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Programme Area: Light Duty Vehicles

Project: Economics and Carbon Benefits

Title: Scenario Development Final Report (Issue 2)

Abstract:

This project was undertaken and delivered prior to 2012, the results of this project were correct at the time of publication and may contain, or be based on, information or assumptions which have subsequently changed. The Economics and Carbon Benefits project is providing a quantified analysis of the UK viability and carbon benefits of plug-in vehicles and the associated energy system. This analysis is being conducted against a range of scenarios. This report defines the scenarios (the range of values for the full set of variables) that will be tested and reported in the final report. A summary of the modelling approach and scenarios is given in the Executive Summary on pages i to iii.

Context:

A strategic level analysis of the potential size of the market for plug-in vehicles, the total level of investment needed and the total carbon offset for the UK.

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Energy Technologies Institute

Plug-In Vehicles Economics & Infrastructure Project

Scenarios Development Final Report

WS3/ARUP/10

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Ove Arup & Partners Ltd
13 Fitzroy Street
London
W1T 4BQ
United Kingdom
www.arup.com

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Contents

Tables

Figures

Appendices

Executive Summary

The ETI's Plug-in Vehicle (PiV) Economics and Infrastructure Project has two primary objectives:

- Evaluate the potential role and economics of plug-in vehicles in the low carbon transport system.
- Develop the technology tool-kit for delivering an intelligent infrastructure

Stage 1 of the project will develop a comprehensive set of computer models comprising vehicles, supporting infrastructure and the consumer response. It will cover technical, behavioural and economic aspects and will enable the potential role and economics of plug-in vehicles to be extensively evaluated.

This report describes the work completed within Work Package (WP)3.1 of the Economics and Carbon Benefits sub-project – development of the scenarios to be analysed.

The scenarios (described in Section 4) incorporate the variables that have been identified to be tested within the project (see Section 2.3). An extensive process of consultation with stakeholders has ensured agreement of the proposed scenarios, and a series of modellers' meetings have ensured an understanding of the 'inputs' and 'outputs' from the various models.

The description of the detailed scenarios should be read in conjunction with Figure 2 (detailed and high level modelling diagrams) and Appendix A (master matrix – which shows the 'level' of each variable for every sensitivity and theme modelling run).

The high level modelling diagram is also shown in Figure 1 below. This shows the main areas that will be addressed in the modelling.

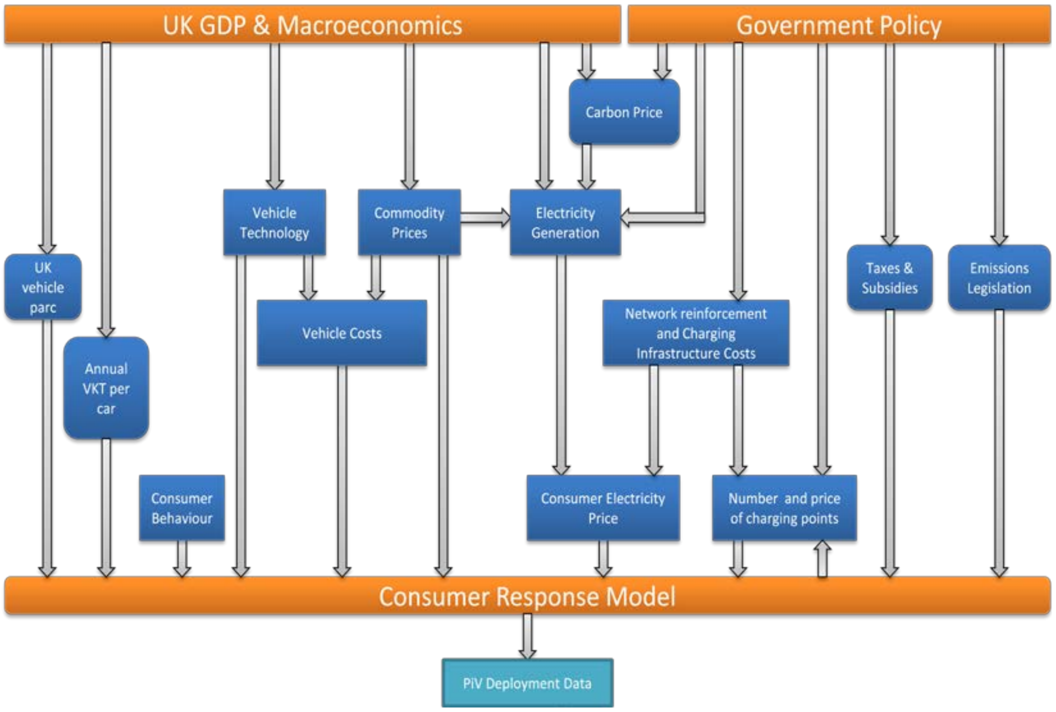

Figure 1 High Level Modelling Diagram

The detailed modelling diagram (Figure 2) covers all the key inputs and outputs. Each box on the diagram is numbered, and the associated table cross references each box to the relevant scenarios within Section 4.

With the large number of variables that can influence the deployment of PiVs, there are literally millions of scenarios that could be analysed. It is thus necessary to focus on a sensible set of scenarios that cover the broad areas of interest.

In order to answer the key questions underlying the project (see Section 2.2), it is therefore proposed that the modelling work should explore the effect of varying the key inputs through a systematic programme of sensitivity testing followed by more formal tests of themed scenarios and statistical analyses designed to identify “optimal” policy interventions.

The sensitivity tests will establish the sensitivity of key outputs to each of the input variables in the base scenario. This information is important in its own right (and will duly be reported) but is also an input to the specification of values for the themed scenarios and of tests to be run in order to calibrate a statistical model.

The base run and the 12 themed scenarios are as follows: -

- T0 Base (in which all variables are set to their base levels)
- T1 All circumstances are maximally favourable to PiV sales
- T2 All circumstances are minimally favourable to PiV sales
- T3 Government incentives as announced and all other factors are maximally favourable to PiV sales
- T4 Government incentives as announced and all other factors are minimally favourable to PiV sales
- T5 High rate of growth in UK GDP
- T6 Low rate of growth in UK GDP
- T7 High rate of growth in global economy
- T8 Medium rate of growth in global economy with a green emphasis
- T9 Medium rate of growth in global economy with high oil price
- T10 Medium rate of growth in global economy with oil price spike
- T11 Low rate of growth in global economy
- T12 Minimised carbon emissions

There are a total of 94 sensitivity runs as follows: -

Variables linked to UK GDP (UK)	5 runs
Vehicle Showroom (S)	18 runs
Electricity Generation (EG)	3 runs
Electricity Price (EP)	17 runs
Supply & Price of Charge Points (CP)	14 runs
Consumer Behaviour (CB)	16 runs
Government Policy (P)	21 runs

Further ‘statistical’ runs will be required to test for interaction between different input variables. The number of extra runs will be decided following review of the first runs of the Consumer Response Model. Initial indications point to a requirement for at least 500 statistical runs.

It must be recognised that the scenario work is constrained by the capabilities of the models and data available at this stage in the PiVEIP project. A number of the processes which would, in real life, affect the uptake and use of PiVs are not included in the models at our disposal, some key aspects of behaviour are not yet known and a number of these simplifying assumptions are inevitable at this early stage in the overall project.

We recommend that the project proceeds using the scenarios in section 4 of this report, and we would recommend that these are revisited with real data during Stages 2-5 of the project. We would also recommend that the precise values of the variables affecting the deployment and price of non-domestic charge points should be agreed in February in the light of initial runs from Consumer Response model.

1 Introduction

1.1 Project Overview

The ETI's Plug-in Vehicle (PiV) Economics and Infrastructure Project has two primary objectives:

- Evaluate the potential role and economics of plug-in vehicles in the low carbon transport system.
- Develop the technology tool-kit for delivering an intelligent infrastructure

Stage 1 of the project will develop a comprehensive set of models comprising vehicles, supporting infrastructure and the consumer response. It will cover technical, behavioural and economic aspects and will enable the potential role and economics of plug-in vehicles to be extensively evaluated.

Stages 2-5 of the project will test and validate these models and tool-kit by evaluating the response of consumers in real life situations. This will be planned and implemented through real-world testing of these models.

Stage 1 has been split into three sub-projects. Each has a consortium and a consortium leader (shown in parenthesis below):

- SP 1 – Consumers and Vehicles (Ricardo)
- SP 2 – Electricity Distribution and Intelligent Infrastructure (IBM)
- SP 3 – Economics and Carbon Benefits (Arup)

This report is written by Arup and University of Leeds ITS.

1.1.1 SP3 – Economics and Carbon Benefits

Sub-project 3 – Economics and Carbon Benefits has three project participants:

- Arup (Lead coordinator)
- E.ON (Project partner)
- University of Leeds ITS (Project partner)

The sub-project will consider the interaction between technological, economic, fiscal and consumer response factors to evaluate Battery Electric Vehicle (BEV) and Plug-in Hybrid Electric Vehicle (PHEV) deployment scenarios through to 2050.

Computer models will be generated to predict future carbon emissions and electricity costs, and values of potential new revenue streams. These models will be combined with data from the two other research projects to generate both a whole system cost model and a whole system life cycle carbon emission model.

Sub-Project 3 is split into three Work Packages (WP):

- WP3.1 – Scenario Development
- WP3.2 – Revenue Stream Analysis

- WP3.3 – Economic sensitivity and carbon offset analysis

1.2 The role of modelling within the overall project

The overall project makes use of a number of different models. Some are complex mathematical representations of subsystems of interest while others are more akin to spreadsheets. Between them, these models are designed to answer a range of questions anticipated by the ETI when the project was established. For example, there are models which:

- estimate the cost of reinforcing the distribution network which might be required to cater for the recharge patterns of PiVs
- estimate the cost of charge points of various types in various locations
- predict the likely content of the “vehicle showroom” (i.e. the price, and specification of ICEs and PiVs on offer); and
- consumers’ purchase decisions when faced with a given vehicle showroom.

Each of these models was specified (in the original contract) to produce specified outputs as a function of specified inputs. The inputs were to come from a variety of sources including:

- previous forecasts and estimates (e.g. of PiV uptake and recharge behaviour, of commodity prices and of background demand for electricity)
- new analyses of available data (e.g. on network reinforcement costs); and
- new data (e.g. from consumer research)

SP3 was tasked with using the available models to explore and report on the performance of the overall system via a combination of sensitivity testing and scenario testing. This required a thorough understanding of the available models and of the assumptions that underlie them, and also of the constraints affecting their use[1].

1.3 Scenario Development

This report describes the work completed within WP3.1 of the Economics and Carbon Benefits project – development of the scenarios to be analysed.

A scenario is a unique set of values for all of the input variables which defines the state of the system of interest. A large range of factors can influence the deployment of PiVs and, if all combinations of all these factors were to be explored, it would be necessary to test millions (literally) of potential scenarios. This is clearly impractical. It is thus necessary to focus on a feasible number of scenarios which, between them, throw light on the important questions. In order to help specify these scenarios, and to answer some very specific questions, it is also necessary to conduct sensitivity analyses to establish the likely impact of individual variables.

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[1] The contract for the various subprojects stipulated that some of the models should be run only once while others should be available to test a range of input assumptions.

In order to answer the key questions underlying the project (see Section 2.2), it is therefore proposed that the modelling work should explore the effect of varying the key inputs through a systematic programme of sensitivity testing followed by more formal scenario tests.

The scenarios have been designed to answer broad questions such as:

- What would happen if all circumstances evolve as expected?
- What would happen if all circumstances were maximally favourable to the uptake of PiVs?
- What would happen if all circumstances were minimally favourable to the uptake of PiVs?
- What could Government intervention achieve if all external circumstances were minimally favourable to the uptake of PiVs?

The scenarios have been developed through an iterative process of consultation and research during which the key interactions within the overall system were identified and the capabilities of the available models were assessed. The proposed scenarios are presented in this document along with the proposed sensitivity tests.

2 Method

2.1 Procedure

Within WP3.1 of the Economics and Carbon Benefits Contract, 'Scenario Development', Arup and Leeds ITS were responsible for leading the following work packages: -

- WP 3.1.2 - Coordinate with the other two contracts to define the 'economics' scenarios to be used within the main project, and
- WP 3.1.3 - Coordinate with the other two contracts to define the 'functionality' scenarios to be used within the main project

Task 1 of the two work packages was the Agreement of Variables; to understand the specific questions to be answered and therefore the variables to be considered.

The two deliverables from Task 1 were: -

- WS3/ARUP/07 - The variables, agreed with the ETI members and appropriate stakeholders, which define the scenarios (see Appendix D)
- WS3/ARUP/08 - A list of the specific questions to be answered by the project. (see Appendix D)

The specific questions and the variables were each agreed in parallel using the same methodology. The initial aim was to gain a broad range of views and ideas from a large number of sources to ensure that no issue was overlooked. Three approaches were utilised to achieve this:

- Stakeholder workshop – in which all stakeholders and sub-project participants consulted
- On-going consultation – involving sub-project participants and stakeholders
- Literature review

The stakeholder workshop was held at Arup's offices in London on 30th March 2010. The broad range of views from the workshop were rationalized and sorted into related groups. The variable data from the workshop required significant interpretation to convert it into variables that could be defined in quantifiable terms.

The draft variables and questions were sent to the other sub-projects on 6th April 2010 and their feedback integrated into the proposals. A full-day session with lead coordinators was held on 9th April 2010 to discuss the revised variables and questions following the feedback from the sub-project partners. On 12th April 2010, a modified list of questions and variables was sent out for agreement by the lead coordinators, and this was modified again following comments during a teleconference on 13th April 2010.

On 13th April 2010 the questions and variables were sent to all stakeholders. Feedback from the stakeholders was incorporated prior to presentation at the Modelling and Experimental Design Advisory Group (MEDAG) meeting on 19th April 2010.

Final comments from MEDAG and stakeholders not present at MEDAG, and the ETI deliverable reviewers, were also incorporated.

2.2 Specific questions to be answered

A list of twelve key questions was drawn up using the procedures described above. The list reflects the diversity of interests of the project stakeholders. The questions range from the quite specific (e.g. "*How will the relative uptakes of BEVs and PHEVs change over the time period*?") to the rather general (e.g. "*What other external factors might influence any of the above?).*

The full list (presented in more detail in deliverable WS3/ARUP/08 (attached as Appendix D)) was as follows:

1. *What sort of vehicles will consumers buy, and how much will they be willing to pay for them?*
2. *How will consumers use the BEVs and PHEVs?*
3. *How do we quicken the pace of consumer uptake of PiVs? How much will we need to spend and what effect will it have?*
4. *What are the impacts on the uptake of PiVs of different levels, technology specifications and locations of infrastructure provision? What is the optimum level, technology mix and location of infrastructure?*
5. *What will be the effect on the electricity grid generation needs? How can we minimise the effect and encourage charging at off-peak times? How much will it cost?*
6. *What reinforcement of the electricity grid is required for distribution to where the energy is needed? How much will it cost?*
7. *What new business models are likely to appear? What business opportunities are opened up by the new sector? How much revenue can be generated?*
8. *What other external factors might influence any of the above?*
9. *What is the effect on CO2 emissions for all the above?*
10. *What are the most significant relationships between the issues discussed above?*
11. *What will happen in terms of the evolution of BEV and PHEV technology over the time period?*
12. *How will the relative uptakes of BEVs and PHEVs change over the time period e.g. initial preference for PHEVs leading into a later preference for BEVs?*

The scenarios described later in this report were defined such that the outputs from the models (for these scenarios) will provide data that can help answer the above questions. It should be noted, however, that some of the questions (e.g. question 2) cannot be fully addressed within the scenarios because the required data and analyses are not available.

2.3 Variables

A list of input variables required to address the questions listed in Section 2.2 was approved by the ETI in June 2010. The list included eighty separate items which were thought to have a potential impact on the uptake of PiVs and on overall carbon emissions from the UK car parc[2] and which would thus help to define the scenarios. The items ranged from the very specific (e.g. the number of seats in vehicles in different segments) to the general (e.g. consumer acceptance of new technology).

The list presented to MEDAG is included in Appendix D.

2.4 Modellers' Meetings

In parallel to the work on the 'specific questions' and the 'variables', a series of modellers meetings took place. These meetings were a mixture of face-to-face and teleconferences and all modellers working across the PiVEIP were invited.

These meetings allowed the modellers to develop an understanding of the modelling work being completed in each of the sub-projects to ensure coordination and identify any gaps and inconsistencies. This process was assisted by the development, by SP3, of a "system diagram" showing all the models within the PiVEIP project, together with the links between them (see Section 2.5).

The meetings ensured understanding of the 'inputs' and 'outputs' from the various models, and utilising the variables agreed in Section 2.3. For each variable the following was defined:

- Who was responsible for the variable and for producing the data
- The number of values to be tested for that variable
- The intended granularity (time/spatial and other)
- The values for each variable (if already known)

One of the conclusions from this phase of the work was that the development of scenarios would be constrained by the fact that, contractually, some of the models were only to be run with one set of assumptions.

2.5 Development of the Modelling Diagram

The modelling diagram went through numerous iterations during the consultation between the modellers in SP1, SP2 and SP3.

The final 'detailed scenario modelling diagram' is included as Figure 2.

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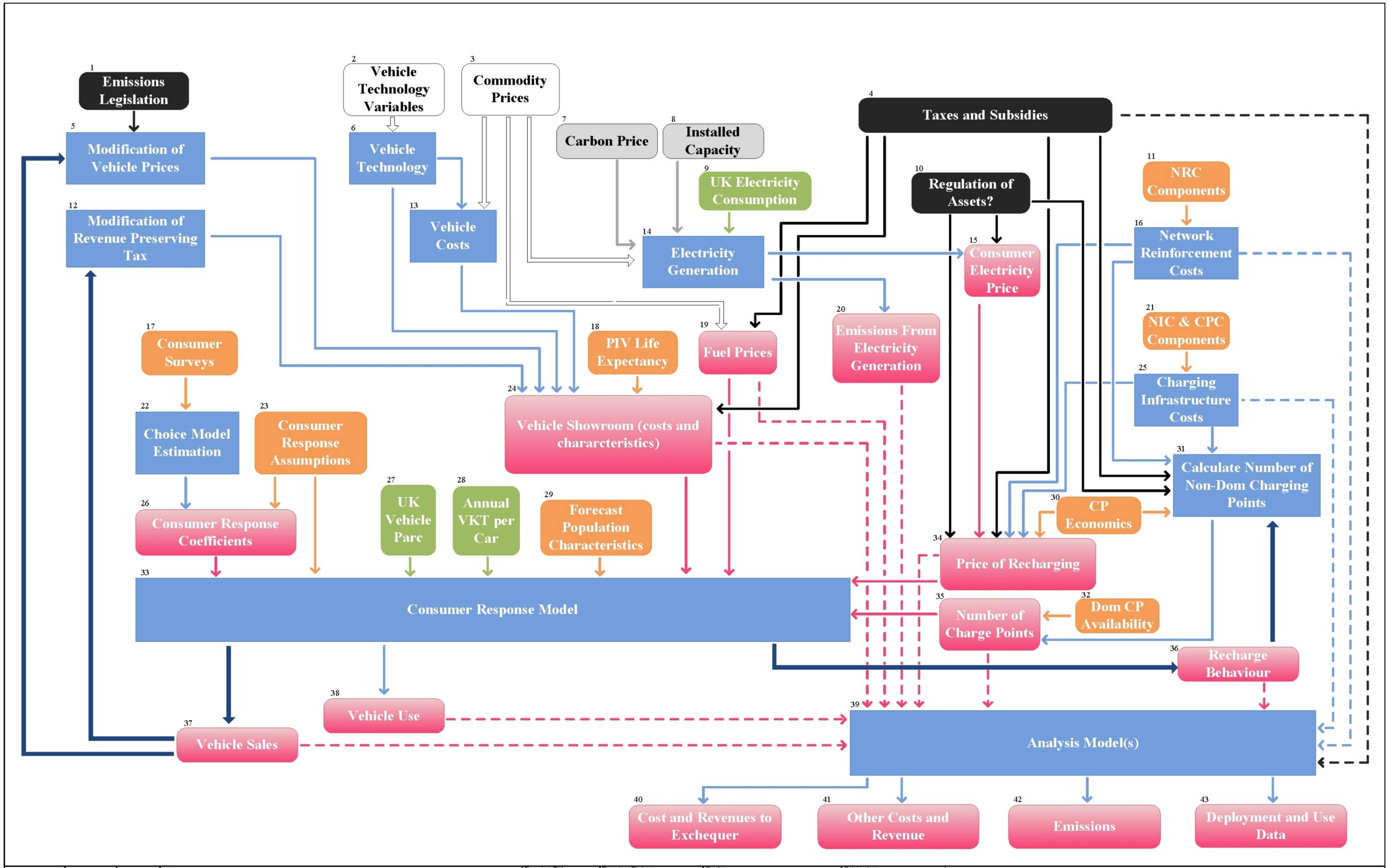
[2] Note that it was agreed that the project, and hence the variables, are limited to vehicles of the M1 category within the UK, excluding Northern Ireland, between 2010 and 2050



Issue	Date	By
2.0	22/10/2010	HJB

Key:
- Black box = Policy lever
- White box = Macroeconomic related variable
- Grey box = Part policy, part macroeconomics
- Green box = UK GDP-related variable
- Orange box = Independent estimate
- Blue box = Model or calculation
- Pink box = Derived estimate
- Thick blue arrows = Part of recursive feedback from consumer response model for previous year
- Dashed arrows = To analysis models

Drawing Title: PiVEIP Modelling Diagram
Drawing Status: 1st Issue
Scale: N/A
Originator: JFR
Checked: RKR, PB
Approved: NB
Client: ETI
Job Title: PiVEIP
Date: 22/10/2010
Job No.: 212799-00
Drawing No.:

Figure 2 Detailed Modelling Diagram (see key on following page)

Box	Variable Name	Report Section
1	Emissions legislation – at EU level	4.8.11
2	Vehicle technology variables	4.3
3	Commodity prices	4.1
4	Taxes and subsidies	4.8
5	Modification of vehicle price in response to fleet average emissions legislation	4.8.11
6	Vehicle technology roadmap	4.3
7	Carbon price	4.1.5, 4.8.12
8	Installed generating capacity	4.4
9	UK electricity consumption	4.4
10	Regulation of assets	4.5, 4.8.9
11	Components of cost of network reinforcement by area type	4.5
12	Modification of revenue-preserving road user charge	4.8.7
13	Vehicle costs – to suit technology roadmap	4.3
14	Electricity generation	4.4
15	Consumer electricity price	4.5
16	Network reinforcement costs	4.5
17	Survey of consumer response	4.7
18	PiV life expectancy	4.3.2
19	Fuel price	4.1, 4.3
20	Emissions associated with electricity generation	4.4
21	Components of cost of charge points, network intelligence and associated infrastructure by type of charge point	4.5
22	Choice model estimation	to be reported by SP 1
23	Consumer response assumptions	4.7
24	Vehicle showroom	4.3
25	Charging infrastructure costs	4.5
26	Consumer response coefficients	4.7
27	UK vehicle parc annual increments	4.2.1
28	Annual Vehicle Kilometre Travelled (VKT) per car	4.2.2
29	Population forecasts by consumer type, with/without off street parking at home, and area type.	to be reported by SP 1
30	Economics of non-domestic charge point supply	4.6.2, 4.6.3
31	Calculation of new non-domestic charging points to be installed next year	4.6.2, 4.6.3
32	Assumed access to domestic charge points	4.6.1
33	Consumer response model	4.7
34	Price of recharging at public charge points	4.5.5
35	Number of charge points	4.6
36	Recharge behaviour	4.7.8, 4.7.9
37	Vehicle sales	5
38	Vehicle usage	5
39	Analysis models	5
40	Costs and revenues to Exchequer	5
41	Summary of other costs and revenues	5
42	Emissions	5
43	Summary of deployment and use	5

Table 1 Key for detailed modelling diagram

2.6 Scenario Consultation

Following creation of a defined set of scenarios and detailed modelling diagram, a further consultation process was undertaken.

SP1 and SP2 were consulted and several face-to-face meetings and teleconferences were arranged with the relevant sub-project partners to discuss and agree the proposed scenarios.

Once the scenarios were preliminary agreed, a consultation document was issued to all the ETI stakeholders on the 26th July 2010 for comment. To supplement this, each stakeholder was given the opportunity to take part in a further workshop meeting to discuss the proposed scenarios in detail.

On the 17th August 2010 at the SP3 Project Review an update was provided on the scenario development to MEDAG. Several comments from MEDAG were incorporated into the development process including:

- Provide a simplified ‘high level’ modelling diagram
- Review the vehicle technology scenarios and coordinate with Ricardo
- Review commodity prices

Following feedback from MEDAG and other interested stakeholders, the revised scenarios were then reviewed and discussed with sub-project partners within SP1 and SP2.

The final stage of the scenario consultation process was the presentation of the proposed scenarios (deliverable WS3/ARUP/09) to MEDAG at the SP3 Project Review No.3 on the 12th October 2010.

The proposed scenarios were agreed by MEDAG with minor direction as follows:

- ‘High’ Gas Price Projection was thought to be too high
- ‘High’ Coal Price Projection should be higher. Check against International Energy Agency (IEA) World Energy Outlook (WEO) forecasts
- Investigate ‘Fleet Average Emission’ scenarios further
- Review vehicle technology scenarios in light of the fact that Ricardo will only be providing one vehicle technology roadmap of the future
- Provide a clearer definition of PiV life expectancy
- Review ‘No. of Charge Point’ scenarios
- Review ‘Recharging Behaviour’ scenarios

All comments and directions from the ETI, MEDAG, project partners and stakeholders have been addressed and incorporated into the description of scenarios within Section 4.

3 Outline of Scenario Testing

3.1 Role of Scenario Testing

In order to answer the key questions underlying the project (see Section 2.2), it is proposed that the modelling work will explore the effect of varying the key inputs. This will be done by a systematic programme of sensitivity testing, themed scenario tests and some additional tests designed to calibrate a statistical model which can then be used to identify optimal values for a final set of tests (see Sections 3.2, 3.3 and 3.4 respectively).

