 'Better Places' battery swapping business in Denmark / Israel went into administration in 2013 and Tesla have recently dropped plans to commercialise battery swapping stations, instead focusing on their rapid charging network
- *Enabling demand management*
  - Demand management of PIV charging in the UK has been delivered through DNO-led innovation trials under Ofgem's Low Carbon Network Fund, such as SSEPD's My Electric Avenue project and UKPN's Low Carbon London project. To date the focus has been on been on the technical and economic issues associated with managed charging at the DNO level and less on new commercial arrangements.
  - Whilst aggregators could at present monetise PIV demand management services and sell these to the TSO (e.g. as part of National Grid's Short Term Operating Reserve programme) commercial routes to monetise these services at the DNO level are still in their relative infancy. This is driven in large part by the clear separation of network ownership from supply of energy in the GB market, which does not exist in many other countries (e.g. some utilities in California) and hence these markets are often more developed in terms of their commercial structures to facilitate demand management
  - At the distribution level active management of PIV demand is closely tied into the broader evolution of the DNO in the UK to more actively manage both supply (e.g. distributed generation) and demand as part of a move to a DSO (Distribution System Operator model).
- *Facilitating new hydrogen infrastructure*

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- Large-scale hydrogen network development for transport is not necessarily contingent on significant Government intervention and bodies of work such as the H2Mobility project in the UK have illustrated how such a network could be developed organically through coordinated private sector activity.
- This does have implications for how such infrastructure may be developed as it tends to favour e.g. truck and trailer distribution to facilitate more incremental roll-out and avoid the potential for significant lumpy investments in larger scale pipeline infrastructure. These could be more economic with larger volumes of hydrogen in later years, but have a higher risk of asset stranding

4.4.2 Areas for further research and known gaps

Many of the business models on the CVC are traditional and therefore well-understood. There is less information available on the potential success and commercial viability of novel business models, such as those that do not yet exist at scale, including:

- The **DNO becoming a DSO**, which is at the early stages of discussion within the GB market and covers a wide range of potential roles[15] including more active management of both supply and demand – the latter is of more direct relevance in terms of demand management of PIVs, potentially via aggregators. There is little information on the costs to such a business of attracting consumers to engage in provision of active services.
  - For example UKPN's Low Carbon London trials focused primarily on the technical and economic implications of integrating a range of low carbon technologies at the distribution level, with some initial exploration of possible commercial arrangements[16]
- **battery leasing** models,
- large scale provision of **mobility as a service** products, enabling consumers en-masse to relinquish vehicle ownership and convert to vehicle use when required,
- The impact on the commercial operations of electricity suppliers of **large scale adoption of ToUTs**,
- **battery swapping** (this has been trialled internationally but not in the UK),
- and the **IT / data provider** (especially the appetite of the consumer for smart, consumer-oriented apps and bundling).

4.4.3 Key focus areas for the Analytical Framework

The short list of commercial entities on the CVC is shown in Table 8, and can broadly be categorised into

- **Electricity:** retail suppliers, network operators, aggregators and charging point operators

[15] https://www.ofgem.gov.uk/sites/default/files/docs/2014/02/role_of_the_dso_slides.pdf

[16] Such as contract templates for the provision of demand management from direct customers or via aggregators http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/Project-Documents/LCL%20Learning%20Report%20-%20D1%20-%20Development%20of%20new%20network%20design%20and%20operation%20practices.pdf

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- **Liquid fossil:** distributers (to forecourt) and retailer (to forecourt)
- **Hydrogen**: retailers (either forecourt or to home / depot[17]), distribution (road, pipeline network, gas distribution network repurposing), localised H2 producers
- **Vehicles:** retailers, leasers, sharing business models (e.g. car clubs)

Table 8 also identifies those commercial entities that are stand-alone (i.e. represented as a single entity on the Analytical Framework) and those that are a merger of two or more commercial entities (i.e. where a combined offering creates value, represented on the Analytical Framework via a shared P&L belonging to this 'multiple-entity company'). Partnerships between entities are used in some Narratives, although there is no intent to quantify the value associated with partnerships via the Analytical Framework.

Table 8 Summary of BBs included in the CVC

Described by business model framework
Described as variant on framework
Not described/ limited notes in supporting spreadsheet

Category	Business model	Stand-alone Entity	Building Block Name	Sheet with Further Information
Vehicles	Manufacturer	×	1. Vehicle Manufacturer	Vehicle Manufacturer
		×	2. Vehicle Manufacturer and Charging Point Owner/ Operator	Vehicle Manufacturer
	Retailer	✓	3. Vehicle Retailer (retail arm of manufacturer)	Vehicle Sales
	Leaser	✓	4. Vehicle Leaser	Vehicle Sales
		×	5. Battery Leaser	Vehicle Sales
		✓	6. Vehicle Sharing Scheme	Vehicle Sharing
Electricity	Retailer	✓	7. Electricity Supplier	Electricity Supplier
		×	8. Electricity Supplier with Vehicle Manufacturer	Electricity Supplier
	Distribution Network Operator	✓	9. Electricity DNO	Electricity Network Operator
		×	10. Electricity DNO as DSO	Electricity Network Operator
		✓	11. Electricity DNO / DSO with Charging Point Network	Electricity Network Operator
	Charging Point Owner	✓	12. Charging Point Operator / Network/ Owner	Charging Point Operator
		×	13. Charging Point Operator/ Network/ Owner with Electricity Supplier	Charging Point Operator
		×	14. Battery Swapping	Charging Point Operator
	Aggregator	✓	15. DM Aggregator	Aggregator & Digital
		✓	16. IT/ Data Provider	Aggregator & Digital

[17] 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.

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Liquid Fuel	**Retailer**	✓	17. Liquid Forecourt Retailer	Liquid Fuel & H2 Retailer
	Distribution Network Operator	✓	18. Liquid Fuel Road Distributor	Liquid Fuel & H2 Network Operator

Hydrogen	**Retailer**	✓	19. Hydrogen Retailer (at Forecourt)	Liquid Fuel & H2 Retailer
	Producer	✓	20. Localised Hydrogen Producer	Liquid Fuel & H2 Retailer
		×	21. Localised Hydrogen Producer with Forecourt Retailer	Liquid Fuel & H2 Retailer
	Distribution Network Operator	✓	22. Hydrogen Network Operator (Pipe)	Liquid Fuel & H2 Network Operator
		✓	23. Hydrogen Road Distributor	Liquid Fuel & H2 Network Operator
	Centralised Producer	✓	24. Centralised Hydrogen Producer	Not described – boundary condition

The entities in Table 8 are the Building Blocks that will be represented on the Analytical Framework and are, by definition, the focus for the framework.

The CVC building blocks have been applied in a manner consistent with the description of the Narratives as shown in the summary in Table 9, further detail is provided in D4.1 Section 7.

Table 9 Summary of BBs to Narrative mapping for the Commercial Value Chain

✓	Captured quantitatively
✓	Captured qualitatively
✓	Exists as per BaU

Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
1. Vehicle Manufacturer	✓	✓	✓	✓	✓	✓
2. Vehicle Manufacturer and Charging Point Owner/ Operator		✓				
3. Vehicle Retailer (retail arm of manufacturer)	✓ (private)	✓ (private)		✓ (private)	✓ (private)	
4. Vehicle Leaser	✓ (fleet)	✓ (fleet)	✓	✓ (fleet)	✓ (fleet)	✓
5. Battery Leaser	As per vehicle model					
6. Vehicle Sharing Scheme			✓			✓
7. Electricity Supplier	✓	✓	✓	✓	✓	✓
8. Electricity Supplier with Vehicle Manufacturer		Partnered				
9. Electricity DNO	✓	✓	✓		✓	
10. Electricity DNO as DSO						
11. Electricity DNO/ DSO with Charging Point Network				✓		✓
12. Charging Point Operator / Network/ Owner	✓	✓ (vehicle OEM)	✓			
13. Charging Point Operator/ Network/ Owner with Electricity Supplier						
14. Battery Swapping						
15. DM Aggregator			✓			
16. IT/ Data Provider			✓			✓

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Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
17. Liquid Fuel Forecourt Retailer	✓	✓	✓	✓	✓	✓
18. Liquid Fuel Road Distributor	✓	✓	✓	✓	✓	✓
19. Hydrogen Retailer (at Forecourt)	✓	✓	✓	✓	✓	
20. Localised Hydrogen Producer			✓ (depots)			
21. Localised Hydrogen Producer with Forecourt Retailer						
22. Hydrogen Network Operator (Pipe)				✓ (LT)	✓ (pipes)	
23. Hydrogen Road Distributor	✓	✓	✓	✓ (ST)		
34. Centralised Hydrogen Producer	✓	✓	✓	✓	✓	

There are, however, several simplifying assumptions that have been made, including putting in place defined boundary conditions (these conditions are described in section 8.1) as part of the way the CVC BBs have been applied to the Narratives. These are described below for each of the categories.

- **Electricity:**
  - **Large-scale generation and transmission are treated as part of the boundary conditions reflecting a "wholesale price".**
  - **Potential changes to the risk premium and hedging strategies, or differences due to economies of scale, for the Electricity Supplier in different Narratives will not be modelled**[18], therefore changes are likely to be described qualitatively. Similarly it is assumed that in general, Electricity Suppliers continue to exist in their current format.
  - **The DNO model for electricity is assumed to be a regulated 'natural monopoly' model**; independent DNOs could exist but for simplicity these are only reflected for hydrogen where multiple private distribution network operators could distribute hydrogen via high-pressure trailers, as opposed to a pipeline network.
  - **The DSO model is "very broadly[19]" considered to be equivalent to a DNO together with a DM Aggregator.** The Aggregator is assumed to provide DM and / or ancillary services from control of ULEV charging directly to the distribution network[20]. The use of managed ULEV charging/discharging for energy arbitrage revenues is considered to be less material and should be described qualitatively.
  - **There are various permutations of the Charging Point Operator / Network / Owner in existence today, however, in general the Charging Point Operator/ Network / Owner will be set up in a 'generic' specified configuration.** Exceptions are the Charging Point Operator / Network / Owner may partner with an Electricity Supplier and provide discounted tariffs for EV use; or the DNO may also form a merger or partnership with a Charging Point Network (for instance, with Government guaranteeing a regulated return to the DNO for rolling out the network), capturing the cost of the network through distribution network charges as a regulated entity.
- **Liquid fossil:**

[18] Consistent with the key simplifying assumptions in D1.1

[19] As the focus is not on exploring the wider set of issues around commercial management of e.g. different forms of distributed and intermittent generation at the distribution level, which are somewhat removed from the benefit of directly manage PiV charging to minimise network investments

[20] As opposed to current forms of aggregation which tend to be based around I&C customers with services provided directly to the TSO.

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- **Production and supply is treated as part of the boundary conditions reflecting a "wholesale price"** – the forecourt retailer and distributor are accounted for because any changes to ULEV uptake and use will naturally have an impact on the liquid fuel value chain in terms of its ongoing commercial viability.

- **Hydrogen**:
  - **Large-scale generation and transmission are treated as part of the boundary conditions reflecting a "wholesale price".**
  - **Repurposing of the gas network for H2 delivered direct to the household / depot is not currently considered as part of any of the core Narratives, but may be tested as a sensitivity.** The business case for doing so would not be ULEV specific and as such would need to include the costs of e.g. repurposing all heat, cooking and small scale industrial appliances to either hydrogen or electricity. The options for distribution and production have been somewhat simplified and it is the timescales of transition that are particularly important (e.g. from trailers to potentially pipeline distribution, from localised methane reforming to electrolysis or large scale hydrogen production).

- **Vehicles:**
  - **Manufacturers and the secondary vehicle market for ULEVs are treated as part of the boundary conditions,** however the price of the vehicles from the vehicle retailer contains the margin required by both the manufacturer and retailer itself.
  - **For simplification, the Battery Leaser is only used in instances when the Vehicle Leaser applies.**
  - **Battery swapping may be described qualitatively where applicable**. It is not clear how successful this would be in the UK – Denmark and China are examples of countries that have battery swapping stations, however, these also have a relatively low EV market share for a relatively high degree of incentives. Battery swapping relies on a high degree of standardisation and hence may be more suited to fleets that use standardised battery packs.

- **The IT / Data Provider will be described qualitatively where applicable.** This entity collects data and converts it into products, such as apps showing charging station locations, apps giving the ability to choose, reserve and locate the vehicle, remote temperature control, state of charge monitoring, advanced services such as modelling the battery life, and information provision on the electricity prices/ tariffs to encourage smart charging.

4.5 Market Policy Framework (MPF)

4.5.1 Synthesis of evidence and literature

The Market and Policy Framework (MPF) Dimension covers all market and policy components relevant to the transport sector and ULEVs in particular. The literature review focussed on understanding the current market for ULEVs in the UK and for other targeted countries, the strategies taken in different countries together with the government policies that underpin these, and the use of incentives, dis-incentives and laws/ regulations. The review aimed to address the following questions:

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- ***Which market and policy instruments have been applied,*** *either currently or historically, and how successful have these been at promoting high ULEV uptake?*
  - *In the UK, and for targeted countries (those that have been particularly successful or unsuccessful)*
  - *Have pre-determined **strategies** been developed and used? What did these contain? Do these address the primary concerns of the consumer e.g. range anxiety?*
- *Are there are **novel instruments** that have not yet been implemented in the UK or have had limited use elsewhere but that have the potential to be particularly effective?*
- *What value does the consumer place on **financial measures** targeting fixed costs compared to those targeting running costs, **or non-financial incentives**?*
  - *How can these be grouped effectively into a suite of complementary measures?*
- *How can **regulation be targeted at entities on the supply chain** to incentivise the production, marketing and sale of ULEVs?*
  - *For instance, enforced limits on emissions, requirements to provide and disseminate information, common standards for equipment and planning regulations*
- *Who should invest in ULEVs and supporting infrastructure?*
  - *What is the **role of the government and local authorities in both investing** in the physical supply chain directly **and in providing information** and educating others?*
  - *How can **private financing** be supported?*

The **market framework** that provides an overarching set of rules by which *all* commercial entities and/or consumers must operate. This includes energy sector regulation in general, i.e. one of the most significant examples in the UK is the clear separation of monopoly ownership of electricity and gas network assets (via regulated return business models) and the supply of energy through them.

Policy options which are specific interventions enacted within the overarching market framework, such as a tax or subsidy, and which may be targeted or differentiated by entities operating in the same part of the market

For the MPF it is both the value and the combination of measures (BBs) that is important. An equivalent level of subsidy or value to the consumer can be established using various combinations of different BBs. Key initial insights from the review of literature are:

- *Current measures*
  - In the UK, most of the instruments identified are already used, or have been used to varying extents.
  - The Government's current activities are aimed at supporting the early market, shaping the required infrastructure, securing the right regulatory and fiscal measures (strong, clear, lasting tax incentives to at least 2020 and making funding available to cities that commit to supporting a step change in ULEV adoption), investing in UK automotive capability and preparing the energy sector (e.g. ensure smart meters support charging).
- *Strategies*

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- Different countries have aimed to encourage high uptake of ULEVs in different ways and further detail is given on the specific approaches that countries have taken in the supporting D4.1 spreadsheet.
- In delivering its current vision for the ULEV sector in the UK, the Government's goals are: helping support the purchase of ULEVs through direct grants, incentives and advice; facilitating the provision of recharging infrastructure through provision where consumers would use it most (primarily homes and workplaces), with some provision of public recharging where needed; preparing for hydrogen fuel cell electric vehicles in the UK following Government's technology neutral approach; encouraging and investing in R&D; lowering emissions from other vehicles.
- The primary barriers to purchasing an electric vehicle are range, certainty of access, cost and lack of knowledge, and for a hydrogen vehicle are availability of hydrogen, cost and supply of FCVs.

- *Financial incentives versus 'perks'*
  - Upfront incentives are viewed as important and likely to be a barrier until at least 2030, however, these may not be enough alone to result in significant uptake (e.g. as was the case in China). It is primarily the overall value of the upfront incentives that is important; these have been applied as tax exemptions in the Netherlands, grants in Norway and fee-bates in France, whereby vehicles with low emissions are rewarded whilst those with higher emissions are penalised[21].
  - Refund/ buyback schemes may also be material; particularly for fleet users, which may be more concerned about residual value and battery replacement (Nissan is addressing these concerns by last year introducing a scheme through which buyers will receive cashback for their old battery).
  - Access to HOV lanes is also considered to be important in California, and in Norway bus lane access is considered to be as important in EV uptake as main financial incentives in regions with high rush-hour traffic.
- *Combining measures*
  - A country that has been particularly successful in incentivising ULEV uptake through a combination of measures is Norway. Incentives in Norway are focused on tax exemptions rather than subsidies, and making the electric car purchase price competitive with, or at a small premium to, conventional cars. Growth in the market has been organic and sales increased significantly once models were available from major OEMs. Incentives such as road toll exemptions and access to bus lanes are viewed as important. Many incentives either have no cost, or are covered by those who pay more or over a longer period, and support measures are guaranteed for relatively long periods of time. Commitment is demonstrated by public procurement for municipal vehicles and the provision of public charge points with free charging and parking, and awareness of ULEVs is raised via the Norwegian Electric Vehicle Association.
- *Role of government and local authorities in investment*

[21] A fee-bate on the purchase of new cars, the "Bonus/Malus", was introduced in France in 2008. The system was neutral for cars emitting between 130 and 160 g/km. The less polluting cars benefited from a price reduction of up to €1,000, while the most polluting ones were subject to a taxation of €2,600.

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- The importance of anticipatory investment is still an unknown. It is argued that in Norway, growth in EVs was organic and did not require anticipatory investment in a public charging network. However, it has been shown that high proportions of some consumer segments believe a rapid public charging infrastructure needs to be in place before they would adopt vehicles.
- In the UK, the Government intends to make up to £35m available to the 2 to 4 cities that commit to supporting a step change in ULEV adoption in their areas through measures and £20m available to local authorities who commit to introducing ULEV taxis.

- *Information and education*
  - Measures such as *education / marketing,* and *mandatory / voluntary reporting* may increase awareness and, consequently, uptake. Other than range concerns and purchase price, lack of knowledge/ familiarity with EVs is one of the most commonly cited barriers to uptake; various schemes have been used in the past, currently or are planned to try and meet this need – the Go Ultra Low Government website, various trials such as the Ultra Low Carbon Vehicle Demonstrator Programme, the Green Bus Fund, Plugged-in-Places and Plugged-in-Fleets initiatives, a National Consumer Campaign with manufacturers and various apps. In particular, it is thought that direct user experience (e.g. test drives for fleet users) is important.

4.5.2 Areas for further research and known gaps

The majority of the market and policy instruments identified have been applied either in the UK or internationally, and studies have assessed the success of some of these measures.

Aspects that are less well understood and that have a direct impact on the consumer are:

- market and policy instruments used to introduce 'perks', such as **cheaper mobility** (road tolls) and **cheaper access to parking**,
- the impact of **resale value and the secondary market** on ULEV uptake is unclear; measures that support the secondary market and maximise the residual value may therefore be interesting to explore
- the impact of novel taxation / incentive schemes such **as road pricing** which can be designed to address a combination of congestion, CO2, Air Quality and tax revenue objectives. The most complicated aspects are the quantifiable impact on driving patterns / modal shift as a result of different forms of road pricing and their subsequent effect on congestion / CO_2 / air quality

4.5.3 Key focus areas for the Analytical Framework

This section focuses on those BBs that have been identified as high and medium materiality for the MPF. Materiality has been primarily determined based on the approximate value of the measure (typically for the consumer), the extent of buyers covered (i.e. individual or fleet specific, targeted at specific powertrains), and the perceived importance of that measure to the consumer.

The high *and medium* materiality Building Blocks for the MPF are considered to be:

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- Financial measures aimed at reducing fixed costs are **direct *and private* grants to consumers** (e.g. for cars, vans and home charging points)**, VAT on assets** (e.g. reclaimable if used for business, or can reclaim part if leasing) and ***purchase / registration taxes*** (these are particularly low in the UK).
- BBs targeted at running costs and considered material are **fuel price, *VED*** ('road tax', currently varies in the UK according to emissions), ***fuel duty*** (electricity and hydrogen are currently exempt)***, VAT on fuel*** (electricity has a reduced rate).
    - ***Company car tax*** is currently lower for ULEVs than for petrol / diesel cars and means that the individual user benefits from paying less tax; this could be important – low uptake of ULEVs in Denmark is thought to be due to lower incentives for company cars vs. individual purchase.
    - Differentiated **road pricing** could be used to recover loss of revenue from fuel duty due to the reduction in the proportion of cars that are fossil-fuelled decreases as the uptake of ULEVs increases.
- 'Perks' such as ***cheaper mobility*** (e.g. congestion charge exemptions for ULEVs in the near term) and ***cheaper access to parking*** could be important, although likely to be valued more in urban areas, affecting a smaller number of overall users. Currently in the UK, Local Authorities operate a range of schemes to provide discounted or free parking or resident's parking permits.
- Potentially important non-financial incentives are focused on ***increased mobility*** (e.g. local low-emissions zones in cities) and intangible measures such as ***simplification*** (e.g. of taxes for ULEV users, badge schemes to simplify the identification of ULEVs, interoperability, removal of Vehicle Special Orders for hydrogen vehicles) and ***status*** (i.e. in Norway users have reserved number plates, and in France eco-labels) – whilst they are difficult to quantify these measures should be described qualitatively.

