This document was prepared for the ETI by third parties under contract to the ETI. The ETI is making these documents and data available to the public to inform the debate on low carbon energy innovation and deployment.

Programme Area: Light Duty Vehicles

Project: Economics and Carbon Benefits

Title: Economics and Carbon Offset Analysis Final Report

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. This is the final report from the Economics and Carbon Benefits project. It presents an overview of the analysis and modelling, an overview of the results and a discussion of the key findings and their implications. An Executive Summary is presented on pages i to vii, which highlights the key findings, implications and recommendations. Generic business models which may be effective during the initial launch / take-off of a plug-in vehicle market in the UK were evaluated in deliverable WS3/ARUP/06. The potential for complimentary revenue streams to contribute to overall economic viability was evaluated in deliverable WS3/ARUP/13. Specific scenarios and sensitivity tests were defined in deliverable WS3/ARUP/10. The detailed analysis and modelling against these scenarios and sensitivity tests was explained in deliverable WS3/ITS/02.

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.

Energy Technologies Institute

ETI PiVEIP

E&CB Analysis Final Report

WS3/ARUP/19

Issue 2 | September 2011

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 212799-00

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

Document Verification

ARUP

Job title		ETI PiVEIP		**Job number** 212799-00	
Document title		E&CB Analysis Final Report		**File reference**	
Document ref		WS3/ARUP/19			
Revision	**Date**	**Filename**	WS3.ARUP.19_E&CB Analysis Final Report_v0.15.docx		
Draft 1	23/06/11	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	Jac Cross / Richard Reid / Neil Butcher / Peter Bonsall / Simon Shepherd	Neil Butcher	Peter Young
		Signature			
Issue 1	03/08/11	**Filename**	WS3 ARUP 19_ECB Analysis Final Report_v2.0.docx		
		Description	Issue to ETI		
			Prepared by	Checked by	Approved by
		Name	Jac Cross / Richard Reid / Neil Butcher / Peter Bonsall / Simon Shepherd	Neil Butcher	Peter Young
		Signature			
Issue 2	02/09/11	**Filename**	WS3 ARUP 19_ECB Analysis Final		
		Description			
			Prepared by	Checked by	Approved by
		Name	Jac Cross / Richard Reid / Neil Butcher / Peter Bonsall / Simon Shepherd	Neil Butcher	Neil Butcher
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document Verification with Document ✓

CONFIDENTIAL - Not to be disclosed other than in-line with the terms of the ETI Technology Contract

IP OWNERSHIP – As defined in the ETI Technology Contract

Contents

Tables

Figures

Appendices

Appendix A

Dieter Helm Peer Review

Appendix B

Modelling Caveats

B1 Modelling Caveats

Appendix C

Carbon Abatement Costs

Appendix D

Theme Descriptions

Appendix E

Carbon Reduction Targets

E1 Carbon Reduction Targets

Executive Summary

Background to the Project

The Energy Technologies Institute (ETI) has a high-level Energy System Modelling Environment (ESME), which enables the most cost effective overall energy system for 2050 to be identified (taking into account the uncertainties). This high-level analysis has identified plug-in vehicles[1] (PiVs) as one of the key technologies for achieving the 80% reduction in greenhouse gas emissions required by 2050.

In 2009, the ETI highlighted a requirement to undertake a more detailed assessment of the business case for the mass-market deployment of PiVs in the UK and the required energy infrastructure. To do this, new research was needed together with analysis and modelling, where appropriate, to understand the interrelationships between government policy, consumer attitudes, automotive industry investment and energy industry investment. The effects of the wider macroeconomic environment were also considered to be important.

The Economics and Carbon Benefits project is one of three projects on PiVs commissioned by the ETI to meet the above requirement. These projects have conducted new research to develop the underlying knowledge base:

- Detailed projections of future vehicle performance (such as electric range and efficiency) and costs to 2050 have been developed for the full range of future power-train options;
- Consumer attitudes and behaviours have been researched through real-world trials and extensive surveys with 'mass-market' consumers; and
- The requirements and costs for the supporting recharging infrastructure and its integration into the UK electricity system have been identified.

Building on this detailed knowledge base development, the Economics and Carbon Benefits project has undertaken analysis and modelling to determine the potential role, economics and carbon benefits of PiVs in the UK's future low carbon transport system. The implications for the various stakeholders have also been identified.

The ETI is planning a follow-on project to deliver the necessary commercial confidence for mass-scale investment.

Key Findings

PiVs and in particular BEVs offer the potential to decarbonise a large proportion of passenger car transport. However, consumer attitudes, battery technology and PiV purchase costs are expected to be a significant barrier to PiVs outselling conventional vehicles. In the base case, in 2050, the OEMs provide cross-subsidies between cars to encourage purchase of low emission cars. Penalties of

[1] 'Plug-in Vehicle' refers to any vehicle capable of being powered by an external electricity supply. It includes Battery Electric Vehicles (BEVs), which can only be powered by an external electricity supply, and Plug-in Hybrid and Range Extended Electric Vehicles (PHEVs and RE-EVs), which can be powered by either an external electricity supply or petrol/diesel fuel.

the order of £10,000 are given to the worst CO_2 emitting conventional cars compared to BEVs, but still the conventional vehicles outsell the BEVs many times over.