The role of scenario testing is to:

- explore system performance in alternative (credible) futures, and to
- establish sensitivity of system performance to key input assumptions

3.2 Sensitivity Tests

For the sensitivity testing the effect of different values of each input variable will be determined while holding the value of all other variables at their “base” level (except in those cases where it is beyond doubt that other variables would take on a particular value which differs from its base value). Thus defined, the sensitivity tests are only valid in the context of the base scenario. Sensitivity in other contexts is explored via the statistical model (see Section 3.4).

The definition of the base level for each variable is thus a very important part of the scenario specification. The general rule is that the base value should reflect the most likely future. A considerable amount of effort has been devoted to selection of appropriate base values. The combination of these base values is referred to as “the base scenario”.

The sensitivity tests will establish the sensitivity of key outputs to each of the input variables in the base scenario. This information is important in its own right (and will duly be reported) but is also an input to the specification of values for the themed scenarios and of tests to be run in order to calibrate the statistical model.

Note that, in the context of sensitivity analyses, when the variable of interest takes a high value, so too will all the variables that are dependent on it. Similarly, when the variable of interest takes a low value, so too will all the variables that are dependent on it. For example, when testing the sensitivity of the system to UK GDP, a ‘high’ value of UK GDP will cause a ‘high’ value of ‘annual vehicle kilometres travelled’, ‘UK vehicle parc’ and ‘reduction in sensitivity to price’. Each of these in turn will have further influences down the line. However, when testing the sensitivity of the system to ‘annual vehicle kilometres travelled’, the high ‘annual vehicle kilometres travelled’ would not in turn require a high ‘UK vehicle parc’, nor high ‘reduction in sensitivity to price’.

3.3 Themed Scenarios

A number of themed scenario tests will be run. They differ from the sensitivity analyses in that all variables are set at the level appropriate to the theme (in the sensitivity analyses all variables except the variable of interest were set at their base values). The following themes have been identified:

- T0 Base (in which all variables are set to their base levels)
- T1 All circumstances are maximally favourable to PiV sales
- T2 All circumstances are minimally favourable to PiV sales
- T3 Government incentives as announced but all other factors are maximally favourable to PiV sales
- T4 Government incentives as announced and all other factors are minimally favourable to PiV sales
- T5 High rate of growth of UK GDP
- T6 Low rate of growth of UK GDP
- T7 High rate of growth in the global economy
- T8 Medium rate of growth in the global economy with a green emphasis
- T9 Medium rate of growth in the global economy with high oil price
- T10 Medium rate of growth in the global economy with oil price spike
- T11 Low rate of growth in the global economy
- T12 Minimised carbon emissions

Themes T5-T11 (the macroeconomic themes) are described in more detail in Section 4.1.8)

Note that, although the levels for some of the variables in themes 1-4 can be anticipated in advance, they may need to be revised in the light of findings from the consumer research being conducted in SP1 and in the light of the results from the sensitivity analyses.

3.4 Statistical Modelling

Additional runs are required to establish non-linearities in the response (e.g. a declining marginal rate of return from additional subsidy) as well as interactions between different input variables (e.g. the effect of a subsidy for purchasing PiVs might be reduced if there were fewer charge points in place than is envisaged in the base case).

Although it might be useful to test all possible combinations of the values of all input variables, this is not a practical proposition (it would require millions of runs of the Consumer Response Model being created by Element Energy). It is therefore necessary to prioritise the extra runs, over and above the sensitivity analyses, to be undertaken.

The number of extra statistical runs that can be performed within the timing of this project is dependent on how long the Consumer Response Model will take to run. Element Energy expect to carry out the first full run of their model in mid

January 2011, and once the run time is determined the number of ‘statistical’ runs can be quantified.

3.5 Constraints on the Scenario Modelling

Modelling always involves simplification and compromise. A balance has to be struck between the desire to encapsulate all the possible effects and the feasibility of doing so. The main limitations are resources and knowledge. Limitations on time and budget inevitably result in it being impossible to explore all possible factors. Limitations on knowledge mean that, even if resources were unlimited, the data required to develop a given aspect of the model may not be available. The PiVEIP project is no exception to this rule.

A number of the processes which would, in real life, affect the uptake and use of PiVs are not included in the models at our disposal. For example:

- The Consumer Response Model was designed to predict the purchase of PiVs but was not designed to predict the manner in which they might be used or the time(s) and place(s) where they would be recharged[3]. We have therefore had to develop a representation of PiV usage and recharge behaviour which reflects a series of simple assumptions rather than any real evidence or any behavioural model.
- There is not yet any evidence on the number of charge points which will be provided by commercial organisations for their employees, customers or members of the public. We have therefore had to specify an algorithm based on our belief about the processes likely to be involved rather than on any real evidence.

A number of these simplifying assumptions are inevitable at this early stage in the overall project and may be able to be replaced by evidence-based models in later stages of the project.

A more comprehensive list of modelling caveats affecting the Stage 1 modelling is attached as Appendix C.

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[3] It was reasoned that it would not be possible, at this early stage in the development of the PiV market, to collect any meaningful data on usage or recharge behaviour.

4 Description of Scenario Tests

This Section of the report sets out our proposed scenario tests. They have been grouped into eight categories:

1. Macroeconomic variables
2. Variables related to the UK GDP
3. Vehicle showroom
4. Electricity generation
5. Electricity price paid by consumers
6. Deployment of charge points
7. Consumer behaviour
8. Government policy

Sections 4.1- 4.8 deal with each of the eight categories in turn and present the proposed values to be used in each variant scenario. The base values (i.e. those to be used in the T0 Base run) are shown highlighted in red.

A matrix showing the levels to be taken by each variable in each run is appended as Appendix A. Further details of the formulae involved in operationalisation of the scenarios are provided in Appendix B.

4.1 Macroeconomic Variables

Some of the variables of interest are dependent on the prevailing economic conditions. Of particular interest are the effects of UK GDP, fuel prices, the price of carbon credits, commodity prices and the speed of development of automotive technologies. Also of interest is the rate of return required when capital is invested in “risky” projects.

We propose scenarios covering:

- The rate of growth of the UK GDP
- The wholesale price of oil
- The wholesale price of gas
- The wholesale price of coal
- The price of carbon credits
- The speed of development of automotive technologies
- Required rate of return on capital

Sections 4.1.1 to 4.1.7 deal with each of the items in turn. Section 4.1.8 shows how they are combined into macroeconomic themes.

4.1.1 UK GDP

We wish to test the effect of three different rates of growth in the UK GDP. The impacts of the assumed rate of growth in UK GDP are discussed in Section 4.2.

We have assumed constant compound growth rates not because we expect that to happen but because any more realistic scenarios (with varying, probably cyclical growth rates) would be so subject to uncertainty. Following advice from several sources we have chosen a base rate of 2% with variants at 3% and at 1%. The base rate accords with assumptions adopted by UK Energy Research Centre (UKERC) and thus aligns with work elsewhere in SP3 and in SP2. The adoption of 1% and 3% follows advice from the peer review by our advisor on macroeconomics Dieter Helm (see Appendix I), that we should test a wider range of values than was originally proposed.

We thus have three scenarios:

- L = low: 1% compound per year
- M = medium : 2% compound per year
- H = high: 3% compound per year

4.1.2 Oil Price Projections

The price of oil has obvious potential impact on the relative attractiveness of PiVs and ICEs and it will also affect the price of electricity and the electricity grid mix. It is therefore an important variable for us to consider.

Figure 3 shows the oil price forecasts from Department of Energy and Climate Change (DECC) - Updated Short Term Traded Carbon Values – June 2010, IEA (World Energy Outlook, 2009), UKERC (Energy 2050: The Transition to a Secure Low Carbon Energy System for the UK. UKERC 2009) and the ETI Energy System Modelling Environment (ESME). The figure also shows the four values we propose to test:

- L = “Low”: falling from 70 $/bbl in 2010 to 35 $/bbl in 2050
- B = “Base”: rising from 70 $/bbl in 2010 to 104 $/bbl in 2050
- S = “Spike”: similar to the base case but departing from that trend between 2020 and 2030 (peaking in 2025 at 149 $/bbl)
- H = “High”: rising from 70 $/bbl in 2010 to 280 $/bbl in 2050

The proposed values for the high and medium price trends are higher than those in WS3/ARUP/17 following direction by MEDAG and other stakeholders within the project.

The main impact of the global oil price on PiV uptake and use is via its effect on the pump price of petrol and diesel. This effect is encapsulated in the formulae in Appendix B1.

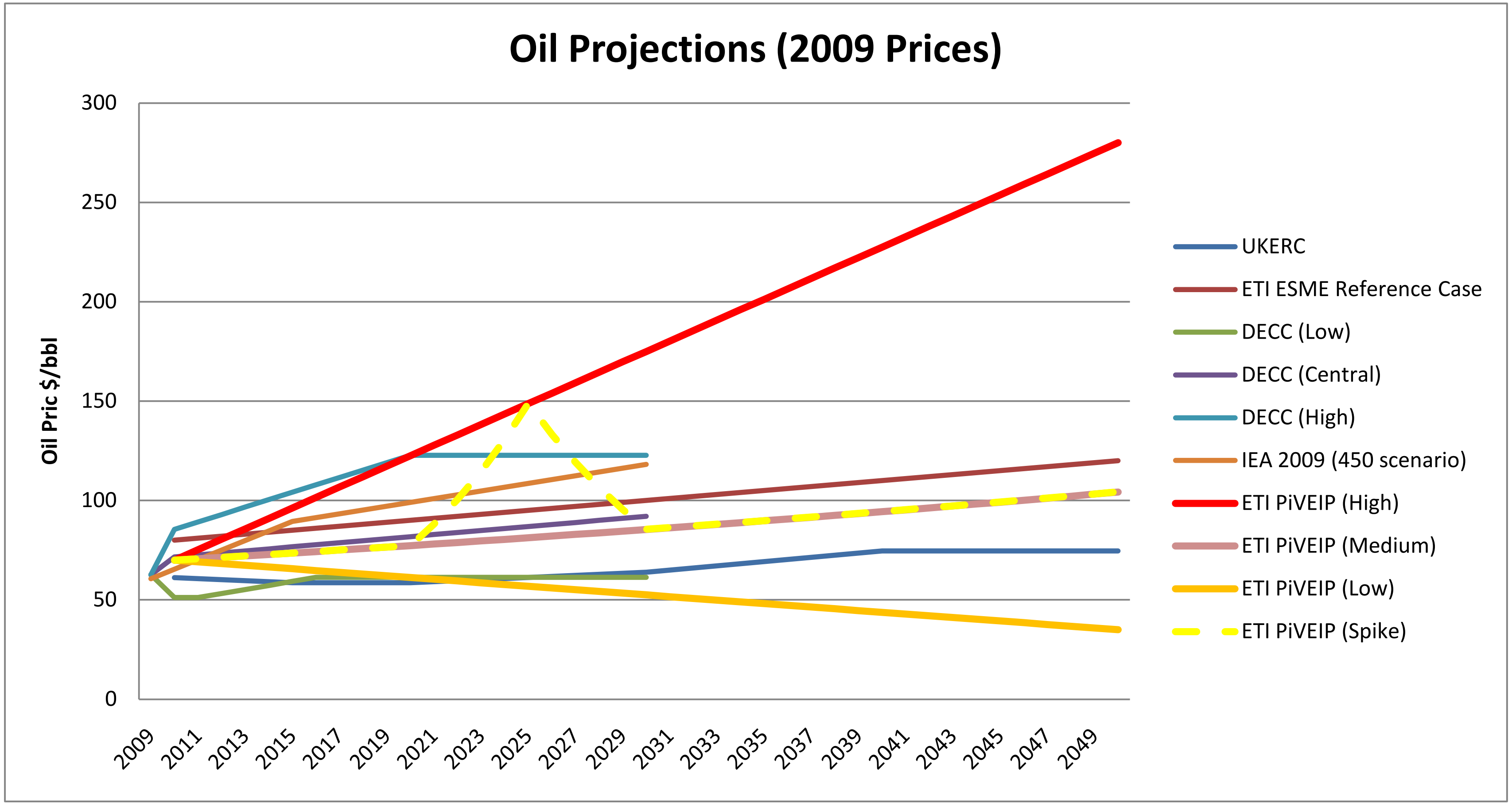

Figure 3 Oil Price Projections

4.1.3 Gas Price Projections

The price of gas will affect the price of electricity and thus has potential impact on the relative attractiveness of PiVs and ICEs as well as the electricity grid mix. It is therefore an important variable for us to consider.

Figure 4 shows forecasts from DECC (Updated Short Term Traded Carbon Values – June 2010), UKERC (Energy 2050: The Transition to a Secure Low Carbon Energy System for the UK. UKERC 2009) and the ETI Energy System Modelling Environment (ESME). The figure also shows the three values we propose to test:

- L = "Low": falling from 44 pence/therm in 2010 to 13 pence/therm in 2050
- B = "Base" : staying at 44 pence/therm throughout 2010 to 2050
- H = "High": rising from 44 pence/therm in 2010 to 118 pence/therm in 2050

The proposed values for the high and medium price trends are higher than those in WS3/ARUP/17 following direction by MEDAG and other stakeholders within the project.

4.1.4 Coal Price Projections

The price of coal will affect the price of electricity and thus has obvious potential impact on the relative attractiveness of PiVs and ICEs as well as the electricity grid mix. It is therefore an important variable for us to consider.

Figure 5 shows the coal price forecasts from DECC (Updated Short Term Traded Carbon Values – June 2010), IEA (World Energy Outlook, 2009), UKERC (Energy 2050: The Transition to a Secure Low Carbon Energy System for the UK. UKERC 2009) and the ETI Energy System Modelling Environment (ESME). The figure also shows the three values we propose to test:

- L = "Low": falling from 70 £/tonne in 2010 to 51 £/tonne in 2015 and then to 30 £/tonne in 2050
- B = "Base" : falling from 70 £/tonne in 2010 to 55 £/tonne in 2050
- H = "High": rising from 70 £/tonne in 2010 to 80 £/tonne in 2050

The proposed values for the high and medium price trends are higher than those in WS3/ARUP/17 following direction by MEDAG and other stakeholders within the project.

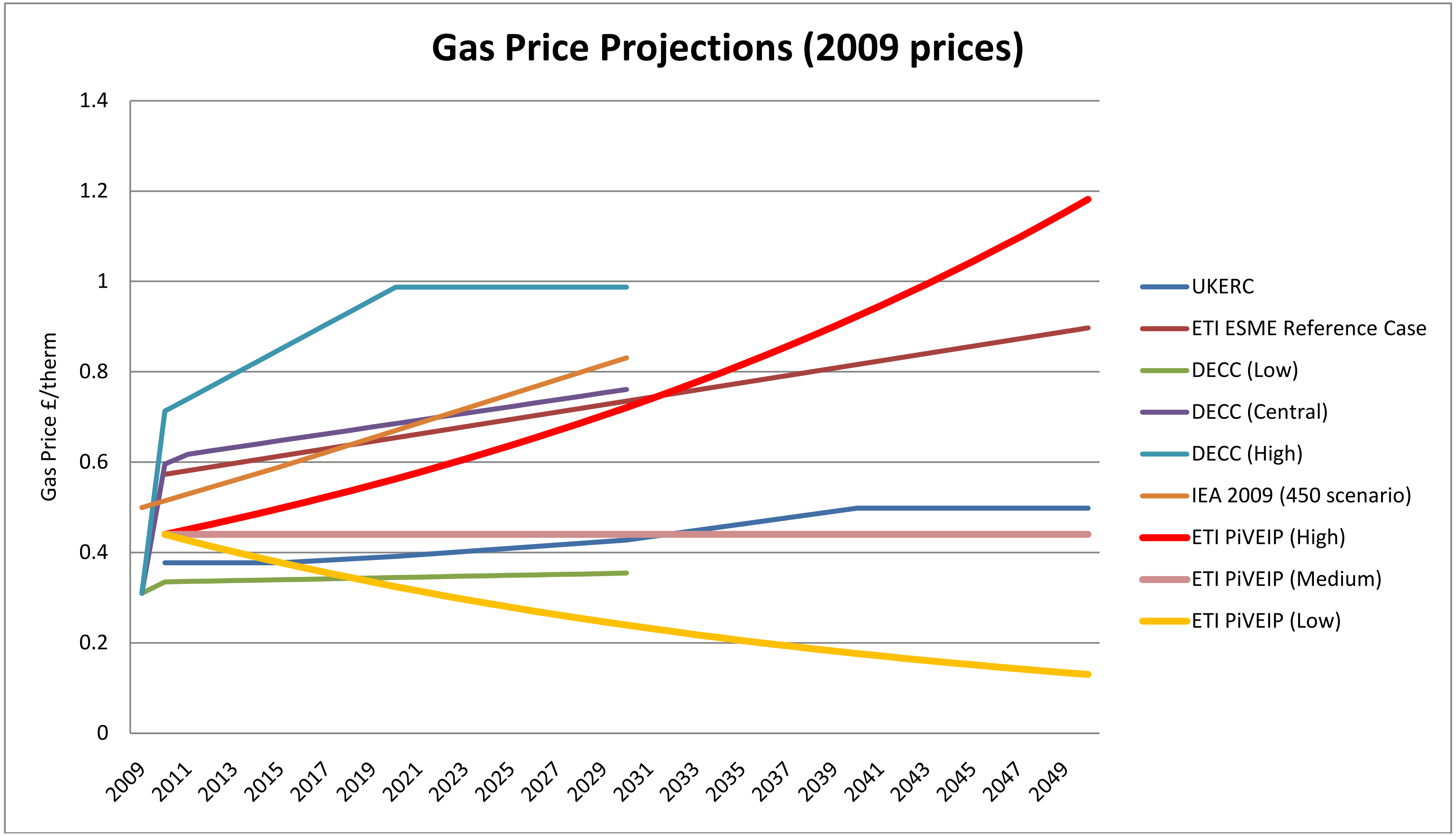

Figure 4 Gas Price Projections

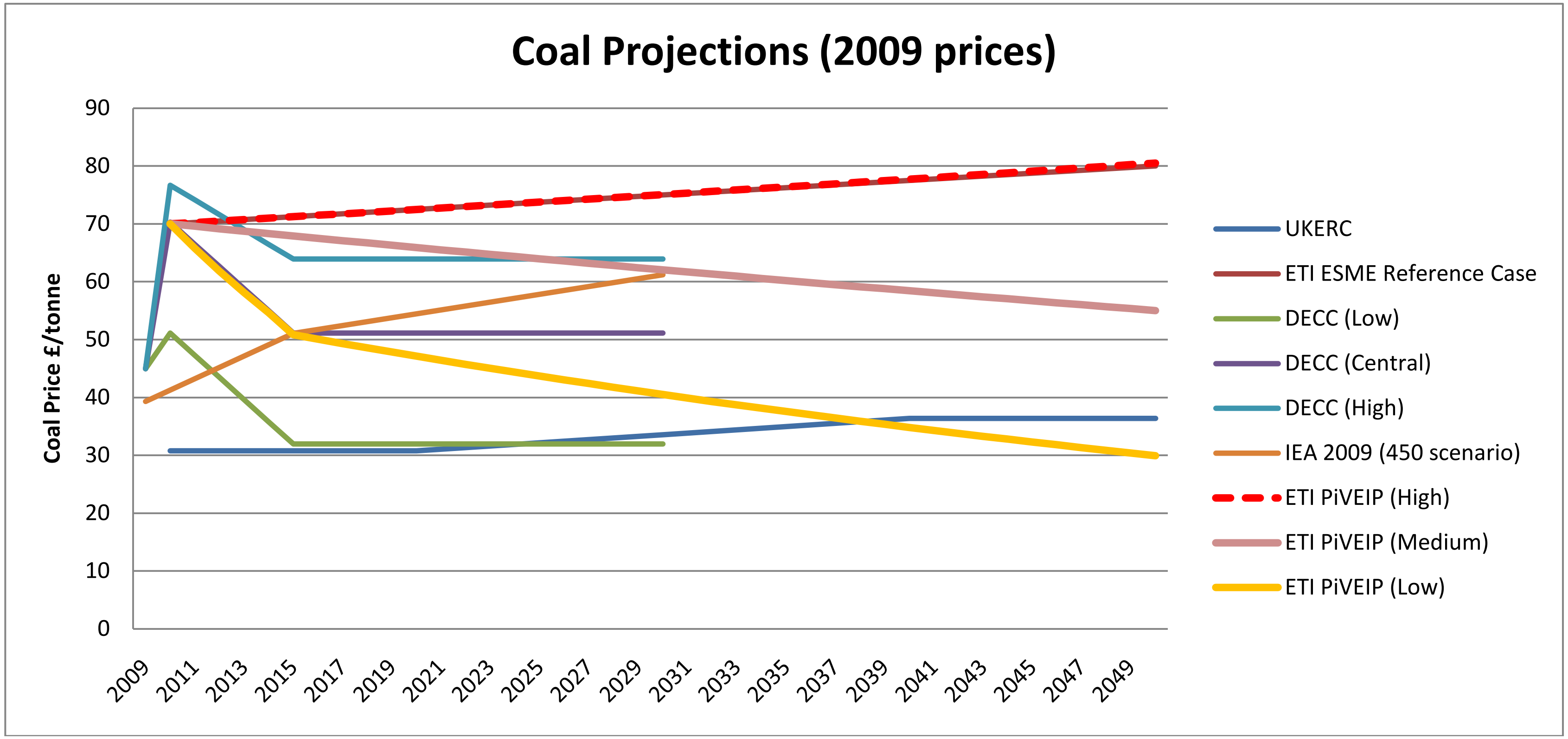

Figure 5 Coal Price Projections

4.1.5 Price of Carbon Credits

The price of carbon credits will affect the energy market and hence the electricity grid mix and the relative attractiveness of PiVs and ICEs. It is therefore an important variable in our analysis.

The price is fixed partly by market conditions but can be influenced by Government action – for example EU decisions on the supply of credits.

We wish to test three values (expressed in £ per tonne) based on those used by DECC (DECC Carbon Valuation in UK Policy Appraisal – Updated short term traded carbon values for UK public policy appraisal – June 2010) – see Figure 6. Namely:

- L = "Low": almost flat at £8 per tonne until 2020 then rising to £100 per tonne by 2050
- B = "Base": almost flat at £15 per tonne until 2020 then rising to £200 per tonne by 2050
- H = "High": almost flat at £19 per tonne until 2020 then rising to £300 per tonne by 2050

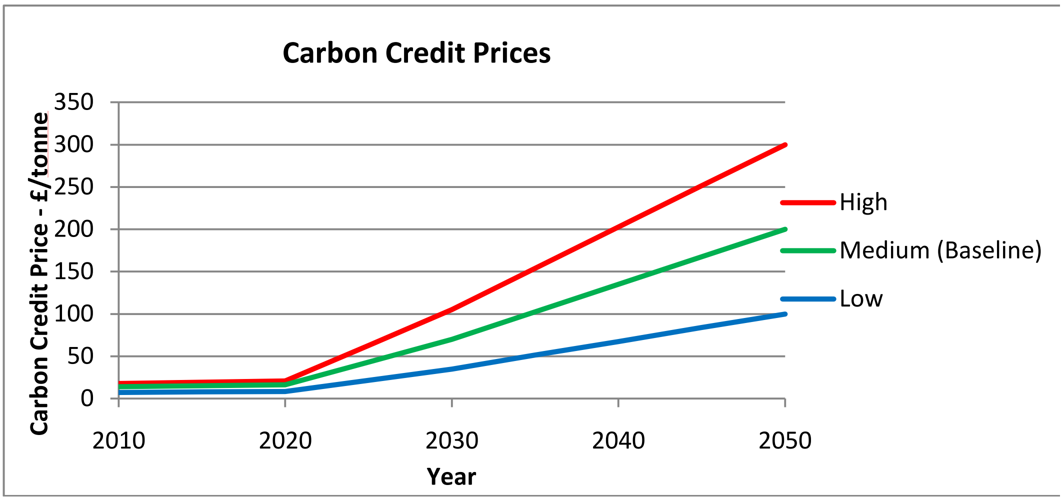

Figure 6 Carbon Credit Price Forecasts

These scenarios are restated in Section 4.8.12, within the section on Government Policy.

4.1.6 Speed of Development of Automotive Technology

The strength of the global economy is likely to affect the level of funding available for research into improved technology of both PiVs and conventional vehicles. For example, high economic growth is likely to lead to increased potential for profit and hence to more research and faster development of new technologies for vehicles – and batteries.

We wish to test three different speeds of development of automotive technologies:

- S = "Slow": in line with the most pessimistic industry projections

- B = “Base”: as per the “roadmap “ developed in SP1
- F = “Fast”: in line with the most optimistic industry projections

Section 4.3 describes how these rates of growth are assumed to affect the content of the vehicle showroom.

4.1.7 Required Rate of Return on Capital

The rate of return required by investors in “risky” projects could affect the price of charge points and associated infrastructure, and of network reinforcement costs if these are not designated as regulated assets (if they are so designated then the “risk” element is removed). If this resulted in very high premiums on users of charge points this could affect the attractiveness of PiVs. We therefore wish to test the effect of three different required rates of return on capital:

- L = “Low”: 4%
- B = “Base”: 6.5%
- H = “High”: 9%

The “Low” case is based on a risk-free rate. The “High” case includes an equity risk premium of 5%. The “Base” case is an interim position.

Section 4.5.6 describes how these required rates of return on capital might affect the price and deployment of non-domestic charge points.

4.1.8 Macroeconomic Themes

Four macroeconomic themes, including the base case, were described in detail in the separate Preliminary Macroeconomics Report WS3/ARUP/17 (Appendix F). Two further themes (labelled T9 and T10 in the table below), with different assumptions about the price of oil, have been added following comments from the peer review by our macroeconomic advisor, Dieter Helm.

Table 2 details the combinations of value settings which constitute our macroeconomic themes. Note that the themes do not include specified values for the rate of growth of the UK GDP or for required rate of return on capital in the UK (these are not deemed to be entirely dependent on global macroeconomic factors).

Code	Oil	Gas	Coal	Carbon Credit	Vehicle Development
T0 (Base)					
T1 Max fav to PiV sales	H	L	L	L	F
T2 Min fav to PiV sales	L	H	H	H	S
T3 Govt incentives as T0, otherwise max fav to PiVs	H	L	L	L	F
T4 Gvnt incentives/policies as announced in T0, but all other factors unfav to PiV sales	L	H	H	H	S
T7 High growth in Global Economy (G.E)	H	H	H	H	F
T8 Medium growth in G.E with green emphasis	H	H	H	H	F
T9 Medium growth in G.E with high oil	H				
T10 Medium growth with oil spike	S				
T11 Slow growth in G.E	L	L	L	L	S
T12 Minimum carbon emissions	H	H	H	H	F

Table 2 Macroeconomic Themes

Note that, in this and in subsequent tables of the same kind, blank cells indicate that the base value applies – where a themed scenario is not listed then all values are as for the base case in that theme.