- A **direct CO_2 tax** will be applied in the MPF to account for the cost of meeting EU and national carbon targets. The level of carbon tax will be informed by the whole energy system element of the Analytical Framework and importantly reflects the most cost-effective level of abatement from transport as part of the system as a whole. This will be applied as a price on emissions in transport (e.g. as fuel duty to ICEV users) and will be used to offset the implementation of 'subsidy' BBs when tracking an acceptable level of Government spending applied to transport abatement.
- ***Direct emissions limits,*** on manufacturers - currently there are limits imposed on vehicle manufacturers at EU level, requiring them to achieve specific fleet-average emissions targets by 2015 and 2020/21 for cars and vans[22] and, for instance, car manufacturers in California need to sell a set number of EVs each year. As part of the EU regulation there are also various adjustments applied to calculating compliance with these targets, including super-credits for ULEVs with CO_2 emissions of 50g or less, aimed at encouraging the development of breakthrough technologies.
    - There are also other potential measures that could be applied which focus directly on emissions such as emissions cap-and-trade schemes (Vehicle Owners/ Fuel Suppliers get certificates depending on emissions rate of vehicle/ emissions of fuel and can trade these)

[22] Fleet average values for new sales of cars of 95gCO_2/km by 2021 and 147gCO_2/km by 2020 for vans.

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- Measures such as ***education / marketing,*** and ***mandatory / voluntary reporting*** may increase awareness and, consequently, uptake. Other than range concerns and purchase price, lack of knowledge / familiarity with EVs is one of the most commonly cited barriers to uptake; various schemes have been used in the past, currently or are planned to try and meet this need – the Go Ultra Low Government website, various trials such as the Ultra Low Carbon Vehicle Demonstrator Programme, the Green Bus Fund, Plugged-in-Places and Plugged-in-Fleets initiatives, a National Consumer Campaign with manufacturers and various apps.
- Direct investment BBs considered particularly material are:
    - **Government funding** (e.g. funding to local authorities, to public-private partnerships such as match funding, and to private companies such as funding of charging infrastructure and vehicle manufacturing facilities)**,**
    - **Private investment** leveraged by direct or indirect Government 'support' (e.g. low interest loans versus guaranteed / regulated returns), particularly with respect to network infrastructure (including charging points).
    - ***Capital allowances*** (for instance write-downs in the first year for ULEVs, which Element Energy has previously estimated to be worth around 7-10% of the value of the vehicle over four years), are also thought to be important. Note that this benefit no longer applies to rental companies, including car clubs; it has been suggested that it would be highly advantageous to re-instate enhanced capital allowances for leased and rental fleets to support ULEV uptake.
    - ***Investment in R&D*** could also be important; the current focus is on improving the range of the battery, battery management systems and novel technologies such as dynamic charging
- More **novel taxation/ incentive schemes** for transport such as **road pricing**, which are not necessarily ULEV specific, but can be designed to address multiple policy objectives simultaneously. For example, road pricing designed primarily to address congestion (via static or dynamic pricing strategies), but with secondary objectives to replace lost revenue from liquid fuel duty and/or reduce CO2/Air Quality emissions (e.g. via more efficient driving patterns or modal shift). In addition, congestion charging could alter PIV charging patterns indirectly by shifting the pattern of when vehicles need to be charged

Aside from this, there are highly material elements of the overarching policy framework such as **other laws and regulations** (e.g. compliance with EU directives) and adequate **access to infrastructure** (extent of coverage, whether investment is anticipatory vs. organic, led by public authorities or private companies, perceived vs. actual access requirements). Organic investment can be reflected in the 'Organic' Narratives, whereas investing somewhat more ahead of need (in order to increase consumer awareness or reduce perceived barriers such as lack of access to refuelling infrastructure) could be reflected in the 'Co-ordinated' Narratives.

There are other aspects of the overarching policy framework for which it is harder to quantify the impact but that are still important, such as:

- ***Commitment*** (e.g. Government commitment to a strategy – for instance leading by example by using ULEVs in Government fleets, and Government commitment to

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industry – for instance through grandfathering of subsidies and timely announcements of changes),

- The ***role of local authorities*** (e.g. mandates for a certain number of charging points or parking spaces),
- ***Standardisation*** (e.g. Government only funding public charge points with a certain type of sockets, standards for autonomous vehicles), all of which are likely to be described qualitatively rather than quantitatively.

The CP building blocks have been applied in a manner consistent with the description of the Narratives as shown in the summary Table 10, further detail is provided in D4.1 Section 7.

Table 10 Summary of BBs to Narrative mapping for the Market and Policy Framework

Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
1. Gov. grants to consumers	✓	✓	✓	✓	✓	✓
2. Private grants to consumers	✓					
3. VAT on assets	✓	✓	✓	✓	✓	✓
4. Purchase/ registration tax	✓	✓	✓	✓	✓	✓
5. Refund schemes		✓	✓			
6. Subsidies for other fixed costs						
7. Fuel price subsidies						✓
8. Vehicle excise duty	✓	✓	✓	✓	✓	✓
9. Company car tax	✓	✓	✓	✓	✓	✓
10. Fuel duty	✓	✓	✓	✓	✓	✓
11. VAT on fuel	✓	✓	✓	✓	✓	✓
12. Cheaper mobility	✓	✓	✓	✓	✓	✓
13. Cheaper access to parking			✓			
14. National insurance	✓					
15. Subsidies for other running costs						
16. Road pricing						✓
17. Weight tax						
18. Increased mobility	✓		✓			
19. Simplification						
20. Status						
21. Increased access to parking			✓			
22. Direct CO2 tax	✓	✓	✓	✓	✓	✓
23. Direct emissions limit	✓	✓	✓	✓	✓	✓
24. Emissions cap and trade scheme						
25. Emissions credits scheme						
26. Education/ marketing	✓	✓	✓	✓	✓	✓
27. Mandatory/ voluntary reporting	✓	✓	✓	✓	✓	✓
28. Government funding/ investment	✓					
29. Private investment	✓	✓	✓	✓	✓	✓
30. Investment in R&D	✓	✓	✓	✓	✓	✓
31. Capital allowances	✓					
32. Government guarantees	✓					
33. Adequate access to infrastructure					✓	✓
34. Other laws/ wider energy sector regulations	✓	✓	✓	✓	✓	✓
35. Commitment	✓					

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Building Block Name	BaU	OEM innovation	City led	ULEV enabled	Hydrogen push	Transport on demand
36. Role of local authorities	✓		✓			
37. Standardisation	✓					✓
38. Co-ordination/ National initiatives	✓			✓		✓
39. Planning regulations	✓		✓	✓		

In terms of building blocks that are not considered explicitly or tackled more qualitatively across the Narratives the rationale for these is as follows:

- MPF2 – private grants are not considered directly as one of the key simplifying assumptions within the Commercial and Policy Accounting Tool (CPAT) – see section 8 - is that commercial entities set prices to be as reflective of underlying costs as possible rather than undertake strategic pricing or use cross-subsidies in a wider business to achieve market share
- MPF6/15 – subsidies for other fixed/ running costs are likely to have limited impact in relation to the upfront vehicle grants for example
- MPF13 – cheaper access to parking could particularly valuable in urban areas, however, this may have limited influence on the total number of EVs unless parking spaces are converted to EV parking on a larger scale
- MPF17 – weight tax does not differentiate between ULEVs and conventional vehicles and the value of including it in the analysis is thought to be negligible
- MPF19/20 – simplification (e.g. of all taxes for ULEVs or of access methods for charging points) and status (e.g. different number plates or status symbols for ULEVs) can be assessed qualitatively if needed, however, the value of including them in the analysis is thought to be negligible
- MPF24/25 – other emission schemes are not modelled because a carbon tax is already accounted for in defining the overall amount of tax that is recovered by Government and can be distributed through subsidies

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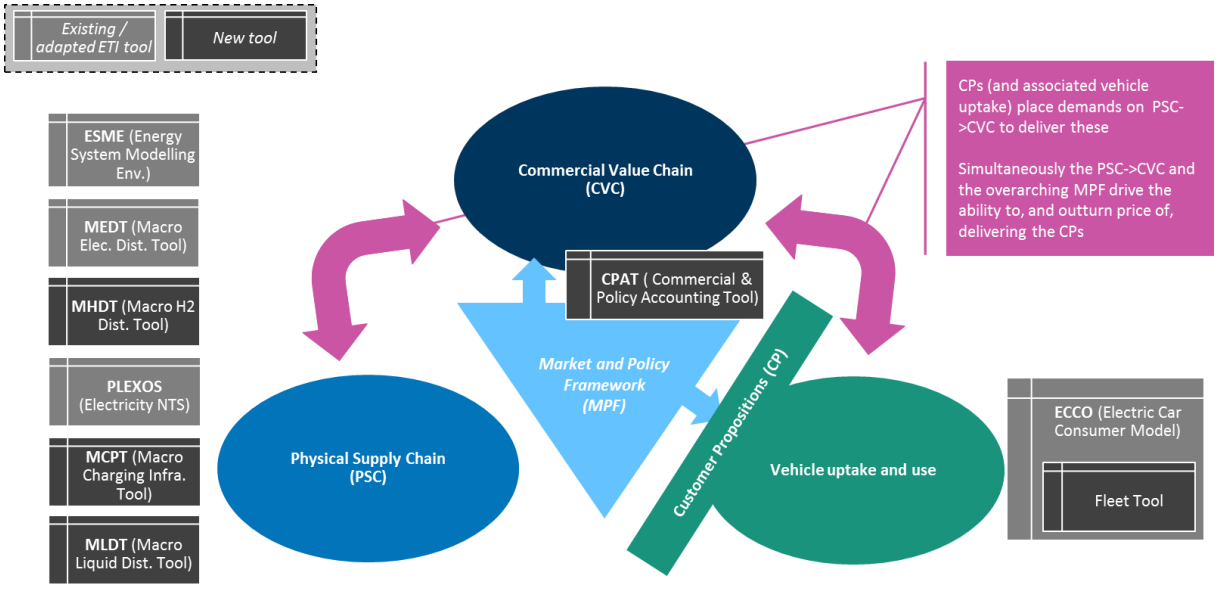
5 Overview of analytical tools

5.1 Overview

As outlined in section 2 the purpose of the Analytical Framework is to quantify, where possible, the Success Metrics for each Narrative. This will facilitate understanding of how effectively the choices fit together across the four overarching Dimensions that are being considered and comparisons across the Narratives. Where quantification is not possible the Analytical Framework also comprises a set of qualitative assessment metrics.

To enable quantification of the quantitative Success Metrics a combined set of analytical tools has been proposed as outlined in Figure 34. It is important to highlight that the aim is *to use these tools in an integrated, holistic framework to enable meaningful quantification, to an appropriate level of detail, in an internally consistent manner.*

Figure 34 Overview of analytical tools



The proposed tools comprise a mix of pre-existing tools (which will be adapted to varying degrees as required to enhance or integrate them as part of this framework) and new tools reflecting standalone development. 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 whole energy system model **ESME**, which will give a consistent picture of how the UK can meet its GHG targets in a feasible manner (in line with the quantitative Success Metrics for the PSC), for both transport and the wider system.
  - By considering the whole system, ESME is naturally less detailed on a sector by sector basis and it is proposed to supplement the understanding of the costs of

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infrastructure investment for electricity (via the **MEDT**), hydrogen distribution (via a new **MHDT**), liquid fuels (via the **MLDT**) and charging infrastructure (via the **MCDT**)

  - In a similar manner, **PLEXOS** will be used as a means to explore the feasibility of the electricity system in more detail. It is *not envisaged* that PLEXOS will be 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 use and or less direct control over charging – i.e. where the electricity system is more significantly stressed.

- Tools used to understand the response of consumers and fleets to different **Customer Propositions** (price and other aspects) on the uptake and utilisation of ULEVs in line with the proposed quantitative Success Metric. For this it is proposed to use the existing **ECCO** model, but with significant improvements to the way that fleets are represented by incorporation therein of a new Fleet Tool.

- A new tool – **CPAT** - to represent the flows across the **Commercial Value Chain** (CVC) as this acts as *2-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 tool calculates the cashflows for (and between) each of the entities who exist on the CVC (e.g. to recover the investment in developing and operating the infrastructure and energy supply to provide various ULEV-related goods and services). From this it constructs an estimate of the prices that need to be charged to ensure these entities are commercially viable - in line with the quantitative Success Metrics - and thus the prices seen by the consumer at the end of the CVC[23].

  - The **Market and Policy Framework** is also included within CPAT, both to track various Government revenue streams (taxes, subsidies, wider investments) for the quantitative Success Metric, 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. VAT)

The proposed Analytical Framework is described in more detail in the following sections, but it is important to note that the final design specifics may vary during the more detailed implementation phase for deliverable D1.2.

In addition, the Stage 2 trial is likely to provide quantitative insights that could be fed directly into the Analytical Framework to refresh the analysis at the end Stage 2, these have been summarised in section **Error! Reference source not found.**. This clearly depends on the trial design, but could nclude the impact on different charging profiles as a result of simulated electricity tariffs or managed charging requirements, or the result of choice experiments on the factors that influence ULEV uptake and use (as the ECCO tool already captures parameterised elements of this).

[23] 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.

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5.1.1 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 of ULEVs within the overall national vehicle parc, along with the infrastructure requirements 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 soft-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. It is proposed that the following 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 would need to be interpolated
- 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 an hourly aggregate peak winter[24] working day profile will be used in MEDT. ESME has a peak day representation, but only 5 diurnal timeslices and so will be shaped to provide a granular profile
  - To understand peak hydrogen demands (outside of those for hydrogen for power generation) the daily average load for each characteristic day is deemed sufficient[25]. This is the current representation in ESME as input vehicle 'load factors' are flat across the day.
  - To calculate annual costs of electricity supply (e.g. to inform the economics of vehicle ownership in ECCO) it is proposed to use the simpler 2 season (winter/summer), 5 diurnal timeslice definition that is the default within ESME. For hydrogen this would reflect seasonal variation only.
- 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/urban and urban electricity networks is considered, along with where charging occurs (home, on-street, workplace, public car park) within MEDT
  - Cost implications for technical options such as distribution of hydrogen will be considered in MHDT (e.g. higher costs per km in urban areas)

[24] 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 EV uptake on distribution network reinforcements

[25] 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).

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5.1.2 Common conventions

To maintain consistency across the tools it will be important to ensure that data is based on a set of common conventions, in particular using the same:

- Price basis – e.g. ESME currently uses real 2010 prices
- Calorific value basis – e.g. ESME currently uses Net Calorific Value

5.2 Key inputs and interactions between the tools

Using the tools in an integrated manner to assess each narrative requires careful consideration of 4 key issues

- **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
- **Data flows between tools** due to endogenously calculated parameters e.g. the purpose of CPAT is to help translate the underlying resource costs of infrastructure investment and energy supply into prices seen by the consumer as part of the Customer Proposition
- **General iteration** between the tools (through CPAT) 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. E.g. increasing uptake and use of EVs will drive increasing network reinforcement leading to higher electricity prices which may in turn reduce demand for EVs, ceteris paribus.
- **Key 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[26]). It is important to ensure that the ULEV uptakes in ESME are 'broadly' consistent with ECCO as this has implications for consistency in the cost of infrastructure and energy supply which ultimately through into the prices seen by ECCO.

A summary of each tool (covering its core purpose, key inputs and consistency issues) is provided in Table 11. Further information on each individual tool is provided in the following sections and a more detailed system diagram of the tools and key inputs / outputs is provided Appendix A.

Examples of illustrative outputs from the Analytical tools are shown in Figure 35. In addition, a worked example - of how the impacts of managed versus unmanaged charging permeate across the different tools in an integrated and holistic manner – is shown in Figure 36.

[26] 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).

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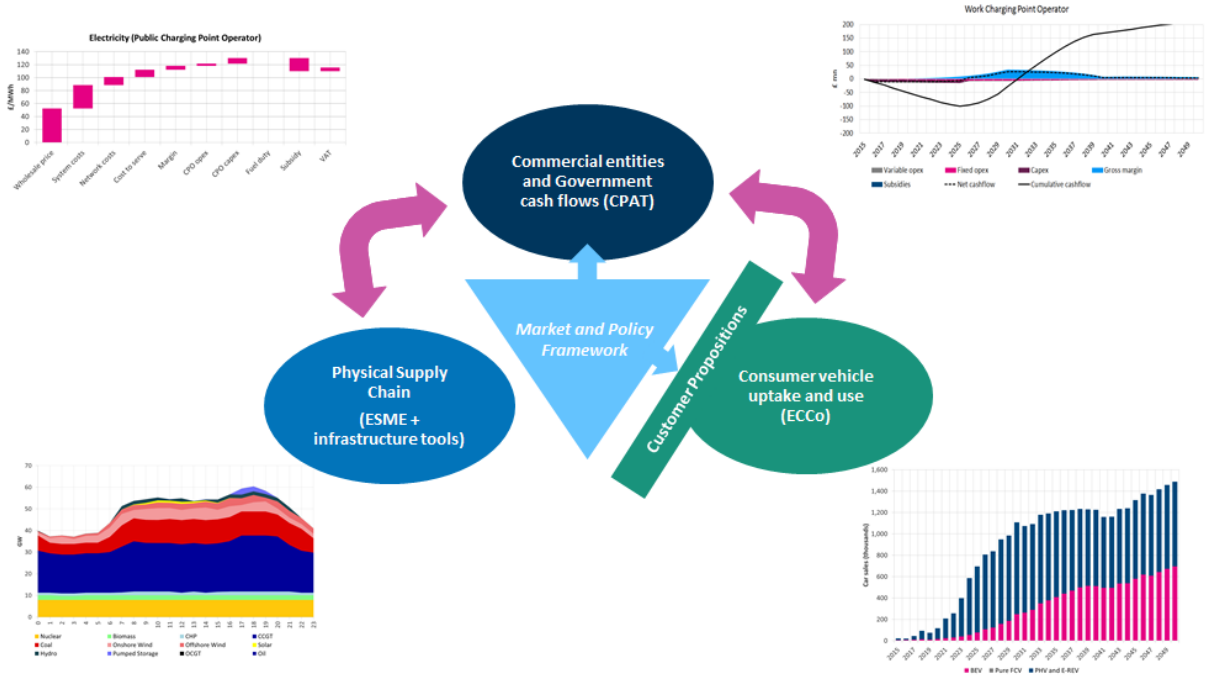
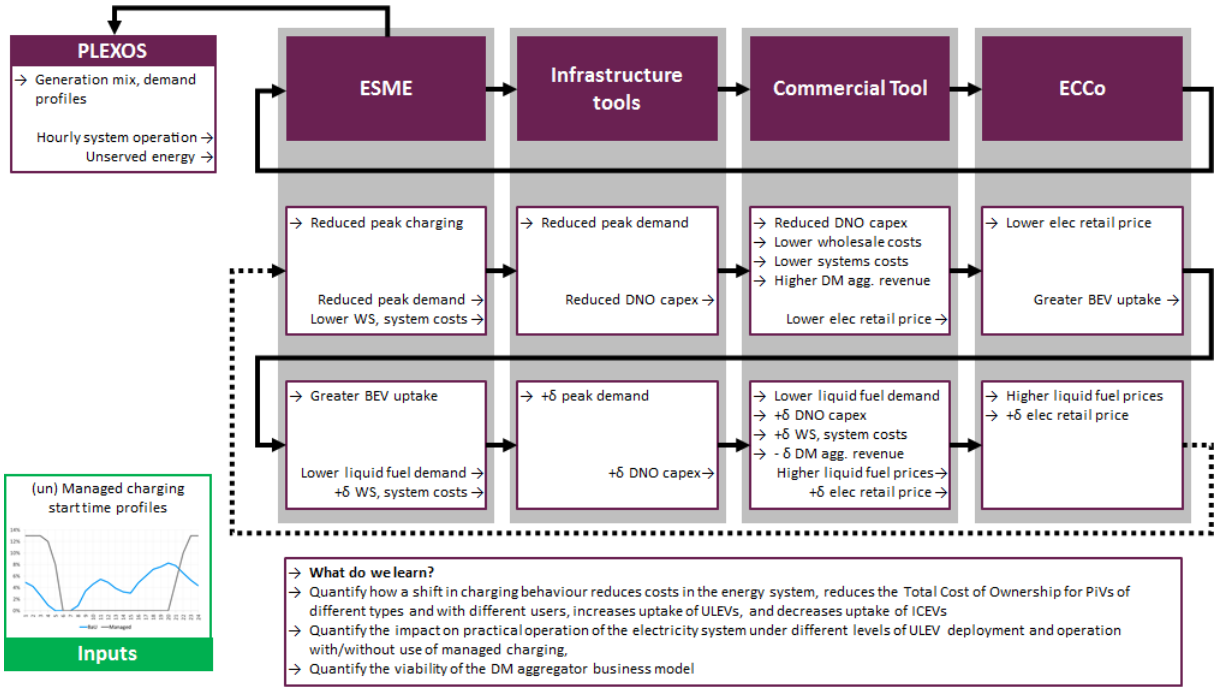
Figure 35 Illustrative outputs



Note: Clockwise from top left the components of a retail price stack for electricity from a public charging point (from CPAT), cashflows associated with a commercial charging point entity (from CPAT), ULEV uptake as a share of the total vehicle parc (from ECCo), an electricity system dispatch profile (from PLEXOS).