4.2 Variables Related to UK GDP

It is considered important to test the sensitivity of the overall model forecasts to assumptions about the average rate of growth of the UK GDP. As noted in Section 4.1.1, we propose to test three levels:

- L = 1.0% compound growth per year
- M = 2.0% compound growth per year
- H = 3.0% compound growth per year

We have identified four key variables, each of which is described below, which are related to the rate of growth of the UK GDP:

1. the annual increment to the UK car parc
2. the annual vehicle kilometres travelled (VKT) per car
3. sensitivity of consumers to prices
4. the demand for electricity in the UK

4.2.1 Annual Increment to the UK Car Parc

This, together with assumptions about vehicle life and scrappage, determines the annual sales of new cars. It is therefore a key input to the consumer response model.

A considerable amount of research has been performed on the relationship between GDP and the size of the car parc. Our starting point is to adopt the value of the elasticity of the car parc to GDP derived by Graham and Glaister (2004). This elasticity is 0.74. It should be noted that simplistic use of this value ignores the possibility that the overall size of the parc might be affected by a saturation effect and/or by the constraining influence of increased congestion if road capacity does not keep pace with demand. Unconstrained projection on the basis of the elasticity with respect to GDP growth rates results in unrealistically high levels of car ownership by 2050, most especially for high levels of annual growth in UK GDP.

Having considered a number of variations on a simple elasticity model of UK car parc growth, it was decided that the best approach would be to utilise population predictions from the Office of National Statistics for the forecast period and the expected growth in the car parc for 2041 as set out in the DfT TEMPRO projections.

We thus propose three scenarios (in each of which the growth in the car parc is appropriately constrained in the light of the TEMPRO projections for 2041):

- H = applying an elasticity of 0.74 to a 3% annual growth in UK GDP
- M = applying an elasticity of 0.74 to a 2% annual growth in UK GDP
- L = applying an elasticity of 0.74 to a 1% annual growth in UK GDP

Our method was as follows. Firstly we took the 2040 value of carparc from TEMPRO and used that as our 2041 M value (i.e. 2% annual GDP growth). Secondly we took other M values to lie on a curve drawn between the actual 2009 value and this 2041 M value. Thirdly we projected this curve forward to 2050. Finally, we derived H and L values using the following formulae.

$$\mathrm{Carparc}_{H,t} = \mathrm{Carparc}_{M,t} \times \left(1 + 0.74 \times \left(\left(\frac{1.03}{1.02}\right)^{N} - 1\right)\right)$$

$$\mathrm{Carparc}_{L,t} = \mathrm{Carparc}_{M,t} \times \left(1 + 0.74 \times \left(\left(\frac{1.01}{1.02}\right)^{N} - 1\right)\right)$$

where

N = number of years since 2009 (the GDP growth rate is cumulative per annum)

$t = 2009 + N$

The resulting values for the UK car parc are provided in tables in Appendix B5.2.

4.2.2 Annual VKT per Car

This will determine the usage, fuel consumption and emissions of the conventional vehicle fleet and the use and recharge requirement of the PiV fleet and is thus a key input to the consumer response model.

Evidence from past data clearly shows a general decline in VKT per car over time. This is generally assumed to reflect increases in the number of cars in circulation and the particular increase in multi-car households – recognizing that second and third cars cannot be used as intensively as first cars. Research has been conducted on the relationship between VKT and GDP. Graham and Glaister (2004) suggest that this relationship can be summarized as an elasticity of total GBVKT to GDP. Their research suggests that this elasticity has a value of 0.73. Using this value, together with the 0.74 for the car parc to GDP, the ratio of the growth in total GBVKT to the growth in the car parc will be 0.73/0.74 (=0.986) – implying a marginal reduction in VKT per car as GDP increases. We propose to adopt these values and so propose three scenarios in which our initial estimate of VKT per car in year t (IEVKTTPC$_t$) is calculated using the formula:

$$IEVKTPC_t = IEVKTPC_{2009} \times \frac{(73 \times (1+A)^N + 27)}{(74 \times (1+\mathrm{A})^{\mathrm{N}} + 26)}$$

where

A = the annual rate of change in GDP specified for the scenario (0.03, 0.02 or 0.01)

N = number of years since 2009 (the GDP growth rate is cumulative per annum)

The three scenarios are:

- H = with a 3% annual growth in UK GDP
- M = with a 2% annual growth in UK GDP
- L = with a 1% annual growth in UK GDP

However, we propose not to use these initial estimates because factors other than multiple car ownership have also been mooted as contributing to falling VKT per car over time, such that VKT per car will fall more quickly than the above formulae would suggest. The most significant such factor is probably the increased congestion which is likely to occur if road space is not increased in line with increased fleet size. Evidence from international cross-sectional studies of the relationship between car ownership levels and VKT per car (e.g. as summarised in Table 2.2 of the RAC Foundation's 'Motoring towards 2050' report on the impact of reducing travel speeds) suggests a strong inverse relationship between VKT per car and the size of the car parc.. Assuming that, in 2050, the GB population will be 75 million and the GB car parc will be 45 million (see 4.2.1 above), we deduce that there will be 0.6 cars per head in 2050. Using data from Table 2.2 of the RAC report to plot the relationship between annual VKT per car and cars per head, we then deduce that the 2050 figure for annual VKT per car is likely to be around 10,000. We adopt that figure for the base (2%) GDP growth scenario. Given a fall of 4,000 (from 14,000 to 10,000) in the 2% case we think it appropriate to assume a fall of 2,000 (to 12,000) for the 1% case and of 6,000 (to 8,000) in the 3% case. Our initial estimates of annual VKT per car (IEVKTPC), derived using the formulae set out above, were then scaled back in order to pass through 10,000, 12,000 and 8,000 (for the 2%, 1% and 3% cases respectively) in 2050.

Total GBVKT in any year is then calculated by multiplying the scaled value of IEVKTPC for that year by the GB car parc for that year. A table containing the scaled back forecasts for GBVKT is included in Appendix B5.2.

4.2.3 Reducing Sensitivity to Price Changes

As GDP rises, GDP per capita also rises (though at a rate about 12%[4] slower due to effects such as net immigration – for our high, medium, and low rates of GDP growth the corresponding rates of increase in GDP per head should therefore be 2.63, 1.77 and 0.88, respectively). Standard economic theory suggests that, as people's real income rises their sensitivity to real price should reduce (Beardshaw, J, Economics: A Student's Guide. Pitman, 2nd Ed. 1989). It is standard practice in UK[5] demand forecasting to increase preparedness to pay in line with with GDP per head. This is implemented in travel demand models by applying a elasticity of 0.8 to the Value of Time. Given that the forecasts in the current project are for a period of 40 years this would become a significant issue for the prediction of consumers' purchase decisions and their vehicle use decisions. Although it is unusual to adjust coefficients derived from SP studies in this way when forecasting in the short term, we think it is appropriate to do so in the current context. This adjustment affects all those coefficients in the consumer response model which relate to prices (sensitivity of the purchase decision to showroom price and to assumed running costs, and sensitivity of annual and daily VKT to the price of fuel and electricity).

We propose to explore this assumption via four scenarios:

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[4] Evidence suggests that GDP per head rises at 0.877 of the GDP rise

[5] Encapsulated in paragraph 1.2.21 of Section 3.5.6 of The Department for Transport's WebTAG advice

- H = deflating the relevant coefficients in line with a 2.63% annual compound rate of increase in GDP per capita
- M = deflating the relevant coefficients in line with a 1.77% annual compound rate of increase in GDP per capita
- L = deflating the relevant coefficients in line with a 0.88% annual compound rate of increase in GDP per capita
- N = assume no change in the relevant coefficients despite the change in GDP per capita

Note that this deflation should not be applied to the relationship between GDP and total car parc or between GDP and VKT per car (Sections 4.2.1 and 4.2.2 respectively) because the effect of increasing GDP per head is already accounted for in the elasticities. The equations used to implement these elasticity effects are given in Appendix B5.2.

4.2.4 Total Electricity Demand in the UK

The overall level of demand for electricity will affect decisions about the installed generating capacity and will certainly affect the use of that capacity. This in turn will affect the cost of each unit of electricity and the emissions associated with generation and transmission.

On the assumption that demand for electricity is related to the size of the economy (research suggests a 0.27% increase in demand for each 1% increase in GDP)[6], we had planned to include three scenarios for UK electricity demand (to match the three levels for UK GDP). However, three considerations led us to withdraw this idea:

1. Our Macroeconomic advisor suggests that the relationship between GDP and electricity demand is unlikely to continue given the increased emphasis on energy efficiency and improved insulation.
2. Large changes in the assumed level of demand for electricity would require complete reworking of the assumptions about installed capacity which are inherent in the UKERC scenarios (the UKERC scenarios show installed capacities designed to meet specified carbon reduction targets against a background of a 2% annual growth in GDP – these targets would not be met if the demand was substantially greater). We are informed that such reworking is beyond the scope of the existing contract and that, in the absence of such reworking, no meaningful estimates of the effect on electricity price or carbon intensity can be made.
3. Although Network Reinforcement Cost would be different at different levels of demand, there is no reason to assume that the marginal effect of a given level of PiV-related demand would depend on the overall level of

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[6] Smyth, M and Bailey, M, (2008), An economic analysis for the elasticity of demand for energy in Northern Ireland. Report prepared by the School of Economics & Politics, University of Ulster for the Northern Ireland Authority for Utility Regulation (NIAUR), available online at *www.uregni.gov.uk/uploads/publications/NIAUR_Report_UU_revised.doc*

Oxford Economics (2008), *Review of the BERR Energy Demand Model*. Oxford, Oxford Economics demand – the pattern of troughs and peaks in the base demand would still be the same.

4.2.5 Tests Related to the UK GDP

The required tests are as shown in Table 3

Code	UK vehicle parc	Annual VKT	Reduced sensitivity to prices
UK1	H	H	
UK2	L	L	
UK3			H
UK4			L
UK5			N
T1 Max fav to PiV sales	H	H	H
T2 Min fav to PiV sales	L	L	N
T3 Govt incentives as T0, otherwise max fav PIV	H	H	H
T4 Gvnt incentives/policies as announced in T0 but all other factors unfav to PiV sales	L	L	N
T5 High rate of growth in UK GDP	H	H	H
T6 Low rate of growth in UK GDP	L	L	L
T7 High rate of growth in the global economy	H	H	H
T8 Medium rate of growth in the global economy with a green emphasis	L	L	L
T11 Low rate of growth is the global economy	L	L	L
T12 Minimum carbon emissions	L	L	L

Table 3 Tests related to the UK GDP

4.3 Vehicle Showroom

4.3.1 Vehicle Technology & Cost Scenarios

A number of vehicle technology and costs scenarios were agreed with the ETI and MEDAG. These scenarios were included within our ‘proposed scenarios’ deliverable (WS3/ARUP/09) and are described in Appendix J. However, it was subsequently determined that Ricardo will only create one vehicle technology and cost forecast, and therefore the original 23 scenarios that were proposed cannot be tested.

This Section provides alternative scenarios that will now be used to test ‘key’ vehicle attributes within the Consumer Response Model.

4.3.2 Scenarios for what is available in the “showroom”

We have identified 10 key vehicle attributes which might affect purchase decisions (PD) or the required accounting of costs (C) or of Well to Wheel (WTW) emissions (E). All costs will exclude taxes and subsidies. They are:

1. Purchase price (excluding battery)
2. Purchase price of batteries (per kWh)

3. Annual costs of ownership (insurance, servicing etc)
4. Residual value after 4 years
5. Fossil fuel consumption per 100 km
6. Electricity consumption per 100 km
7. Maximum fully electric range
8. Performance (seconds to accelerate from 0 – 100 km/h)
9. Average life expectancy (age when vehicle is scrapped)
10. Emissions associated with manufacture, distribution and scrappage

Table 4 indicates what vehicle types are affected and the implications of a variation in each aspect.

	Affects Purchase?	Affects Costs?	Affects CO2?
Purchase price (excluding battery)	y	y	
Purchase price of batteries (per kWh)	y	y	
Annual costs of ownership	y	y	
Residual value after 4 years	y	y	
Fossil fuel consumption per 100km	y	y	y
Electricity consumption per 100km	y	y	y
Maximum fully electric range	y		
Performance	y		
Average life expectancy			y
WTW Emissions			y

Table 4 Vehicle Attributes

Note that some of these are not independent. For example, we would expect to see some correlation between residual values and life expectancy.

Battery price has a major influence on the purchase price of PiVs and hybrids, and justifies having its own variable. The vehicle price is therefore split into two components.

1. The purchase price of PiV (excluding battery)
2. The price per kWh of a vehicle battery

The total vehicle price will therefore be equal to: -

Price (excluding battery) + (Price per kWh of battery x *Battery size in kWh)*

The ±30% variation given to the PiV’s residual value is deemed to include the uncertainty on battery life as a transport energy storage unit, the ability of batteries to be used as stationary energy storage units at the end of their transport usage, and the cost of recycling batteries at the end of their life.

For each category of vehicle we propose to use the values for each vehicle segment and powertrain type in the Ricardo roadmap as the base values for each year and then to test variations on that value.

Given that future values for conventional vehicles are, arguably, more predictable, we propose to minimise the number of scenarios by varying only those attributes, which relate to PiVs (although, as an exception to this general rule, we do propose to test variations in “fossil fuel consumption” and “emissions due to manufacture, distribution and scrappage”).

Other than for average life expectancy, the proposed High and Low values are shown in Table 5 below as percentage variations from the base. These values have been confirmed by Ricardo as appropriate for a most optimistic and most pessimistic view of the future. To account for the increasing uncertainty the further into the future one looks, the variations will increase linearly from 0% in 2010 to the maximum percentage shown in the table for 2050.

For average life expectancy, the variation is expressed as a revision to the year in which a specific life is expected to be attained.

			Variation from Base Value in 2050 *											
		Base Value	**BEVs**		**PHEVs and REEVs**		**Mild & Full Hybrids**		**ICEs (including those with stop-start) excluding H2 ICEs**		**H2 ICEs**		**Fuel Cell vehicles**	
			High	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Purchase price (excluding battery)		From Ricardo roadmap	20%	-20%	20%	-20%	0%	0%	0%	0%	20%	-20%	20%	-20%
Purchase price of batteries (per kWh)			40%	-40%	40%	-40%	40%	-40%	N/A	N/A	N/A	N/A	40%	-40%
Annual costs of ownership (insurance etc)			10%	-10%	10%	-10%	0%	0%	0%	0%	10%	-10%	10%	-10%
Residual value after 4 years			30%	-30%	30%	-30%	0%	0%	0%	0%	30%[7]	30%[8]	30%[8]	30%[8]
Fossil fuel consumption per 100 km			N/A	N/A	10%	-10%	10%	-10%	10%	-10%	10%	-10%	20%	-20%
Electricity consumption per 100 km			10%	-10%	10%	-10%	N/A	N/A	N/A	N/A	N/A	N/A	10%	-10%
Maximum fully electric range			30%	-30%	30%	-30%	N/A	N/A	N/A	N/A	N/A	N/A	30%	-30%
Performance (acceleration - secs for 0 – 100 km h)			-10%	10%	-10%	10%	0%	0%	0%	0%	-10%	10%	-10%	10%
Emissions due to manufacture, distribution and scrappage			20%	-20%	20%	-20%	20%	-20%	20%	-20%	20%	-20%	20%	-0.2
Date for average life expectancy in years to be achieved	8 years	2010	2010	2010	2010	2010	For Mild & Full Hybrids and ICEs, life expectancy from 2010 is 12 years under all scenarios				2010[8]	2010[8]	2010[8]	2010[8]
	10 years	2020	2015	2030	2015	2030					2015[8]	2030[8]	2015[8]	2030[8]
	12 years	2030	2020	2050	2020	2050					2020[8]	2050[8]	2020[8]	2050[8]

* Where variations are shown as a percentage change from Base Value shown in above Table, these should increase linearly from 0% in 2010 to the those shown in Table for 2050. For average life expectancy, the life should increase as a step change in the year shown.

Table 5 Vehicle Attribute High & Low Scenario Values

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[7] Life expectancy and residual value cannot be tested within the Consumer Response Model. Therefore they will be defined as per the base value from the Ricardo roadmap in all scenarios.

4.3.3 Tests Related to the Vehicle Showroom

The required tests, which include sensitivity analyses, and allow for correlation between some of the attributes, are specified in Table 6.

	Vehicle Attributes ('1' = BEVs, '2' = PHEVs and REEVs, '3' = mild & full hybrids, '4' = ICEs (including those with stop-start) excluding Hydrogen ICE, '5' = Hydrogen ICE, '6' = Fuel Cell) - (S)																																																										
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Code	up front price (exc. Battery)						Battery Price						Other costs of owner						Residual Value						Fossil fuel cons per 100 km						Elec cons per 100 km						Max fully electric range						Perf (acc)						Ave. life exp						Production & Scrappage Emm					
S1	H	H	H	H	H	H				n.a.	n.a.														n.a								n.a	n.a	n.a	n.a			n.a	n.a	n.a																			
S2	L	L	L	L	L	L				n.a.	n.a.														n.a								n.a	n.a	n.a	n.a			n.a	n.a	n.a																			
S3							H	H	H	n.a.	n.a.	H													n.a								n.a	n.a	n.a	n.a			n.a	n.a	n.a																			
S4							L	L	L	n.a.	n.a.	L													n.a								n.a	n.a	n.a	n.a			n.a	n.a	n.a																			
S5										n.a.	n.a.		H	H	H	H	H	H							n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S6										n.a.	n.a.		L	L	L	L	L	L							n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S7										n.a.	n.a.								H	H					n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.								H	H										
S8										n.a.	n.a.								L	L					n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.								L	L										
S9										n.a.	n.a.														n.a.	H	H	H	H	H			n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S10										n.a.	n.a.														n.a.	L	L	L	L	L			n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S11										n.a.	n.a.														n.a.						H	H	n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S12										n.a.	n.a.														n.a.						L	L	n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.																			
S13										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.	H																		
S14										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.	L	L	n.a.	n.a.	n.a.	L																		
S15										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.		H	H																
S16										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.		L	L																
S17										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.														H	H	H	H	H	H
S18										n.a.	n.a.														n.a.								n.a.	n.a.	n.a.	n.a.			n.a.	n.a.	n.a.														L	L	L	L	L	L
T1 Max fav to PiV sales	L	L	L	L	L	L	L	L	L	n.a.	n.a.	L	L	L	L	L	L	L	H	H		L	L	L	n.a.	H	H	H	H	H	L	L	n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.		H	H	L	L	L	L	H	H		L	L	L	L	L	L	L	L	L
T2 Min fav to PiV sales	H	H	H	H	H	H	H	H	H	n.a.	n.a.	H	H	H	H	H	H	H	L	L		H	H	H	n.a.	L	L	L	L	L	H	H	n.a.	n.a.	n.a.	n.a.	L	L	n.a.	n.a.	n.a.		L	L	H	H	H	H	L	L		H	H	H	H	H	H	H	H	H
T3 Govt incentives/policies as T0, otherwise max fav PIV	L	L	L	L	L	L	L	L	L	n.a.	n.a.	L	L	L	L	L	L	L	H	H		L	L	L	n.a.	H	H	H	H	H	L	L	n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.		H	H	L	L	L	L	H	H		L	L	L	L	L	L	L	L	L
T4 Gvnt incentives/policies as T0, but all other factors unfav to PiV	H	H	H	H	H	H	H	H	H	n.a.	n.a.	H	H	H	H	H	H	H	L	L		H	H	H	n.a.	L	L	L	L	L	H	H	n.a.	n.a.	n.a.	n.a.	L	L	n.a.	n.a.	n.a.		L	L	H	H	H	H	L	L		H	H	H	H	H	H	H	H	H
T7 High rate of growth in the global economy	L	L	L	L	L	L	L	L	L	n.a.	n.a.	L	L	L	L	L	L	L	H	H	H	H	H	H	n.a.	L	L	L	L	L	L	L	n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.		H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L
T8 Medium rate of growth in the global economy with a green emphasis - fast tech theme	H	H	H	H	H	H	H	H	H	n.a.	n.a.	H	L	L	L	L	L	L	H	H	H	H	H	H	n.a.	L	L	L	L	L	L	L	n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.		H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L
T11 Low rate of growth in the global economy - slow tech theme	H	H	H	H	H	H	H	H	H	n.a.	n.a.	H	H	H	H	H	H	H	L	L	L	L	L	L	n.a.	H	H	H	H	H	H	H	n.a.	n.a.	n.a.	n.a.	L	L	n.a.	n.a.	n.a.		L	L	L	L	L	L	L	L	L	L	L	L	H	H	H	H	H	H
T12 Minimum Carbon Emissions	L	L	L	L	L	L	L	L	L	n.a.	n.a.	L	L	L	L	L	L	L	H	H	H	H	H	H	n.a.	L	L	L	L	L	L	L	n.a.	n.a.	n.a.	n.a.	H	H	n.a.	n.a.	n.a.		H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L

Table 6 Tests related to the vehicle showroom

4.4 Electricity Generation

4.4.1 Outline

Assumptions about electricity generation are required because, as shown in Figure 7, they affect the prices paid by PiV users and emissions produced during production of that electricity.

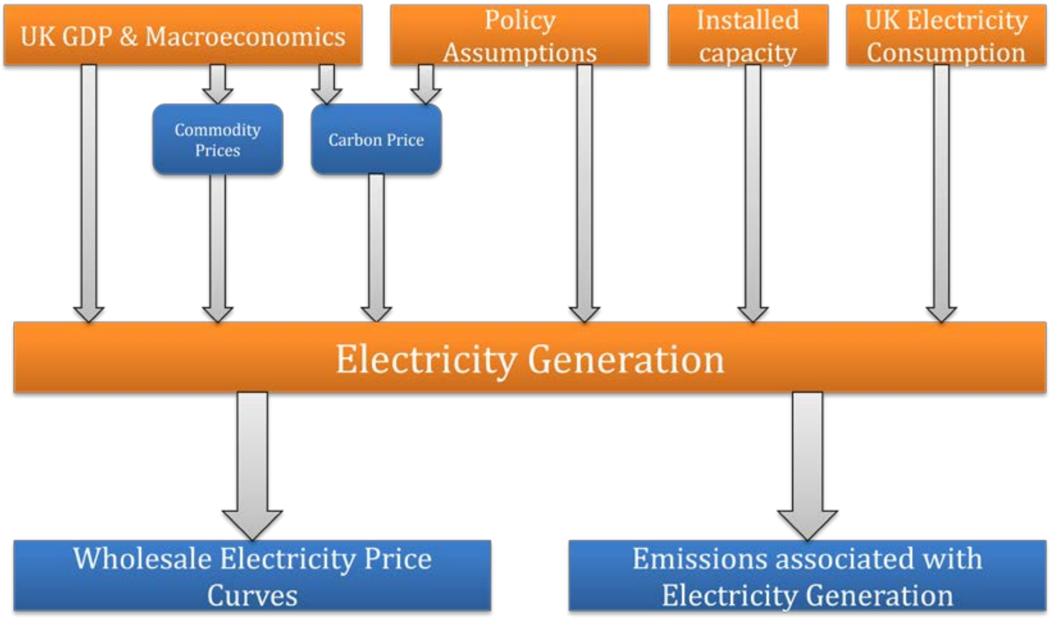

Figure 7 Electricity Generation Overview Diagram

E.ON and EDF are creating projections for the UK's Consumer Electricity Price excluding the effects of PiVs (WEP) and the associated CO2eq intensity for the generation, transmission and distribution of electricity. The price projections are based on adding wholesale electricity prices, an allowance for meeting ROCs (renewables obligation certificate) compliance, and an uplift of 4.2p/kWh to cover the business costs and profits of the generating companies, plus the costs of transmission and distribution. Their work is to be reported separately in E.ON deliverable WS3/EON/03.

There are two stages in the process being followed by E.ON and EDF:

1. Determination of the installed assets to generate the electricity. These are dependent upon Government policies and on the long term predictions of prices of competitor fuels. This project is using a selection of the scenarios published by UKERC (Energy 2050: The Transition to a Secure Low Carbon Energy System for the UK. UKERC 2009) as the basis for the assumptions on installed assets. The UKERC scenarios used in this project are discussed in Section 4.4.2 below.
2. Prediction of the usage of the installed assets on an hour-to-hour basis to meet the UK's electricity grid demands. The prediction will be dependent on: -
    a) The installed assets
    b) The electricity grid demand

c) Fuel and carbon prices

E.ON and EDF will report costs for different years, different seasons, for different hours of the day and for different regions of the country. The scenario work does not require this level of detail (not least because the Consumer Response Model will not distinguish between PiV usage patterns in different regions or seasons). The raw results from E.ON and EDF therefore need to be aggregated to provide:

- for each decade, national average consumer electricity prices per kW h for two periods (peak and off-peak).
- for each decade, national average CO2eq emissions per kW h for values of the total electricity grid demand. Emissions are calculated and reported as both average and marginal CO2 intensity in tonnes of CO2 per MWh.

4.4.2 UKERC Scenarios

The UKERC scenarios (described in detail in “Energy 2050: The Transition to a Secure Low Carbon Energy System for the UK. UKERC 2009”, and in E.ON deliverable WS3/EON/01) are based on assumptions about differing fuel and carbon prices.

Some of the UKERC scenarios are more appropriate than others for inclusion in the themed scenarios. Having considered this, we propose to use four UKERC carbon reduction scenarios for the installed electricity grid capacity to 2050.

- CSAM – Super ambition (90% CO2 reduction by 2050)
- CAM – Core Ambition (Low carbon) scenario (80% CO2 reduction by 2050)
- CCSP – Socially optimal least-cost path (Optimised carbon pathway using the 2010-2050 budget from the CEA (early action) scenario and a social discount rate)
- CLC – low carbon reduction scenario (60% CO2 reduction)

These scenarios will be used by E.ON and EDF in their predictions of the wholesale electricity price and of CO2 emissions per unit of electricity.