Figure 36 Example: impact of managed charging across the Analytical Tools



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Further discussion of how these metrics are used collectively to assess different Narratives against each other, for example the weighting to put on different metrics, can be found in section 10.1.

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Table 11 Overview of analytical tools (Exo. = Exogenous)

Dim.	Tool	Purpose	Key Inputs (from)	Key consistency issues (with)
CP	**ECCO** (Electric Car Consumer Model)	– Endogenous choice model of vehicle uptake (both consumers and fleets) including ULEVs – Reflects economic TCO and wider 'choice factors' for different consumer segments	– Vehicle/Fleet attributes (Exo.) – Transport service demands (Exo) – Impact of prices / policy (vehicle / fuel) (CPAT) – Infrastructure availability (PSC tools) – Consumer attributes (Exo.)	– Vehicle uptake and implied transport decarbonisation (ESME) – Peak network demands (PSC tools)
PSC	**ESME** (Energy System Modelling Environment)	– Provide whole energy system view consistent with meeting UK CO2 targets – Reflect combined transport / non-transport impacts (e.g. heat + EV electrification on network) – Reflect primary centralised production costs for H2 and electricity energy carriers	– Standard set of tech costs, resource costs, service demands outside of those specified for car/LDVs. – Starting point Patchwork / Clockwork dataset (Exo.)	– Implications of radically different transport uptake for car/LDVs on whole system - e.g. annual / peak energy requirements (ECCO)
PSC	**PLEXOS**	– Test feasibility of operation of the electricity system in cases where there is likely to be significant system stress (e.g. high PiV uptake and limited direct control over charging patterns)	– Capacity mix, commodity costs, average timeslice demands (ESME) – Dynamic plant parameters (Exo) – Hourly shaping profiles for wind / demand (Exo)	– Impact of vehicle uptake and Customer Proposition, charging management on transport demand profiles at LDN level (CPAT / ECCO)
PSC	**MEDT** (Macro Electricity Distribution Tool)	– Provide more detailed view of investment requirements from EVs (in conjunction with that from wider system)	– Network demands for transport (ECCO) and wider system e.g. electrified heat (ESME) – Network type mix, charging point availability, mitigation options (Exo)	– Interaction between network costs and impact on electricity prices / vehicle uptake / charging patterns (ECCO / CPAT)
PSC	**H2DT** (H2 Distribution Tool)	– Provide more detailed view of investment requirements from H2 vehicles (in conjunction with that from wider system)	– Network demands for transport (ECCO) and wider system e.g. power, industry, heat (ESME)	– Interaction between network costs and impact on hydrogen prices / vehicle uptake / use (ECCO / CPAT)
CVC / MPF	**CPAT** (Commercial and Policy Accounting Tool)	– Track financial cost/revenue flows within / between CVC entities to assess viability – Develop price stacks seen by consumers – Track high-level Gov. policy / fiscal flows	– Combines investment requirements and operating costs from PSC tools with final consumer revenue streams based on ECCO vehicle uptake	– Acts as core interface between PSC and CP (costs/availability <> prices <> uptake)

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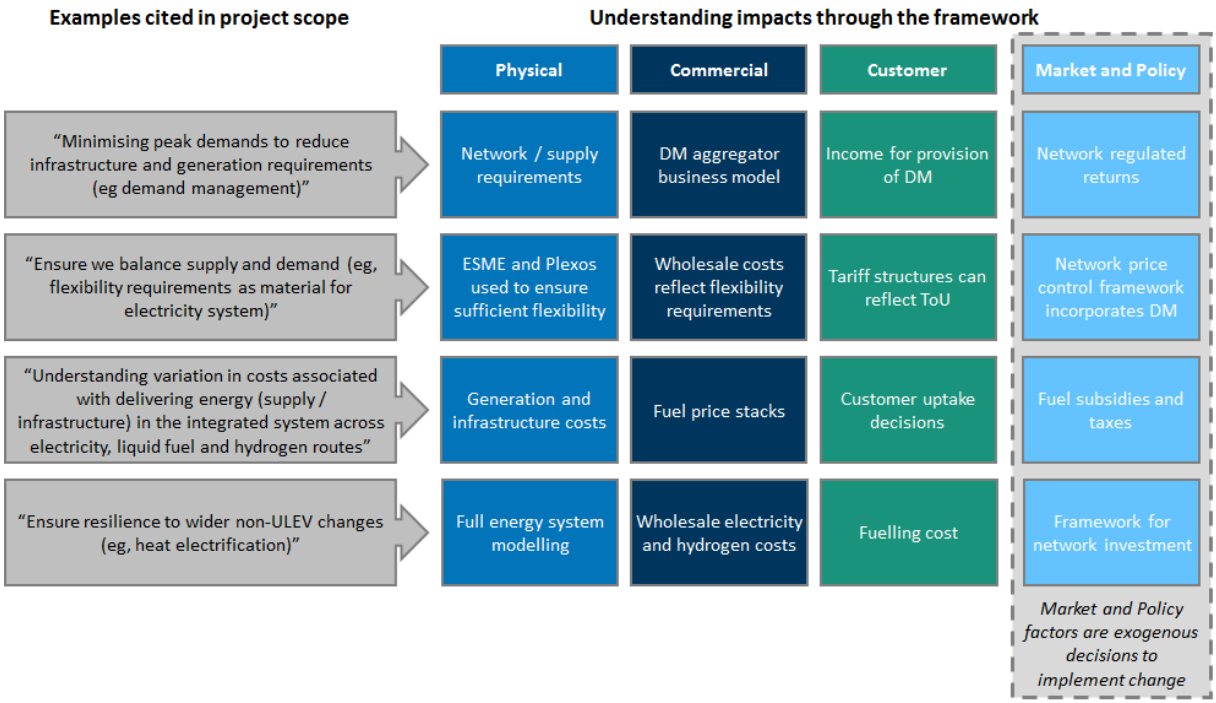
5.3 Using the Analytical Tools and Framework to understand system-wide impacts

As described in section 1.2, one of the key project objectives is to understand what the impacts are on the costs and operation of the system as a whole, from substantively different configurations of ULEV deployment and use, and their integration with the wider system.

The original project scope provided a number of key examples of impacts that it will be important to understand via the Analytical Framework and the tools contained within this. A summary of these examples and how their impact can be understood is shown in Figure 34.

Figure 37 How Analytical Framework helps to understand key system impacts



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6 Physical Supply Chain Tools

6.1 ESME (Energy System Modelling Environment)

6.1.1 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.)[27].

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[28]

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 3.12 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.

6.1.2 Electricity price outputs

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

[27] Further background on the ESME model is available here http://www.eti.co.uk/wp-content/uploads/2014/04/ESME_Modelling_Paper.pdf

[28] This would provide an additional source of revenue which could be recycled to ULEVs via e.g. subsidies or tax reductions

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fundamentals. As a result a number of key simplifying assumptions will be 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
- Prices are reflective of the LRMC (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 SRMC 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 SRMCs, 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 CfDs (Contracts for Difference), the CM (Capacity Market)[29].

By calculating prices on LRMC basis 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 will be reflected within the electricity price stack constructed in the CPAT tool (see section 8) and appear 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 LRMC estimated prices from the ESME outputs will be combined with 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:

- Absolute levels of demand
- Overarching changes in shape of demand due to e.g. more electrified heating, use of storage etc.

[29] 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.

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6.1.3 Key inputs /outputs and interaction with other tools

It is assumed that the default set of full inputs to ESME will be aligned broadly with the datasets used for the published Patchwork / Clockwork Scenarios[30] (using v3.4) and are not listed explicitly in Table 12.

Only the key inputs that are likely to be changed as part of sensitivity testing, or that need to be updated to ensure consistency with information provided by the other analytical tools, are highlighted in Table 12. In particular, this relates to consistency in the more detailed representation of vehicles (their performance characteristics) and their uptake and use modelled within ECCo.

[30] http://www.eti.co.uk/wp-content/uploads/2015/02/Options-Choices-Actions-Hyperlinked-Version-for-Digital.pdf

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Table 12 ESME key inputs (vehicles = project scope for cars and fleets)

Data field	Purpose	Granularity	Source	Notes
Petrol / diesel wholesale prices	Drives energy system solution and boundary prices for use in wider tools	£/kWh by time period	Patchwork/clock starting point with potential variation for sensitivities	-
Vehicle service demands	Understand impact of different service demand requirements on wider system solution (e.g. cost of energy supply)	Annual service demand vkm by transport segment (cars, LDVs, etc)	Patchwork/clock starting point with potential variation for relevant Narratives and sensitivities	-
Vehicle efficiencies and load factors	Understand impact of different service demand requirements on wider system solution (e.g. cost of energy supply)	Ratio of fuel inputs to vkm output and mix of fuel use for PHEVs by vehicle type by build year vintage	Consistent with ECCO inputs	-
Vehicle charging profiles	Understand impact of aggregate peak demands (transport + non-transport) and impact wider system solution (e.g. cost of energy supply / infrastructure)	Hourly profiles for characteristic peak winter working day and typical winter/summer day aggregated to simpler ESME timeslice definition	Based on typical profile patterns from ETI PiV (2011) analysis	Charging profiles will also be impacted by Market and Policy Framework – e.g. more dynamic tariffs or direct DNO control of charging will alter profiles
Vehicle uptake	ECCO is the primary determinant of ULEV uptake and hence the vehicle parc modelled needs to be reflected in ESME	Total stock of ULEVs by time period by build year vintage (i.e. to reflect changing efficiency and operating cost parameters)	ECCO output	Will need to be forced into the solution by a custom constraint

Table 13 ESME key calculated outputs

Data field	Purpose	Granularity	Destination	Notes

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Electricity demand profile (net of ULEV demand)	Provides evolution of wider system demands outside of those driven by changing ULEV uptake	Average GW by ESME timeslice by time period	MEDT	Profiles will need to be converted to hourly shape. Hourly EV charging profiles are calculated separately already and layered back on top to create the combined electricity demand profile
Non-ULEV hydrogen use	Estimates of evolution of wider use of hydrogen outside of ULEVs, e.g. HGVs, industry,	GWh by time period, by season, by use type	MHDT CPAT	-
Carbon shadow prices	Used to inform prices seen by Customer Proposition for fossil fuels and electricity	£/tCO2 by time period	CPAT	-
Hydrogen shadow prices	Proxy for price of centralised large-scale hydrogen production (includes shadow carbon price)	£/MWh by time period by season	CPAT	-
Biofuel shadow prices	Proxy for price of centralised large-scale liquid biofuel production (includes shadow carbon price)	£/MWh by time period	CPAT	-
Transmission Investment and OPEX	Used to adjust element of electricity price reflecting transmission costs	£bn per time period	CPAT	-
LRMC-based wholesale Electricity Prices	Used as key input to modelling of commercial entities in CPAT and key determinant of final electricity price seen by the Customer Proposition	£/MWh by time period, season (peak winter, typical winter/summer), by hour	CPAT	Additional post-processing tool

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6.2 PLEXOS

6.2.1 Key functional requirements

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 diurnal timeslices in ESME). It is *not envisaged* that PLEXOS will be 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[31] 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.

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. As a result a number of key simplifying assumptions will be 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
- Prices used as part of the dispatch optimisation are calculated on the basis of SRMC (short run marginal costs) + carbon price + technical uplift[32] only, with no calibrated scarcity uplift during periods of system tightness.

6.2.2 Key inputs/outputs and interaction with other tools

The majority of the PLEXOS inputs come from ESME data as the latter is used to frame the long-term evolution of the electricity system. However, a number of the ESME outputs are adapted (e.g. converting more aggregated timeslice profiles to hourly resolution) or supplemented by additional parameters (e.g. more dynamic operational parameters that ESME does not need to consider).

[31] See http://energyexemplar.com/software/plexos-desktop-edition/ for further information
[32] To recover start and no-load costs

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Table 14 PLEXOS key inputs

Data field	Purpose	Granularity	Source	Notes
Power system mix and supporting data	Used to define underlying electricity system – Generation – Storage – Transmission (+ node structure)	GW by time period and build year vintage –	ESME	-
Electricity demand profile	Demand profile against which system is dispatched	GW by timeperiod, by season, by hour	ESME ECCO Exogenous	Profiles from ESME need to be shaped to hourly level and do not include EVs. Hourly EV demand profiles are an exogenous assumption and combined with # of ULEVs deployed from ECCO
Hydrogen and carbon shadow prices	Proxy for price of 'energy carriers produced in ESME used by generators and price of carbon	£/MWh by time period (and by seasonal timeslice for hydrogen) £/tCO2 by time period	ESME	-
Other resource costs	Costs for other fuels used by generators	£/MWh		
Emission factors	For each product	tCO2/MWh by product	ESME	-
Core plant parameters	Needed by PLEXOS to inform dispatch decision – Average efficiency – CO2 capture rate – Maintenance / outage rates	% by technology type by build year vintage		-
Dynamic plant parameters	Needed by PLEXOS to inform dispatch decision – Unit size – Min stable generation – Min on/off time	By technology type by build year vintage	ESME2PLEXOS tool	-

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	– Ramp up/down – Start cost / fixed cost – Mean time to repair – Reserve status – Heat rate load points			
Hourly profiles for fixed load profile plant	Provide shape for production from plant which have flat average load factors in ESME – Wind, Tidal, Solar	% max output by time period by day by hour	ETI	-

Table 15 PLEXOS key calculated outputs

Data field	Purpose	Granularity	Destination	Notes
Unserved Energy	Key metric to understand the feasibility of the system in terms of electricity demand which cannot be satisfied due to operational constraints	MWh by timeperiod, season (peak winter, typical winter/summer), by hour	Reporting	-

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6.3 MEDT (Macro Electricity Distribution Tool)

6.3.1 Key functional requirements

The MEDT is based on the "Macro-Level Model" created as part of the ETI's previous PiV (Plug-in Vehicle) project[33]. 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[34] charges).

6.3.2 Key inputs / outputs and interaction with other tools

The key inputs to MEDT form two groups

- The evolution of the wider energy system demands on the electricity LDN from a combination of ESME LRMC-based prices / further hourly shaping
- EV-specific demand impacts and wider assumptions (e.g. around availability of non-home charging points) based on uptake from ECCo and factors consistent with the overarching Narratives

[33] 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
[34] Distribution Use of System charges

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Table 16 MEDT key inputs

Data field	Purpose	Granularity	Source	Notes
Number of EVs	–	# by time period by area type	ECCo (adjusted by area for Narratives where relevant)	Base split by area assumed to be consistent with previous PiV work
Number of non-home charging points	–	# by time period by area type (public / workplace / on street)	Exogenous - consistent with Narratives	-
Aggregate electricity demand profiles (peak winter working day)	–	kW by time period by area type (public / workplace / on street) *by hour*	ECCo Exogenous profiles - consistent with Narratives	Uptake from ECCo combined with base profiles for charging demand
Future non-EV loads	–	All by time period by area types – # Heat pumps / micro-CHPs – % Peak demand growth (outside of EVs) net of peak demand reduction from efficiency improvements	ESME	Base split by area assumed to be consistent with previous PiV work
Smart load management (non-EV specific)	–	All by time period by area types – % of appliances with smart controls – % of DE7 consumers available smart control of heat load	Consistent with previous PiV analysis	-
Smart load management EVs	–	All by time period by area types – % of EVs subject to load management – Year which smart voltage control is introduced	Exogenous consistent with Narratives	

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Table 17 MEDT key calculated outputs

Data field	Purpose	Granularity	Destination	Notes
Cumulative network reinforcement cost	Reflect additional investment that DNOs will need to make to cover both EV and other incremental peak electricity load	£M by time period	CPAT	- Network OPEX costs are not provided by MEDT and hence an estimate of these (and any e.g. REPEX expenditure) will be estimated within CPAT based on published price control information

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6.4 MHDT (Macro H2 Distribution Tool)

6.4.1 Key functional requirements

In a similar manner to the MEDT, 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-user rather than large scale production of hydrogen (captured within ESME) or localised production of hydrogen (within CPAT).

The exact structure of distribution options will vary by narrative, but a simple spreadsheet tool is envisaged to enable assessment of the following key areas

- **HRS** (Hydrogen Refuelling Station) infrastructure costs and the relationship between ULEV (and non-ULEV) demand and number of HRS required
- **Truck 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[35]
- **Pipeline distribution** and the relationship between ULEV (and non-ULEV) demand, form of the HRS network, and scale of the pipe network

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 H2 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 in section 3.4.

6.4.2 Key inputs/outputs and interaction with other tools

The key inputs to the tool are divided into two main categories

- Component costs – e.g. CAPEX and OPEX costs per HRS, per truck or per metre of pipe
- HRS network development – i.e. an understanding of how a forecourt based refuelling network might sensibly develop to maximise the coverage of stations (relative to demand) whilst attempting to minimise the associated infrastructure costs. Given the scope of the

[35] Primarily trading off more tube trailers to deliver an given level of hydrogen versus additional costs/losses associated with liquefaction

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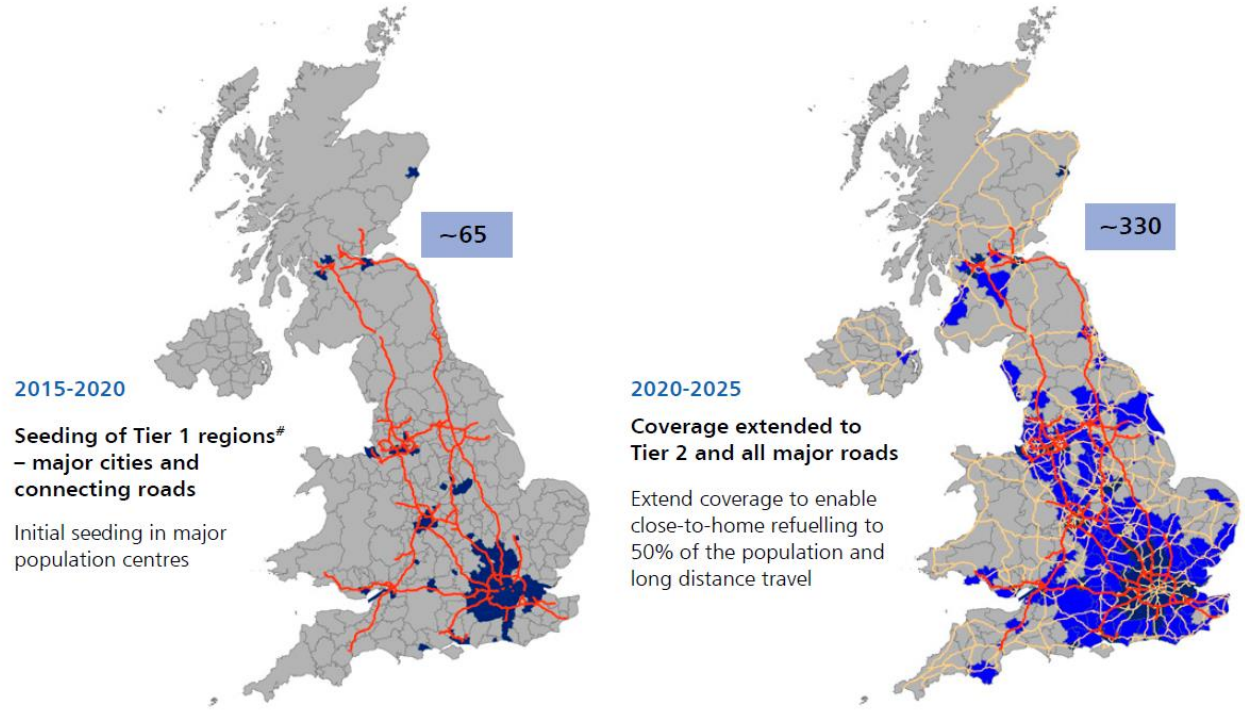
project it is proposed to anchor primarily around published work from UK H2 Mobility[36] and LowCVP hydrogen infrastructure roadmap[37]

Figure 38 Example of HRS network development from UK H2 Mobility (2013) report



[36] http://www.ukh2mobility.co.uk/the-project/

[37] http://www.lowcvp.org.uk/assets/reports/20150307_LowCVP%20Infrastructure%20Roadmap_HYDROGEN_Final%20(with%20graphics).pdf

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Table 18 MHDT key inputs

Data field	Purpose	Granularity	Source	Notes
Number of hydrogen vehicles	Key driver of requirement for hydrogen infrastructure	# by time period GWh demand by time period	ECCO	-
Future non-ULEV hydrogen loads	Number of hydrogen HGVs and associated fuel demand to inform number and overall utilisation of HRS	# by time period GWh demand by time period	ESME	-
Pipeline component costs and other characteristics	Investment and operational costs requirements for pipeline distribution	– £ CAPEX and OPEX per m, by build year vintage by pipe size – Max flow rate by pipe size – Technical lifetimes	ETI Energy Infrastructure 2050: Cost Model	Requirement dependent on narrative
HRS costs and other characteristics	Investment and operational costs requirements for HRS forecourts	– £ CAPEX per station and OPEX per station per year (by size of station) by build year vintage – Max kg H2 / cars per day (by size of station) by build year vintage – Technical lifetime	ECCO dataset	
Truck distribution costs	Used to create all in cost per unit delivery of hydrogen including trucks, drivers, trailers, fuel, etc	– £ CAPEX / Opex / max daily load per truck by build year vintage – Technical lifetime	ECCO dataset ESME	Liquid fossil fuel costs consistent with wider ESME scenario
Distribution requirements	Data to derive relationship between hydrogen transport demand and total distribution requirements	– # of HRS, trucks and/or pipeline metres per time period as a function of total # of hydrogen vehicles and total	ECCO dataset UK H2 Mobility LowCVP H2 roadmap	-

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	GWh hydrogen volume required

Table 19 MHDT key calculated outputs

Data field	Purpose	Granularity	Destination	Notes
Cumulative distribution investment and operating costs	Reflect additional investment that commercial entities associated with hydrogen distribution will need to make to cover both ULEV and other incremental hydrogen demand	£M by time period for investment and fixed OPEX	CPAT	-

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7 ECCo (Electric Car Consumer Model)

7.1 Overview of 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 new version of ECCo will be a deliverable of the project.