The UKERC scenarios were defined prior to the announcement of the proposals for Energy Market Reform. The initial proposals have now emerged, and it is understood that their effect will be to reduce the carbon intensity whilst increasing the price to the consumer. If it becomes apparent that these changes are more radical than those encapsulated in the CSAM scenario consideration will be given to an addition of a new scenario.

4.4.3 Tests Related to Electricity Generation

Table 7 shows the proposed tests. The three “EG” tests are included in order to cover a range of alternative strategies for achieving CO2 reduction in the electricity generation sector.

Code	Oil	Gas	Coal	Carbon	Base Demand	UKERC
EG1 Greenest	H	H	H	H	H (CSAM)	CSAM
EG2 Least green	L	L	L	L	L (CLC)	CLC
EG3 Early action to reduce CO2					MV (CCSP)	CCSP
T1 Max favourable PIVs	H	L	L	L	H	CLC
T2 Min favourable PIVs	L	H	H	H	L	CCSP
T3 Govt incentives as T0, otherwise max fav to PiVs	H	L	L	L	H	CLC
T4 Gvnt incentives/policies as announced in T0, but all other factors unfav to PiV sales	L	H	H	H	L	CCSP
T5 High rate of growth in UK GDP					H	
T6 Low rate of growth in UK GDP					L	
T7 High growth in Global Economy (G.E)	H	H	H	H	H	
T8 Medium growth in G.E with green emphasis	H	H	H	H	L	CSAM
T9 Medium growth in G.E with high oil	H					
T10 Medium growth in G.E with oil spike	S					
T11 Low growth in G.E	L	L	L	L	L	
T12 Minimum Carbon Emissions	H	H	H	H	L	CSAM

Table 7 Tests related to Electricity Generation

Note that blank cells indicate that the base value should be applied (CAM in the UKERC and base load column).

Table 7 shows 15 tests. These, plus the base, would require 16 runs of the electricity generation models. This is a larger number than had been anticipated and some simplifications have been required. Given the limited contribution of oil in the generation mix, the price of oil is assumed not to have any significant effect on the wholesale price of electricity (or on the associated carbon intensity) and thus:

- T1 & T3 will use the EG2 electricity generation model results
- T9 will use the Base electricity generation model results
- T10 will use the Base electricity generation model results
- The results for T2 & T4 cannot be directly derived from the other scenarios. As an approximation, T2 & T4 results have been calculated to be [EG3 + (T7 – Base)], where (T7 – Base) is approximately the effect of raising fuel and carbon prices.

4.5 Electricity Price Paid by Consumers

Figure 8 shows the method being used to calculate electricity prices paid by the end consumer.

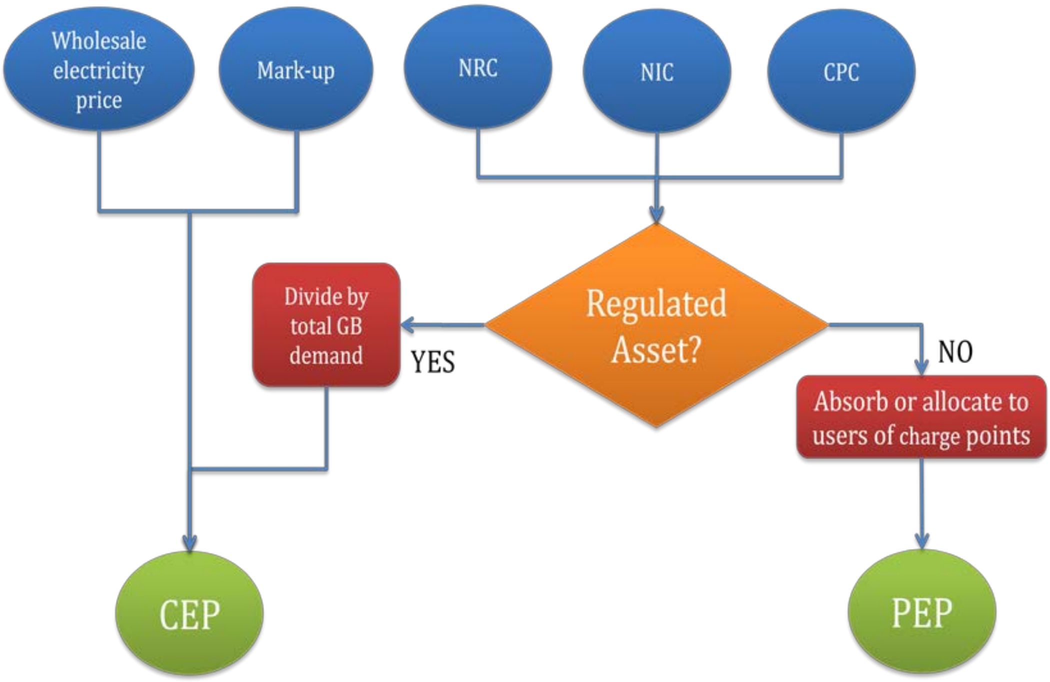

Figure 8 Electricity Price Overview Diagram

Electricity drawn from domestic charge points will be priced at CEP (it is not deemed feasible to charge householders a higher price for electricity to be used in PiVs than for electricity to be used for other purposes).

The price charged to the consumer at a public charging point is Consumer Electricity Price (CEP) + Public Electricity Premium (PEP).

The price charged to the consumer at workplace and retail charging points will depend on decisions by employers and retailer respectively (see Section 4.5.4).

4.5.1 Consumer Electricity Price Mark Up

The Consumer Electricity Price (excluding the effect of PiVs) is being calculated by E.ON and EDF (see Section 4.4) for a description of the scenarios they are employing. The mark-up in Figure 8 includes costs to cover ROCS compliance, and the business costs and profits of the generating companies, plus the costs of transmission and distribution. CEP (including the effect of PiVs) is then calculated by adding in the cost of regulated PiV-related assets per unit of electricity.

4.5.2 Costs of Network Reinforcement, Network Intelligence and Charge Points

Three cost items are associated with the provision and use of PiV charging infrastructure:

- **Network Reinforcement Costs (NRC)** - the costs required to upgrade the distribution network to deliver the additional peak power demand. The majority of these costs are being provided by a module written by Imperial College in sub-project 2. Imperial's module calculates a high, base and low value for NRC, and these will be used as appropriate in the various scenarios.

  The output from the Imperial model also includes costs that are necessary due to increase in the base load of the Grid. The method used to remove this portion of NRC is described in Appendix B2.1.. It has also been necessary to smooth the results over 5 years as the results from the module vary significantly from year to year, which is considered unrealistic for infrastructure investment.

  In addition, the asset regulation of some aspects of the Network Intelligence Costs (NIC) is more closely related to NRC than NIC. The costs for these have therefore been added to Imperial's NRC, as shown below.

YEAR	The aspects of NIC that have been added to NRC in £m per annum		
	Base	**Low**	**High**
2013	6	3	
2014	12	5	
2015	18	8	40
2016	20	10	80
2017	22	12	80
2018-2025	22	12	100
2026-2050	22	12	43

  The distribution of NRC to consumers is dependent upon whether the upgrade is considered to be a regulated asset or not. The methodology used to assign costs is summarized in Appendix B2.1.

- **Network Intelligence Costs (NIC)** - the costs required to run and maintain the charging infrastructure, and the costs required to control the billing of electricity back to the car owner. The unit costs for network intelligence have been provided by IBM in sub-project 2 as shown below. These unit costs are used to calculate the NIC to be met in a given year using the methodology summarized in Appendix B2.2.

PiV Parc	NIC per PiV	Additional NIC
0-500k	£215	£0
500k-1.2m	£215	£27m
>1.2m	£0	£285m

  - In the Base case, the above values will be increased by 2% compound from 2020.
  - In the Low case, the above values will be increased by 0% compound from 2020.
  - In the High case, the above values will be increased by 4% compound from 2020.

- **Charging Point Costs (CPC)** - the costs associated with the purchase, installation and maintenance of public charging points. The relevant unit costs are being provided by E.ON in sub-project 2. They are split by charge point type, and year. Both capital and annual running costs are provided, as is average life expectancy of the charge points. Three sets of figures are for the three scenarios below. The unit costs are used to calculate the CPC to be met in a given year using the methodology summarized in Appendix B2.3.

Estimates of NRC, NIC and of CPC are, of course, subject to error. We therefore propose to test the following scenarios:

- H = High - costs are at the upper end of the spectrum considered likely by the specialist teams producing the estimates
- B = Base values - best estimates of costs from the specialist teams
- L = Low - costs are at the lower end of the spectrum considered likely by the specialist teams producing the estimate

The scenarios above currently assume that the three cost terms, NRC, NIC and CPC are all either High, Base or Low. There is little logic behind this, other than that they are added together in some form to calculate electricity prices, and if one were Low, and the others High, the effects on electricity price would tend to cancel out.

4.5.3 Allocation of the costs of network reinforcement, network intelligence and charge points

It is as yet unclear whether these three elements will be considered as regulated assets, so we have introduced scenarios to allow for either case. If they are regulated assets, their costs will be shared amongst all electricity consumers. If unregulated, then the costs must be recovered from the users of the charging points, or subsidised by the owner of the points or by the Government.

As shown in Figure 8, if one or more of the above elements is regulated, then those costs are divided by the total GB demand and added to the wholesale electricity price, together with the mark-up, to produce the Consumer Electricity Price (CEP). Preliminary calculations (shown in WS3/ARUP/09) suggest that the impact on CEP would be marginal even if NRC, NIC and CPC were all deemed to be regulated assets.

If the elements are not regulated, their costs are divided by the public charging point electricity demand and used in calculating the premium that would need to be applied (PEP). Two PEP values will be used within this project. One will cover standard charging up to 22 kW; the other will include rapid charging of over 22 kW.

Due to the lack of disaggregation in the consumer response model it has to be assumed that PEP will be independent of the location of a public charge point, i.e. there is no variation between rural / suburban / urban, or between different regions of the UK. Similarly it has to be assumed that PEP will not vary by day of week, or season. Appropriately averaged values will be used. PEP will however vary by year. Preliminary calculations (shown in WS3/ARUP/09) suggest that PEP could be quite significant if NRC, NIC and CPC were all deemed to be unregulated assets.

We propose scenarios for this as follows:

- A = CPC[8], NIC and NRC are all designated as regulated assets (see Section 4.6.2)
- N = NRC and NIC are designated as regulated assets (CPC is not)
- Z = none are designated as regulated assets.

These scenarios are also described, along with other Government actions, in Section 4.8.9.

Appendices B2.4 and B2.5 shows the conversion of NRC, NIC and CPC into regulated costs and unregulated costs respectively.

4.5.4 Other Decisions by Government

As noted above, the unregulated costs of NRC, NIC and CPC would normally need to be met by users of non domestic charge points via a charge or a premium on the cost of electricity drawn from non-domestic charge points. These costs might, however, be absorbed by Government in order to stimulate PiV sales. We propose a number of scenarios on how this might be done:

- H = 50% grant until 2015, can write off cost against tax in 1 year
- B = no grants but can write off cost against tax in first year
- Z = no special incentives

Government might also offer to meet any shortfall in funding for new charge points. Scenarios for this are discussed in Section 4.6.2.2.

Scenarios for government involvement in the pricing of electricity drawn from non-domestic charge points are also described, along with other Government actions, in Section 4.8.

4.5.5 Decisions by Employers and Retailers

Employers might be prepared to absorb the cost of the PEP, or might even offer free electricity, in order to derive kudos and/or to benefit their employees. Retailers might act similarly – except, in their case, the prime motive would presumably be to attract customers (we assume that, to avoid abuse, access would be for a limited number of hours only). We propose scenarios to allow for this possibility.

- F = Employers and retailers offer free electricity to their employees and customers respectively
- FP = Employers and retailers charge the full price (CEP+PEP)

Even when employers and retailers do not offer free electricity, they may decide to absorb a proportion of the cost of the charge points because of the value (in goodwill or revenue streams) which usage of their charge points by employees and/or customers might bring. We propose to represent this via a “notional value” (*NV*) that an installer assigns to the charging point: an employer may install charging points as a benefit to his employees; a retailer may install points to encourage customers to enter his premises. We have no direct evidence on what these notional values might be and so propose to test three values for each (see below). We suggest that the value to employers in goodwill earned might be in the

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[8] When CPC is a regulated asset the question will arise of how deployment will be driven

order of £2.50 per day (which, given that a 3kW point might supply 24kW per working day, implies a value of around 10p per kWh) and that the value to retailers in goodwill and increased profits might be in the order of £3 per two hour visit (which, given that a 3kW point might supply 6kW per two hour visit, implies a value of around 50p per kWh).

The values we propose to test for the NV for employers are:

- H = High: 20p/kW h of electricity drawn
- M = Medium: 10p/kW h of electricity drawn
- L = Low: 0p/kW h of electricity drawn

The values we propose to test for the NV for retailers are:

- H = High: 100p/kWh of electricity drawn
- M = Medium: 50p/kWh of electricity drawn
- L = Low: 0p/kWh of electricity drawn

4.5.6 Electricity Price Calculations

Electricity drawn from domestic charge points will be priced at CEP.

Electricity drawn from public charge points will be priced at CEP+PEP.

Electricity drawn from charge points provided by employers or retailers will be priced at CEP+PEP (although PEP may, in practice, be reduced to zero – see above), or may be free.

The formulae for calculation of CEP and PEP are shown in Appendix B3.

From these formulae it will be appreciated that CEP is dependent on:

- the wholesale price of electricity (see scenarios in Section 4.4)
- whether NRC, NIC and CPC are regulated assets (see scenarios in Section 4.8.9) and if so, what they cost (see Appendix B2)

and that PEP is dependent on:

- Whether NRC, NIC and CPC are regulated assets (see scenarios in Section 4.8.9) and if not, what they cost (see Appendix B2)
- The rate of return is required from the charging infrastructure (see scenarios in Section 4.1.7)
- Assumptions about the maximum price that consumers would be willing to pay to recharge their vehicles. As explained in Section 4.7.9.2, it is assumed that consumers, particularly those driving PHEVs and RE-EVs, would consider the relative costs of recharging and of using conventional fuels and that this would effectively constrain the maximum price that could be levied for electricity via non-domestic charge points. This constraint is achieved via a factor (MaxPEPFactor) explained in Appendix B3.2 which indicates the maximum multiple of the cost of a given mileage using a typical petrol engine that consumers would be willing to pay. We propose to test three values of MaxPEPfactor:

  - H – "High MaxPEPfactor" = 1.5
  - M – "Medium MaxPEPfactor" = 1.0
  - L – "Low MaxPEPfactor" = 0.5
- Assumptions about the likely utilization (LU) of public charging points. This value is used in the calculation of the likely revenues from charge points and thus affects the required price premium. Values were derived in the light of assumptions about the logistics of parking /unparking and the likely patterns of demand. We propose to test 3 different levels for the minimum value of this :
  - H – High LU: standard = 25kWh/day rapid = 250kW h/day
  - M – Medium LU : standard = 10kWh/day rapid = 100kWh/day
  - L – Low LU: standard = 5kWh/day rapid = 50kWh/day
- The availability of Government grants and subsidies (see Section 4.6.2.2)
- The notional value which employers and retailers place on having employees and customers use charge points on their premises (see Section 4.6.2.2
- Whether employers and retailers charge for electricity at their installed points
- The ratio of the prices for peak/off-peak electricity

4.5.7 The ratio of the prices for peak/off-peak electricity

For Stage 1 of this project, it is assumed that CEP will only have two values in each year (a peak day-time value for the period 07:00 – 24:00, and an off-peak night-time value for the period 00:00 – 07:00). This requires a modification to the values of CEP to create day-time and night-time CEP values, weighted by electricity demand, to ensure that the overall revenue is maintained. In Stages 2-5, when more consumer charging behaviour is understood, it is likely that other variations of CEP will be considered, e.g. hourly variation, 4-hourly variation, weekday/weekend variation.

A formula to calculate the daytime (peak) and night-time (off-peak) CEP values for year T from the average value, is shown in Appendix B3.2. It uses a factor ("K") to give a Ratio between peak CEP rate and off-peak CEP rate. The ratio in UK market in 2011 is approximately K = 2.5 on Economy 7 with the current ratio of power demand between peak and off-peak of 1.39. But only 25% of domestic users have Economy 7. Hence the weighted ratio for all domestic consumers is 1.375. A decision at the MEDAG meeting of 17th February 2011, requested us to test three values for this ratio, as follows: -

- H (High ratio) K = 2.5
- M (Medium ratio) K = 1.375
- L (Low ratio) K = 1.0

4.5.8 Electricity Price Tests to be Run

Table 8 indicates the tests required.

Note that the results of the sensitivity tests outlined above may provide insufficient impact on electricity prices to affect consumer behaviour. If this is the case, additional scenarios may be run with prices as high, and as low, as can realistically be envisaged.

Code	Costs for NR, NI & CP	Required rate of return on capital	Regulated asset status	Gov't grants & subsidies	MaxPEP factor	Employers & Retailers action		Likely utilisation	Peak/Off Peak Elec Price Ratio
						Charge for Elec?	NV		
EP1	H								
EP2	L								
EP3		H							
EP4		L							
EP5			A						
EP6			Z						
EP7				H					
EP8				Z					
EP9					H				
EP10					L				
EP11						F	n.a		
EP12							H		
EP13							L		
EP14								H	
EP15								L	
EP16									H
EP17									L
T1 (max fav)	L	L	A	H		F	n.a	H	H
T2 (min fav)	H	H	Z	Z	L		L	L	L

Table 8 Tests relevant to electricity price

Note that T3, T8 and T12 are as T1 while T4 is as T2.

4.6 Deployment of Charge Points

The following types of charge points are distinguished:

Domestic	(Dom)
Workplace free	(Wo_free)
Workplace charged	(Wo_charged)
Retail free	(Re_free)
Retail	(Re_charged)
Public On-street	(Pu_on-street)
Public Car-park	(Pu_car park)
Public Rapid	(Pu_rapid)

The number of charge points of a given type will affect the probability that potential purchasers will have access to that type of charge point. This in turn may affect their purchase decision (see Section 4.7.6) and their recharge behaviour (see Section 4.7.8).

We understand that the surveys will distinguish between the following levels of access to charge points:

- at home, at work and at 30% of "public car parks (CPP) and on-street spaces (OSS)"
- at home, at work and at 10% of CPP&OSS
- at home and at work
- at home and at 30% of CPP&OSS
- at home and at 10% of CPP&OSS
- at home (only)
- at work and at 30% of CPP&OSS
- at work and at 10% of CPP&OSS
- at work (only)
- at 30% of CPP&OSS (only)
- at 10% of CPP&OSS (only)
- no access

The way in which access to charge points evolves over time will need to be calculated (see Sections 4.6.1 and 4.6.2 below).

4.6.1 Domestic Charge Points

Three scenarios are defined to determine consumers' perception of their ability to recharge at home. They reflect findings from the SP1 survey work and are:

- H = 100% of those with off-street parking at home
- M = 80% of those with off-street parking at home

- L = 60% of those with off-street parking at home

The cost of electricity at domestic charge points will be CEP in all scenarios.

4.6.2 Non-Domestic Charge Points

4.6.2.1 Initial Deployment of Non-Domestic Charge Points

In the early years, up to 2013, we assume installation of a number of charge points. We propose to test three levels based on those in Table 9 (See also Section 4.8.10). These levels have been estimated with consideration of the numbers included in the successful first and second round Plugged-in Places bids.

	Cumulative Numbers					
	TOTAL	**Work**	**On-street**	**Public car parks**	**Retail**	**Rapid**
2009	180	20	40	80	40	0
2010	637	70	240	245	80	2
2011	1854	514	561	640	130	9
2012	3312	1110	871	1115	180	36
2013	5017	1873	1241	1626	220	57

Table 9 Base case assumptions for initial deployment of charge points

The three scenarios for initial deployment are:

- H = Double the values shown in Table 9
- M = Base values as shown in Table 9
- L = 25% of the values as shown in Table 9

4.6.2.2 Continued Deployment of Non-Domestic Charge Points

Beyond 2013, we assume that further installation of non-domestic charge points will depend on there being a commercial case for so doing. This case will depend on revenue predictions (based on utilisation of the existing supply), costs and other commercial considerations. The estimation of this case is summarized in Figure 9 and in the following text.

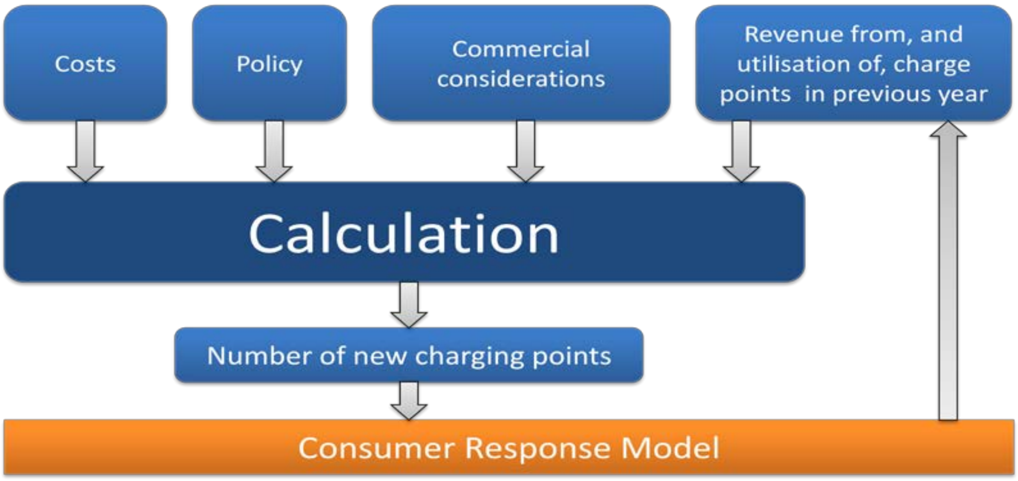

Figure 9 Number of Non-domestic Charge Points Overview Diagram

A formula to calculate the number of new charge points is given in Appendix B4.1. The formula is based on the logic encapsulated in Figure 9 and ensures that, in the absence of a commercial justification for additional points, none will be installed unless Government agree to meet any shortfall between the maximum premium (*PEPMAX*) and the PEP required to fund installation of the required number of charge points of a given type.

We propose to test two scenarios (See also Section 4.8.10):

- G = Government agree to meet any shortfall in funding required
- N = No government support is available to meet any shortfall.

When government agree to meet the shortfall, they might also agree to sponsor a higher level of deployment than would have been defined using “normal” rules (see Appendix 4.1). We represent this via a coefficient (LOSCoef) for which we propose to test three values:

- VH = Very High Level of Service (LOSCoef = 1.5)
- H = High Level of Service (LOSCoef = 1.1)
- N = Normal Level of Service (LOSCoef = 1.0)

As will be appreciated from the formulae in Appendix B4.1, the deployment of charge points will also depend on the premium which is charged over and above CEP. Section 4.5 has explained that this is dependent on:

- whether the CPC, NIC and NRC are deemed to be regulated assets (see Section 4.5.3),
- the costs of unregulated assets (see Section 4.5.2),
- the required rate of return on capital ,(see Section 4.1.7),
- any government grants and subsidies (see Section 4.5.4),
- assumptions about the maximum premium that can be charged (see Section 4.5.5)the notional value placed on use of workplace and retail charge points (see Section 4.5.5),, and

- the assumed utilisation of charge points (see discussion of LU in Section 4.5.6).

We recognise that the formula set out in Appendix B4.1, and the values which steer it, are a matter of conjecture. We recommend that some preliminary tests be undertaken using this formula in conjunction with the calibrated Consumer Response Model before settling on the values for the base case. We wish to allow for the possibility that the formula fails to perform satisfactorily by including scenarios in which the deployment of non-domestic charge points is pre-specified for all years. We suggest that five different levels of pre-specified deployment should be tested alongside the formula-based method, as follows:

- H = High level of deployment (the 2009 installation is 200,000 for workplace CPs and 40,000 for each other type of CP, these initial installations then increase by 10,000 p.a. for each type of CP)
- M = Medium level of deployment (the 2009 installation is 100,000 for workplace CPs and 20,000 for each other type of CP, these initial installations then increase by 5,000 p.a. for each type of CP)
- L = Low level of deployment (the 2009 installation is 50,000 for workplace CPs and 10,000 for each other type of CP, these initial installations then increase by 2,500 p.a. for each type of CP)
- VL = Very low level of deployment (the 2009 installation is 10,000 for workplace CPs and 2,000 for each other type of CP, these initial installations then increase by 500 p.a. for each type of CP)
- Z = There are none deployed
- F = Formula-based deployment between 2014 and 2050 (as per Appendix B4.1).

Note that, when deployment is fixed (values H, M and L) it will be assumed that the government agree to meet any shortfall in profits required to meet a normal Rate of return on investment (see previous page).

Values for the High, Medium and Low levels of pre-specified deployment may be revised in the light of evidence from early runs of the Consumer Response Model.

4.6.2.3 Estimation of Perceived Access to Non-domestic Charge Points

Having predicted the number of charge points that are likely to be deployed, it is now necessary to consider the effect that this has on perceived access to charge points (this being required as an input to the purchase decisions and recharge behaviour assumptions used in the Consumer Response model). A formula for this calculation was devised by SP3 and detailed in previous versions of this report.

However, Element Energy, the developers of the CRM subsequently proposed an alternative formulation which made fuller use of the "value of access" which they had estimated from the consumer surveys. Their formulation has now been tested and is shown in Appendix B4.2.

4.6.3 Power drawn from Charge Points

The assumed power that will be drawn from charge points is shown in Table 10. This describes the migration of all charge points towards higher power solutions between 2010 and 2050. The power shown in the table is assumed to be the minimum of the power that can be supplied by the point, and the power that can be accepted by the vehicle.