7.1.1 Definition of consumers, fleets and vehicles covered

In terms of vehicle segmentation, ECCo covers ten car segments (the nine segments defined by the SMMT plus a 'sub-mini' segment) and 13 powertrains within each of them[38]. 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[39].

In terms of customer segmentation, they have been divided into private buyers and fleet vehicle buyers, as they have fundamentally different criteria underpinning their purchase decision making. Fleets are defined as those vehicles chosen by fleet managers or organisations, where the end user has no choice in the purchase decision. A rational Total Cost of Ownership (TCO) and duty cycle suitability approach is taken by fleets. Conversely, private consumers are free to choose their vehicle, and they value other attributes in their purchase decision making such as the availability of public infrastructure or the availability of their preferred model/make. Their purchase decision is driven by both financial and non-financial vehicle attributes.

Among cars, consumers have been divided in six segments (e.g. 'innovators', 'cost-conscious greens'), and fleets have been divided in three ('depot', 'perks' and 'workhorse'). All vans are considered to be fleet vehicles and are not segmented further.

7.1.2 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.

[38] Petrol ICE, Diesel ICE, Petrol Mild Hybrid, Petrol Full Hybrid, Diesel Mild Hybrid, Diesel Full Hybrid, Petrol PHEV, Diesel PHEV, Petrol RE-EV, Diesel RE-EV, BEV, Fuel Cell, Fuel Cell RE-EV

[39] Petrol ICE, Diesel ICE, Petrol Full Hybrid, Diesel Full Hybrid, Petrol PHEV, Diesel PHEV, BEV, Fuel Cell, Fuel Cell RE-EV

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7.1.3 Key inputs/outputs and interaction with other tools

Although most of ECCo inputs will be exogenous, there are several key consistency issues with the Physical Supply Chain tools and the Commercial and Policy Accounting Tool that need to be addressed.

Only the key inputs that are likely to be changed as part of sensitivity testing, or that need to be updated to ensure consistency with information provided by the other analytical tools, are highlighted in Table 20. In particular, this relates to consistency of ECCos' input/outputs with the wider energy assumptions provided by ESME, with the infrastructure inputs in the other Physical Supply Chain tools, and policy incentives in the Commercial and Policy Accounting Tool.

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Table 20 ECCo key inputs

Data field	Purpose	Granularity	Source	Notes
Wholesale Vehicle (and battery) costs	Critical parameter in the equation underpinning vehicle choice, both for fleet and consumers	£/vehicle; Cars: 10 segments with 13 powertrains within each Vans: 5 segments with 9 powertrains within each	Exogenous (database updated in 2015); WP3 update	Where relevant, home / depot charging costs will need to be incorporated into
Vehicle Commercial Entity Adjustment Parameters	ECCO constructs the upfront/ongoing TCO components from the wholesale vehicle costs, but will need to add further costs and or change the TCO cost split and profile depending on the wider Commercial Model for vehicles (e.g. retailer, leasing, vehicle sharing, etc)	Values from CPAT used in ECCO TCO conversion – Hurdle rates % – Leasing length (where relevant) – Additional OPEX (fixed and variable) related to cost-to-serve and risk management costs £/unit sale – Secondary market value (for fleets) – Other MPF inputs targeted directly at the vehicle commercial entity are outlined under *MPF inputs* below	CPAT	Constructing Commercial Model adjustments in ECCO means that some element of the cashflows for these commercial entities need to be reported back to CPAT *Specific structure of entities and values changes by Narrative*
Vehicle efficiencies and other technical parameters	They determine fuel and electricity consumption, a critical parameter in the equation underpinning vehicle choice, both for fleet and consumers	l/km or kWh/km for each of the segments and powertrains above Efficiency by vehicle type by energy vector by time period	Exogenous	ESME to use consistent values to inform the impact of different service demand requirements on wider system solution (e.g. cost of energy supply)
Vehicle service demands	At the moment, ECCo uses input parc service demand (bn km) and fleet size to calculate an average mileage across the fleet Differences in mileage across car/van	Annual service demand bn vkm by transport segment (cars and vans) For purchase decision, each of the car consumer segments and van segments has a different	ESME Patchwork/clock starting point with potential variation for relevant Narratives and sensitivities	More limited granularity in ESME so ECCO numbers will only match at a high-level of aggregation

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	segments is captured at the purchase decision stage	mileage		
Private consumer segments and coefficients	Critical values in the equation underpinning consumer car choice	Six segments, seven attributes	Exogenous	Updated in 2015
Fleet segments and coefficients	Critical values in the equation underpinning fleet car choice	Cars: three segments, seven attributes Vans: one segment, no attributes (TCO and supply penalty calculated instead)	Exogenous	Updated in 2015 Fleet cars will be modelled by a TCO approach in the updated ECCo Fleet segmentation will be revised in collaboration with Route Monkey
Wider energy system: grid carbon intensity	It is an input to ECCo, need to be consistent with ESME outputs	Average gCO_2/kWh	ESME	Influences uptake only used if carbon price policy is applied on a Well-to-Wheels basis[40]
Wider energy system: electricity, H2 and fuel price	It is an input to ECCo, need to be consistent with ESME outputs	Hourly profile for electricity seasonal variation only for H2. Characteristic peak, winter, summer days. Further variation by charging point location – home/depot, local public/work, rapid network where the price reflects additional infrastructure cost	ESME	Further shaping applied to ESME outputs convert to hourly prices
Vehicle charging profiles	Understand impact of peak demands for transport and inform total elec and H2 demand	Hourly profiles for characteristic peak winter working day and typical winter/summer day aggregated to simpler ESME timeslice definition Further variation by charging point location – home/depot, local public/work, rapid network	Exogenous	Based on typical profile patterns in line with National Travel Survey, developed for the ETI PiV (2011) analysis

[40] In this case the electricity price would need to exclude the price of carbon to avoid double counting. However, as the carbon price from ESME reflects the most cost-effective level of economy-wide abatement a specific WtW policy, as opposed to applying the carbon price directly on fossil transport use, is unnecessary

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Charging demand diversity curve	ECCO reports aggregate electricity demand profiles from ULEVs, but these need to account for underlying diversity in charging	Incremental increase in peak load as a function of number of buildings/EVs charging on feeder	UKPN Low Carbon London Analysis	-
Infrastructure inputs	Critical for purchase decision of consumers and fleets	% of population with access to: overnight electricity charging, local public charging, work charging, rapid network and rapid charging rate, by year	Exogenous, consistent with Narratives	Separate estimates of physical # of required charge points will be converted into % coverage
MPF inputs	Factored-in in utility equation. CPAT provides source of values consistent with Narrative, but ECCO builds them directly into TCO calculation where they are applied directly at the point of the Customer Proposition or to the vehicle-based Commercial Entity models	Values for policy inputs, by time period – Direct vehicle grant (£/vehicle) – VAT on vehicle (%/vehicle) – Fuel duty (£/MWh) – VED (£/CO2 banding for first year and £/vehicle for subsequent years – Company car tax (£/CO_2 banding) – VAT fuels – Congestion charge (£/day, threshold gCO_2/km, share of buyers concerned) – Vehicle registration tax (£/unit) – Refund schemes (£/vehicle) – Direct fuel price subsidy (£/MWh) – Direct CO2 tax on fuel use (£/tCO2) – Additional ongoing monetised perks £/vehicle/year – Capital allowances (£/% per vehicle) for non-retailer vehicle business models	CPAT	*Differentiation in policy inputs as necessary by* – *Individual powertrain (or at least high-level ULEV grouping)* – *Segments (private/fleet)* – *energy type* Tax / subsidy cashflows associated with direct Customer Proposition MPF instruments need to be passed back to CPAT to be accounted for alongside wider Government cashflows
Other Commercial Model payments to consumer	Where other Commercial Entities make payments to consumer or fleets this needs to be factored into the TCO calculation within ECCO. For example DNO payments for network services, or payments by an aggregator to TSO	Value for inputs by time period – £/Vehicle – £/MWh	CPAT	Total cashflow associated with payments needs to be passed back to CPAT, by each commercial entity which will vary by narrative

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Segment market share	Inputs the shares of small/medium/large cars	Percentages per segment type (10 for cars, 5 for vans) for private and fleet vehicles	Exogenous	It can be changed when testing sensitivity of 'Push towards smaller / very small cars'

Table 21 ECCo key calculated outputs

Data field	Purpose	Granularity	Destination	Notes
Vehicle uptake and associated fleet average parameters	ECCo is the primary determinant of ULEV uptake and hence the vehicle parc modelled needs to be reflected in ESME	Total stock of vehicles by time period Average efficiency parameters by vehicle type	ESME	Uptake constrained directly in ESME using stock average parameters rather than by vintage
Electricity network demands	ECCo is the primary determinant of peak network demands, feeding into the Macro Electricity/ H2 Distribution Tools. Need to ensure consistency with other tools	Hourly EV demand profiles (and number of ULEVs), informing the macro electricity distribution tool Hourly profile for electricity seasonal variation by characteristic peak, winter, summer days. Further variation by charging point location – home/depot, local public/work, rapid network where the price reflects additional infrastructure cost	ESME MEDT	-
Total fuel and electricity consumption	Need to ensure consistency with other tools	Billion litres or TWh per year	ESME	Need to ensure consistency with ESME (check implications of radically different transport uptake for cars / vans on whole system - e.g. annual energy requirements)
MPF Government Cashflows	Input to CPAT to track overall Success Metric. Units of "sales" volumes are also necessary to	£M expenditure or incoming cashflow per time period for each of	CPAT	Differentiation in results required by – by powertrain, or at least high-

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	enable CPAT to construct overall final price stack seen by customer,	– Direct vehicle grant – VAT on vehicle – Fuel duty – VED (# vehicles) – Company car tax – VAT fuels – Congestion charge – Vehicle registration tax – Refund schemes – Direct fuel price subsidy – Direct CO2 tax on fuel use – Additional ongoing monetised perks – Capital allowances for non-retailer vehicle business models In each case also need the relevant units (# of vehicles / MWh of energy) to which the MPF is applied to create final price stacks for reporting		level ULEV grouping – Energy type
Vehicle Commercial Entity Cashflows	Constructing Commercial Model adjustments to base vehicle prices in ECCO for TCO calculations means that the corresponding cashflow for each relevant commercial entity needs to be reported back to CPAT	£M by each vehicle commercial entity (retailer, leaser, sharing-based models) as relevant – Investment costs – OPEX costs – Government tax outgoings by type – Government subsidy incomings by type – Total revenue	CPAT	Relevant entity structure and associated values vary by Narrative
Other Commercial Entity Cashflows	Where other Commercial Entities make payments to consumer or fleets this needs to be factored into the TCO calculation within	£M by time period by payment type by commercial entity	CPAT	Total cashflow associated with payments needs to be passed back to CPAT, by each commercial entity by

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ECCO. For example DNO payments for network services, or payments by an aggregator to TSO	payment type which will vary with narrative

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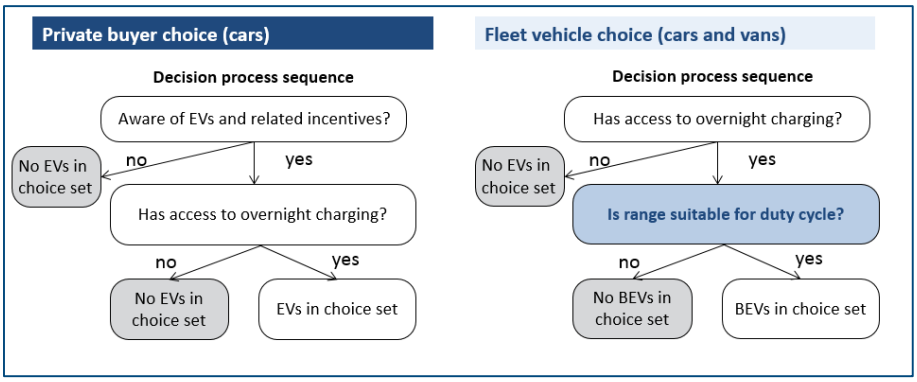
7.2 Segmentation of vehicle buyers in ECCo

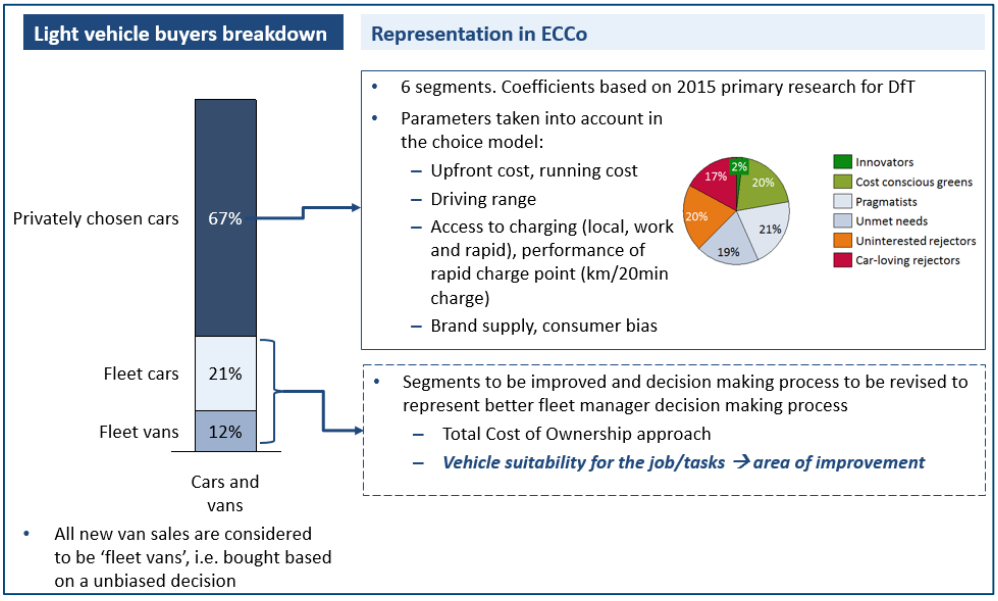
ECCo differentiates private vehicle buyers and fleet vehicle buyers. Fleet vehicles are defined as vehicles chosen by fleet managers/organisations, they represent the majority of van purchase (90%, currently simplified to 100% in ECCo) and a minority of car sales (44% of company registered cars, so c. 25% of total car sales). A key difference between the private and fleet vehicle choice is in the purchase decision tree approach, illustrated in Figure 39.

Figure 39 Purchase decision tree as implemented in ECCo



Beyond the purchase decision tree, private and fleet buyers are also differentiated by the attributes taken into account in the comparison and choice of vehicles. Figure 40 summarises this and highlights some areas of improvement that are discussed further in the next section.

Figure 40 Summary of the current buyers' segmentation in ECCo



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8 CPAT (Commercial and Policy Accounting Tool)

8.1 Key functional requirements

The core requirement of CPAT is to provide the point of **translation** between requirements from the Physical Supply Chain (PSC) 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 (MPF) 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 customer requirements (which may then affect the price), there is likely to be some iteration required to achieve a *sensible* supply/demand position consistent with the wider narrative[41].

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 / H2). This will also allow exploration of the potential distributional impact on 'ULEV owning households' versus 'non-ULEV owning households'
- Assess the viability **quantitative Success Metric** for all **commercial entities**. As outlined in Table 3 this is defined in terms of the ability to maintain net undiscounted cashflows over the pathway for all commercial entities sufficient to provide required profit margin (potentially with Government support) and in the final period of the pathway (without any Government support)
- Assess the **quantitative Success Metric** associated with Government cashflows, as outlined in Table 3 that **net socially discounted Government cashflows** 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 due to monetisable societal benefits, primarily from CO2 abatement, but also AQ or congestion where it is possible to quantify these.

Key drivers of the values for the Success Metrics within CPAT are likely to be

[41] It is not envisaged that this represents a perfect equilibrium position

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- 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 will provide understanding of how the benefit of these avoided costs are distributed across the value chain.

8.1.1 Focus of CPAT tool

As outlined in section 4.2 and in the separate D4.1 deliverable (initial analysis of Building Blocks) 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 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 D4.1, 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[42]), 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)
  - Manufacturers and the secondary vehicle market for ULEVs are treated as part of the boundary conditions

Figure 41 provides a schematic illustration of the CVC, which will be represented by CPAT, and shows the:

[42] 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.

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- 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 will vary between the Narratives
- The boundary conditions feeding into the different commercial entities and the other tools within the Analytical Framework which will inform these
- An illustration of potential Market and Policy Framework interventions such as taxes or subsidies, and where these could interact with the CVC

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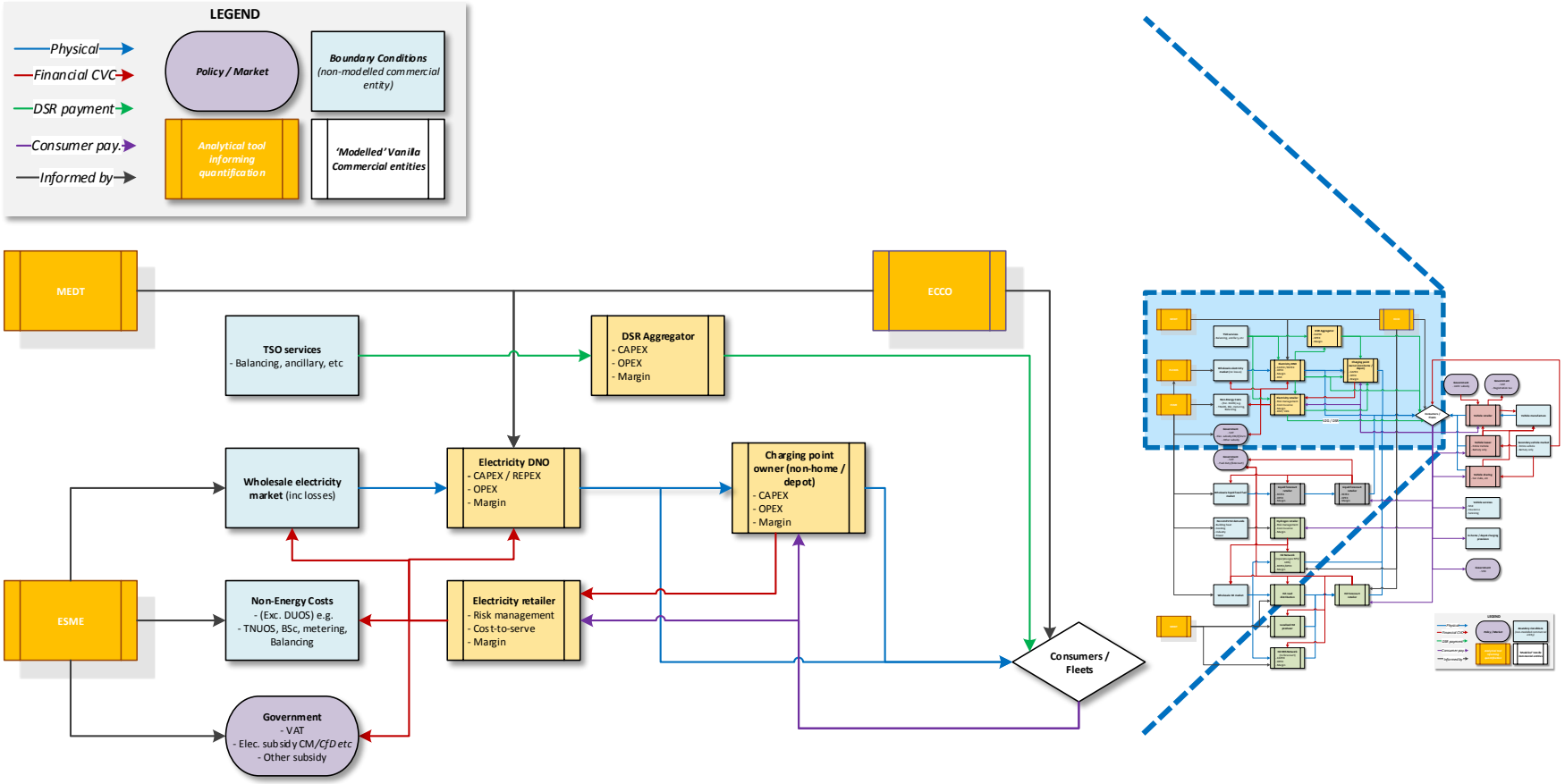
Figure 41 Conceptual structure of CPAT focusing on electricity value chain



Note: Shaded blue area represents subset of CVC used in example of electricity price stack in Figure 42

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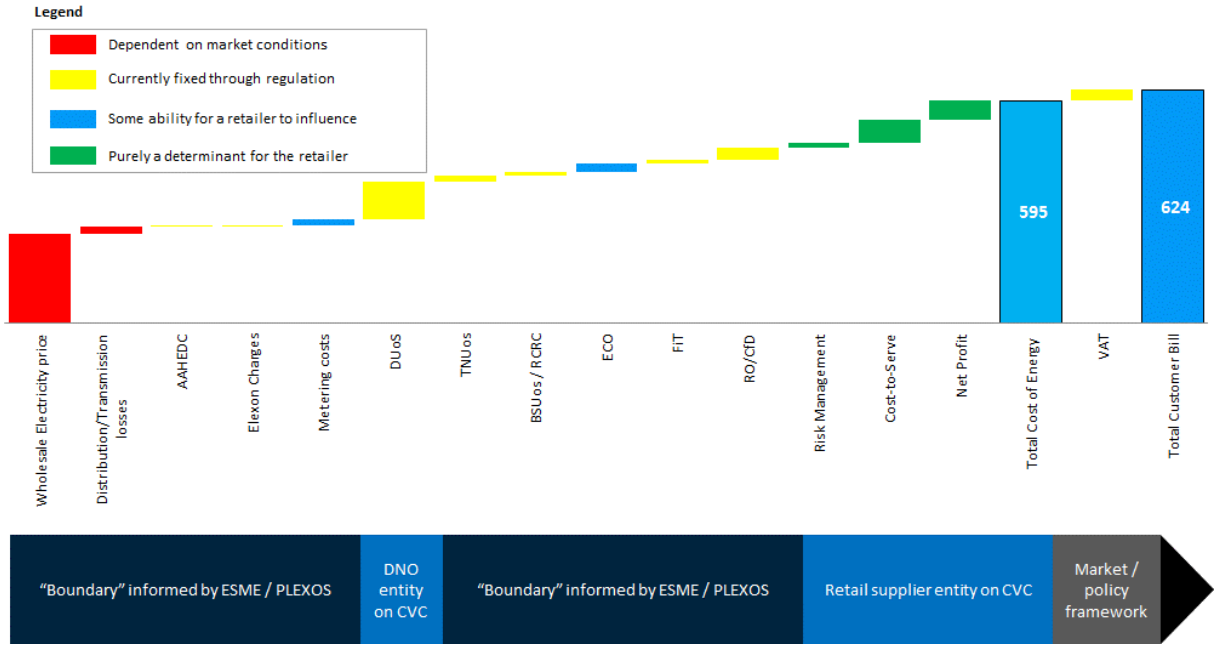
To demonstrate how CPAT will develop the price stack seen by the consumer as part of the Customer Proposition the illustrative example of the electricity price as seen at the point of the electricity retail supplier is shown in Figure 42. This reflects the current stack of components that exist given the regulatory and policy framework. It is not proposed to model all steps on this in detail, but focus 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 42 Illustrative electricity stack price build-up at point of retailer on CVC



The size of the components will vary 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) it is not proposed to model all of them in detail, but simplify them appropriately. As illustrated at the bottom of Figure 42, the price stack will be simplified to:

- 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

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- Estimated subsidies[43] 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
- 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

8.1.2 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 customer 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 cashflows 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 cashflows as there is a clear preference to prioritise public income sooner and public expenditure later in the pathway
  - N.b. 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 more

[43] See section 6.2 for further discussion of how a more generic representation of these subsidies is proposed to be reflected.

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complicated policy instruments such as capital allowances, which can 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 so will be 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 42 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 ToUTs 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.
- **Distributional impacts on consumers** – it is proposed to be able to explore the differential impact on a ULEV versus non-ULEV owning house, but not e.g. equity implications for different income groups
- **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-serve – e.g. a reduction in administrative costs for smaller versus larger retailer electricity suppliers

8.1.3 Assessing commercial viability

Figure 43 provides an illustration of how the cash flows across a generic entity will be 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[44]) due to the commissioning period and a slow growth in revenues as market demand gradually grows[45].

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 cashflow) – 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

[44] 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.
[45] E.g. in the case of developing a piece of network infrastructure which does not reach required utilisation straight away.

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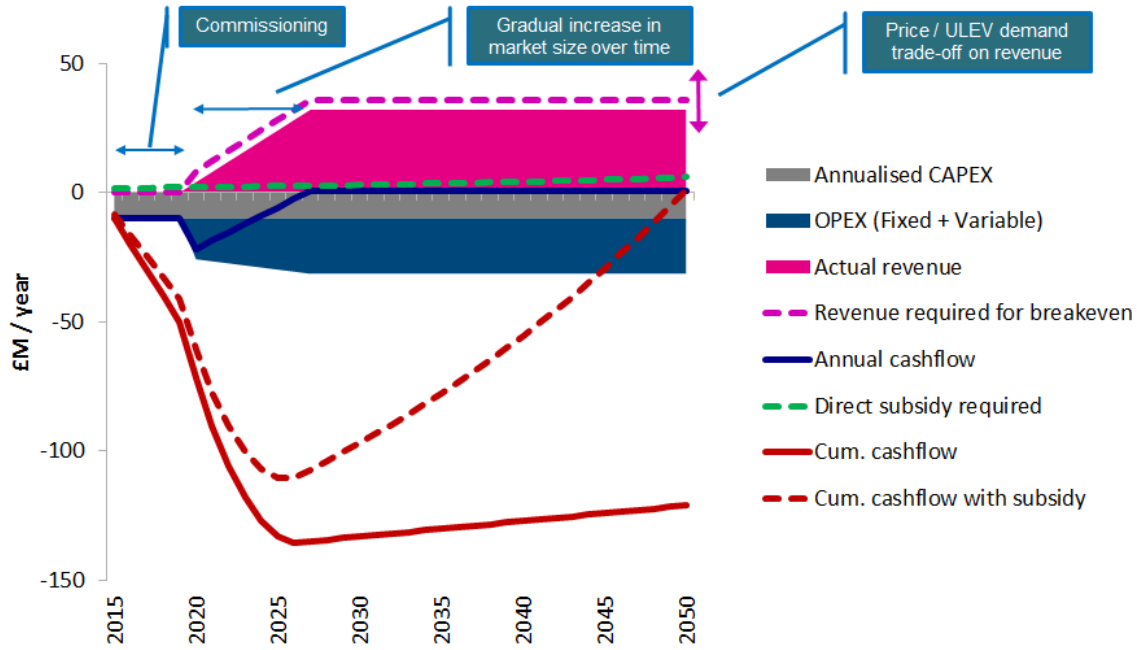
Government is providing subsidy support to the consumer which means they do not see the fully impact of the higher price.

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 cashflow (red dotted line) is shown in Figure 43. 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 43 Illustration of cash flows and viability assessment for generic commercial entity



Not considering the full economic and technical life of all investments by cutting off the pathway in 2050 may mean that level of support to make the commercial entity viable is overestimated in absolute terms – i.e. as later periods where revenues significantly exceed costs, after all capital investment has been recovered, are not being modelled explicitly.

However, for the purposes of the Analytical Framework all commercial entities are being assessed on the same basis and the overarching metric of viability reflects a position of "what do is needed to make the delivery of the end-state system and supporting infrastructure viable by 2050 at the latest."

8.2 Key inputs / outputs and interaction with other tools

The key inputs to CPAT divide into five main categories

- Vehicle uptake / energy demand from ECCO and cost data (vehicle, insurance, etc)
- Energy wholesale proxy prices from the PSC tools (translated into prices seen by the Customer Proposition through CPAT)

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- Infrastructure investment requirements from the PSC tools
- Assumptions on key MPF interventions consistent with the overarching narrative (e.g. the level and targeting of a specific subsidy)
- Other supplementary data associated with the commercial entity (e.g. hurdle rate, 'cost-to-serve'

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Table 22 CPAT key inputs

Group	Data field	Purpose	Granularity	Source	Notes
Vehicles	Vehicle uptake	– Drives demand placed on PSC and CVC affecting prices seen for consumer proposition	# vehicles by build year vintage by time period	ECCo	-
	Vehicle charging profiles/efficiency, and load factors	– Operational characteristics of vehicles combined with fuel prices to create fuel costs used in TCO	– kWh by vehicle by build year vintage, by time period for ▪ Also by season, by hour for electricity ▪ By season for hydrogen – vkm per year (+ by mode for PHEV)	ESME / ECCo base datasets Charging profiles based those used in ETI PiV (2011) analysis	Also dependent on narrative (e.g. where dynamic tariffs or DNO control applied)
	'Wholesale vehicle price'	– Base price for each vehicle used to inform the Customer Proposition, prior to e.g. additional margin from retailer/leaser, taxes, subsidies etc – used to create price stack	£ by vehicle build year vintage, by time period	ESME/ECCo base datasets	-
	Secondary vehicle market prices	– Estimate of the price achieved by fleets for resale of the vehicle at the end of its commercial life	£ by vehicle build year vintage, by time period	Exogenous	Potentially dependent on narrative
	Supplementary vehicle service costs	– Additional costs which need to be considered within the TCO such as MoT, insurance, servicing	£ by vehicle build year vintage, by time period	Exogenous	

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Energy costs	Carbon shadow price	– Used to inform prices seen by Customer Proposition for liquid fossil fuels, applied as generic carbon tax on use	£/tCO2 by time period	ESME	-
	Biofuel wholesale price proxy	– Proxy for price of centralised large-scale liquid biofuel production	£/MWh by time period	ESME	Includes shadow carbon price
	Carbon intensity liquid fuels	– To reflect any biofuel blending	tCO2/MWh	ESME	
	Liquid fossil wholesale price	–			
	Hydrogen wholesale price proxy	– Proxy for price of centralised large-scale hydrogen production	£/MWh by time period by season	ESME	Includes shadow carbon price
	Wholesale electricity price proxy	– Proxy for price of centralised large-scale electricity production, assumes recovery of 'missing money' via LRMC pricing		ESME	Includes shadow carbon price and network losses
	Electricity transmission Investment and OPEX costs	– Used to adjust wholesale electricity price	–	ESME	
Infrastructure requirements	Electricity distribution network reinforcement and operating costs	Reflect additional investment that commercial entities associated with electricity distribution will need to make to cover both ULEV and other incremental demand – Investment costs – Economic / technical lifetimes	– £bn cumulative CAPEX by time period – £bn OPEX/REPEX by time period – Years for lifetimes	– MEDT – Published data, e.g. DNO price controls	-
	Hydrogen distribution investment and operating costs	As above, but type of investment requirement and commercial entity delivering this will vary by narrative (e.g. trailer to forecourt versus	– As above	MHDT	-

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		dedicated pipe network			
	Electricity charging network investment and operating costs	As above, but type of investment requirement and commercial entity delivering this will vary by narrative (e.g. in home versus public charging)	– As above	Exogenous assumption consistent with narrative	-
	Localised hydrogen production	Small-scale SMR and electrolyser investment and operating costs and operating parameters	All by build year vintage by time period – £ / unit and OPEX – Economic / technical lif	– ECCO base datasets – Exogenous – e.g. LowCVP[46] / H2 Mobility	Large scale H2 production and/or fuel inputs for local production provided separately
Commercial entities	Supplementary operating costs	Additional OPEX (fixed and variable) related to cost-to-serve and risk management costs	£/unit sales (e.g. MWh energy or vehicle) by time period	– Exogenous – Published data, e.g. DNO price controls, Ofgem Consolidated Segmental Statements for electricity suppliers – For hydrogen use current gas network/liquid fossil distribution costs as sensible proxy	-
	Hurdle rates	Required for new investments including profit margin	%	As above	May vary by e.g. entity type, technology, market framework, etc
	Non-ULEV utilisation	Some forms of investment may also be used to	MWh by time period, by	ESME	-

[46] http://www.lowcvp.org.uk/assets/reports/20150307_LowCVP%20Infrastructure%20Roadmap_HYDROGEN_Final%20(with%20graphics).pdf

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		support non-ULEV demands (e.g. hydrogen for HGVs), and the price set by the commercial entity needs to reflect the wider demand base over which its cost can be spread (e.g. a HRS used by both ULEVs and HGVs)	energy type			
Market and Policy	Narrative specific MPF inputs	Reflection of existing and proposed subsidies, taxes, public investments, etc on the CVC or at the point of the Customer Proposition – data includes: – Type – tax, subsidy, etc – Target entity – Form of implementation – e.g. capacity/utilisation – Value by time period (by timeslice where relevant)	– Dependent on MPF intervention	Exogenous – see D4.1. Building Block deliverable	-	

Table 23 CPAT key calculated outputs

Data field	Purpose	Granularity	Destination	Notes
Final prices for energy used by vehicles	Price for use in TCO calculation (i.e. combination of unit prices and consumption to single £ figure)	£ by vehicle by time period	ECCO	Prices see by consumer in TCO calculation are myopic – i.e. current time period prices only used across TCO lifetime Does not include final tax subsidy
Vehicle Commercial Entity Adjustment Parameters	ECCO constructs the upfront/ongoing TCO components from the wholesale vehicle costs, but will need to add further costs and or change the TCO cost split	Values from CPAT used in ECCO TCO conversion – Hurdle rates % – Leasing length (where relevant)	ECCO	Constructing Commercial Model adjustments in ECCO means that some element of the cashflows for these commercial entities need to be reported

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	and profile depending on the wider Commercial Model for vehicles (e.g. retailer, leasing, vehicle sharing, etc)	– Additional OPEX (fixed and variable) related to cost-to-serve and risk management costs £/unit sale – Secondary market value (for fleets) Other MPF inputs targeted directly at the vehicle commercial entity are outlined under *MPF inputs* below		back to CPAT *Specific structure of entities and values changes by Narrative*
MPF inputs	Factored-in into eCCO utility equation. CPAT provides source of values consistent with Narrative, but ECCO builds them directly into TCO calculation where they are applied directly at the point of the Customer Proposition or to the vehicle-based Commercial Entity models	Values for policy inputs, by time period – Direct vehicle grant (£/vehicle) – VAT on vehicle (£/vehicle) – Fuel duty (£/MWh) – VED (£/CO_2 banding) – Company car tax (£/CO_2 banding) – VAT fuels – Congestion charge (£/day, threshold gCO_2/km, share of buyers concerned) – Vehicle registration tax (£/unit) – Refund schemes (£/vehicle) – Direct fuel price subsidy (£/MWh) – Direct CO2 tax on fuel use (£/tCO2) – Additional ongoing monetised perks £/vehicle/year – Capital allowances (£/% per vehicle) for non-retailer vehicle business models	ECCO	*Differentiation in policy inputs as necessary by* – *Individual powertrain (or at least high-level ULEV grouping)* – *segments* – *energy type* Tax / subsidy cashflows associated with direct Customer Proposition MPF instruments need to be passed back to CPAT to be accounted for alongside wider Government cashflows
Government cashflows	Tracking of income and expenditure for quantitative Success Metric	£ by time period	Reporting	-
Commercial entity cashflows	Tracking of income and expenditure for quantitative Success Metric	£ by time period	Reporting	-

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9 Analytical representation of BBs

9.1 Representation of high and medium materiality BBs

The following sections provide a more explicit mapping of how the key Building Blocks (BB) identified in the separate deliverable D4.1 ***could*** be assessed within the Analytical Framework (e.g. quantitatively or more qualitatively) and any development required within each analytical tool to achieve this:

- Only high and medium materiality BBs are considered for the Customer Proposition (CP), Physical Supply Chain (PSC), and Market and Policy Framework. Low materiality BBs are not discussed further at this stage
- Where development is required in the underlying tools this is focused on the BBs that are included within the currently proposed Narratives and not across all BBs
- The Commercial Value Chain is treated slightly differently to the other Dimensions and the representation of the BBs, in terms of key commercial entities to model, has already been outlined in section 8 as part of the overview of the Commercial and Policy Accounting Tool. In addition, the CVC naturally interacts with the CP, therefore by definition the quantitative approach to assessing the latter must be mirrored in the former
- For the Market and Policy Framework, those that can be directly included within the Analytical Framework will mostly be from the Financial Measures (Fixed Cost) and Financial Measures (Running Cost) categories, or other BBs that have an absolute monetary value. The Non-Financial Incentives, Limits, Information, Investment and Regulation are more difficult to quantify via the Analytical Framework, although those that are high materiality should at least be assessed qualitatively

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9.1.1 Customer Proposition

Table 24 High materiality Building Blocks for the Customer Proposition

Code	Building Block	Primary Assessment	Used in Narrative(s)	Context	Applied in Tool(s)	Primary interfaces
CP1	**Outright Purchase**	Quantitative	Y	Outright purchase constitutes a third of total new car and a half of total new van sales	ULEV uptake is calculated in ECCo assuming an outright purchase access model by default (i.e. market data gathered from surveys and choice experiments targeting new or nearly new car buyers) and split the TCO (Total Cost of Ownership) into up front and ongoing cost components The key restriction in ECCo is that the purchase access model is consistent for cars (a separate approach can be applied for fleets in the updated model, but must be consistent across all fleet types)	Market Policy Framework (grants)
CP2	**Contract Purchase**	Quantitative	Y	Increasingly popular in the UK, delaying or avoiding vehicle ownership. This trend could benefit the PiV sector, removing high upfront costs Constitutes ca. 20% of total new private cars sales. Negligible use in the van market Other purchase variants such as Hire Purchase and Lease purchase are also included in this BB	Contract purchase could be reflected in ECCo by adjusting the split in upfront (i.e. 0) vs ongoing cost components potentially combined with a longer overall TCO period.	Market Policy Framework (grants)
CP3	**Hybrid (own vehicle, lease battery)**	Quantitative	N	Not offered in all BEV models, but present in the market Nissan Leaf battery lease offers cheaper capex options than a comparable ICE vehicle	ECCo has the option to model battery leasing access model for BEVs, removing battery from capex and spreading battery costs across a number of leasing years	Market Policy Framework (grants)

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CP4	**Contract Hire**	Quantitative	Y	Very popular option among fleet cars (40% of new fleet cars annual sales) No option to own at the end of contract Finance lease is considered under this BB	As per **CP1** Contract Purchase in ECCO, but used for fleets only and costs reflect resale of vehicle onto secondary market.	Market Policy Framework (grants)
CP5	**Short-term hire/ car club**	Quantitative	Y	London is the largest market in Europe for car clubs, 155,000 members, 2,300 cars TfL car club roadmap ambition is of 1,000,000 car club members and 10,000 cars by 2025	As per **CP4** Contract Hire in ECCO, but with likely different underlying data parameters (e.g. vkm / vehicle). In this representation ***fleets*** are making the vehicle purchase decision and consumers are indirectly using the vehicles through the short-term hire/club	Commercial Value Chain Market Policy Framework (grants)
CP6	**Secondary market**	Quantitative	Y	The volume (in numbers) of the secondary car market in the UK is around three times that of the new car market Currently, the used market for ULEVs in the UK is non-existent	Assumed for fleets only, adjust costs seen in TCO calculation (depending on Narrative depreciation assumed for vehicle may differ)	Commercial Value Chain
CP10	**Static ToU**	Quantitative	Y	17% of UK households use Economy7/10[47] Several trials in the UK/internationally Already among half-hourly metered fleets and expected to be more prevalent by the mid-2020s	Exogenous profile shapes will embed ex-ante any consumer response and hence composite of charging profiles and price profiles (e.g. reflecting tariff) wo;; directly drive ongoing TCO component in ECCO	Commercial Value Chain
CP11	**Dynamic ToU**	Quantitative	Y	Low Carbon London trials Dynamic pricing is not expected to become commercial for at least the next 10 years and current peak / off	As per **CP10** Static ToU	Commercial Value Chain

[47] Economy 7/10….

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				peak tariffs do not appear sufficient to Entice EV owners to a two rate tariff		
CP15	**Private charging**	Quantitative	Y	Evidence shows that in the first years of PiV deployment and use, home charging will be prevalent and a pre-requisite for PiV acquisition When the PiV uptake scales up, the role of semi-public charging will increase	ECCo considers access to overnight charging as a pre-requisite to vehicle choice. Only customers with access to off-street parking will see a ULEV in the showroom	Commercial Value Chain Market Policy Framework (grants)
CP16	**Public charging in motorways and A-roads**	Quantitative	Y	Access to recharging is one of the key requirements for PiV purchase, and rapid chargers are potentially an efficient way to compliment overnight charging	ECCo factors-in density and performance of rapid chargers in the decision making. % of population with access to rapid chargers is an input	Commercial Value Chain
CP18	**H2 refuelling stations**	Quantitative	Y	A dense, interoperable and safe refuelling infrastructure is a pre-requisite of mass uptake of FCVs	ECCo factors-in the number of H2 refuelling stations in the decision making process, through the introduction of a penalty that is a function of the number of H2 stations	Commercial Value Chain Market and Policy Framework (grants)
CP28	**Sole vs shared**	Quantitative	Y	This parameter reflects the level of control of the vehicle, and it is flagged under the 'short-term hire/ car club' access model	Under the mobility as a service based Narratives the uptake decision in ECCo is effectively based on ***fleet*** decision making with consumers accessing the service through the fleet vehicles.	Commercial Value Chain

Note: congestion charge concessions have been identified as a component of high materiality for the Customer Proposition (included under the 'cheaper mobility' Building Block in the Market and Policy Dimension). At the current £11.50 daily payments in London, this means close to £2,000 per annum. ECCo factors in congestion charge exemptions for ULEVs, applying either only to London or to London and other cities (1.6 and 13% of buyers, respectively).