	Power output					
	2010	**2015**	**2020**	**2030**	**2040**	**2050**
Domestic outlets	3kW	3kW	7kW	7kW	7kW	7kW
Workplace car parks	3kW	3kW	7kW	7kW	7kW	7kW
Points installed by retail outlets	3kW *	3kW & 7kW **	7kW	7kW	7kW	7kW
Commercial points installed on streets	3kW *	3kW & 7kW **	7kW	7kW	7kW	7kW
Commercial points installed in public car parks	3kW *	3kW & 7kW **	7kW	7kW	7kW	7kW
Rapid charge points	50kW AC/DC	50kW AC/DC	50kW AC/DC	50kW AC/DC	50kW AC/DC	50kW AC/DC
* At present, there aren't any vehicles that can charge at 240V, 32A = 7kW, even if the charge posts allow it.						
** We expect that all charge points by 2015 will have 7kW charging capability, but not all vehicles will be able to use that power - many will still charge at 3kW. In overall terms, an assumption that all public charging is at 3kW in 2010, 7kW in 2020, and increases linearly between would be a reasonable representation.						

Table 10 Power drawn from Charge Points

4.6.4 Tests Related to the Supply of Charge Points

Table 11 indicates the tests required. Note that tests of the effect of different required rates of return on capital, different assumptions about the designation of regulated assets, the cost of regulated assets, values for Government grants and subsidies, the treatment of shortfalls and the likely levels of utilisation are already included within the "EP" tests in Table 8.

Code	Domestic avail	Non-domestic				
		Level of fixed deployment	Initial install	Gov't meet shortfall	Max Utilisation	Level of service co-eff
CP1	H					
CP2	L					
CP3		H		G		
CP4		M		G		
CP5		L		G		
CP6			H			
CP7			L			
CP8				G		H
CP9[9]					H	
CP10[9]					L	
CP11				G		
CP12				G		VH
CP13		VL		G		
CP14		Z		G		
T1 (max fav) to PiV sales	H		H	G	H	H
T2 (min fav) to PiV sales	L		L		L	

Table 11 Tests relating to supply of Charge Points

Note

Note that T3, T8 and T12 are as T1 while T4 is as T2

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[9] Section 4.7.6 Sensitivity of Purchase Decisions to the Availability of Public Charge Points describes the ‘Maximum Utilisation’ tests, and how this affects the deployment of charge points

4.7 Consumer Behaviour

The forecasts of PiV uptake, their use and the consequential impact on emissions requires predictions of behavioural response to the availability, price and characteristics of PiVs and of the way in which PiVs are used and recharged. Consumer behaviour will be predicted within the Consumer Response Model. However, given the absence of observed data at this stage in the work, many of these predictions have to be based on assumptions rather than hard evidence. (See Appendix C for further discussion of the limitations which necessarily affect the consumer response modelling at this stage in the work).

We have identified the following as key unknowns where some assumptions have to be made and where some sensitivity testing is necessary:

1. Vehicle segment preference
2. Private individuals as a proportion of new car purchasers
3. Sensitivity of purchase decisions to the underlying acceptance of the idea of PiVs
4. Sensitivity of purchase decisions to limited range
5. Sensitivity of purchase decisions to showroom price
6. Sensitivity of purchase decisions to the availability of public charge points
7. Sensitivity of car use patterns to cost of car use
8. Recharge behaviour patterns
9. Recharge behaviour – response to price

Each of these will now be considered. It should be noted that the scenarios specified in this section have been developed in the light of the expected form and structure of the Consumer Response Model. That model is still under development and final decisions on some key details (such as the number of consumer groups to be identified) await the results of the analysis of the consumer response surveys. It is possible, therefore, that some of the disaggregation which we envisage in the scenarios described below may not be implemented in the final model.

4.7.1 Vehicle Segment Preference

This is included because it could have a significant impact on the overall carbon emissions of ICEs – and would mitigate, or complement, what is achieved by a switch to PiVs.

- B – As now (current shares – based on an average of recent years – is maintained through to 2050)
- SM – Increased preference for smaller vehicles ("downsizing"[10])
- L – Increased preference for larger vehicles ("upsizing"[11])

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[10] Extent of upsizing has been estimated by Element Energy

[11] Extent of downsizing has been estimated by Element Energy

Note that any change in preferences for different segments does not itself affect the ratio of private individuals among buyers of new cars.

4.7.2 Private Buyers as a Proportion of Total New Car Purchasers

This is included because it is anticipated that fleet and business purchasers are likely to respond to the availability of PiVs differently to private purchasers. This difference is due to the different tax regimes, recharging practicalities, attitude to costs and to the public relations aspects of owning PiVs.

Private purchasers currently account for 42% of new car sales (Department for Transport (2009), *Vehicle Licensing Statistics 2009*). We propose two scenarios:

- C – current share (42%) is maintained through to 2050
- HP – current share increases to 52% by 2020 and remains at that level through to 2050

4.7.3 Sensitivity of Purchase Decisions to the Underlying Acceptance of the Idea of PiVs

Given the novelty of the PiV concept it is inevitable that responses to the stated preference (SP) questions will reflect some prejudice and misunderstandings about the very idea of PiVs. Data from the SP surveys is to be used to estimate discrete choice logit models. We understand that these models will include alternative-specific constants (ASCs) which should capture any underlying preference for or against PiVs which are not explained by measurable characteristics such as range or price.

We propose to test the sensitivity of the forecasts to the underlying attitudes towards PiVs for example by varying these ASCs. We propose four tests:

- B = that ASC values remain as calibrated on survey data
- H = that ASCs are 50% higher (more disutility)
- L = that ASCs are 50% lower (less disutility)
- S = that ASCs decline as a function of PiV sales to date (e.g. decline from calibrated value to zero as PiV parc grows to match ICE parc)

The precise definition of these variants, and possibility of having a familiarity feedback, must await final estimation of the discrete choice model (e.g. if the ASCs turned out to reflect utility rather than disutility then H, L and S would need to be modified).

4.7.4 Sensitivity of Purchase Decisions to Limited Range

The discrete choice models are expected to result in coefficients which reflect the sensitivity to the (limited) range of PiVs. We think it important to test the sensitivity of the forecast to this coefficient. We therefore propose three tests:

- B = that sensitivity to restricted range remains as calibrated on survey data

- H = assume coefficient is 50% higher (more sensitive to restricted range)
- L = assume coefficient is 50% lower (less sensitive to restricted range)

The precise definition of these variants must await final estimation of the discrete choice model – if range is not found to be a significant determinant of response then this test might be omitted.

4.7.5 Sensitivity of Purchase Decisions to Showroom Price

The discrete choice models are expected to result in coefficients which reflect the sensitivity to the (high) showroom price of PiVs (including the battery). We think it important to test the sensitivity of the forecast to this coefficient. We therefore propose three tests:

- B = that sensitivity to price remains as calibrated on survey data
- H = assume coefficient is 50% higher (more sensitive to price)
- L = assume coefficient is 50% lower (less sensitive to price)

The precise definition of these variants must await final estimation of the discrete choice model – if showroom price is not found to be a significant determinant of response then this test might be omitted.

4.7.6 Sensitivity of Purchase Decisions to the Availability of Public Charge Points

If the consumer surveys indicate that purchase decisions are sensitive to assumptions about the individual's propensity to public charge points this could have important and obvious policy implications. We therefore propose to explore the effect of varying this sensitivity via three tests:

- B = base assumption, i.e. that parameters are as calibrated on survey data
- H = assume that responsiveness of those who assume highest level of availability is true of all potential purchasers
- L = assume that responsiveness of those who assume lowest level of availability is true of all potential purchasers

The precise definition of these variants must await final estimation of the discrete choice model – if access to public charge points is not found to be a significant determinant of response then this test might be omitted.

A further factor affecting the sensitivity of purchase decisions to the availability of public charge points is the assumption made about the purchasers' perception of that availability. The Consumer response model has an algorithm (described in Appendix B4.2) to represent this. One of the key inputs to this algorithm is the maximum utilisation (MU) of charge points beyond which they are deemed to be effectively unavailable. Values for this coefficient were based on the likely occupancy of charge points given the charge rate, the likely incidence of charging over a 24 hour period and the logistics of parking and unparking. We propose to test three values for this:

- H - high value of MU = 70kWh/day (standard) 500 kWh/day (rapid)
- M – Medium value of MU = 42kWh/day (standard) 300 kWh/day (rapid)

- L – Low value of MU = 21kWh/day (standard) 150 kWh/day (rapid)

4.7.7 Sensitivity of Car Use Patterns to the Cost of Car Use

There is widespread evidence to show that the volume of car use (e.g. VKT/car) is sensitive to the real costs of car use. An elasticity of -0.26 is generally recognised[12]. Exclusion of this effect from the Consumer Response Model would tend to result in an underestimate of kilometres travelled per PiV and hence to an over estimate of the emissions reduction (and an underestimation of electricity consumption) associated with an increase in the PiVs' market share.

The overall effect of changes in the relative costs of using ICEs and PiVs is, of course, very complex and beyond the agreed scope of the Consumer Response Model. However, we suggest that the true effect might be approximated by applying a simple elasticity formula to adjust the assumed annual and daily VKT per car as a function of changes in the cost per km of that car. Note that we attenuate the effect of the elasticity (using the ratio of costs raised to the power 0.2) to allow for the fact that the strength of the elasticity effect will rise (fall) as the cost of vehicle use becomes a greater (lesser) proportion of overall expenditure. Note also that, following the logic introduced in Section 4.2.3, the elasticity of -0.26 will need to be deflated to allow for increase in GDP per capita and that, following the logic introduced in Section 4.2.2, the underlying VKT per car will need to be adjusted to reflect changes in UK GDP.

The equation in Appendix B5.2 indicates how this effect should be operationalised.

We propose to test the implications of different assumptions by running a test in which the elasticity effect is ignored entirely. Thus we have two tests as follows:

- I = ignore the elasticity effect for all classes of vehicles
- E = apply an elasticity of -0.26 to the VKT/car of all vehicles

It should be noted that, since the elasticity effect will change the distance driven, it will also affect the amount of electricity required for recharging and, via the distance-related running costs, the perceived costs of ownership.

4.7.8 Patterns of Recharging Behaviour

There is not yet any data to consult on this issue but some assumptions have to be made in order to generate predictions of charge point use (and, indirectly, of network reinforcement costs). Best-guess assumptions have therefore been made for the percentage of recharging which will occur at different types of location and charge point at different times of day.

Behaviour is assumed to depend on:

- availability of charging points of different types (domestic, free workplace, charged workplace, free retail, charged retail, normal speed public, rapid speed public)
- the nature of trip destination (home / work / other)

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[12] Graham, D J and Glaister, S (2004), Road Traffic Demand Elasticity Estimates: A Review. Transport Reviews, vol 24, no.3, May 2004, pages 261-274.

- whether it is the last trip of the day (y/n)
- type of PiV (BEV / PHEV / Range Extended Electric Vehicle (REEV))
- Whether the car is privately owned or company owned (or more precisely, whether they are used as private vehicles)

4.7.8.1 Recharging Behaviour Patterns for Privately Owned Cars

There is, as yet, no reliable data on the recharge patterns of PiV users. We therefore have to make some assumptions. We have based these assumptions on discussions with current users and potential users but they cannot be said to be more than educated guesses. Four scenarios are to be tested:

- B = Base assumptions (see Table 12)
- LD = Base assumptions modified to have lower percentage charging at home (see Table 13)
- FWR = Base assumptions modified to show effect of having access to free electricity via workplace and at retail charge points (see Table 14)
- PR = Base assumptions modified to reflect non-availability of normal speed public charge points (see Table 15)

Scenario LD is included because it has been suggested that our base assumptions may show too high a proportion of recharge events occurring at home.

Scenario FWR is included because it has been suggested that employers and retailers might use the offer of free electricity as an incentive for their employees and customers.

Scenario PR is included because it has been suggested that the only commercially viable role for public charge points will be for rapid recharge (and that, consequentially, all public charge points will be rapid).

Percentage of Recharge Performed at Different Times and Locations												
Access to charge points at home and at workplace?	Type of trip	Charge at end of trip at:								Delay until end of day, then charge at:		
		Domestic	Workplace free	Workplace charged	On-street	Car park	Retail free	Retail charged	Rapid	Domestic	On-street	Car park
Domestic, work, retail and public	Homebound	50	■				■			50		
	Workbound		■	70			■			30		
	Other		■	12*	12	12	■	14		50		
Domestic, and work only	Homebound	50	■		■	■	■	■	■	50	■	■
	Workbound		■	70	■	■	■	■	■	30	■	■
	Other		■	50*	■	■	■	■	■	50	■	■
Domestic public and retail only	Homebound	50	■	■			■			50		
	Workbound		■	■	5	5	■			90		
	Other		■	■	4	4	■	2		90		
Domestic only	Homebound	50	■	■	■	■	■	■	■	50	■	■
	Workbound		■	■	■	■	■	■	■	100	■	■
	Other	10	■	■	■	■	■	■	■	90	■	■
Work public and retail only	Homebound	■	■	80*	5	5	■			■	6	4
	Workbound	■	■	100			■			■		
	Other	■	■	70*	7	7	■	5	1	■	6	4
Work only	Homebound	■	■	100*	■	■	■	■	■	■	■	■
	Workbound	■	■	100	■	■	■	■	■	■	■	■
	Other	■	■	100*	■	■	■	■	■	■	■	■
Public and retail only	Homebound	■	■	■	29	20	■		2	■	29	20
	Workbound	■	■	■	35	53	■		2	■	6	4
	Other	■	■	■	28	38	■	20	4	■	6	4

Table 12 Base case assumptions about recharge behaviour for private cars

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for “homebound” and “other” trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to end of trip, on-street)

Percentage of Recharge Performed at Different Times and Locations												
Access to charge points at home and at workplace?	Type of trip	Charge at end of trip at:								Delay until end of day, then charge at:		
		Domestic	Workplace free	Workplace charged	On-street	Car park	Retail free	Retail charged	Rapid	Domestic	On-street	Car park
Domestic, work, retail and public	Homebound	50	■				■			50		
	Workbound		■	75	4	4	■	2		15		
	Other		■	18*	18	18	■	20	1	25		
Domestic, and work only	Homebound	50	■		■	■	■	■	■	50	■	■
	Workbound		■	85	■	■	■	■	■	15	■	■
	Other		■	75*	■	■	■	■	■	25	■	■
Domestic public and retail only	Homebound	50	■	■			■			50		
	Workbound		■	■	25	25	■	4	1	45		
	Other		■	■	25	25	■	4	1	45		
Domestic only	Homebound	50	■	■	■	■	■	■	■	50	■	■
	Workbound		■	■	■	■	■	■	■	100	■	■
	Other	10*	■	■	■	■	■	■	■	90	■	■
Work public and retail only	Homebound	■	■	80*	5	5	■			■	6	4
	Workbound	■	■	100			■			■		
	Other	■	■	70*	7	7	■	5	1	■	6	4
Work only	Homebound	■	■	100*	■	■	■	■	■	■	■	■
	Workbound	■	■	100	■	■	■	■	■	■	■	■
	Other	■	■	100*	■	■	■	■	■	■	■	■
Public and retail only	Homebound	■	■	■	29	20	■		2	■	29	20
	Workbound	■	■	■	35	53	■		2	■	6	4
	Other	■	■	■	28	38	■	20	4	■	6	4

Table 13 Assumed recharge behaviour for private cars if lower proportion charge at home

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for “homebound” and “other” trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to end of trip, on-street)

Percentage of Recharge Performed at Different Times and Locations												
Access to charge points at home and at workplace?	Type of trip	Charge at end of trip at:								Delay until end of day, then charge at:		
		Domestic	Workplace free	Workplace charged	On-street	Car park	Retail free	Retail charged	Rapid	Domestic	On-street	Car park
Domestic, work, retail and public	Homebound	5	90*	▨				▨		5		
	Workbound		100	▨				▨				
	Other		75*	▨	3	2	10	▨		10		
Domestic, and work only	Homebound	5	90*	▨	▨	▨		▨	▨	5	▨	▨
	Workbound		100	▨	▨	▨		▨	▨		▨	▨
	Other	5	80*	▨	▨	▨		▨	▨	15	▨	▨
Domestic public and retail only	Homebound	30		▨			40*	▨		30		
	Workbound			▨	2	3	15*	▨		80		
	Other			▨	3	2	50*	▨		45		
Domestic only	Homebound	50	▨	▨	▨	▨	▨	▨	▨	50	▨	▨
	Workbound		▨	▨	▨	▨	▨	▨	▨	100	▨	▨
	Other	10	▨	▨	▨	▨	▨	▨	▨	90	▨	▨
Work public and retail only	Homebound	▨	75*	▨	3	2	20*	▨		▨		
	Workbound	▨	100	▨				▨		▨		
	Other	▨	80*	▨	5	2	3	▨	1	▨	5	4
Work only	Homebound	▨	100*	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Workbound	▨	100	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Other	▨	100*	▨	▨	▨	▨	▨	▨	▨	▨	▨
Public and retail only	Homebound	▨	▨	▨	20	10	25*	▨	1	▨	24	20
	Workbound	▨	▨	▨	15	30	25*	▨	1	▨	19	10
	Other	▨	▨	▨	20	10	55*	▨	3	▨	7	5

Table 14 Assumed recharge behaviour for private cars if free workplace and free retail exist

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for "homebound" and "other" trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to end of trip, on-street).

Percentage of Recharge Performed at Different Times and Locations													
Access to charge points at home and at workplace?	Type of trip	Charge at end of trip at:								Delay until end of day, then charge at:			
		Domestic	Workplace free	Workplace charged	On-street	Car park	Retail free	Retail charged	Rapid	Domestic	On-street	Car park	rapid
Domestic, work, retail and public	Homebound	50	■		■	■	■			50	■	■	
	Workbound		■	70	■	■	■			30	■	■	
	Other		■	20*	■	■	■	15	10	50	■	■	5
Domestic, and work only	Homebound	50	■		■	■	■	■	■	50	■	■	■
	Workbound		■	70	■	■	■	■	■	30	■	■	■
	Other		■	50*	■	■	■	■	■	50	■	■	■
Domestic, retail and public only	Homebound	50	■	■	■	■	■			50	■	■	
	Workbound		■	■	■	■	■	3	2	95	■	■	
	Other		■	■	■	■	■	5	3	90	■	■	2
Domestic only	Homebound	50	■	■	■	■	■	■	■	50	■	■	■
	Workbound		■	■	■	■	■	■	■	100	■	■	■
	Other	10	■	■	■	■	■	■	■	90	■	■	■
Work , retail and public only	Homebound	■	■	95*	■	■	■	2	1	■	■	■	2
	Workbound	■	■	100	■	■	■			■	■	■	
	Other	■	■	70*	■	■	■	15	10	■	■	■	5
Work only	Homebound	■	■	100*	■	■	■	■	■	■	■	■	■
	Workbound	■	■	100	■	■	■	■	■	■	■	■	■
	Other	■	■	100*	■	■	■	■	■	■	■	■	■
Public and retail only	Homebound	■	■	■	■	■	■	40	30	■	■	■	30
	Workbound	■	■	■	■	■	■	45	33	■	■	■	22
	Other	■	■	■	■	■	■	50	25	■	■	■	25

Table 15 Assumed recharge behaviour for private cars if all public charge points are rapid

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for "homebound" and "other" trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to domestic, or if domestic is unavailable, to workplace and if neither domestic nor workplace is available, to retail).

4.7.8.2 Recharge Behaviour Patterns for Company-Owned Cars

As in the case of privately owned cars, there is not yet any reliable data on recharge patterns for company owned cars and some assumptions have to be made. We have adapted our assumptions for privately owned cars to include a higher proportion of charging at workplaces. Two scenarios are envisaged:

- B = Base: (see Table 16)
- PR = Base assumptions modified to reflect non-availability of normal speed public charge points (see Table 17)

Scenario PR is included because it has been suggested that the only commercially viable role for public charge points will be for rapid recharge (and that, consequentially, all public charge points will be rapid).

to charge points	Type of trip	Charge at end of trip						Delay until end of day, then charge at:		
		Domestic	Workplace free	On-street	Car park	Retail	Rapid	Domestic	On-street	Car park
Domestic, work, retail and public	Homebound	5	90*					5		
	Workbound		100							
	Other		75*	5	2	2	1	15		
Domestic and work	Homebound	5	90*	■	■	■	■	5	■	■
	Workbound		100	■	■	■	■		■	■
	Other		85*	■	■	■	■	15	■	■
Work, public and retail	Homebound	■	95*					■	5	
	Workbound	■	100					■		
	Other	■	85*	5	2	2	1	■	5	
Work only	Homebound	■	100*	■	■	■	■	■	■	■
	Workbound	■	100	■	■	■	■	■	■	■
	Other	■	100*	■	■	■	■	■	■	■

Table 16 Base case assumptions for recharge behaviour for company-owned cars

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for “homebound” and “other” trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to end of trip, on-street).

to charge points	Type of trip	Charge at end of trip						Delay until end of day, then charge at:			
		Domestic	Workplace free	On-street	Car park	Retail	Rapid	Domestic	On-street	Car park	rapid
Domestic, work, retail and public	Homebound	5	90*	■	■			5	■	■	
	Workbound		100	■	■				■	■	
	Other		80*	■	■	3	2	15	■	■	
Domestic and work	Homebound	5	90*	■	■	■	■	5	■	■	■
	Workbound		100	■	■	■	■		■	■	■
	Other		85*	■	■	■	■	15	■	■	■
Work, public and retail	Homebound	■	97*	■	■	1	1	■	■	■	1
	Workbound	■	100	■	■			■	■	■	
	Other	■	90*	■	■	6	2	■	■	■	2
Work only	Homebound	■	100*	■	■	■	■	■	■	■	■
	Workbound	■	100	■	■	■	■	■	■	■	■
	Other	■	100*	■	■	■	■	■	■	■	■

Table 17 Assumptions for recharge behaviour for company-owned cars if all public charge points are rapid

Notes:

- Asterisked figures assume wait until next visit to this type of location
- All figures relate to weekday patterns. Weekend values are similar but it is assumed that workplace charging is not available (except for workbound trips) and so values shown in the workplace column for "homebound" and "other" trips should be reallocated to other columns pro-rata.
- Rapid charge not used by PHEVs or REEVs (% shown as rapid is, for PHEVs and REEVs, re-allocated to end of trip, workplace)

4.7.9 Recharge Behaviour – Response to Price

It is likely that recharge behaviour would change if the prices charged at different types of charge point, or at different times of day, were very different. Unfortunately, there is not yet any data on which to base any such changes in behaviour and the consumer response model has, accordingly, not been designed to redistribute demand for recharging in response to price.

The absence of such a model leaves two issues to be considered; the potential response to discounts for charging off peak and the potential response to high premiums on the use of public charge points.

4.7.9.1 Recharge Behaviour – Response to Low Off-Peak Tariff

To understand the effects on the electricity grid, it is necessary to know whether the charging performed at the end of the day takes place as soon as the vehicle is plugged in, or whether it is delayed until the off-peak period during the night. Two scenarios are considered:

- B = Yes, end-of-day charging is delayed until off-peak
- ND = No it isn't delayed

Note the decision to charge during the off peak period might be related to concerns other than price. E.g. Environmental concerns.

4.7.9.2 Recharge Behaviour – Maximum Premium for Non-domestic Charging Points

The algorithm used to determine the price premium of non-domestic charge points (see Appendix B3.2) is very sensitive to the price premium that can be charged at public charge points. In practice, of course, the presence of a high premium would dissuade people from using such charge points. In the absence of a model to effect a redistribution of usage patterns it is possible that, when PEPMAX is set to a high value, the patterns of recharging would not be credible. It is assumed that consumers, particularly those driving PHEVs and RE-EVs, would actually consider the relative costs of recharging and of using conventional fuels and that this would effectively constrain the maximum price that could be levied for electricity via non-domestic charge points. This constraint is achieved via a factor (MaxPEPFactor) which indicates the maximum multiple of the cost of a given mileage using a typical petrol engine that consumers would be willing to pay. We propose to test three values of MaxPEPfactor:

- H – "High MaxPEPfactor = 1.5
- M – "Medium MaxPEPfactor = 1.0
- L– "Low MaxPEPfactor = 0.5

4.7.10 Tests Related to Consumer Behaviour

The required tests are set out in Table 18 (note that tests for the value of MaxPEPFactor have been included in Table 8 along with tests of other variables affecting the electricity price).

Code	Segment Preference	Proportion Private	Purchase sensitivity to				Use sensitivity	Recharge behaviour		
			PIV idea	Range	Price	CP avlblty		Patterns	Company patterns	Off peak
CB1	SM									
CB2	L									
CB3		HP								
CB4			H							
CB5			L							
CB6			S							
CB7				H						
CB8				L						
CB9					H					
CB10					L					
CB11						H				
CB12						L				
CB13							I			
CB14								LD		
EP11[13]								FWR		
CB15								PR	PR	
CB16										ND
T1 (max fav)	SM		L	L	L	L	I	FWR		
T2 (min fav)	L	HP	H	H	H	H		PR	PR	ND

Table 18 Tests related to Consumer Behaviour

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[13] Please note that the sensitivity EP11 tests the effect of 'free' electricity provided by work and retail.
Note that T3, T8 and T12 are as T1 while T4 is as T2 but that these values will be reassessed after the sensitivity tests.

4.8 Government Policy

It is assumed that policy on taxation, subsidies and regulation will affect the market for PiVs in various ways. Twelve policy levers have been identified as particularly important and, by varying their assumed levels, their effect on the sales and use of PiVs and on associated emissions, can be explored.

The twelve levers are:

1. Subsidy on purchase of PiVs
2. Tax treatment of PiV purchases by companies
3. Tax treatment of PiVs as company cars
4. VAT
5. Taxes on vehicle purchase and ownership
6. Fuel Tax
7. Revenue Preserving Tax (New tax designed to make up any reduction in revenue from fuel tax)
8. Congestion Charges
9. Definition of regulated assets in electricity supply
10. Incentives or subsidies to support installation of public charge points
11. Average fleet emissions regulations
12. Influencing the price of carbon credits

4.8.1 Subsidy on Purchase of PiVs

These would be designed to stimulate the market for PiVs until it has become sustainable. The level of this subsidy will affect the showroom price of vehicles on offer. We propose six levels:

- B = as announced (maximum of £5k or 25%, subject to a budget cap of £43m, until March 2012)
- Z = zero (not introduced at all – test shows the effect of the subsidy)
- H3 = as announced but uncapped and extended for a further three years (until 2015)
- H5 = as announced but uncapped and extended for a further five years (until 2017)
- H10 = as announced but uncapped and extended for a further ten years (until 2022)
- H10B = as announced but uncapped and extended for a further ten years (until 2022) but beyond 2015 subsidy is only available for BEVs

4.8.2 Tax Treatment of PiV Purchases by Companies - Favourable Terms on Capital Allowances for PiVs

The December 2009 statement to Parliament states that companies can (until 2013) write down the capital cost of new PiVs against tax in the first year[14]. This influences the total cost of ownership of new fleet vehicles and should therefore be reflected in the showroom price of vehicles on offer to fleet buyers. We propose two values:

- B = (base as now) until 2013 first year capital allowance advantage is available on cars emitting no more than 110g/km, beyond 2013 only on cars emitting no more than 95g/km
- S = (Stringent) as above until 2013 but, beyond 2013 the first year capital allowance advantage is only available on cars emitting no more than 42g/km

4.8.3 Tax Treatment of PiVs as Company Cars

Company car tax is based on CO2 emissions. This reduces the income tax payable by employees. We argue that it also effectively changes the cost to employers because, if the value of the employee parc goes up, the employer can take this into account in deciding on other elements of the remuneration package. In addition, the purchase decision is often made by the employee. We therefore argue that this should be taken into account in determining the cost of fleet cars and so be reflected in the showroom price of vehicles on offer to fleet buyers. We propose two values:

- A= as now (i.e. with low tax liability for PiVs)[15]

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[14] This only affects cars purchased, or on hire purchase. Leased cars get no favourable treatment. The capital allowance is equivalent to a discount on the purchase price of approximately ROR/2. The enhanced capital allowance is available until 2012-13. (ROR is defined in Section 4.1.7).

[15] A simplified set of taxes will be used with zero tailpipe emission (TE) vehicles remaining exempt. It is assumed that future tax changes will follow the reduction in fleet average CO2 emissions. Tax liabilities should be linearly interpolated in years between those specified below.

Tailpipe emissions gCO2/km (TE)	Percentage tax liability		
	2010	2020	2050
0	0	0	0
1 - 20	5	5	5
21 - 35	5	5	TE/2.5 - 3
36 - 75	5	TE/5 - 2	TE/2.5 - 3
76 - 95	10	TE/5 - 2	TE/2.5 - 3
96 - 185	TE/5 - 9	TE/5 - 2	35
186 - 220	TE/5 - 9	35	35
220 upwards	35	35	35

The effect on annual costs to employee/employer should be calculated as follows (and assumes that employees' marginal rate of tax is 40%):

Annual cost = 0.4 x *Purchase price of vehicle* x *Percentage tax liability*

- E = as above for 2010 to 2020, but extended to cover all vehicles (based on WTW CO2eq) after 2020 [16]

4.8.4 Value Added Tax (VAT)

The rate of Value Added Tax affects Government Revenues and so needs to be considered in the economic accounting model.

The VAT rate might also affect behaviour of individual purchasers via its effect on the price of new vehicles, the price of fuels and, indirectly, the cost of recharging at public charge points (via its influence on the costs of electricity at charge points). It should therefore be reflected in the showroom price of vehicles on offer, the consumer electricity price, any additional premium on electricity drawn from non-domestic charge points and any ICE fuels.

If the full rate of VAT were to be charged on electricity, the relative attractiveness of PiVs over conventionally-fuelled vehicles would decline. We propose two values:

- B = 20% (but 5% on domestic electricity) i.e. position from January 1st 2011
- E = 20% on everything including electricity

4.8.5 Taxes on Vehicle Purchase and Ownership

Currently, Vehicle Excise Duty (VED) is based on tailpipe emissions of CO2 and is charged at a special (high) rate in the first year. VED thus favours PiVs relative to conventionally-fuelled vehicles (part of the justification for the introduction of the higher first year rate was that it would help focus the purchaser's mind on the benefits of choosing a low emission vehicle). Levels of taxes on vehicle purchase and ownership should, of course, be reflected in the showroom of vehicles on offer.

We envisage that the relative attractiveness of PiVs over conventionally fuelled vehicles might be adjusted via these taxes and we propose four values:

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[16] Proposed tax treatment of company car WTW emissions from 2020

Well to wheel emissions gCO2/km (WTW)	Percentage tax liability	
	2020	2050
0 - 24	5	5
25 - 42	5	WTW/3 - 3
43 - 85	WTW/6 - 2	WTW/3 - 3
86 - 114	WTW/6 - 2	WTW/3 - 3
115 - 222	WTW/6 - 2	35
223 - 255	35	35
255 upwards	35	35

The effect on annual costs to employee/employer should be calculated as follows (and assumes that employees' marginal rate of tax is 40%):

Annual cost = 0.4 x *Purchase price of vehicle* x *Percentage tax liability*

- Z = zero (might be part of policy to switch taxes from car ownership to car use)
- M = as now - see Table 19 for values
- H = double current values (might be designed to raise revenue or further favour low emission vehicles)
- W = revised to be proportional to well-to-wheel emissions (and hence include electricity generation emissions - see Table 19 for values

				VED rates for Scenario M		VED rates for Scenario W	
Band	**CO2 emissions (g/km)**			**Duty for year of purchase**	**Duty for subsequent years**	**Duty for year of purchase**	**Duty for subsequent years**
	Band Limits in Year						
	2010	**2020**	**2050**	12 months rate		12 months rate	
A	Up to 100	Up to 60	Up to 35	£0.00	£0.00	£0.00	£0.00
B	101-110	61-70	36-40	£0.00	£20.00	£0.00	£20.00
C	111-120	71-80	41-46	£0.00	£30.00	£0.00	£25.00
D	121-130	81-90	46-50	£0.00	£90.00	£0.00	£80.00
E	131-140	91-100	51-55	£110.00	£110.00	£100.00	£100.00
F	141-150	101-110	56-60	£125.00	£125.00	£110.00	£115.00
G	151-165	111-125	61-70	£155.00	£155.00	£140.00	£140.00
H	166-175	126-135	71-75	£250.00	£180.00	£225.00	£165.00
I	176-185	136-145	76-80	£300.00	£200.00	£270.00	£180.00
J	186-200	146-160	81-85	£425.00	£235.00	£385.00	£215.00
K*	201-225	161-185	86-95	£550.00	£245.00	£500.00	£220.00
L	226-255	186-210	96-110	£750.00	£425.00	£680.00	£385.00
M	Over 255	Over 210	Over 110	£950.00	£435.00	£865.00	£395.00
For duty over £10 per annum, £10 discount is given for alternative fuel vehicles between 2010 and 2019. Assumed abolished in 2020.							
VED rates to be linearly interpolated between years 2010, 2020 and 2050 as appropriate.							

Table 19 Taxes on Vehicle Purchase and Ownership

4.8.6 Fuel Tax

Fuel taxes affect the price of vehicle use and need to be calculated to help determine the costs of vehicle use registered in the showroom of vehicles on offer. We assume that it would be impractical to apply a tax on the use of electricity in vehicles because there would be no easy way to prevent people from drawing their supply from a standard outlet[17]. We do, however, envisage the possibility that taxes on other fuels might be increased. We propose four values:

- L = fuel taxes at half current rate (test to show effect of what would undoubtedly be a politically popular move)
- B = fuel taxes as now/announced (i.e. with low rate for biofuels removed in 2011) – see Table 20 for values

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[17] Adoption of standards / specifications for EV sockets with Level 2 or Level 3 designs will make this harder but by no means impossible.

- H = fuel taxes at double current values (part of policy to switch taxes from ownership onto use)
- C = existing fuel taxes remain as now but all fuels currently not taxed (except electricity) would be taxed proportionately in line with their relative contribution to WTW CO2eq - – see Table 20 for values

Fuel taxes in 2010 economics	For Scenario B and C					Scenario B	Scenario C
Summary	**2010**	**2011**	**2012**	**2013**	**2014**	**2015 - 2050**	**2015 -2050**
Petrol (p/litre)	57.19	59.95	60.95	61.95	62.95	62.95	62.95
Diesel (p/litre)	57.19	59.95	60.95	61.95	62.95	62.95	62.95
Bioethanol (p/litre)	57.19	59.95	60.95	61.95	62.95	62.95	62.95
Biodiesel (p/litre)	57.19	59.95	60.95	61.95	62.95	62.95	62.95
LPG (p/kg)	30.53	35.89	38.74	41.59	44.45	44.45	44.45
CNG (p/kg)	23.60	27.68	29.21	30.73	32.26	32.26	32.26
Hydrogen (p/kg)	0.00	0.00	0.00	0.00	0.00	0.00	17.75
Electricity (p/kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 20 Fuel tax rates

Note that any changes already announced by HRMC will apply up to 2014. The scenario changes in the rate of fuel tax will be introduced as a gradual (linear) change from current values starting in 2015 and completed by 2020 - then remaining at the new level through to 2050.

4.8.7 Revenue Preserving Tax

If vehicles using untaxed fuels take a significantly higher share of the overall market there will be a serious reduction in revenue from fuel duty. We have assumed that this would lead Government to seek a mechanism for raising an equivalent sum via some other charge. Any decision on a tax of this kind would, of course, need to be calculated to help determine the costs of vehicle use registered in the "showroom" of vehicles on offer.

One possibility for this tax would be a per-kilometre charge applied to all vehicles (this might simply be collected annually on the basis of the odometer reading). Another might be a fixed tax on vehicle ownership. In either case, the value of the tax would need to be calculated in the light of reductions in the fuel consumed (and hence tax paid) by conventionally fuelled vehicles relative to a base level.

We propose that that it has three values:

- YO = revenue-preserving charge is introduced in 2011 as an annual charge per vehicle [*Taxpervehicle in year t = (fuel tax revenue in 2010 - fuel tax revenue in year t-1) / vehicle parc in year t-1*]
- N = No such charge introduced
- YU = revenue-preserving charge is introduced in 2011 and is based on kilometres travelled during the year [*charge per km in year t = (fuel tax revenue in 2010 - fuel tax revenue in year t-1) / (total kms in year t-1)*]

4.8.8 Congestion Charges

Congestion charging is in place in London and is periodically mooted for introduction more widely in order to combat congestion and raise revenue. Any such charges will obviously need to be taken into account when determining the costs of vehicle use registered in the showroom of vehicles on offer. We propose three values:

- AN = as now (London only, £10 per day (£8 in 2010, £10 from 4th January 2011) with discount for residents and, until 2014, exemptions for PIVs and any vehicle emitting less than 100g per km)
- E = as now until 2014 but exemptions for low emitting vehicles continue beyond 2015 – albeit at increasingly lower levels[18]
- EUK = as now until 2014 but from 2015 onwards applied in all major cities (with exemptions as described for case "E").

Where congestion charges apply, the following additional costs are assumed to apply:

- In the showroom: purchasers of cars for Private, "Perk" or "Workhorse" use see an increased annual running cost of 365-104 weekend days - 5weeks off = 236 days x £10 = £2,360 (£8 x 236 in 2010), while purchasers of cars for "depot" use see annual running costs increased by 236 days x £9 = £2,124 (£7x 236 in 2010)
- In the usage model, each car bought by drivers who 'see' the zone (1.6% London only or 13.1% if London + other cities) pay the fee 225 days x 40% motorists[19] = 90 times per year.

4.8.9 Definition of Regulated Assets in Electricity Supply

The costs associated with recharging (Charge Point Costs (CPC), Network Intelligence Costs (NIC) and Network Reinforcement Costs (NRC) – all of which are described further in Section 4.5.2) might be treated as regulated assets and thus spread across all electricity consumers. If this is done, the resulting increment in the cost of a unit of electricity would be trivial (see calculations in WS3/ARUP/09) and would not be expected to influence the purchase or use of PiVs. However, if all these costs were passed on to the users of non-domestic charge points the resulting increment in cost would be significant and would need to be reflected in the annual usage costs represented in the showroom of vehicles on offer. We propose three values (as also stated in 4.5.3):

- A = CPC, NIC and NRC are all designated as regulated assets
- N = NRC and NIC are designated as regulated assets (CPC is not)
- Z = none are designated as regulated assets

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[18] 2015-2029 <75g exempt, 2030 -2044 <50g exempt, From 2045 <25g exempt
[19] Calibrated by Element Energy on 2005-2009 values

4.8.10 Incentives or Subsidies to Support the Installation of Public Charge Points

A number of the policy levers described here have already been discussed in previous sections (most notably in Section 4.5.4 and in Section 4.6.2.2) . They are repeated here so that all policy levers are mentioned in one place.

Government will be a major player in the initial deployment of public charge points. We propose to test three levels (all relative to values shown inTable 9):

- H = Double the values shown in Table 9
- M = Base values as shown in Table 9
- L = 25% of the values as shown in Table 9

Beyond 2013, Government might incentivise the installation of non-domestic charge points via grants and/or favourable tax treatment. We envisage the following possibilities:

- H = 50% grant until 2015, can write off cost against tax in 1 year
- B = no grants but can write off cost against tax in first year
- Z = no special incentives.

Alternatively, Government might offer to meet any shortfall in funding for new charge points and we propose to test two possibilities:

- G = Government agree to meet any shortfall in funding required
- N = No government support is available to meet any shortfall

When government agree to meet the shortfall, they might also agree to sponsor a higher level of deployment than would have been defined using “normal” rules (see Appendix B4.1). We represent this via a coefficient (LOSCoef) for which we propose to test two values:

- H = High Level of Service (LOSCoef = 1.1)
- N = Normal Level of Service (LOSCoef = 1.0)

The impact of these scenarios on the price and deployment of non-domestic charge points is discussed in Section 4.5.4 and 4.6.2.

4.8.11 Average Fleet Emissions Regulation

Government can, in concert with other European Governments (under Regulation (EC) No. 443/2009), set maximum levels on fleet average emissions for specific manufacturers (with fines imposed if those limits are exceeded). The level from 2015 is set at 130g CO2/km with a target to decrease this to 95g of CO2/km in 2020. This lever could affect the manufacturers’ offerings in the vehicle showroom (they might, for example, reduce the price of PiVs and other low-emitting vehicles and increase those of high-emitting vehicles in order to drive down the fleet average emissions).

Such regulations are currently applied on tail pipe emissions but they could, in theory, be based on an estimate of well-to-wheel emissions. This would ensure that electric and hydrogen vehicles were treated fairly in comparison with conventional fossil-fuelled vehicles.

Although the models available to the project do not distinguish between the products of different manufacturers, we intend to test the possible effect of such regulations across UK sales as a whole. We assume that the changes to the showroom price/availability will depend on whether the average emissions of sales in the previous year had met the designated cap.

We propose four values for the maximum fleet average emissions:

- B = as now / expected – 130g tailpipe at 2015, dropping (say) linearly to 95g at 2020 and then dropping linearly to 42g by 2050
- H = targets become more stringent beyond 2020 - 130g tailpipe at 2015, dropping linearly to 95g tailpipe at 2020 and dropping linearly to 25g by 2050
- WB= based on WTW rather than tailpipe after 2020 (but likely to achieve same overall CO2 cap as B). 95g tailpipe at 2020. 110g WTW in 2021 dropping linearly to 50g by 2050
- WH = based on WTW rather than tailpipe after 2020 (but likely to achieve same overall CO2 cap as H). 95g tailpipe at 2020. 110g WTW in 2021 dropping linearly to 30g by 2050

It is proposed that the equations in Appendix B7 are used to modify the vehicle prices in year T.

4.8.12 Influencing the Price of Carbon Credits

Although Government cannot control the price of carbon credits, it could, in concert with other Governments, seek to control the supply of such credits and thus influence their price. Although we have included this lever as a policy variable, it also appears in Section 4.1.5 (macroeconomic variables).

The price of carbon credits affects electricity generation and thus, indirectly, the cost of recharging PiVs, even though the transport sector per se is exempt from the carbon trading scheme.

As noted in Section 4.1.5, we have assumed three values (expressed in £ per tonne) based on those used by DECC:

- H = almost flat at £19 per tonne until 2020 then rising to £300 per tonne by 2050
- M = almost flat at £15 per tonne until 2020 then rising to £200 per tonne by 2050
- L = almost flat at £8 per tonne until 2020 then rising to £100 per tonne by 2050

4.8.13 Tests Related to Policy Options

Table 21 indicates the required tests (note that sensitivity tests for the regulated asset variable and for the charge point subsidy variable have already been covered by “EP” tests in Table 8. Tests of the initial deployment, “shortfall” and LOSCoef variables have already been covered by “CP” tests in Table 11, and tests of the price of carbon have already been covered by “EG” tests in Table 7).

Code	PIV purch subs	Fave terms on PIV Cap alwnc	Comp Car tax	VAT	Veh purch and o'ship tax	FuelTax	Rev-pres chrge	Cong Chrge	Fleet av Emissns reg
P1	Z								
P2	H3								
P3	H5								
P4	H10								
P5	H10B								
P6		S							
P7			E						
P8				E					
P9					Z	H*			
P10					H				
P11					W				
P12						L			
P13						H			
P14						C			
P15							N		
P16							YU		
P17								E	
P18								EUK	
P19									H
P20									WB
P21									WH
T1 max PIV	H10	S			H	H			H
T2 min PIV	Z		E	E	W	C	YU	EUK	

Table 21 Tests related to Policy

(* fuel tax is 'high' because we assume that VED would only be set to zero in the context of a policy of switching taxes from car ownership to car use)

Note that T1,T2, T8 and T12 values will be reassessed after the sensitivity tests while all other Themed Scenarios are as the base in terms of policy

5 Outputs Related to Scenario Modelling

The following outputs will need to be output from the Consumer Response Model for the whole of the UK (i.e. aggregated over regions). Except where specified to the contrary, these values are required for each year 2010 to 2050.

The scenario values used in the scenario run shall be included in the output file.

1. Vehicle Sales & Car Parc (number in thousands)
    a. Sales disaggregated by 60 vehicle segments x architecture combinations [3 segments (small/medium/other)[20] x 20 architecture categories[21]]
    b. UK car parc disaggregated by 60 vehicle segments x architecture combinations [3 segments (small/medium/other)[20] x 20 architecture categories[21]]
2. Charge points (number in thousands)
    a. Number installed in the year disaggregated by type (workplace, retail, public on-street, public car-park, rapid)
    b. Number in the parc in the year (i.e cumulative installation minus cumulative obsolescence) – disaggregated by type (workplace, retail, public on-street, public car-park, rapid)
3. Vehicle Usage (millions of vehicle kms)
    a. disaggregated by 20 architecture categories[21]
4. Vehicle Fuel Usage (in appropriate units)
    a. disaggregated by the 20 architecture categories[21]
5. Feed of Electricity into PiV Batteries (GW h)
    a. disaggregated by type (domestic, workplace, retail, public on-street, public car-park, rapid)
    b. disaggregated by 2 days (weekday and weekend), 24 hours
    c. PiVs (inc. BEV)
    d. BEVs only
6. Emissions (tonnes CO2eq)

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[20] Small = Mini and Supermini (SMMT segments S+A+B), Medium = lower medium and upper medium (SMMT segments C+D), Other = the rest (SMMT segments E-I)

[21] Gasoline / Gasoline stop-start / Gasoline mild hybrid / Gasoline Full hybrid / Gasoline PHEV / Gasoline RE-EV / Diesel / Diesel stop-start / Diesel mild hybrid / Diesel Full hybrid / Diesel PHEV / Diesel RE-EV / Pure electric / H2 Fuel Cell / H2 ICE / H2 Fuel Cell RE-EV / Gasoline E85 / Diesel B100 / LPG / CNG

   a. associated with PiV (inc. BEV) manufacture and scrappage (If a realistic estimate of the proportion of total production and scrappage emissions that should be associated with scrappage becomes available, we would want that proportion to be associated with the year in which the vehicle is scrapped)
   b. associated with BEV manufacture and scrappage
   c. associated with all non PiVs manufacture and scrappage (this would need to be disaggregated if different classes of non PiVs have different life expectancies)
   d. associated with PiV (inc. BEV) use – in electric mode (hourly marginal and hourly average) – noting that these emissions are based on carbon intensity of the electricity used (actually CO2 rather than CO2eq)
   e. associated with PHEV and RE-EV use – in non-electric mode (average)
   f. associated with BEV use – hourly marginal and hourly average – noting that these emissions are based on carbon intensity of the electricity used (actually CO2 rather than CO2eq)
   g. associated with use of all non PiVs (WTW)

7. Cost and revenues to the Exchequer associated with vehicle purchase and use (£m), separately identifying:
   a. Subsidies for PiV (inc. BEV) purchase
   b. Subsidies for BEV purchase
   c. Total capital cost of sales of fleet vehicles <42g/km, total capital cost of sales of fleet vehicles ≥42<95g/km, total capital cost of sales of fleet vehicles ≥95<110g/km, total capital cost of sales of fleet vehicles ≥110g/km
   d. Total sales in each year for 8 tailpipe emission categories split by depot and workhorse/perks. Total sales in each year for the 7 WTW categories split by depot and workhorse/perks
   e. VED receipts (including the special rate in the first year)
   f. Fuel tax receipts (all fuels) – separately for PiVs and for non PiVs
   g. Income from revenue-preserving tax
   h. Income from congestion charges
   i. Grants and subsidies for non-domestic charge point installation
   j. Cost of meeting any short-fall in non-domestic charge point financing

8. Other costs and revenues associated with the PiV & ICE System (£m), separately identifying:

   a. Value of new vehicles sold – price excluding tax - disaggregated by 20 architecture categories[21]
   b. Expenditure on electricity for PiVs (inc. BEV) (excl tax)
   c. Expenditure on electricity for BEVs (excl tax)
   d. Expenditure on fuels by PHEVs and RE-EVs (excl tax)
   e. Expenditure on fuels by all non PiVs (excl tax)
   f. Costs of charge points installed – disaggregated by type (workplace, retail, public on-street, public car-park, rapid) (= UKCPCc – see appendix B2)
   g. Cost of associated communications and intelligence of charge points installed – disaggregated by standard and rapid (=UKNICc – see appendix B2)
   h. Cost of network reinforcement required (UKNRC – see appendix B2)
   i. Profit made on non-domestic charge points (excl NV) - disaggregated by type (workplace, retail, public on-street, public car-park, rapid)
   j. Revenue streams (NV for retailers and for employers separately)

9. The output from each run will identify the scenario to which it relates and will record the following values calculated during the run:
   a. UK average VKT per car (see Section 4.2.2)
   b. Penalty$_{S,P}$- Price adjustment per car designed to meet Average Fleet Emission Regulations(see Section 4.8.11)
   c. CPCc – charge point costs - UK total (see strict definitions in Appendix B2)
   d. NICc – network intelligence - UK total (see strict definitions in Appendix B2)
   e. CEP – consumer electricity price (see strict definitions in Appendix B3)
   f. REVRPAc – revenue required to cover regulated asset costs (see strict definitions in Appendix B2.4)
   g. REVUPAc – revenue required to cover unregulated asset costs (see strict definitions in Appendix B2.5)
   h. PEPc – premium on electricity price at non domestic charge points (see strict definitions in Appendix B3)
   i. ICP - income from charging points (see strict definitions in Appendix B6)
   j. D - deficit on non-domestic charging points (see strict definitions in Appendix B6)

k. PACc – percentage of consumers with access to charging points (see strict definitions in Appendix B4)

l. Price adjustment to lowest emitting vehicle segment & powertrain combination (see section 4.8.11)

m. Price adjustment to highest emitting vehicle segment & powertrain combination (see section 4.8.11)

n. Penalty being paid by vehicle manufacturers due to failure to meet fleet emission standards

o. Consumer price of fuel (excl tax) (see Appendix B1)

6 Number of Scenarios and Runs

6.1 Themed Scenarios

There are a total of 13 themed scenarios including the base run, as detailed within Section 3.3.

6.2 Sensitivity Analysis Scenarios:

The sensitivity analysis runs are:

Variables linked to UK GDP (UK)	5 runs
Vehicle Showroom (S)	18 runs
Electricity Generation (EG)	3 run
Electricity Price (EP)	17 runs
Supply & Price of Charge Points (CP)	14 runs
Consumer Behaviour (CB)	16 runs
Government Policy (P)	21 runs
Total	**94 sensitivity analysis runs**

6.3 Additional Tests Required for Statistical Modelling:

As noted in Section 3.4 further statistical runs (over and above the sensitivity analyses and twelve scenario themes) will be required to test for the possibility of interaction between different input variables. This could result in a requirement for more runs than can be conducted in the time available.

The number of extra statistical runs cannot be determined until it is known how long the Consumer Response Model will take to run. Element Energy will carry out the first run of this model in mid January 2011, and once the run time is determined the number of ‘statistical’ runs can be quantified.

Initial indications point to the need to run at least 500 statistical runs.

7 Conclusions/Recommendations

The large number of variables that might influence the deployment of PiVs, could, in theory, be combined to generate literally millions of scenarios. It is clearly necessary to focus on a sensible set of scenarios that cover the important questions.

In order to answer the key questions underlying the project (see Section 2.2), it is therefore proposed that the modelling work should explore the effect of varying the key inputs through a systematic programme of sensitivity testing followed by more formal tests of themed scenarios and statistical analyses designed to identify “optimal” policy interventions.

The sensitivity tests will establish the sensitivity of key outputs to each of the input variables in the base scenario. This information is important in its own right (and will duly be reported) but is also an input to the specification of values for the themed scenarios and of tests to be run in order to calibrate a statistical model (see below).

A total of 13 themed scenario tests will be run. They differ from the sensitivity analyses in that all variables are set at the level appropriate to the theme (in the sensitivity analyses all variables except the variable of interest were set at their base values). It should be noted that, although the levels for some of the variables in the themes can be anticipated in advance, they may need to be revised in the light of findings from the consumer research being conducted in SP1 and in the light of the results from the sensitivity analyses.

Additional runs are required to establish non-linearities in the response as well as interactions between different input variables. Although it might be useful to test all possible combinations of the values of all input variables, this is not a practical proposition (it would require millions of runs of the Consumer Response Model being created by Element Energy). It is therefore necessary to prioritise the extra runs, over and above the sensitivity analyses, to be undertaken. The number of extra statistical runs that can be performed within the timing of this project is dependent on how long the Consumer Response Model will take to run.