Table 25 Medium materiality Building Blocks for the Customer Proposition

Code	Building Block	Primary	Used in	Context	Applied in Tool(s)	Primary

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		Assessment	Narrative(s)			interfaces
CP7	**Bundled installation of charge points**	Quantitative	Y	Most PiV Original Equipment Manufacturers have a deal with a provider of home charging	Assumption on the level of bundled services will be reflected in CPAT, to inform what the customer pays – i.e. cost of charge points is included, but the act of them being bundled or not only affects the consumer if it materially effects the TCO (e.g. through lower financing costs if via commercial entity).	Commercial Value Chain
CP12	**Demand Management Payments**	Quantitative	Y	It could be material after 2020 for captive fleets, able to amortise associated investments and to get simpler and more commercially attractive balancing service contracts, similarly for consumers if managed via an aggregator	Services will be reflected in the CPAT, capturing financial benefits for the ULEV user/ aggregator providing the service and for the DNO. The benefit for the consumer will be reflected in an adjusted TCO in ECCO	Commercial Value Chain
CP17	**Public charging in local points**	Quantitative	Y	The materiality of local charging points is lower than home and rapid chargers However, they might have a relevant role in the future, as PiV owners without overnight access to electricity access the market	ECCo factors-in public charging in local points in the decision making. % of population with access to work, local public charging points and intercity rapid charging points are inputs	Commercial Value Chain Market and Policy Framework (grants)
CP23	**Subscription model**	Qualitative	Y	There is no evidence on what is the impact of billing model options on uptake of PiVs Captured as 'medium' materiality, as it provides scope for new business models over the traditional PAYG one in the medium term	Not modelled. Qualitative description to be tested in stage 2 trials	Commercial Value Chain
CP24	**Support for price certainty in between subscription /**	Qualitative	Y	There is no evidence on what is the impact of this BB on uptake of PiVs Captured as 'medium' materiality, as it provides scope for new business	Qualitative description to be tested in the trials	Commercial Value Chain

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	PAYG			models over the traditional PAYG one in the medium term		
CP29	**Charging control**	Quantitative	Y	There is no evidence on what is the impact of this BB on uptake of PiVs Relevant for customer acceptance of the proposition: most research suggests that people have concerns about technology in their homes being controlled by third parties (i.e. direct control).	Reflect in exogenous assumptions, e.g. better management of charging at peak under direct control.	Commercial Value Chain
CP30	**Vehicle choice**	Quantitative	Y	Potential high willingness to pay for availability of the preferred make/model. DfT study on this in PiV market to be published shortly.	ECCo factors this component in for the decision making process of vehicle purchase. For 'Mobility as a Service' based Narratives could indirectly reflect this by altering available segments of the market	

Note: Vehicle Excise Duty and Company Car Tax have been identified as a component of medium materiality for the Customer Proposition (included under the 'vehicle excise duty' and the 'company car tax/ employee car tax' Building Blocks of the Market and Policy Dimension). These perks, although behind in the importance of capex, range or infrastructure are an attractive element to the Customer Proposition, particularly for fleets/companies, mainly taking TCO driven decisions. ECCo factors-in different VED and Company Car Tax rates depending on the CO2 banding in the utility equation that underpins vehicle buying decision making process.

9.1.2 Physical Supply Chain

Table 26 High materiality Building Blocks for the Physical Supply Chain

Code	Building Block	Primary Assessment	Used in Narrative(s)	Context	Applied in Tool(s)	Primary interfaces
PSC1	**Battery**	Quantitative	Y	Battery cost and performance are critical for the uptake of ULEVs For a medium sized BEV, the battery constitutes around 40% of its cost currently and around	Battery cost and technology attributes are part of ECCo's cost and performance database. WP3 will give more information about these	Customer Proposition Commercial Value Chain (V2G)

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				20% in 2050		
PSC2	**Battery Management System**	Quantitative	Y	Enables improvements in battery lifetime and costs as well as integration with wider energy system	BMS costs are part of ECCo's cost and performance database. As above, WP3 will inform on these	Customer Proposition Commercial Value Chain (demand-side management enabler)
PSC3	**Fuel Cell System**	Quantitative	Y	Its cost development will be critical for the uptake of FCVs For a medium sized FCV, the fuel cell system constitutes around 30% of its cost from 2020 to 2050	Fuel cell cost and technology attributes are part of ECCo's cost and performance database.	Customer Proposition
PSC8	**Electricity generation plants**	Quantitative	Y	Contains critical parameters for the analysis such as electricity price and grid carbon levels.	Information on electricity generation costs should come from ESME	
PSC9	**Hydrogen generation plants**	Quantitative	Y	Strong influence on the costs and environmental performance of FCVs	H_2 price is an input to ECCo from ESME	Commercial Value Chain (H_2 direct to the consumer as used for grid services from water electrolysers)
PSC12	**Electricity Distribution Network**	Quantitative	Y	Lower materiality of impacts of EVs in DN, compared to heat electrification levels The difference in reinforcement costs between managed and unmanaged charging Scenarios is high	MEDT provides a view on the investment requirements for the networks, how those costs are recovered is tracked by CPAT (e.g. via EV specific user charges, generic DUoS charges, etc)	Customer Proposition (fuel pricing options) Commercial Value Chain (extent of managed charging)

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PS21	**Private charging infrastructure for PiVs**	Quantitative	Y	Essential part of making a credible offer to consumers and fleets for PiVs Potential investments in infrastructure towards 2050 will be high (low billions) and this is also an enabler for demand management	Influential parameter for vehicle purchase decision making in ECCo. Only those buyers with access to off-street parking will see a PH/BEV in the showroom Network peak demands for transport will be calculated from ECCo's ULEV uptake and assumed charging profiles	Customer Proposition Commercial Value Chain (extent of managed charging, V2G)
PSC22	**Public charging infrastructure for PiVs**	Quantitative	Y	A rapid charging infrastructure is essential for mass ULEV uptake	Influential parameter for vehicle purchase decision making in ECCo. Rapid chargers highly valued (particularly by BEVs)	Customer Proposition Commercial Value Chain (public chargers)
PSC23	**Hydrogen Refuelling Stations**	Quantitative	Y	Mass uptake would require high investments in infrastructure towards 2050 (low billions) Choice of electrolysers vs. truck deliveries has a high impact on cost	MHDT will provide more detailed view of investment requirements from H_2 vehicles ECCo can calculate the deployment of HRS needed to meet demand	Customer Proposition Commercial Value Chain (public chargers, ancillary services for grid e.g. through on-site generation or storage)
PSC25	**Industry Standards**	Qualitative	Y	Critical for the development of the integration of PiVs in a smart grid supply chain	Not a direct input of the Analytical Framework but an overarching parameter in the Narratives	N/A – part of Narratives

Table 27 Medium materiality Building Blocks for the Physical Supply Chain

Code	Building Block	Primary Assessment	Used in Narrative(s)	Context	Applied in Tool(s)	Primary interfaces

Baringa Partners LLP is a Limited Liability Partnership registered in England and Wales with registration number OC303471 and with registered offices at 3rd Floor, Dominican Court, 17 Hatfields, London SE1 8DJ UK.

PSC13	**Electricity Transmission Network**	Quantitative	Y	EVs may be used by the TSO (via aggregators) for the provision of ancillary services (UK revenues attributed to the procurement of ancillary services from a fleet of 23 million EVs by 2050, have been reported to be ~ £800million/year by 2050)	ESME will provide the investment requirements	Customer Proposition (ancillary services) Commercial Value Chain (ancillary services provided by ULEVs)
PSC14	**Hydrogen distribution**	Quantitative	Y	Difference between hydrogen distribution Scenarios likely to be less than 10% of fuel selling price Cost reduction happens naturally during hydrogen rollout as distributed volumes increase. I.e. not a barrier that is critical to unlocking hydrogen mobility	Indirectly factored in to H_2 costs	Commercial Value Chain
PSC17	**Large scale batteries**	Quantitative	N	Indirect link to ULEVs, but their use might accelerate development of commercial models for managed charging/ DM, and provide a use for second life batteries	ESME, but at aggregate system S/D level	Commercial Value Chain
PSC24	**Diesel / petrol forecourts**	Quantitative	Y	Although the costs associated to forecourt infrastructure are low compared to that required for ULEVs, the number of forecourts could potentially be an important factor for ULEV uptake (i.e. rural areas with remote fuel infrastructure, in an scenario of a decrease in the number of forecourts, could be crucial for ULEV uptake)	CPAT assess ongoing commercial viability of given number of forecourts and passes this to ECCo	Commercial Value Chain Market and Policy (support to avoid stranded forecourts)
PSC26	**Assets needed for settlement**	Qualitative	N	DECC estimation of smart meters costs of £10.9billion and revenues of £17.1billion by 2030 for the implementation of smart meter roll-out	Assumed to be in the baseline across Narratives	Commercial Value Chain
PSC27	**Assets needed for communication and central management control**	Quantitative	Y	Potential to enable new business models and new interactions between actors (i.e. battery owner - aggregator - DNO) Their role in enabling a smart grid system is unknown (i.e. they could be made obsolete by apps, mobiles, etc)	Smart Electricity LDN control costs assumed with MEDT	Commercial Value Chain

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9.1.3 Market and Policy Framework

Table 28 High materiality Building Blocks for the Market and Policy Framework

Code	Building Block	Primary Assessment	Used in Narrative(s)	Context	Applied in Tool(s)	Primary interfaces
MPF1	**Direct grants to consumers**	Quantitative	Y	Currently Plug in Car Grant and Van Grant	Factored into TCO calculations in ECCO	Customer Proposition
MPF2	**Private grants to consumers**	Qualitative	Y	Manufacturers offer grants (or alternatives such as low interest loans) on the vehicle or charging points to supplement those offered by Government	Not modelled directly given simplifying assumptions of cost reflective pricing in CPAT	Customer Proposition Commercial Value Chain
MPF3	**VAT on assets**	Quantitative	Y	Currently 20% of the asset cost in the UK, paid at the point of purchase. Some VAT can be reclaimed if the vehicle is leased or is used for business purposes. Norway has exempted targeted ULEVs from paying VAT	Factored into TCO calculations in ECCO	Customer Proposition
MPF22	**Direct CO2 tax**	Quantitative	Y	Simplest mechanism (if applied at point of fuel purchase) to reflect cost of carbon in price seen	Factored into TCO calculations in ECCO for fossil fuels. N.B. carbon price is already embedded in the final price for other energy carriers (electricity, hydrogen)	Customer Proposition Commercial Value Chain

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MPF23	**Direct emissions limit**	Quantitative	Y	Interaction with EU e.g. CO2 target for new vehicles (fleet averages). 95gCO2/km by 2021 for cars and 147gCO2/km for vans by 2020	CO2 target should be inherent in the vehicle choice within ECCO[48]. Proposed to reflect a linear improvement in the current targets from 2020 to 2030, of 75 gCO_2/km for cars and 120gCO_2/km for vans, but hold these constant from 2030 to 2050 for all Narratives	Customer Proposition Physical supply chain
MPF28	**Government funding/ investment**	Quantitative	Y	The primary focus of this is funding for infrastructure, or to Local Authorities that adopt fleets or put in place a package of measures to support ULEV uptake and use. For instance, the UK Government invested in a 'Plugged-in-Places' scheme that delivered 5,500 charging points.	Considered in Commercial Entity revenue streams in the CPAT for infrastructure owners	Customer Proposition Commercial Value Chain Physical Supply Chain
MPF29	**Private investment**	Quantitative	Y	This includes private companies funding infrastructure (e.g. charging points) and fleets etc. (car sharing)	As above	As above
MPF33	**Access to infrastructure**	Qualitative	N	Could have significant value in bolstering support for charging point operators and changing consumer perception Norwegian experience suggests that public charging network not a pre-requisite but consumers perception of driving range and charging time need to be tackled.	Described qualitatively where relevant	Customer Proposition Commercial Value Chain (may affect choice of rapid/ fast/ slow build) for charging point owners/ operators

[48] ECCo has the ability to calculate a "penalty" mark up to the cost of the vehicle where the fleet standard does not meet the target

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MPF34	**Other laws and regulations**	Qualitative	N	Various other laws such as EU directives, price/asset regulations, market structure	Described qualitatively where relevant	Customer Proposition Physical Supply chain

Table 29 Medium materiality Building Blocks for the Market and Policy Framework

Code	Building Block	Primary Assessment	Used in Narrative(s)	Context	Applied in Tool(s)	Primary interfaces
MPF4	**Purchase and registration tax**	Quantitative	Y	In the UK, this is currently only £55, paid as a one-off upfront cost, however, in other countries it is significantly higher (for instance in Denmark this is based on vehicle price, safety equipment and fuel consumption – BEVs are exempt and save around €14,000).	As with direct grants (from Government), VAT, capital allowances, and private grants, it is the total value of the upfront discount that can be applied to ULEVs (or premium added to ICEVs) that is most important – used within ECCo	Customer Proposition
MPF5	**Refund schemes**	Quantitative	Y	For instance refunds for battery recycling (Nissan offer of around £1000)	This is not explicitly considered within ECCo as ECCo which is a purchase-ownership tool and assumes that the battery life is equivalent to the vehicle life. An option is to annuitize the battery replacement cost (less recycle value) and apply as an annual fixed cost; or assume battery leasing becomes widespread and reduces the consumer concern about battery lifetime	Customer Proposition Commercial Value Chain (e.g. Battery Leasing models)
MPF7	**Fuel price subsidies**	Quantitative	Y	Saving money on fuel costs is private and fleet owners' primary reason for buying a ULEV in the UK The annual fuel cost of petrol/ diesel vehicles should be compared against that	Fuel price is an input to ECCo and should be considered automatically depending on vehicle type	Customer Proposition

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				for vehicles using $H_2$and electricity, and with due consideration of the impact of changing fuel subsidies (and taxes)		
MPF8	**Vehicle excise duty (road tax)**	Quantitative	Y	Typically varies with CO2 emissions in the first (changes to VED from 1 April 2017 onwards propose retaining the core CO2 differentiation for the first year of the vehicle life only followed by only 3 bands of VED for all subsequent years which are more strongly delinked from CO2 emissions)	Included within ECCo	Customer Proposition
MPF9	**Company car tax/ employee car tax benefit**	Quantitative	Y	Benefit-in-kind for cars and vans, whereby the users pay less tax	Can be included within ECCo, for 'User Choosers' category, not private buyers	Customer Proposition
MPF10	**Fuel duty**	Quantitative	Y	Varies with fuel; electricity is exempt. No fuel duty applied at present on H_2, but no clarity over taxation in mid-long term.	Included within ECCo (p/l)	Customer Proposition
MPF11	**VAT on fuel**	Quantitative	Y	VAT is charged on fuels; electricity has a reduced rate but is not exempt	Not currently included in ECCO but could be applied within the fuel price inputs	Customer Proposition
MPF12	**Cheaper mobility**	Quantitative	Y	Other monetised benefits such as congestion charge exemption and reduced tolls	Congestion charge is included within ECCo and applies to a portion of users (to represent London); reduced tolls may be excluded due to a probable lower value, although the significance of this should be clarified	Customer Proposition
MPF13	**Cheaper access to parking**	Qualitative	Y	Free parking for ULEVs, typically localised/ depends on Local Authorities and private partners; estimated value of £50-250 p.a. (EE). Needs to be considered as part of the 'overall amount of subsidy' BB as potentially part of measures proposed by Local Authorities and funded	As this is more specific to urban areas (that are not distinguished in ECCo), it will likely be described qualitatively – more relevant for some Narratives than others	Customer Proposition

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				by Government		
MPF16	**Road Pricing**	Semi-Quantitative	Y	More novel instrument designed to address a range of objectives including replacing lost liquid fuel revenue, reduce CO2/AQ emissions (primarily through more efficient driving patterns) and reduce congestion	The primary element quantified will be the policy instrument to replace lost revenue via a simple distance tax. The other elements around congestion, CO2 and potential impact on ULEVs (e.g. charging patterns) will be assessed qualitatively as relevant	Customer Proposition
MPF18	**Increased mobility**	Qualitative	Y	Although not directly monetisable, benefits such as access to HOV lanes have been considered very important for ULEV uptake elsewhere	Described qualitatively where relevant; more important in urban areas.	Customer Proposition
MPF19	**Simplification**	Qualitative	N	Simplify taxes (e.g. into a single 'carbon' tax) and charging options (e.g. pay-as-you-go/ all users can access all charging points/ one key (driving licence/ mobile app etc.)	Described qualitatively where relevant	Customer Proposition Commercial Value Chain (e.g. charge cards, network partnerships, digital/ smart services)
MPF20	**Status**	Qualitative	Y	Special kudos/ status to ULEV owners – potential a factor for early adopters, such as reserved number plates or ECO-labels	Not easily quantifiable, may have more effect in densely populated areas – described qualitatively, most likely as a package of measures to bolster advertising	Customer Proposition
MPF26	**Education/ marketing**	Qualitative	Y	Other than range concerns and purchase price, lack of knowledge / familiarity with EVs is a commonly cited barrier to uptake	Could adjust the Real World Factor in ECCo to represent higher consumer engagement/ less range anxiety, or the split of consumers to increase the amount that have 'awareness' of ULEVs and incentives However, for Narratives assumed that this is assessed qualitatively	Customer Proposition

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MPF27	**Mandatory/ voluntary reporting**	Qualitative	Y	CO2 emissions level for vehicle, Public Attitudes Tracking Survey etc.	Can change the split of consumers to increase the amount that have 'awareness' of ULEVs and incentives, however, may have less impact than pro-active 'Education/ marketing'	Commercial Value Chain
MPF30	**Investment in R&D**	Qualitative	Y	For instance, focusing on extending the battery life and reducing the cost for consumers	Described qualitatively where relevant	Customer Proposition Physical Supply Chain
MPF31	**Capital Allowances**	Qualitative	N	For instance, in the UK some vehicles eligible for a 100% first year capital allowance	Not considered within CPAT as it reflects a pre-tax assessment of commercial viability	Commercial Value Chain
MPF35	**Commitment**	Qualitative	Y	Government commitment to strategy (e.g. leading by example with fleets) and industry (e.g. holding subsidies for a defined length of time)	Described qualitatively where relevant	Customer Proposition Commercial Value Chain
MPF36	**Role of Local Authorities**	Qualitative	Y	For instance, only allowing for replacement of municipal vehicles with electric vehicles and mandating charging point installation in new buildings	Described qualitatively where relevant	Physical Supply Chain
MPF37	**Standardisation**	Qualitative	Y	Charging point technology, payment methods etc.	Described qualitatively where relevant	Physical Supply Chain

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9.2 Analytical tool development required

This section provides a summary of the key enhancements required for each tool within the Analytical Framework, as a result of being able to either:

- Incorporate the individual tool more effectively as part of the wider framework
- Represent the Building Block more effectively

9.2.1 ESME

The following updates will need to be made to the ESME model for this project

- Adjust the *MinBuildQuantity* constraint to force in fleet average vehicle factors specific to each timeperiod rather than by build year period
- Create simple post-processing tools (potentially within the ESME database) to automatically calculate subsidy, transmission investment and abatement cost metrics for use in CPAT

9.2.2 MEDT

No updates are assumed to be required for the MEDT tool. Pre-processing of input data into the required format for MEDT is dealt with under the other tools.

9.2.3 MHDT

The MHDT is to be developed as part of this project. It is envisaged to be a simple spreadsheet tool that can quickly translate a set of hydrogen demands at the distribution level, consistent with each narrative, into a more specific set of investment and operating costs requirements for use in CPAT.

9.2.4 ECCo

A consolidated version of the ECCo model will be developed from the version already developed for the ETI ("ECCo Model (ETI)"), incorporating a list of modifications agreed with ETI. Envisaged updates in respect of private consumers and fleets are outlined below.

Private consumers

The following updates will need to be made to the ECCo consumer model for this project

- Include hourly electric vehicle demand profiles in ECCo and combine this with total ULEV uptake to understand peak network demand
- Provide the flexibility to ECCo to capture attitudes and behaviours to energy demand management investigated under Task 2.1 (i.e. embedding different charging profile types, managed or unmanaged, as well as different time of charge assumptions for work/public slow/rapid and home charging)
- Coefficients obtained during stage 2 choice experiment will be used to sense check/adjust current ones

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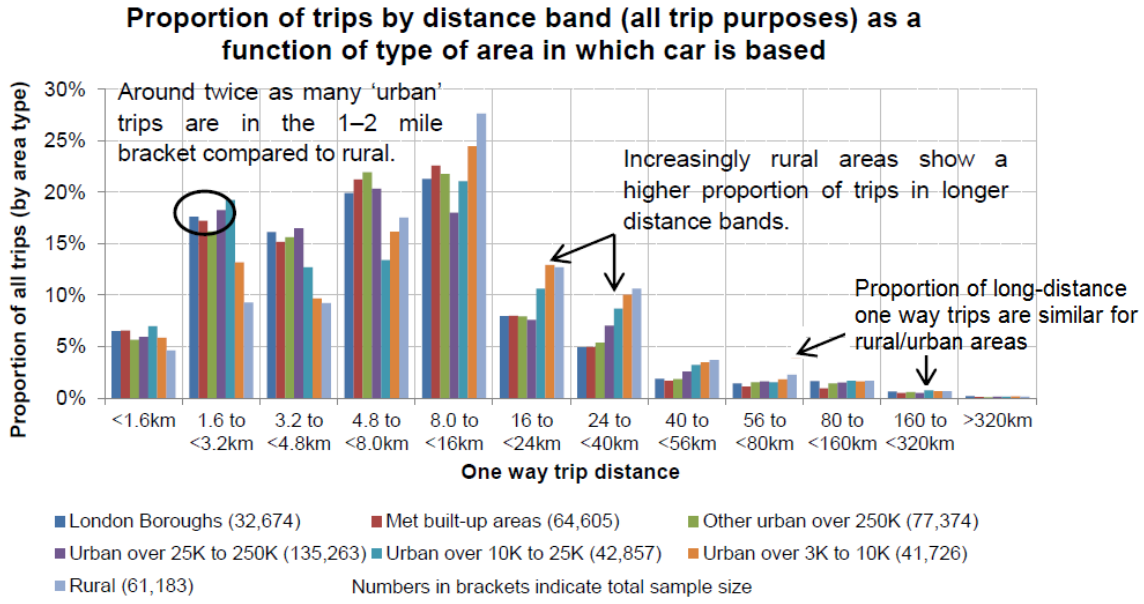
- Research will be conducted to verify that the approach to consider all new van sales as 'fleet vans' (i.e. bought based on an unbiased decision) is appropriate. At the moment the evidence indicates only 10% of vans are user-choosers, but there is a need to understand the extent of fleet vans that are actually bought by private consumers. Data being very limited on this, one approach is to use sensitivity analysis to demonstrate the impact or lack of impact on key outputs.

The introduction in ECCo of a differentiation in private consumer vehicle usage/mileage (and hence purchase behaviour) between urban and rural areas has been considered. However, the analysis carried for the ETI in 2011 shows that the variation in driving patterns between areas is unlikely to be the primary factor limiting uptake of electric cars. It shows that the proportion of one-way trips longer that 56km is very similar among urban and rural areas (Figure 44). A sensitivity on how the percentage of annual mileage driven in electric mode for PHEVs affects their uptake has been conducted, showing that there is a small difference in the percentage of annual mileages that rural and urban drivers could do in electric mode (see Table 30).

For these reasons, it is not proposed to introduce a rural/urban mileage differentiation for private consumers. ECCo can however apply some local incentives to a limited given share of vehicle buyers (e.g. congestion charge). It is, however, important to note that for the City-Led narrative there is a proposed 'mixed' situation where urban consumers shift towards a 'transport as service' model where rural consumers remain focused on mobility as an asset. Although an explicit urban/rural split in ECCo is not deemed necessary this specific example is dealt with via the fact that a portion of private consumer vehicle service demands reflecting urban areas shifts over time into a dedicated "fleet car sharing segment", with its own decision making. The residual vehicle service demands in the private consumer segment then, by definition, represent rural consumers.

For fleet vehicles (see further below) the project team is currently exploring enhanced segmentation that will be derived from the RouteMonkey dataset will allow to differentiate travel patterns across fleets. A rural versus urban focus might emerge from the segmentation.

Figure 44 Proportion of trips by distance as a function of area type



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Source: Evaluation of candidate locations for recharging infrastructure and electric vehicles, D1.5-4'. Element Energy for ETI, in June 2011)

Table 30 Percentage of annual mileage driven in electric mode in a PHEV

PHEV electric range (km)	National average (values used in ECCo)	London Boroughs	Rural
50	62%	61%	61%
80	73%	70%	74%
150	83%	80%	84%

Note: assuming that the vehicle can only charge once a day

Fleets

The following updates will need to be made to the ECCo fleet model for this project

- Car fleet decision making process will be modelled as a Total Cost of Ownership and driving cycle suitability approach. Currently it is based on the same parameters as for private consumers, with the coefficients based on average samples and with the trade-off between running/capital costs calibrated on observed sales
- Fleet vehicle buyers will be segmented, based on the **fleet typologies** defined under WP2. Work on this is under development but expected Dimensions include private/public sector, fleet size and average mileage. This work is supported by the analysis of the Route Monkey's fleet database.
- **The technical feasibility of ULEV adoption** in terms of driving range will be improved:
  - It will be based on the analysis of the Route Monkey database (>300 fleets, > 9,000 vehicles)
  - It will be different across the fleet segments
  - It will vary according to the deployment of charging infrastructure assumed. Three configurations are possible for this: slow charging at depot, rapid charging at depot, depot plus public charging.

  To this effect, the Route Monkey algorithm will be run multiple times (to answer the question 'can vehicles in a given fleet be replaced by a battery EV?'): for the various charging Scenarios, fleet typologies and a set of electric vehicle driving range assumptions. A parametrisation of the results will be conducted and embedded in ECCo.

The materiality of a 'fleet optimisation' functionality in the model will also be explored. Under that function, the mileage of (a share of) fleets could be decreased.

To inform this, the Route Monkey algorithm would be run in its 'route optimisation' mode, where fleet routes are re-optimised to reduce the miles driven by each vehicle. A mileage reduction potential would be derived for each fleet segment.

Reducing the mileage needs facilitate the adoption of ULEVs by lowering the driving range needs but, conversely, the fuel cost saving opportunities are also decreased. Another element that will be explored is the optimisation of the number of vehicles (decrease vehicle numbers and hence increase

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the mileage per vehicle), in which the higher mileages could encourage the adoption of Fuel Cell Vehicles over other ULEVs.

General development

Some developments are required in ECCo to:

- Create additional **flexibility** to apply Market and Policy Framework building block input data to accommodate the options used in the Narratives and report associated spending
- Develop **post-process calculations** to more efficiently feedback relevant data to other Analytical Tools (e.g. CPAT)

9.2.5 CPAT

The CPAT is to be developed as part of this project and is envisaged to be a simple, modular spreadsheet tool, providing the requirements outlined in section 8.

It is not clear at this stage whether a separate copy of the tool will be configured in a bespoke manner for each narrative, or whether the underlying tool is more flexible and allows it to be configured for multiple Narratives within the same core framework.

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10 Application of Analytical Framework

10.1 Combined MCA

For each narrative the Analytical Framework will provide:

- A set of quantitative Success Metrics for each Dimension using the Analytical Tools
- A set of qualitative Success Metrics for each Dimension
- 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 will also be used to more holistically assess the materiality of key factors within and between Narratives, and how effectively the choices fit together across the 4 overarching Dimensions in each narrative.

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 will be used to explore how robust that narrative is to circumstances, which are outside of its control (e.g. international fossil fuel prices) and whether some Narratives are more sensitive to changes in these conditions than others.

Although quantified, the quantitative Success Metrics for each Dimension are not on a common (e.g. monetary) basis that enables direct comparison across Dimensions and Narratives. At this stage it is not proposed to formally weight the Success Metrics, as per some forms of MCA[49], 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 will, however, provide an important evidence basis to understand the implications of applying more weight to one Dimension over another.

10.2 Informing high-level trial design

The Analytical Framework is designed to function as a standalone piece of analysis as well as to inform the high-level design features of the Stage 2 trial. It is important to note that, at this stage ***no*** recommendations are being made on the structure of the trial, this will be the focus of the ***separate*** deliverable *D1.4 –Trial Design, Methodology and Business Case*, which will be completed at the end of Stage 1.

However, the process by which the framework could be used to inform the trial might follow four sequential steps:

- **Step 1**: the Building Blocks identified in Deliverable 4.1 (with a focus on those BBs being explored within the set of Narratives) should be filtered in terms of those which are:
  - Impractical given available time and resources
  - Practical to trial (or indirectly simulate) and an associated estimate of 'effort'

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

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- **Step 2:** Use the outputs of the Analytical Framework to identify those which are deemed "most material" in terms of facilitating or hindering mass market roll-out and use
- **Step 3:** An optimal configuration for the trial might consist of small, self-contained set of BBs:
  - That are material in terms of driving ULEV outcomes
  - That are low 'effort' to trial
  - Where the understanding of the BBs would be improved significantly by information gained from the trial (e.g. how consumers actually respond to different charging tariffs), for example, by reducing the uncertainty in the values used in the analysis framework
  - That allow a sufficient sample size to provide an appropriate degree of statistical significance when interpreting the results
- **Step 4:** an allowance should made, subject to available resources, for BBs for which there is currently limited understanding and as a result they have not been modelled explicitly within the Analytical Framework.

10.3 Summary of known gaps for Stage 2 trial

A number of gaps in the literature have been identified that could be investigated in the Stage 2 trial, with the intention of gathering an evidence base to assist quantification within the Analytical Framework. The various areas of the trial are to be defined as part of wider work within Stage 1, but the focus of the experimental trial is likely to be on charging profiles and various forms of active versus passive management (e.g. simulated direct DNO control versus tariff incentives), and the impact of PiV user charging behaviour on the energy system.

Additional areas where experimental data would be of high value to the analysis include the conditions under which mobility as a service products could represent a significant fraction of vehicle use, and the compensation PiV users require in order to provide Demand Management services. Potential targets for investigation in Stage 2 are summarised in Table 31

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Table 31 Summary of gaps that could be explored in Stage 2 trials

Issue	Value to analysis	Complexity to explore in Stage 2 trial	Potential data
Conditions for shift to mobility as a service	High	High	Compensation to overcome inconvenience Potential penetration of car sharing
DM payments to engage users	High	High	Monetised payment value
Perception of non-home access to charging on uptake	High	Low	Calibration of relationship between infrastructure build and impact on uptake
Charging profiles	High	High (but likely to be core experimental part of the trial)	Improved inputs for charging start profiles and other inputs
Importance of charging price certainty	High	Medium	Selection of tariffs appropriate to Narratives Updated assessment of extent to which risk management costs for suppliers can be passed to consumers
Depreciation	High	Low	Updated resale values
Compensation for 'less viable' ULEV journeys	High	Low	Monetary penalties for certain types of ULEV
Value attributed to other ULEV perks	High	Low	Monetary values

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11 Conclusions

11.1 Summary

This report, in conjunction with the supporting Deliverable D4.1[50], has:

- Undertaken a first principles assessment of the individual components or Building Blocks, drawing on existing literature, Project Team expertise and discussions with the ETI that could be important within each dimension under consideration:
  - Customer Proposition
  - Physical Supply Chain
  - Commercial Value Chain
  - Market and Policy Framework
- Proposed a range of Narratives that explores a broad space of future strategies for ULEV deployment (supported by sensitivities to understand how resilient these strategies are) and the key questions they are trying to explore, and a detailed mapping of how the individual BBs are included within these.
  - The Narratives have been framed in close discussion with ETI and the Project Team
- Outlined in detail an Analytical Framework for undertaking a holistic quantitative and qualitative assessment of each Narrative and Sensitivity, which includes the integration of a number of pre-existing and new modelling tools.
- Described how this Analytical Framework can be applied both in a standalone manner and to help inform the Stage 2 trial design

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 the 4 key dimensions ***holistically***. 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 wide-spread PIV charging or hydrogen refuelling infrastructure dependent on commercial models that can viably invest in these).

As a result, the Narratives under consideration must 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.

11.2 Next steps

The key next steps for the project related to Work Packages 1 and 4 are:

- Develop and soft-link the Analytical Tools necessary for the Analytical Framework - and corresponding dataset - for deliverable D1.2

[50] D4.1 (TR1006_D4.1) Initial Analysis of Technology, Commercial and Market Building Blocks for Energy Infrastructure

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- Apply Analytical Framework to the Narratives and sensitivities and assess implications for successful mass-market deployment and use of ULEVs, and high-level design requirements for the Stage 2 trial, as part of deliverable D1.3
- Finalise the BBs in deliverable D4.2, it is envisaged that this is expansion of the information related to R&D gaps on the Physical Supply Chain, for example, incorporating insights from Work Package 3 on battery technologies

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Appendix A Narrative ‘system’ diagrams

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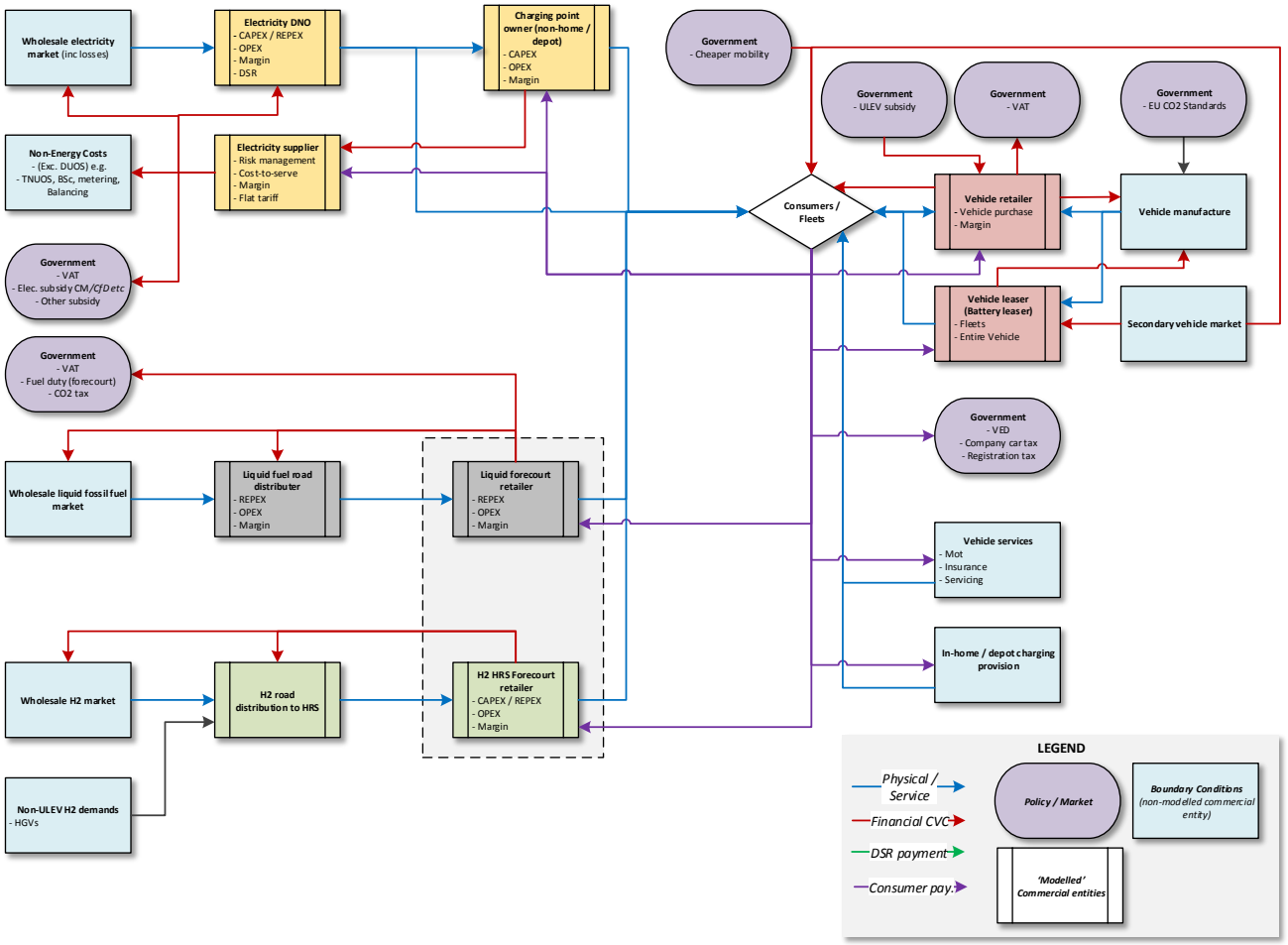
A.1 BaU



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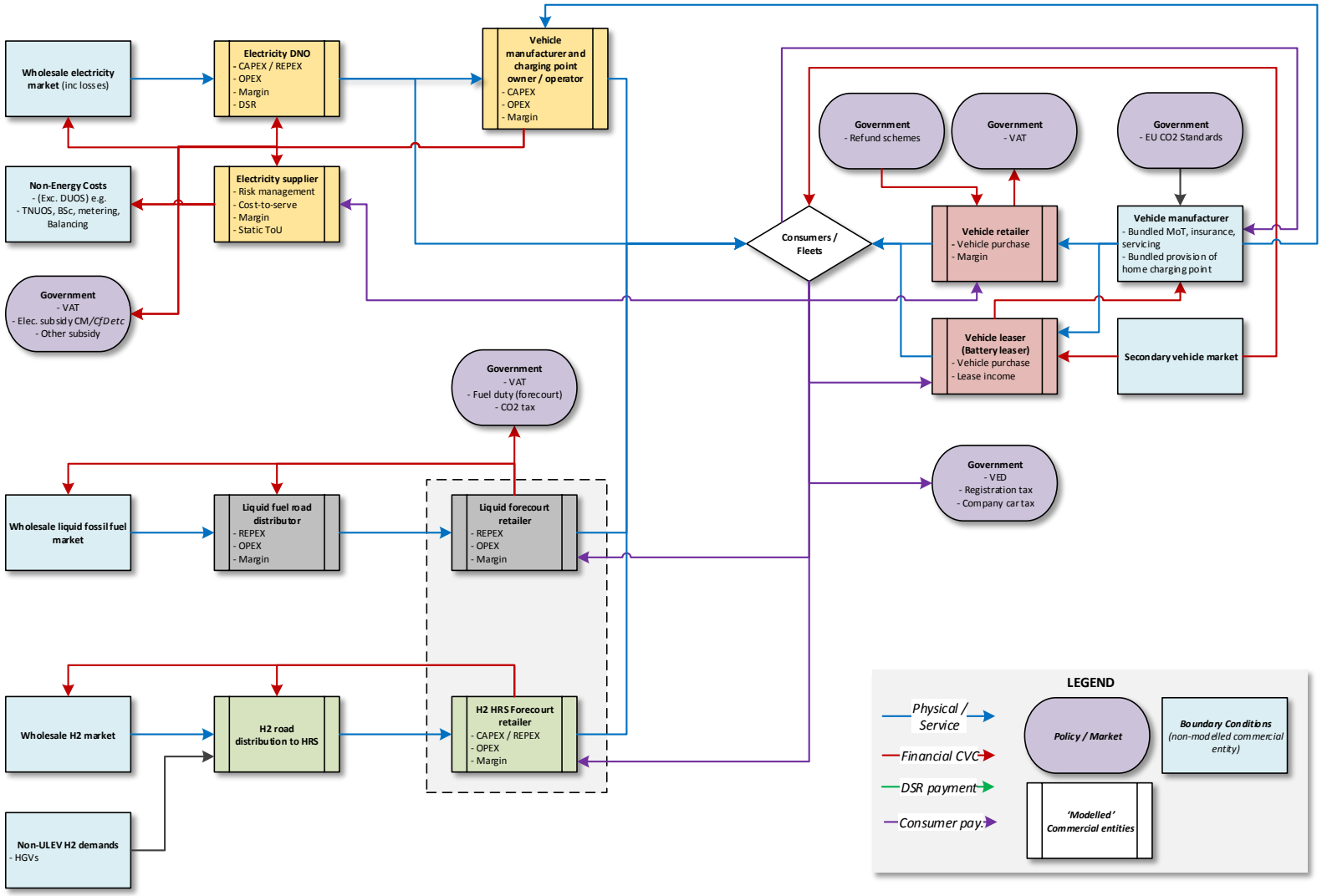
A.2 OEM Innovation