The scenarios (described in Section 4) incorporate the variables that have been identified to be tested within the project (see Section 2.3). The scenarios have been developed through an iterative process of consultation and research during which the key interactions within the overall system were identified and the capabilities of the available models were assessed. This robust process has included (but was not limited to):

- A workshop to define the variables and the questions to be answered by the project
- A series of modellers’ meetings have ensured an understanding of the ‘inputs’ and ‘outputs’ from the various models
- On-going consultation with all sub-project participants and stakeholders
- A scenarios consultation process and document
- A series of project reviews with the ETI and MEDAG to ensure the scenarios meet the requirements of the stakeholders

It must be recognised that the scenario work is constrained by the capabilities of the models and data available at this stage in the PiVEIP project. A number of the processes which would, in real life, affect the uptake and use of PiVs are not included in the models at our disposal, some key aspects of behaviour are not yet known and a number of these simplifying assumptions are inevitable at this early stage in the overall project.

We recommend that the project proceeds using the scenarios in section 4 of this report, and we would recommend that these are revisited with real data during Stages 2-5 of the project. We would also recommend that the precise values of the variables affecting the deployment and price of non-domestic charge points should be agreed in February in the light of initial runs from Consumer Response model.

Appendix B

Formulae involved in Operationalisation of the Scenarios

B1 Calculation of pump prices of ICE fuels

The table below shows the formulae used for the calculation of consumer fuel prices (excluding all taxes and duties) based on wholesale fossil fuel prices. For Example,

Unleaded Petrol Price (p/litre) = 0.42905 x Wholesale Price of Oil ($/barrel) + 8.9

CNG Price (£/kg) = 0.49 x Wholesale Price of Gas in £/therm + 0.778 x Consumer Electricity Price in £/kWh + 0.27

CONSUMER PRICE OF FUELS EXCLUDING ALL TAXES AND DUTIES

Fuel	**Units**	**O**	**G**	**C**	**E**	**T^5**	**T^4**	**T^3**	**T^2**	**T**	**FD**	**Constant**
Unleaded petrol	p/litre	0.42905	0	0	0	0	0	0	0	0	0	8.9
Diesel fuel	p/litre	0.44448	0	0	0	0	0	0	0	0	0	12.2
LPG	p/litre	0.34913	0	0	0	0	0	0	0	0	0	12.3
B100	p/litre	0.46419	0	0	0	0	0	0	0	0	0	43.2
E85	p/litre	0.33523	0	0	0	0	0	0	0	0	-0.2187	6.9
CNG	£/kg	0.00000	0.49	0	0.778	0	0	0	0	0	0	0.27
Hydrogen	£/kg	0.00000	0.58(1 - T/40)	0.0058(1 - T/40)	8.76(1 + 7 x T/120)	-5.788E-07	8.561E-05	-4.847E-03	0.1315	-1.742	0	10.91

where

O = Wholesale price of oil in $/barrel
G = Wholesale price of gas in £/therm
C = Wholesale price of coal in £/Tonne
E = Consumer price of electricity in £/kWh
T = (Year -2010) e.g. in year 2013, T=3
FD = Fuel duty in pence/litre on unleaded fuel

B2 Calculation of Network Reinforcement, Network Intelligence, and Charge Point Costs

B2.1 Calculation of Network Reinforcement Costs

Annual costs for the UK network reinforcement are based on the output from the module provided by Imperial College, and are dependent on any increase in the peak Grid load including PiVs. The costs are modified to remove the contribution necessary to supply an increased Grid base load, and it is smoothed so that the NRC does not exceed 15% per annum.

In addition, some NIC costs have been added as described in Section 4.5.2. The costs are dependent upon the number of points and the volume and timing of the demand for electricity via charge points. The result is the total UK network reinforcement cost $UKNRC_T$.

The cost is required for two different types (C) of charge point – standard and rapid. The formula provides a constant cost per kW h from a charge point on the assumption that rapid charge points supply six times as much electricity as a standard charge point (as assumed in Section 4.6.2.3).

$$Annual\ cost\ per\ standard\ point_T (NRC_{S,T}) = \frac{UKNRC_T}{NCP_{S,T-1} + 6 \times NCP_{R,T-1}}$$

$$Annual\ cost\ per\ rapid\ point_T (NRC_{R,T}) = \frac{6 \times UKNRC_T}{NCP_{S,T-1} + 6 \times NCP_{R,T-1}}$$

Where

$UKNRC_T$ = Total UK network reinforcement cost for charge point type C in year T.

$NCP_{S,T-1}$ = number of standard charge points in year T-1(includes workplace, retail and public)

$NCP_{R,T-1}$ = number of rapid charge points in year T-1

B2.2 Calculation of Network Intelligence Costs

Costs are to be provided by IBM for the UK network intelligence. These are dependent upon the number of PiVs. They are processed to produce a total UK-wide network intelligence cost per charge point type C in year T using the following procedure. The cost is required for two different types (C) of charge point – standard and rapid. The formula provides a constant cost per kW h from a charge point on the assumption that rapid charge points supply six times as much electricity as a standard charge point (as assumed in Section 4.6.2.3).

$$Annual\ cost\ per\ standard\ point_T(NIC_{S,T}) = \frac{UKNIC_T}{NCP_{S,T-1} + 6\ \times\ NCP_{R,T-1}}$$

$$Annual\ cost\ per\ rapid\ point_T(NIC_{R,T}) = \frac{6\ \times UKNIC_T}{NCP_{S,T-1} + 6\ \times\ NCP_{R,T-1}}$$

Where

$UKNIC_T$ = Total UK network intelligence cost to be recovered in year T.

$NCP_{S,T-1}$ = number of standard charge points in year T-1(includes workplace, retail and public)

$NCP_{R,T-1}$ = number of rapid charge points in year T-1

B2.3 Calculation of Charge Point Costs

Costs are provided by E.ON for the supply, installation, maintenance and replacement of charge points. The costs are provided for various specifications, sites and locations, but will be combined into averages for two different types (C) of charge point – standard and rapid. These average costs will be used for all sites and locations across the UK. Both capital and annual running costs are provided, as is average life expectancy of the charge points. The unit costs are used to calculate the CPC to be met in a given year using the methodology summarized in Appendix B2.4 and Appendix B2.5.

B2.4 Calculation of Regulated Asset Costs

Annual UK-wide total costs are required (summing over all types of charge point). This requires:

- Network Reinforcement is already known at UK level

$$UKNRC_T$$

- Network Intelligence is already known at UK level

$$UKNIC_T$$

- Charge Point Costs are to be multiplied by the number of charge points of that type

$$UKCPC_T = \sum_C (CPC_{CAP,C,T} \div LIFE_C + CPC_{ANN,C,T}) \times NCP_{C,T}$$

Where

$CPC_{CAP,C,T}$ = Capital element of costs for charge point type C in year T

$CPC_{ANN,C,T}$ = Annual element of costs for charge point type C in year T

$LIFE_C$ = Assumed life of charge point in years

Then $REVRPA_T$, the total UK-wide required revenue in pence of regulated assets in year T, will be calculated from a simple addition of the three terms dependent upon the scenarios determined in Section 4.5.3. This simplistic approach (without consideration of grants or tax allowances, or a full calculation on ROR) is appropriate as the effect of the regulated asset costs on CEP has been estimated to be small.

$$REVRPA_T = (1 + ROR) \times (UKNRC_T + UKNIC_T + UKCPC_T)$$

Where

> ROR = desired rate of return on capital (9%, 6.5% or 4%, as defined in the RoR scenario – Section 4.1.7).

B2.5 Calculation of Unregulated Asset Costs

Average capital and annual (UK-wide) costs are required per charge point for each type of non-domestic charge point. This requires the following:

- Annual UK wide Network Reinforcement Costs for type C charge points are those calculated in Appendix B2.1. These will be assumed constant for all locations of charging points.

$$NRC_{C,T}$$

- Annual Network Intelligence Costs for type C charge points are those calculated in Appendix B2.2. These will be assumed constant for all locations of charging points.

$$NIC_{C,T}$$

- Capital and annual Charging Point Costs are already known for each type of charge point

$$CPC_{CAP,C,T} \qquad CPC_{ANN,C,T}$$

Then $REVUPA_{C,T}$, the average annualised UK-wide revenue requirement in pence of unregulated assets in year T per charge point of type C, can be calculated using a combination of the following terms dependent upon the scenarios determined in Section 4.8.9.

If CPC is unregulated then,

$$CAP_{C,T} = (1 - G_T) \times (1 - FYTA) \times CPC_{CAP,C,T}$$

otherwise $CAP_{C,T} = 0$

If NRC, NIC and CPC are unregulated,

$$ANN_{C,T} = (CPC_{ANN,C,T} + NRC_{C,T} + NIC_{C,T})$$

If NRC is regulated, and CPC and NIC are unregulated,

$$ANN_{C,T} = (CPC_{ANN,C,T} + NIC_{C,T})$$

If NRC, NIC and CPC are regulated,

$$ANN_{C,T} = 0$$

And then,

$$REVUPA_{C,T} = \frac{ROR \times (CAP_{C,T} + ANN_{C,T})}{1 - \frac{1}{(1+ROR)^{LIFE_c}}} + ANN_{C,T}$$

Where

$REVUPA_{C,T}$ = required average annualised UK-wide revenue in pence of unregulated assets in year T per charge point of type C.

$CAP_{C,T}$ = capital cost to be covered

$ANN_{C,T}$ = annual running cost to be covered

ROR = desired rate of return on capital (9%, 6.5% or 4%, as defined in the RoR scenario – Section 4.1.7).

$LIFE_C$ = Assumed life of charge point in years

$FYTA$ = first year tax allowance adjustment, depending on value of I in incentive scenario described in Section 4.5.4):

- (if I = Z) $FYTA$ = 0
- (if I = H or B) $FYTA$ = (ROR/2). This is approximately equivalent to the difference in value between a full tax allowance in first year and a tax allowance spread over 5 years.

$NCP_{C,T-1}$ = number of charge points of type C (UK-wide) in year T-1

G_T = fraction of charge point cost offered as a grant by Government for installation of charge points in year T, depending on the value of I in incentive scenario described in Section 4.5.4):

IF I =H AND T > 2012 AND T ≤ 2015 G_T = 0.5

ELSE G_T = 0.0

B3 Electricity Prices

B3.1 Calculation of CEP

The procedure for calculating CEP is shown below. Separate values are calculated for each year T. This is performed before the prediction of vehicle deployment, and before the number of charge points has been determined in accordance with Appendix B4.1.

The formula for the calculation of CEP in year T excluding VAT, is shown below. VAT should then be added at the rate determined in Section 4.8.4.

$$CEP_T = WEP_T + \frac{REVRPA_T}{UKGD_{T-1}}$$

where:

CEP_T = average consumer electricity price (in p/kW h) in year T including effect of PiVs

WEP_T = average consumer electricity price (in p/kW h) for the appropriate grid generation scenario in year T excluding effect of PiVs to be linearly interpolated from the table below.

$UKGD_{T-1}$ = Total UK electricity grid demand (in kW h) in year T-1 as calculated by the Consumer Response Model

$REVRPA_T$ = total UK-wide cost in pence of regulated assets in year T (zero, NRC, or NIC+NRC+CPC, as defined in the regulated asset scenario in Section 4.8.9). Calculated as shown in Appendix B2.4

The formula to calculate the daytime (peak) and night-time (off-peak) CEP values for year T from the average value, uses the grid demand values from year T-1 is: -

$$Off\ peak\ CEP_T = \frac{CEP_T \times (UKGD_{PH,T-1} + UKGD_{OPH,T-1})}{UKGD_{PH,T-1} \times K + UKGD_{OPH,T-1}}$$

$$Peak\ CEP_T = K \times Offpeak\ CEP_T$$

Where

CEP_T = consumer electricity price (in p/kW h) in year T

$UKGD_{PH,T-1}$ = Total annual UK peak electricity grid demand (in kW h) in year T-1 as calculated by the Consumer Response Model. Peak hours assumed to be 7am to midnight for this calculation

$UKGD_{OPH,T-1}$ = Total annual UK off-peak electricity grid demand (in kW h) in year T-1 as calculated by the Consumer Response Model. Off-peak hours assumed to be midnight to 7am for this calculation

K = Ratio between peak CEP rate and off-peak CEP rate (see Section 4.5.7)

Application of the CEP formula gives the following results:

	Average Consumer Electricity Price (excluding PiVs) p/KWh							
	Grid Generation Scenario							
	Base	**EG1**	**EG2**	**EG3**	**T11**	**T7**	**T2**	**T8**
2010	9.99	10.19	9.65	10.07	9.63	10.19	10.27	10.12
2020	11.49	12.14	10.35	12.04	10.64	12.19	12.74	11.61
2030	14.43	13.44	13.99	14.41	13.69	14.93	14.90	14.60
2040	14.60	13.84	14.20	15.29	14.05	15.50	16.18	14.83
2050	14.83	16.02	14.30	16.06	13.49	17.92	19.12	15.32

B3.2 Calculation of PEP[22]

The procedure for calculating PEP for each type of non-domestic charge point is shown below. Separate values are calculated for each year (T) - before the prediction of vehicle deployment. The formula for the calculation of PEP, including VAT at the rate determined in Section 4.8.4, is shown below.

$PEP_{C,T} = \frac{REVUPA_{C,T}}{365 \times LU} - NV_{C,T}$, but is constrained to be no greater than $MaxPEP_T$ and no less than $MinPEP_T$

where

$PEP_{C\ T}$ = price premium (in p/kW h) for charge points of type C in year T

$REVUPA_{C,T}$ = average UK-wide annualised cost in pence of unregulated assets in year T per charge point of type C. Calculated as shown in Appendix B2.5

$NV_{C,T}$ = notional value to employer or retailer of 1 kW h of electricity drawn from charge point of type C in year T

LU = assumed likely usage of public charge points (see section 4.5.6)

$MaxPEP_T$ = assumed maximum conceivable price premium (in p/kW h) - see Section 4.6.2.2 – calculated to reflect the cost of refuelling a petrol engine car to run for the same distance as is achieved through a typical recharge event. The calculation is as follows:

$MaxPEP_T = MaxPEPfactor \times (1 + Rapidfactor) \times (LPK_T \times PCPL_T / EPK_T) - CEP_T$

Where:

MaxPEPfactor is a variable (default value 1.0)

LPK_T = average petrol consumption (litres per km) in year *T*

$PCPL_T$ = cost per litre of petrol (incl fuel tax +VAT) in year *T*

EPK_T= average electricity consumption (kW per km) in year *T*

CEP_T = consumer electricity price (peak incl VAT) in year *T*

Rapidfactor = 0.0 for standard rate CPs,

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[22] This section was developed in cooperation with Element Energy

1.0 for rapid CPs in most scenarios but
0.5 in the 'PUBLIC RAPID' charging scenario ,

$MinPEP_T$ has two values:

For retail and workplace charge points it is set such that the combination of CEP and PEP is always zero (i.e $MinPEP_T = - CEP_T$)

For public rapid, on-street and car-park charge points, it is set such that the price to the user of a typical recharge event never falls below 50 pence (It is assumed that a sum lower than this would not be economic to process,s and that consumers would be no more averse to paying 50p than any sum lower than that).

i.e. $MINPEP_T = (50 – (CEP_T \text{ x } AC))/AC$ - where AC is the charge required for an average recharge event and CEP_T is the consumer price of electricity (peak incl VAT) in year T.

B4 Deployment of Non-Domestic Charge Points

B4.1 Calculation of the Number of Non-domestic Charge Points[23]

The procedure for calculating the number of charging points to be installed in year T is described below. The procedure is run separately to give installation numbers for each type of charging point (standard public on-street, standard public car park, public rapid, workplace and retail).

The calculation differs depending on whether there is a market failure unprotected by a government guarantee to meet any shortfall.

IF $Govtshortfallguarantee = \text{N}$, AND $NPprofit_{T-1} < 0$

THEN $NCP_{C,T}$ is the maximum of

$$(Cutback\ \text{x}\ (2\ \text{x}\ ED_{CT-1} - ED_{CT-2}))\ /\ (365\ \text{X}\ LU)$$

and $NCP_{CT-1} - OLD_{CT}$

ELSE $NCP_{C,T}$ is the maximum of

$$(LOSCoef\ \text{x}\ (2\ \text{x}\ ED_{CT-1} - ED_{CT-2}))/\ (365\ \text{X}\ LU)$$

and $NCP_{CT-1} - OLD_{CT}$

where:

$NProfit_{C,T-1}$ = notional profit above ROR made on charge points of type C in year T-1 (= profit + NV – see Appendix B6)

$Cutback$ = market response to losses in previous year

$$= 1 + (\text{K x}\ (\ NProfit_{C,T-1} / NCP_{CT-1}) / REVUPA_{C,T-1})$$

$ED_{C,T-n}$ = electricity in kWh drawn from charge points of type C (across whole of UK) in year T-n. (The expression (2 x $ED_{C,T-1} - ED_{C,T-2}$) is an estimate for $ED_{C,T}$.

$NCP_{C,T}$ = number of charge points of type C (across whole of UK) in year T

$OLD_{C,T}$ = Number of charge points of type C to be replaced in year T.

$LOSCoef$ = level of service coefficient (see section 4.6.2.2)

LU = assumed likely utilisation of electricity in kWh per day drawn from a charge point (see section 4.5.6).

K = a parameter (set to 1.0)

$REVUPA_{C,T}$ = average GB-wide annualised cost in pence of unregulated assets in year T per charge point of type C. Calculated as shown in Appendix B2.5

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[23] This section was developed in cooperation with Element Energy

B4.2 Estimation of level of access to non-domestic charge points

The percentage of consumers with access to charging points of type C (PAC_C) is - required as input to the consumer purchase decision and to the recharge behaviour calculations in year T as described in Section 4.7.8. A formula for calculation of PAC_C was suggested by SP3 (and is now included as Appendix B4.3).

However, in order to make fullest use of the survey data and to make explicit allowance for the number of people likely to "see" charge points, Element Energy devised alternative formulae which derive a value for the number of people who, when considering purchase in year T, are likely to consider that they have access to the relevant spaces (LA_T) and, in the case of public and retail spaces for their "perceived value of access" (PVA_T) to those spaces. Full details are given in the relevant Element Energy Report due to be delivered in May 2011 (WP1.4.8 Final Report – Consumer based uptake and usage model) but the procedure can be summarised as follows:

For public and retail charge points, LA_T is calculated as:

$$LA_T = NCP_{Pub,T} \text{ x } PU$$

where

PU = Assumed usage of public charge points
= 42 (based on 9hours use per day (9am-6pm), 1.5h of parking and 1 weekly pubic charging per car).

PVA_T, which is used in the CRM to determine what fraction of the perceived £5,000 benefit associated with access to public (on street, car park and retail) charge points is available in a given year, is calculated as:

$$PVA_T = DS_T \text{ x } LikeA_T$$

Where:

DS_T = *Destinations served in year T*
= MAX of [$(NCP_{Pub,T-1}) / NRC1000$] AND [1.0]

$NRC1000$ = the number required to cover 1000 towns and cities in GB
= 50,000 (i.e 50 per town or city)

$LikeA_T$ = Likelihood of access in year T
$= 1 – (ADU_{T-1} \;/ MU)^2$

Where

ADU_{T-1} = average daily use of charge points in year T-1
MU = assumed maximum feasible use of public charge points (see Section 4.7.6)

For workplace charge points the number of people assumed to have access is simply: $NCP_{work,T}$ x 7. All drivers thereby assumed to have work access perceive the full value of the access benefit when making their purchase decision.

Once drivers have purchased a PIV, their access to the various types of charge points needs to be calculated in order to predict their recharge behaviour (see section 4.7.8). EE make the following assumptions:

For public charge points (retail, on street, car park and rapid) all drivers have access.

For workplace charge points; drivers who had access in the showroom and bought a PiV continue having access to workplace charge points.

B4.3 Previous methodology for estimation of level of access to non-domestic charge points

$\mathrm{PAC}_{C,T}$ is the minimum of:

$$\frac{\mathrm{PU}_{C,T-1}}{\mathrm{CPCT}_{C,T-1}} - \frac{\mathrm{PU}_{C,T-1} - 1}{\mathrm{CPCT}^2_{C,T-1}}$$

and :

the maximum of: 70 and $\mathrm{PAC}_{C,T} = \left(100 - \mathrm{CPCT}_{C,T}/100\right)$

where

$\mathrm{PU}_{C,T-1}$ = potential customers per charge point of type C in year T-1

$= (\mathrm{MaxLU}_C/\mathrm{ADPC}_{C,T-1})$

where

MaxLU_C = maximum average utilisation in kW h per day for charge points of type C (set as a scenario variable – see Section 4.6.2)

$\mathrm{ADPC}_{C,T-1}$ = average demand per customer (in kW h per day) from charge points of type C in year T-1

$$\mathrm{ADPC}_{C,T-1} = \frac{\mathrm{ED}_{C,T-1}}{365 \times \mathrm{NPV}_{T-1}}$$

$\mathrm{CPCT}_{C,T-1}$ = the number of cars per charge point type C in year T-1

= $(\mathrm{NPV}_{T-1}/\mathrm{NCP}_{C,T-1})$ - but is constrained to be greater than 1.0

where

NPV_{T-1} = number of plug-in vehicles in car parc in year T-1

$\mathrm{NCP}_{C,T-1}$ = number of charging points of type C in year T-1

This formula is designed to account for the fact that, as the number of cars per charge point rises, cars will increasingly be vying for access and hence a lower the proportion of cars will have access to a charge point.

The expression [max of 70 and (100-CPCT/100)] allows for the proportion of cars with access to fall linearly with the increase in cars per charge point. The expression [(PU/CPCT) – ((PU-1)/CPCT^2)] prevents MaxLU$_C$ being exceeded.

B5 Adjustment of VKT per car

B5.1 Tables for GBVKT and GB car parc

	VKT (billion)		
Year	1%	2%	3%
2008	402.000	402.000	402.000
2009	400.614	400.614	400.614
2010	404.435	403.029	401.622
2011	404.125	404.255	404.343
2012	403.839	405.490	407.058
2013	403.574	406.734	409.769
2014	403.328	407.985	412.474
2015	403.102	409.244	415.171
2016	402.896	410.509	417.859
2017	402.709	411.781	420.536
2018	402.540	413.058	423.199
2019	402.391	414.341	425.847
2020	402.259	415.628	428.478
2021	402.146	416.919	431.089
2022	402.050	418.213	433.678
2023	401.971	419.511	436.243
2024	401.910	420.810	438.781
2025	401.865	422.111	441.289
2026	401.837	423.412	443.766
2027	401.826	424.714	446.208
2028	401.830	426.015	448.612
2029	401.8498	427.3149	450.9751
2030	401.8852	428.6124	453.2944
2031	401.9356	429.907	455.5665
2032	402.001	431.1978	457.7879
2033	402.0809	432.4842	459.9551
2034	402.1751	433.7651	462.0645
2035	402.2834	435.0398	464.1122
2036	402.4054	436.3073	466.0944
2037	402.5409	437.5668	468.0068
2038	402.6896	438.8174	469.8453
2039	402.8513	440.0579	471.6054
2040	403.0256	441.2875	473.2825
2041	403.2124	442.5052	474.8719
2042	403.4113	443.7099	476.3687
2043	403.6221	444.9005	477.7679
2044	403.8445	446.076	479.064
2045	404.0782	447.2353	480.2516
2046	404.323	448.3772	481.3251
2047	404.5786	449.5004	482.2786
2048	404.8448	450.6039	483.106
2049	405.1212	451.6864	483.8011
2050	405.4077	452.7466	484.3572

Table 22 GBVKT (billion)

	CARS (thousands)		
Year	**1%**	**2%**	**3%**
2008	28390.0	28390.0	28390.0
2009	28459.0	28459.0	28459.0
2010	28834.2	28834.2	28834.2
2011	28916.5	29129.2	29341.9
2012	29001.2	29429.1	29860.1
2013	29087.9	29733.9	30389.4
2014	29176.8	30043.8	30930.1
2015	29267.7	30358.8	31482.3
2016	29360.7	30679.0	32046.3
2017	29455.8	31004.5	32622.4
2018	29553.0	31335.3	33210.9
2019	29652.3	31671.5	33812.0
2020	29753.7	32013.2	34426.1
2021	29857.1	32360.5	35053.3
2022	29962.7	32713.5	35694.1
2023	30070.4	33072.2	36348.6
2024	30180.2	33436.8	37017.3
2025	30292.0	33807.3	37700.3
2026	30406.0	34183.8	38398.2
2027	30522.1	34566.4	39111.1
2028	30640.4	34955.1	39839.4
2029	30760.7	35350.2	40583.4
2030	30883.1	35751.6	41343.6
2031	31007.7	36159.5	42120.2
2032	31134.4	36574.0	42913.6
2033	31263.3	36995.1	43724.3
2034	31394.3	37423.0	44552.5
2035	31527.4	37857.7	45398.7
2036	31662.6	38299.4	46263.3
2037	31800.0	38748.2	47146.7
2038	31939.6	39204.1	48049.3
2039	32081.3	39667.3	48971.6
2040	32225.2	40137.9	49913.9
2041	32371.2	40616.0	50876.7
2042	32519.5	41101.7	51860.5
2043	32669.8	41595.1	52865.8
2044	32822.4	42096.3	53893.0
2045	32977.2	42605.5	54942.6
2046	33134.1	43122.7	56015.1
2047	33293.3	43648.1	57111.0
2048	33454.6	44181.8	58230.9
2049	33618.2	44724.0	59375.3
2050	33784.0	45274.7	60544.7

Table 23 GB Car Parc

B5.2 Adjustment of VKT per car to reflect cost changes

The basic equation, ignoring any effects of changes in GDP, would be:

$$VKTPC_{T,M} = VKTPC_{10,I} \times \left(1 + E \times \left(\frac{CPK_{T,M}}{CPK_{10,I}}\right)^{0.2} \times \left(\frac{CPK_{T,M} - CPK_{10,\mathrm{I}}}{CPK_{10,I}}\right)\right)$$

where

> $VKTPC_{T,M}$ = annual vehicle kilometres travelled in year T by each car of powertrain M (M=I indicates the petrol ICE powertrain and hence $VKTPC_{10,I}$ will be the kilometres travelled in 2010 by an average petrol ICE car)
>
> *E* = the elasticity value of *VKTPC* with respect to *CPK*
>
> $CPK_{T,M}$ = cost per kilometre travelled in year T by an average car of powertrain M (M=I indicates the petrol ICE powertrain). In estimating *CPK*, the average car is proxied by a medium sized 5 year old car of the given powertrain.

However, in some scenarios, the value of E will be deflated to reflect reduced sensitivity to prices due to increased GDP per head. Thus the equation becomes:

$$VKTPC_{T,M} = VKTPC_{10,I} \times \left(1 + \left(\frac{E}{(1+0.877A)^N}\right) \times \left(\frac{CPK_{T,M}}{CPK_{10,I}}\right)^{0.2} \times \left(\frac{CPK_{T,M} - CPK_{10,\mathrm{I}}}{CPK_{10,I}}\right)\right)$$

where

> *A* = the annual rate of change in GDP specified for the scenario (0.03, 0.02 or 0.01)
>
> *N* = number of years since 2010 (the GDP growth rate is cumulative per annum)

Furthermore, the value of $VKTPC_{T,M}$ will already have been adjusted to reflect reductions in VKT per car associated with the fact that, as GDP increases, total VKT grows faster than the size of the car parc. This effect is encapsulated in the tables in Appendix B5.1. The year T values in the GBVKT table are divided by the year T values in the GBCarParc table to give VKTPC for that year. The fully specified equation is thus:

$$VKTPC_{T,M} = DVKTPC_{T,M} \times \left(1 + \left(\frac{E}{(1+0.877A)^N}\right) \times \left(\frac{CPK_{T,M}}{CPK_{10,I}}\right)^{0.2} \times \left(\frac{CPK_{T,M} - CPK_{10,\mathrm{I}}}{CPK_{10,I}}\right)\right)$$

where

> $DVKTPC_{T,M}$ = value of VKTPC for cars of type *M* in year *T* derived by division of values in GBVKT table by values in GBCarparc table (we understand that Element Energy have assumed that the VKTPC for a typical ICE in 2010 can be approximated by the VKTPC for the average vehicle ion 2010).

B6 Order of Operationalisation Calculations

There are a series of calculations that must be made before the vehicle sales predictions are made for each year. These set up the values for a number of the key variables (e.g. infrastructure installation and prices) for the year. The order of these calculations is as follows: -

1. Calculate UK network reinforcement costs (UKNRC)
2. Calculate UK network intelligence costs (UKNIC)
3. Calculate total regulated asset costs (REVRPA)
4. Calculate annual revenue required per charge point (REVUPA).
5. Calculate consumer electricity price (CEP).
6. Calculate public electricity premium (PEP).
7. Calculate level of access to non-domestic charge points (PAC)
8. Calculate the number of charge points (NCP).

The following calculations are performed after the prediction of vehicle sales and recharge behaviour in year T**.**

1. $Profit_{C,T}$ = notional profit above ROR made on charge points of type C in year T – required for accounting report.

$$Profit_{C,T} = (ED_{C,T} \times PEP_{C,T}) - (REVUPA_{C,T} \times NCP_{C,T})$$

2. $NProfit_{C,T}$ = notional profit above ROR made on charge points of type C in year T – required to choke off unprofitable installation of charge points and in item 4 below.

$$NProfit_{C,T} = Profit_{C,T} + NV_{C,T}$$

3. ICP_T = The income from the charging points in year T – required for accounting report;

$$ICP_T = \Sigma_C \, PEP_{C,T} \times ED_{C,T}$$

4. D_T = deficit in funding for charge points in year T – required for accounting report.

IF *Government Shortfall* (4.6.2.2) = G

AND *NProfit* < 0

THEN $D_T = -\Sigma_C \left(NProfit_{C,T}\right)$

ELSE $D_T = 0$

5. $TotSub_T$ = running total of the cost of charge point grants, subsidies and deficits met by government – required for accounting and for scenarios where grants and subsidies are capped.

$$TotSub_T = TotSub_{T-1} + D_T + \sum \mathrm{C} \left(\left(\left(1 - (1 - \mathrm{G_T}) \times (1 - \mathrm{FYTA}) \right) \times \mathrm{CAP_{C,T}} \right) \times \left(NCP_{C,T} - NCP_{C,T-1} \right) \right)$$

B7 Calculation of Price Changes Designed to Help Meet Average Fleet Emissions Targets

Section 4.8.11 discusses the policy of penalising car manufacturers whose average fleet emissions exceed a specified target. It is assumed that manufacturers would respond to these penalties by modifying the prices of models whose sales would help/hinder their ability to keep below the target.

It is proposed that the equations below are used to modify the vehicle prices from 2021 onwards, using data from vehicles sales in the previous year. Initially, we will use the Regulation's €95 penalty per g CO2/km per new car sale by which the average CO2 emission is above the target. Depending on consumer response, this value may need revision to keep the average emissions on the desired trend, and yet minimise any numerical instability. A constant exchange rate of €1 = £0.80 will be used leading to a penalty of £76 per g CO2/km.

The purchase price of vehicles in the vehicle showroom (excluding taxes) in year T will be the sum of the Ricardo vehicle cost model price in year T, plus the penalty/incentive from year T, all for the appropriate powertrain architecture and segment. The penalty/incentives are directly related to the average CO2 emissions (ACE) of that powertrain architecture and segment .

$$Average\ CO2\ emission\ (ACE)_{T-1} = \frac{\Sigma_{S,P}\left(NC_{S,P,T-1} \times E_{S,P,T-1}\right)}{\Sigma_{S,P}\ NC_{S,P,T-1}}$$

IF $ACE_{T-1} - (0.9 \text{ x } Target_{T-1}) > 0$

THEN $$TUCP_{T-1} = \mathrm{AP}_T \times (ACE_{T-1} - Target_{T-1}) \times NC_{T-1}$$

$$PPC_{S,P,T} = 0.25 \times \mathrm{AP}_T \times \left(E_{S,P,T\text{-}1} - Target_T\right) + 0.75 \times PPCr_{S,P,T\text{-}1}$$

ELSE $$TUCP_{T-1}\ in\ £ = 0$$

$$PPC_{S,P,T} = 0.75 \times PPC_{S,P,T\text{-}1}$$

The equations for the penalty in year T includes a large component of year T-1's penalty. This provides some damping of vehicle price variations between years if the average CO2 emissions are oscillating above and below the target values. The 0.25 and 0.75 factors may require revision when the initial results of the Consumer Response Model are reviewed.

Where:

NC_T = number of new cars in year T

$E_{S,P,T}$ = emissions in g CO2/km of a car in segment *S* and powertrain architecture *P* in year *T*

$\mathrm{A}P_T$ = Adjusted penalty in year T (adjusted to allow for reduced sensitivity to prices resulting from increased national wealth)

$= £76 \text{ x } (A)^N$

Where A = Annual rate of decrease in sensitivity to prices (1.0263, 1.0177 and 1.0088 for annual GDP increases of 3%, 2% and 1% respectively)

N = number of years since 2010

Target = target for average fleet CO2 emissions in g CO2/km

$PPC_{S,P,T}$ = amount in £ to be added to the vehicle showroom price (some will be negative – i.e. incentives) of a car in segment *S* and powertrain architecture *P* in year *T*. Note that the value of PPT is inflated to counteract the effect of reduced sensitivity to prices as described in Section 4.7.5. Thus, in the base case

$TUCP_{T-1}$ = Total UK CO2penalty in £ n year t-1.

Appendix C

Modelling Caveats

C1 Modelling Caveats

The Plug-in Vehicle system is a nascent domain, with many interrelated and interdependent technical and commercial systems, where the existing systems are developing rapidly and some systems are still to be established.

The current modelling is necessarily being developed at a high level to answer high level questions and not to provide detailed answers to all the emerging detailed questions – which Stages 2 to 5 will address.

This appendix documents key caveats which will need to be borne in mind when considering the results of the modelling being conducted in Stage 1 of the project.

C1.1 General

1. The Project is limited to vehicles of the M1 category within the UK, excluding Northern Ireland, between 2010 and 2050.
2. H_2 vehicles have been excluded from the analysis.
    a. It is expected that the wide availability of H_2 vehicles and related refuelling infrastructure would have had a significant effect on the market for PiVs.
    b. The absence of H2 vehicles from the analysis will affect the prediction of CO2 emissions, and arguably negate the relevance of the target reduction of 80% in CO2 by 2050 compared to 1990 values.
3. SORN vehicles are excluded from the models.
4. Most of the sensitivity analyses will have been run only for the base case (i.e. the sensitivity will be known only in the context of all other inputs being at their base values). It is quite possible that some sensitivities will be context specific (e.g. the effect of subsidy on PiV purchase may be much greater if PiVs are inherently more attractive than in the base). Resources do not permit exploration of many of the possible interactions – this could be a particularly serious problem if the base is not correctly defined.
5. Each input variable has a defined trajectory of values for each year between 2010 and 2050. The overall results reflect this trajectory and are not simply a reflection of the 2050 values. Resources do not permit exploration of alternative trajectories.
6. Changes to taxes and subsidies as policy variables (Section 4.8) are assumed to come in instantaneously.
7. All calculations completed at year end are assumed to apply for a whole further year.
8. There is no consideration of benefits to local environment due to reduced noise.

C1.2 Specific

9. The evolution of the showroom offer (specification, price and availability of individual vehicle models) is not affected by sales in previous years.
10. No allowance has been made for the possibility that changes in technology might affect the costs of charge point intelligence and associated communications links.
11. Charge point costs are assumed to be independent of installations to date (and thus of size/efficiency of any specialist companies which might set up to meet the demand).
12. The commodity price scenarios do not encompass all possible combinations of price trends in different commodities. It is possible that some combinations could materially affect the relative prices and performance of PiVs and ICEs
13. The impact of short term volatility in commodity prices is not considered.
14. The electricity price used in predicting the cost of the production of vehicles is not constrained to be the same as electricity price used elsewhere in the modelling.
15. The purchase of vehicles is not constrained by any shortage of supply of individual models.
16. The purchase of vehicles is not constrained by the shortage of supply of batteries or other component parts.
17. There is no consideration of the effect that the different availabilities of alternative minority fuels (H2 or biomass) might have on uptake of these powertrains (Only one base assumption will be made).
18. The calculation of NRC and NIC is subject to the following simplifying assumptions:
    a) The NR requirement is based on assumptions about PiV recharge point locations and the spatio-temporal pattern of their usages (rather than on a behavioural model).
    b) The calculation of the national cost of NR due to PiVs would have to be based on simplified assumptions about the spatial distribution of recharge points of a given type.
    c) NR costs would be calculated assuming that the implication of rapid charging could be represented as a simple multiplier on the effect of standard charging.
    d) No allowance would be made for the possibility that changes in commodity prices (notably copper) might affect the costs of NR.

e) No allowance would be made for the possibility that changes in technology might affect the costs of NR.

19. The effect of the ‘Energy Market Reform’ (as per White Paper in Spring 2011) is excluded

20. It is assumed that operators of non-domestic charge points do not have access to electricity at a significant discount on the Consumer Electricity Price (it is assumed that any such discount is balanced by additional costs – e.g. in processing credit card purchases of electricity via the charge points).

21. The Rate of Return variable is only used to vary the required return on the costs of the charging points. It has no effect on other costs e.g. vehicle manufacture, electricity generation.

22. There is no modelling of the second hand car market (PiVs are purchased new and kept by that owner until scrapped – hence no allowance for possibility that the usage patterns and ownership location might change).

23. There is no modelling of the effect that change in GDP might have on the scrappage rate - and hence on new car sales as a proportion of the change in the vehicle parc.

24. No estimate has been provided of the proportion of total production plus scrappage emissions that ought to be associated with scrappage (it has been suggested that we should assume zero) this introduces some errors because emissions are valued differently in different years.

25. There is no modelling of the effect that change in the price of new vehicles might have on the total volume of new car sales in any year. (an approximation of this effect might be implemented via an aggregate elasticity model).

26. There is no modelling of the effect that change in costs of using PiVs (e.g. due to change in electricity price, annual tax, etc) would have on scrappage rate - and hence on development of parc.

27. There is no consideration of different response to purchase and lease options.

28. Survey work conducted within the project used stated preference questions to establish likely purchase decisions. However, given that PiVs are, as yet, a fairly novel concept to most people, their responses to the stated preference questions must be treated with caution. As with any model based on stated preferences, it will have been necessary to scale the model to avoid gross under/over prediction. During the stage 1 work, the scaling will have been based on historic evidence on uptake of other innovative vehicle types and will need to be reconsidered in later phases of the work when real data becomes available.

29. The consumer purchase model is calibrated on survey work conducted in 2010. It is assumed that behavioural preferences will remain unchanged until 2050.

30. No research has been commissioned to understand or predict PiV usage or recharge behaviour and predictions of these must remain somewhat speculative.

31. The modelling of the effect that charge point availability might have on the purchase of PiVs will be dependent on assumptions about the level of charge point availability which affects purchase decisions. These assumptions are a matter of judgement in stage 1 – not an outcome of the consumer research.

32. There is no model of the choice between vehicle classes (the calibrated model deals only with choice of powertrain). This has particular implications when seeking to model the effect of any restriction in the availability of given powertrain/vehicle class combinations.

33. The prediction of the effect of legislation on OEM fleet average emissions is necessarily simplistic because:

    a) There is no OEM-level modelling

    b) There is no modelling of the European market (the level at which limits might be set)

    c) There is no model to predict how vehicle characteristics might be changed to help achieve fleet average targets

    d) There is no model of consumer response to (un) availability of particular class/powertrain options

    e) Given c and d above, it had to be assumed that manufacturers seek to influence demand for different models solely via changes to prices (see Appendix B7).

34. There is no modelling of the different usages that would emerge for BEVs, REEVs, PiHVs and ICEs – or of the effect of ownership of one on the use of another e.g. in multi-car families.

35. There will be no detailed modelling of the effect that charge point availability might have on the use of PiVs (or indirectly of other vehicle types) – although constraints were introduced to ensure that workplace and domestic recharge will only be used by people with access to it.

36. There is no modelling of the effect that availability of fuel for biomass vehicles might have on the use of such vehicle types (or indirectly on the use of other vehicle types).

37. There is no modelling of the extent to which recharge timing is affected by differentials in recharge cost at different times of day (it is assumed that

logical assumptions will be made about the use of off-peak tariffs for domestic charging but this is only one aspect).

38. There is no modelling of the extent to which vehicle usage and recharge timing differs between seasons (thus any implications which this might have for network reinforcement requirements, or for usage of different electricity generating plant with different carbon emissions, will not be captured).
39. The consumer response model does not fully distinguish between different types of public charge points (retail, public on street, public car park and rapid) – perceived access to such spaces is based on a nominal average of all four.
40. The estimation of access to workplace, retail, public on-street, public off-street and rapid charge points is based on necessarily approximate assumptions about the number of such spaces in the country and of the distribution of installed charge points at such spaces. These assumptions are assumed to hold from 2010 to 2050.
41. There is no detailed modelling of the extent to which recharge locations are chosen in response to differentials in recharge cost at different locations (although the assumptions on recharge behaviour do allow for a preference for free electricity when available).
42. There is no modelling of the extent to which recharge timing and location is affected by the probability of finding that charge points are already occupied by another vehicle (the implicit assumption is that all charge points are unoccupied).
43. Charging behaviour does not vary between consumers in different vehicle segments.
44. The cost of tax incentives for low carbon company cars is based on the employee paying a combined marginal rate of 40% for income tax and National Insurance contributions.

Appendix J

Vehicle Technology & Cost Original Scenarios

J1 Vehicle Technology

Note that this Section is superseded by Section 4.3 and is included solely as a record of the scenarios presented and agreed by MEDAG prior to the decision to consider vehicle technology and pricing scenarios outside the Ricardo models.

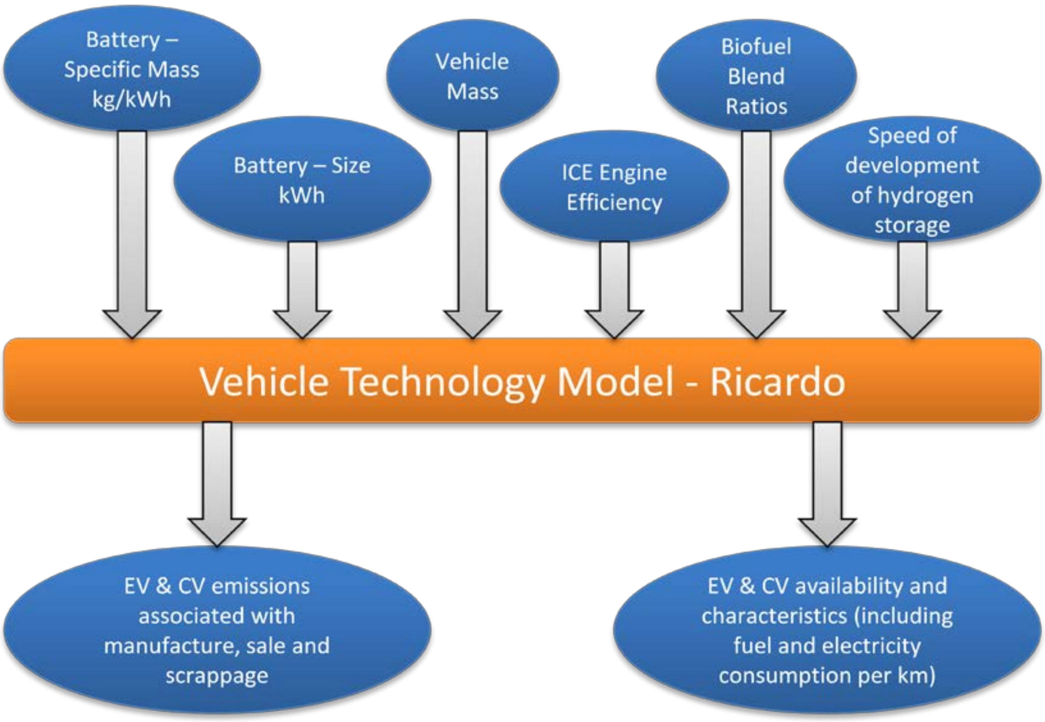

Figure 10 Vehicle Technology Overview Diagram

J1.1 Battery – Specific Mass kg/kW h

- Values:

  H = Most pessimistic industry forecast

  B = Ricardo current vehicle technology roadmap

  L = Most optimistic industry forecast

J1.2 Battery – Size kW h

- Linked to Battery Specific Cost – see Vehicle cost scenarios later
- Values:

  L = Larger (to maintain battery cost as base)

  B = as Ricardo base vehicle specification

  S = Smaller (to maintain battery cost as base)

J1.3 Vehicle Mass

- Values:

  H = Mass of vehicles stays similar

  B = Ricardo current vehicle technology roadmap

  L = Most optimistic industry forecast

J1.4 ICE Engine Efficiency

- Values:

  H = Most optimistic industry forecast

  B = Ricardo current vehicle technology roadmap

  L = Most pessimistic industry forecast

High degree of complexity - Ricardo to assess most important factors to vary for low/high…

J1.5 Speed of Development of Onboard Hydrogen Storage:-

- Values:

  H = In line with the most optimistic industry projections

  B = Ricardo current vehicle technology roadmap

  L = Hydrogen vehicles do not ever exist

J1.6 Biofuel Blend Ratios in Conventional Fuels

- Values:

  H = High

  B = Medium

  L = Low

Measuring CO2 effect

J2 Vehicle Costs

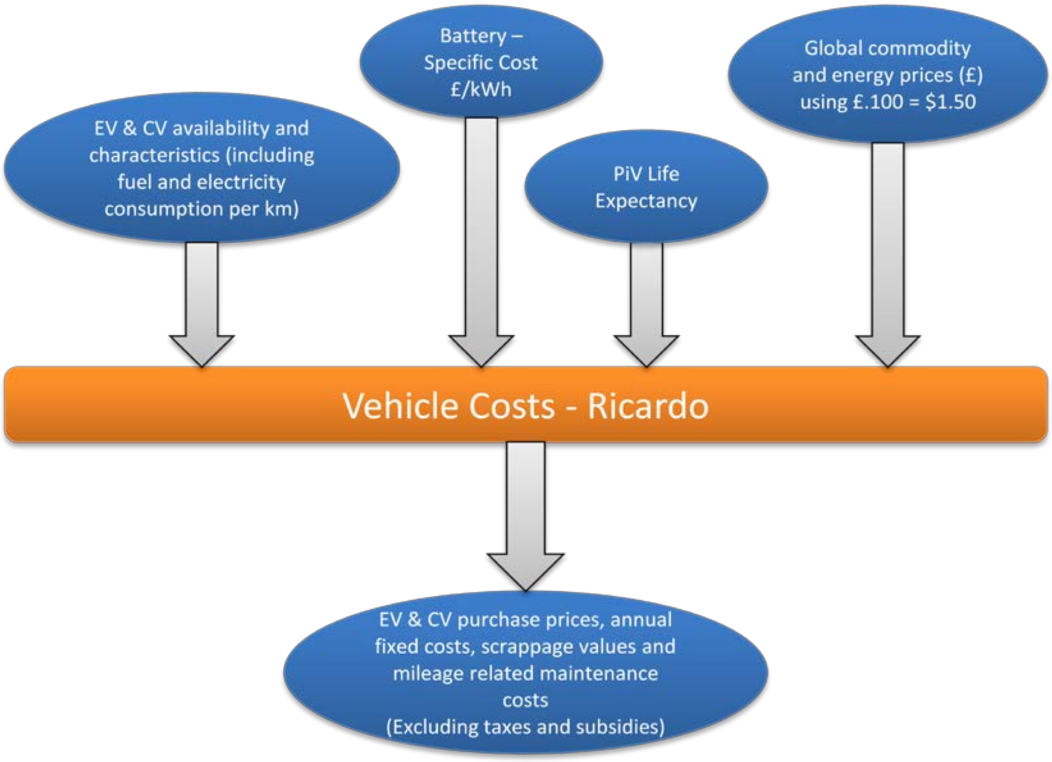

Figure 11 Vehicle Costs Overview Diagram

J2.1 PiV & ICE Availability and Characteristics (including fuel and electricity consumption per km)

- This is an output from the Ricardo Vehicle Technology model

J2.2 Battery – Specific Cost £/kW h

- Values:

H = Most pessimistic industry forecast

B = Ricardo current vehicle technology roadmap

L = Most optimistic industry forecast

J2.3 PiV Average Life Expectancy

- Reflects expected life of batteries
- 3 Values:

H = 10 years now, rising to 14 years by 2050

B = 8 years now, rising to 12 years by 2050

L = 6 years now, rising to 10 years by 2050

J2.4 Global Commodity & Energy Prices (£) using £1.00 = $1.50

- Values:

  H = High commodity prices

  B = Medium commodity prices

  OH = Medium commodity prices – High Oil is growing fast

  OS = Medium commodity prices – Oil price spike in 2025

  L = Low commodity prices

J2.5 Vehicle Technology & Cost Model Sensitivity & Theme Tests

Code	Global Commodity and energy Prices	Battery – Specific Mass kg/kW h	Battery – Size kW h	Battery - Specific Cost £/kW h	Speed of development of hydrogen storage	Vehicle Mass	ICE Engine Efficiency	Biofuels	PiV Life Expectancy
V1	H								
V2	OH								
V3	OS								
V4	L								
V5		H							
V6		L							
V7			H	B					
V8			L	B					
V9			B	H					
V10			B	L					
V11					H				
V12					L				
V13						H			
V14						L			
V15							H		
V16							L		
V17								H	
V18								L	
V19									H
V20									L
T1 – Max fav for PiV’s	OH or OS	L	H&B and/or B&L		L	L	L	L	H
T5 – Min fav for PiV’s	H or L	H	L&B and/or B&H		H	H	H	H	L
M1 – High Global	H	L	H&B and/or B&L		H	L	H	H	H
M2 – High Global green	H	L	H&B and/or B&L		H	L	H	H	H
M5 – Slow Global	L	H	L&B and/or B&H		L	H	L	L	L

Table 24 Vehicle Technology & Cost Model Sensitivity & Theme Tests

Appendix K

Glossary of Terms

K1 Glossary of Terms

ASC – Alternative Specific Constant

BEV – Battery Electric Vehicle

CAGR – Compound Annual Growth Rate

CAM – Core Ambition (Low carbon) UKERC scenario (80% CO2 reduction by 2050)

CCSP – Socially optimal least-cost path (Optimised carbon pathway using the 2010-2050 budget from the CEA (early action) UKERC scenario and a social discount rate)

CEP – Consumer Electricity Price

CLC – low carbon reduction UKERC scenario (60% CO2 reduction)

CO2eq - carbon dioxide or an amount of any other greenhouse gas with an equivalent global warming potential (calculated consistently with international carbon reporting practice).

CP – Charge Point

CPC – Charging Point Costs

CPP – Public Car Park

CSAM – Super ambition (90% CO2 reduction by 2050) UKERC scenario

DECC – Department of Energy and Climate Change

ED – Electricity Demand

ETI – Energy Technologies Institute

ETI ESME – ETI Energy System Modelling Environment

GB – Great Britain

GDP – Gross Domestic Product

IEA WEO – International Energy Agency World Energy Outlook

ICE – Internal Combustion Engine

LEV – Low Emission Vehicle

MEDAG – The ETI ‘Modelling and Experimental Design Advisory Group’

MVRIS – Motor Vehicle Registration Information System

MU – Maximum Utilisation

NCP – Number of Charge Points

NIC – Network Intelligence Cost

NPiV – Number of Plug-in Vehicles

NRC – Network Reinforcement Costs

NV – Notional Value

OSS – On Street Space

PCP – Public Charge Pont

PEP – Public Electricity Premium

PEPMAX - assumed maximum conceivable Public Electricity Premium

PHEV – Plug-in Hybrid Electric Vehicle

PiP – Plugged In Places

PiV – Plug-in Vehicle

PiVEIP - Plug-in Vehicle Economics & Infrastructure Project

RA – Regulated Asset

RAC – Regulated Asset Cost

REEV – Range Extended Electric Vehicle

ROR – Rate of Return

SMMT – The Society of Motor Manufacturers and Traders Ltd

SP - Stated Preference

SP1 – Sub-Project 1

SP2 – Sub-Project 2

SP3 – Sub-Project 3

UK – United Kingdom (for the purposes of this project, the definition of the UK will exclude Northern Ireland)

UKERC – UK Energy Research Centre

UK GDP – UK Gross Domestic Product

URAC – Unregulated Asset Cost

VAT – Value Added Tax

VED – Vehicle Excise Duty

VKT – Vehicle Kilometres Travelled

WEP – Wholesale Electricity Price

WP – Work Package

WTW – Well to wheel