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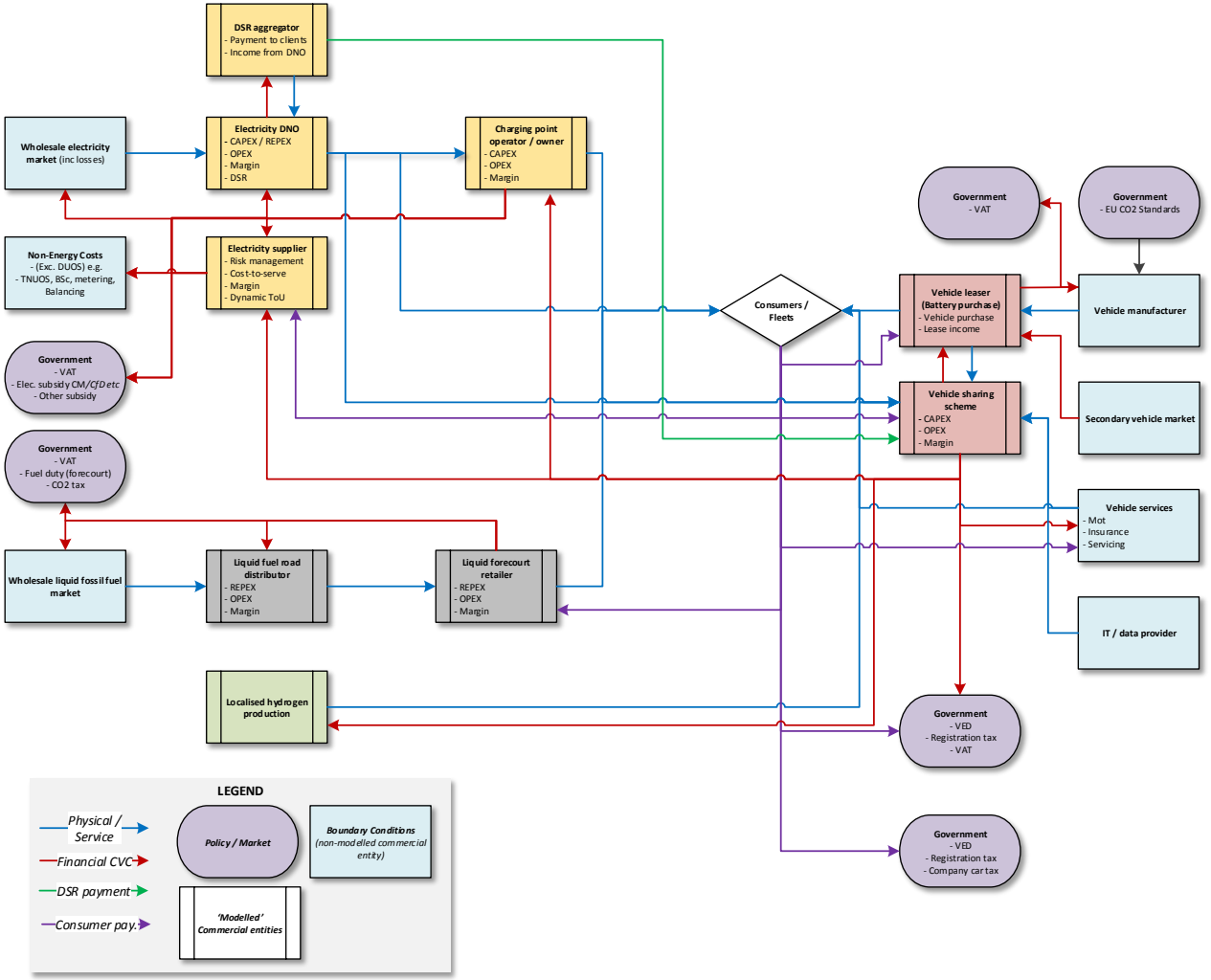
A.3 City Led



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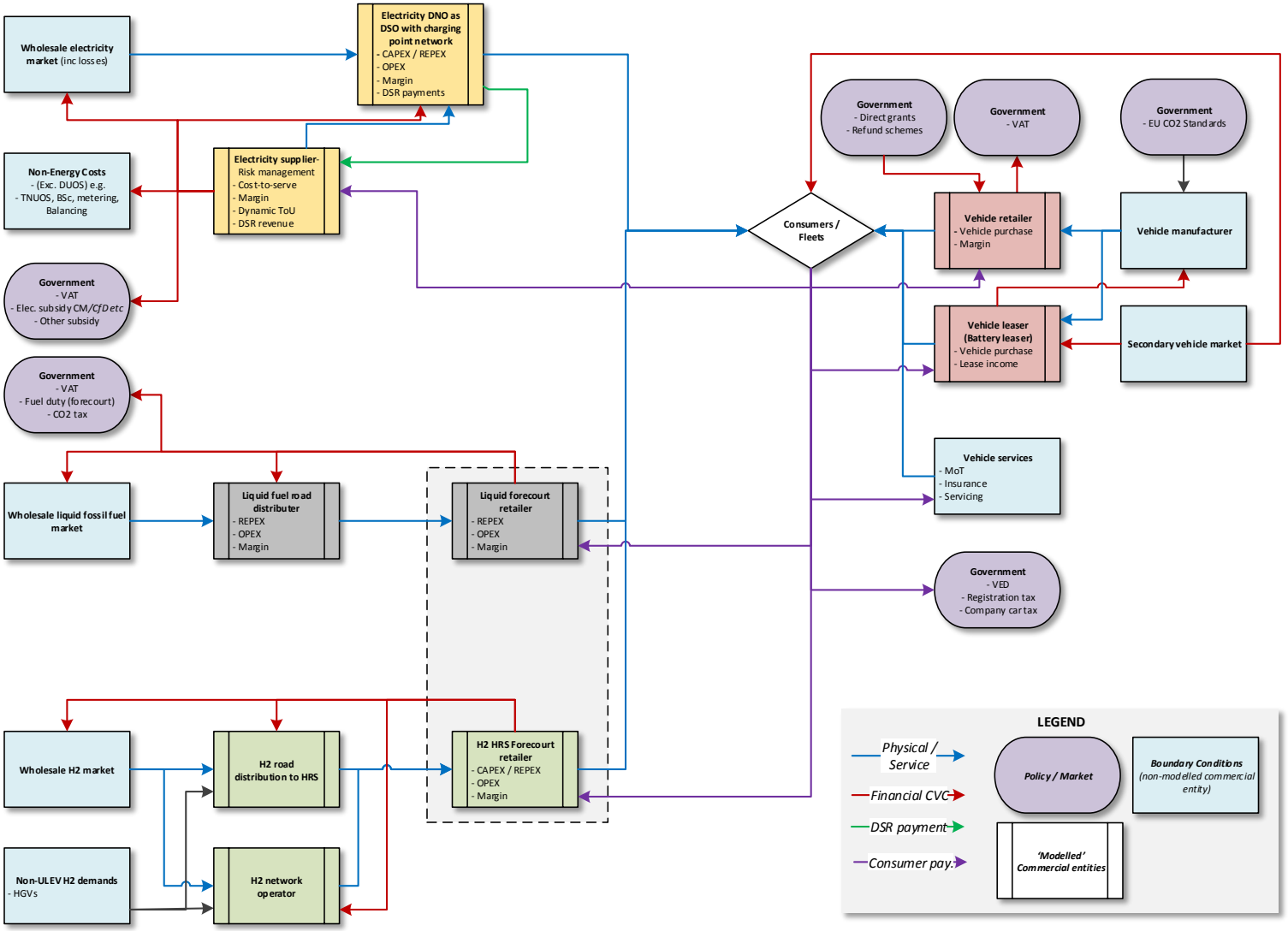
A.4 ULEV Enabled



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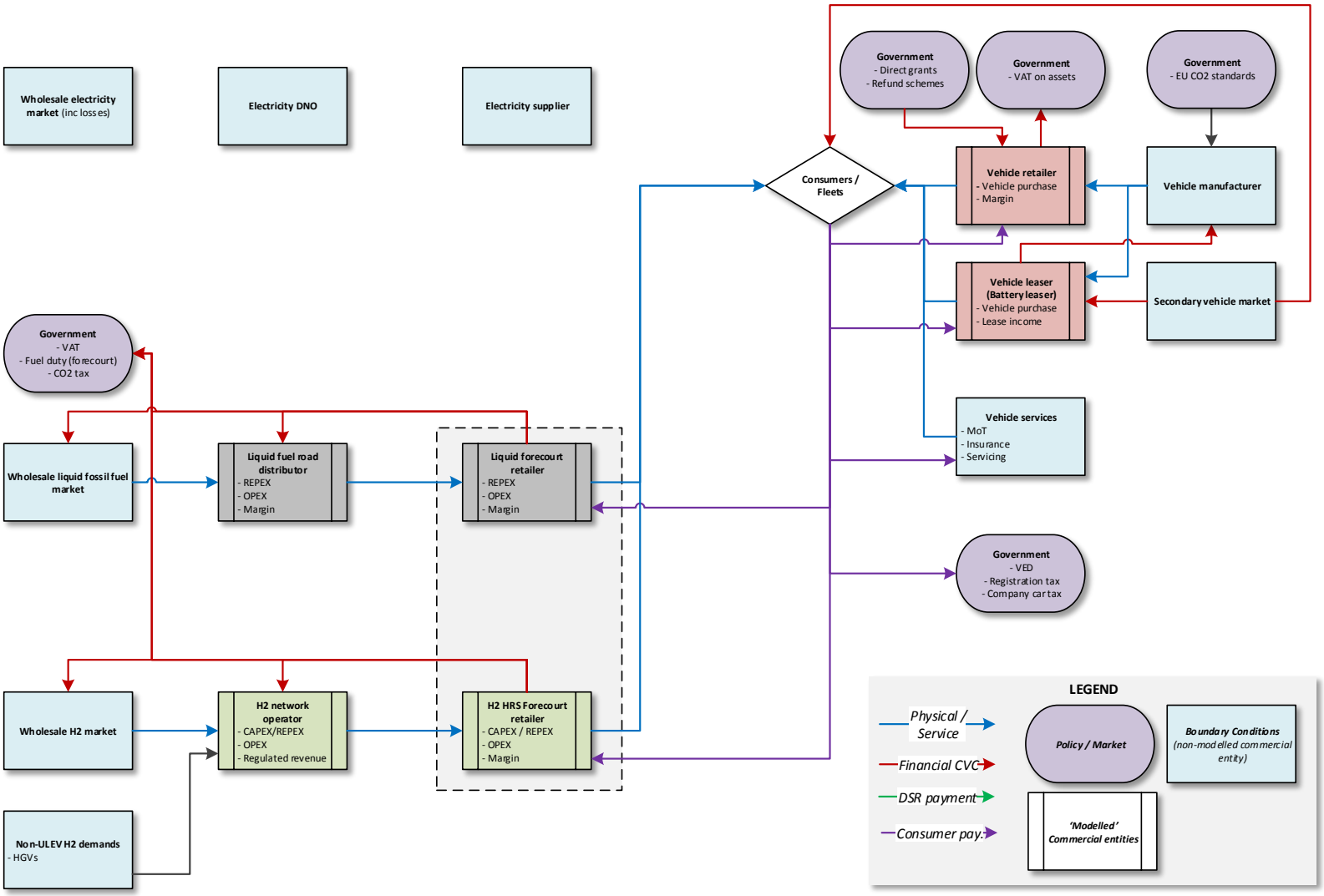
A.5 Hydrogen Push



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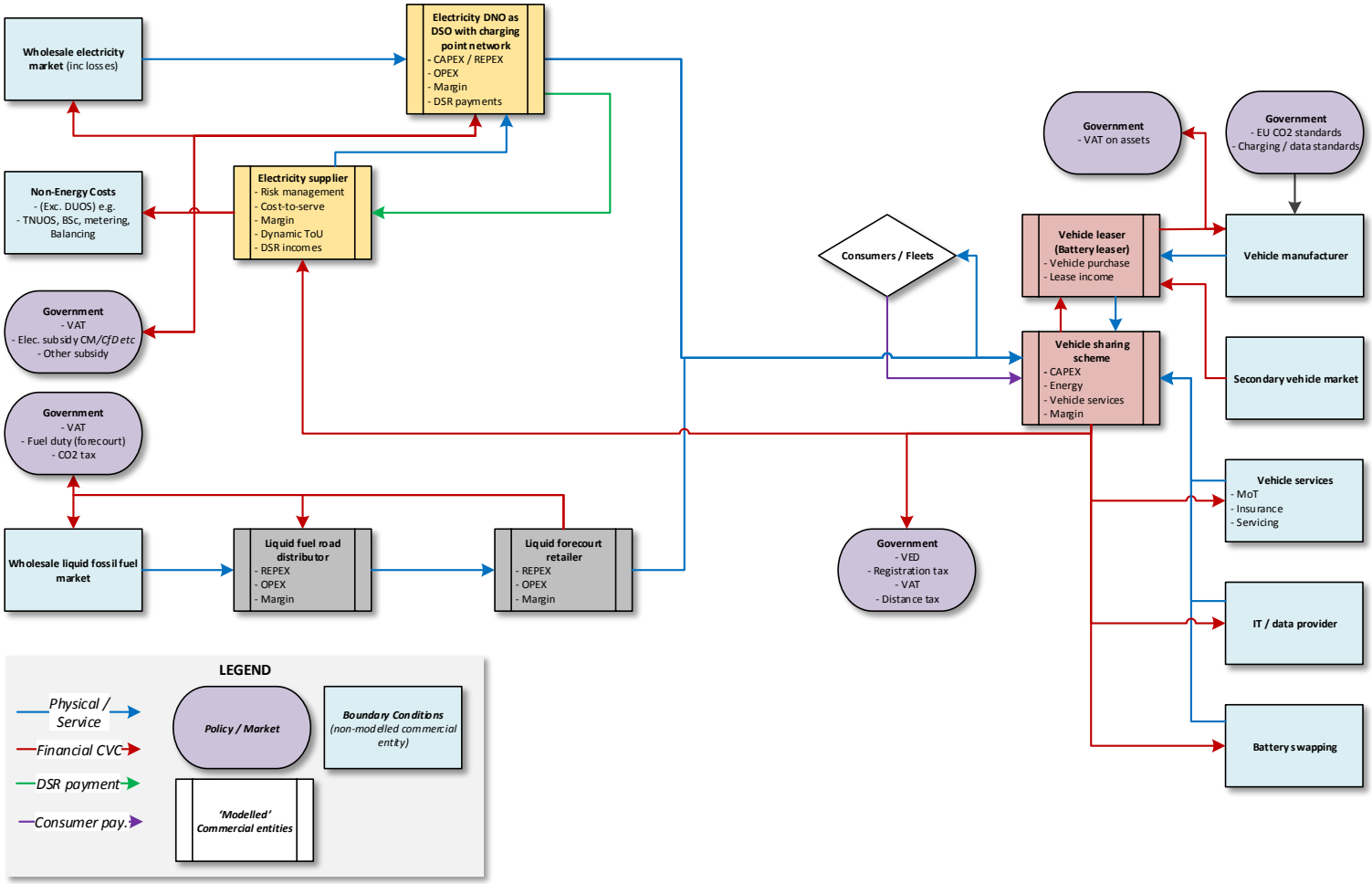
A.6 Transport on Demand



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Appendix B Project scope examples

As described in section 3.13 the original project scope provided a number of examples for what a good 'system solution' might look like with respect to mass market ULEV adoption and use. This Appendix provides further details of how these examples have been tackled with respect to

- **Quantification:** how the example is captured and quantified in the Analytical Framework
- **Variation:** how variation in the Narratives will explore the space relevant to the example
- **Qualification:** how further qualitative analysis will inform the assessment, particularly with respect to what needs to happen to 'delivering a good solution'
- **Verification:** where issues could be explored further via careful structuring of the Stage 2 trial

B.1 Physical Supply Chain

Contract example Robust integration of the vehicle and energy systems, enabling effective and efficient balancing of supply and demand, enabling an increasing proportion of transport demand to be met by a flexible, lower carbon mix of energy vectors (electricity, H_2, conventional and low CO_2 liquid)			
Quantification The Analytical Framework is explicitly designed to integrate energy and vehicle systems	***Variation*** The Narratives explore worlds where emphasis is placed on different vectors to decarbonise road transport	***Qualification*** Further assessment of reliability of transport service delivery	***Verification*** No verification appropriate

Contract example Take account of the availability of, and projected developments to, technology options (developing technology and / or proposing technology developments where appropriate)			
Quantification The Analytical Framework makes assumptions on the future evolution of cost and performance of key technologies	***Variation*** Assumed that most technology development occurs at global level, beyond the influence of individual actors in the UK, inputs are common across Narratives but tested via sensitivities	***Qualification*** Consideration of how technological advance will be incorporated and the robustness of strategies to technological advance	***Verification*** No verification appropriate

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Contract example Support the longer term energy system and facilitate the transition to it			
Quantification The Analytical Framework includes an internally consistent representation of the energy system through ESME, with assumptions based on the Patchwork scenario	***Variation*** The impact of alternative futures explored through sensitivities where more transport decarbonisation required as result of limited progress elsewhere	***Qualification*** Consideration of barriers that might apply to deeper decarbonisation of road transport, and opportunities in modal shift or other options	***Verification*** No verification appropriate

Contract example Work in harmony with vehicle battery management and energy management systems to optimise vehicle efficiencies and to maximise battery performance and lifetime			
Quantification ECCo contains detailed assumptions of battery performance and management informed by WP3	***Variation*** Technological development is uniform across Narratives (varying in some sensitivities)	***Qualification*** Explore further commercial barriers related to investment risks, or barriers to entry for manufacturers and BMS providers	***Verification*** This could be an area where trials could provide additional or improved data

Contract example Provide suggestions for standardisation requirements			
Quantification Standardisation or otherwise is explicitly represented in the AFW	***Variation*** The Narratives imply different outcomes for standardisation along the Organic / Coordinated axis	***Qualification*** We will explore qualitatively how standardisation or the lack of it would impact strategies identified as important	***Verification*** Trials are unlikely to be able to provide useful evidence in this case

B.2 Customer proposition

Contract example Meet the needs of Consumers, Fleet Users and Fleet Operators for usability and convenience, and for choice, certainty and flexibility of travel patterns and of charging and fueling times, whilst providing financial incentives to participate effectively in Demand Management mechanisms, and whilst recognising how Consumers, Fleet Users and Fleet Operators will respond to market propositions			
Quantification Within the Analytical Framework, ECCo provides a detailed representation of all these user types and their behaviour and decisions	***Variation*** The Narratives explore different outcomes for costs of ownership, DM, consumer attitudes to vehicle ownership and use, and changing market conditions	***Qualification*** The barriers posed by consumer acceptance of different propositions will be explored qualitatively (eg, impact on convenience, choice, etc)	***Verification*** Consumer perceptions of different market propositions, such as electricity tariffs or mobility as a service offerings, could be explored as part of the trial

Contract example Provide choice to Consumers and Fleet Operators; the need for day-to-day interaction with Demand Management systems should be optional (eg, automated by default)			
Quantification The inconvenience and change in charging cost resulting from DM is represented in the Analytical Framework	***Variation*** Provision of DM by EV users varies across the Narratives, and is then only assumed in certain locations	***Qualification*** The limitations of consumers' acceptance of charging modulation will be considered	***Verification*** The compensation require by consumers for the inconvenience they experience under DM could be estimated through trials

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Contract example			
Provide clarity, certainty and simplicity to Consumers and Fleet Operators, who are likely to expect to know, upfront, how much the energy for their vehicle will cost			
Quantification	***Variation***	***Qualification***	***Verification***
The impact of different tariff structures on charging costs and consequent vehicle decisions is included in the Analytical Framework	Different Narratives make different assumptions about tariffs (flat, SToU, DToU), and the response in charging behavior	The level of uncertainty consumers will accept in managing their charging and implications will be explored	Consumer response to different charging products and controls could be the subject of trials

Contract example			
Initial evaluation of adoption likelihood by major classes of Vehicle Users (across both Consumers and Fleets), to be fully evaluated in Stage 2			
Quantification	***Variation***	***Qualification***	***Verification***
Charging behavior is differentiated by user type	Assumptions on tariffs used by different user types varies by Narrative	The barriers to consumer adoption of charging behavior which is beneficial to the system at large will be explored	The appeal of DM and tariff products to consumers could be tested in the trial

Contract example			
Accommodate uncertainty over vehicle adoption, usage behaviour and future changes			
Quantification	***Variation***	***Qualification***	***Verification***
Vehicle choices and usage are modelled in ECCo	The Narratives explore different situations regarding consumer attitudes to vehicle ownership and choices	The barriers to changing consumers' perceptions to owning vehicles, the type of vehicle they choose and how they use it will be explored qualitatively	Consumer survey may offer scope to explore attitudes to alternative arrangements for accessing vehicle services

B.3 Commercial Value Chain

Contract example			
Provide sufficient incentives for each of the key Actors to make the necessary investments/adjustments, propose business cases for each key actor, based on indications of the likelihood of their adoption by each Actor, for testing in Stage 2			
Quantification	***Variation***	***Qualification***	***Verification***
Cashflows for each commercial entity are tracked in CPAT, where success metrics will determine their viability	The Narratives explore alternative business models (eg, regulated versus commercial provision of charging networks; truck versus pipe based hydrogen distribution), and new business models (eg, large scale car sharing)	More detailed analysis of critical and unproven business models will consider how they are structured (especially where multiple options are possible, eg for the DM aggregator) the risks to which they would be exposed, the conditions required for investment and the need for subsidy	Trials could explore the price points at which consumers become amenable to the products of potential new businesses, eg car sharing and DM

B.4 Market and Policy Framework

Contract example			
Deliver a clear view of the most appropriate market and policy framework to support the deployment of ULEVs in an integrated manner with the overall energy system, have a practical roadmap/route to implementation of the preferred market and policy frameworks and provide an initial assessment of the risks to implementation, complete with mitigation strategies			
Quantification	***Variation***	***Qualification***	***Verification***
The impact on Government costs and revenues, and end user TCO of policy tools is tracked through the tools	Different policy tools are employed in different Narratives, with different focusses (eg, on infrastructure, incentivising ULEVs, disincentivising ICEVs)	Interactions between effective policy tools will be considered to make recommendations for implementation on a coherent framework, within a sensible fiscal envelope. The consideration will also include policy tools that are not modellable but which are consistent with themes of different Narratives as part of D1.3	Consumer survey may could investigate how the impact of different policy tools would be perceived or valued

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