Under the "most likely" assumptions for the global and national environment and Government policy, PiVs are expected to achieve a 19% share of the UK car parc by 2050, with this share being dominated by PHEVs (11%), and REEVs (7%), rather than BEVs (1%). In-use CO_2 emissions reduction is predicted to be 69% on 1990 levels for this case.

Very high levels of PiV take-up are only achieved with favourable factors occurring simultaneously; in particular faster than expected PiV development, a positive shift in consumer attitudes towards PiVs, and high levels of charging infrastructure deployment. With this environment, the parc is dominated by PiVs - PHEVs (35%), REEVs (26%) and BEVs (28%) in 2050, and an 84% reduction in in-use CO_2 emissions on 1990 levels is achieved.

Given that PiVs are likely to make up around 20% of the vehicle parc in 2050, the vast majority of emissions reduction is likely to come from improvements in the fuel efficiency of conventional vehicles. This improvement is primarily driven by fleet average emissions legislation which is defined in EU Regulation (EC) No 443/2009 until 2020. There after a linearly decreasing tailpipe target to 42g by 2050. Setting an appropriate 2050 target to achieve required emissions reduction and a penalty to incentivise OEMs adequately to develop their showroom offer within that target will form an important part of emissions reduction strategy.

Government incentives considered in this study, including vehicle subsidies, have little lasting effect on PiV take-up and CO_2 emissions. The most effective policy is subsidising the deployment of charging infrastructure, including that in the domestic and workplace environment.

The success of the long term business case for public charging infrastructure is dependent on the scenario, with installation of charge points stalling in unfavourable scenarios and expanding rapidly and profitably in favourable scenarios.

The plug-in car grant is currently insufficient to increase PiV sales other than to a small number of early adopters. The grant only has short term benefit on sales and they return to the unsubsidised level when it is removed.

To decarbonise the passenger car sector further, it appears that more extreme policies that support ultra-low WTW emission vehicles, will be required. (i.e. lower emissions than PHEV and REEV capabilities). For example potential government policies could include:

- Only allowing ultra-low WTW emission vehicles in major cities around the UK;
- Raising taxes even more significantly for all vehicles other than ultra-low WTW emission vehicles to overcome the preference consumers have for the former.

The success of the PiV market depends critically on the purchase prices of PiVs, which are outside the direct control of the UK Government. EU fleet average emissions legislation can however encourage manufacturers to subsidise PiVs at the expense of higher emitting vehicles.

Hydrogen-fuelled and 100% bio-fuel cars have been omitted from this study, because insufficient data was available to model their impact accurately. If they are made available at a price competitive with conventionally fuelled vehicles, and the necessary infrastructure is deployed, they could displace some conventional vehicles (and some PiVs) in the UK parc and help to reduce emissions further than predicted in our scenarios.

There appears to be little chance for profitable public charging point operation until PiVs are widespread.

In-use emissions will be greatly reduced by 2050, so production and scrappage emissions will become a significant proportion of whole life emissions. To reduce this contribution, increasing the life of vehicles will be important and, in the case of PiVs, the hurdles to battery replacement may need to be addressed, so vehicle life is not limited to battery life. This could lead to a market for vehicle reconditioning – upgrading dated powertrain components, including batteries, and potentially reskinning chasses to meet changing fashions. A high carbon tax would encourage the retention of vehicle systems with high-embodied carbon.

The carbon abatement costs in 2050 for BEVs in the baseline scenario are predicted to be £530/tCO_2, and range between £230/tCO_2 and £350/tCO_2 for PHEV/REEVs. These compare to the “high” 2050 carbon price of £300/tCO_2 forecast by DECC in June 2010. Therefore, PHEV/REEVs are attractive around the “high” DECC 2050 carbon price, but BEVs remain economically unattractive.

Implications

Government

The success of the PiV market depends critically on consumer behaviour and attitudes. The (primarily financial) incentives resulting from most of the modelled policies have little effect on consumers’ purchase decisions. Other types of Government action targeting attitude change may be more cost effective, although there is currently no data to support this.

Financial support of charging infrastructure offers a more cost effective means to stimulate PiV sales than PiV subsidies. A particularly cost effective policy might be to subsidise domestic and workplace charging infrastructure.

Increasing the plug-in car grant would encourage a short term increase in PiV sales. However, on removal of the grant sales would return to the unsubsidised level.

It should also be noted that the modelling does not take account of the effect the plug-in car grant has on encouraging vehicle manufacturers to sell their vehicles in the UK, or the effect it has on UK GDP in increasing manufacturing and industry in the UK. Its removal would send a negative message to vehicle manufacturers, who currently see the UK as a prime market for early sales of PiVs.

Increases in fuel duty and CO_2-based VED or the introduction of road user charging could help finance Government support. These measures would also assist in reducing transport emissions, by increasing PiV uptake and reducing total Vehicle Kilometres Travelled (VKT).

Growth in the vehicle parc and increase in vehicle usage are linked to GDP growth, which consequently has a significant effect on emissions in the absence of mitigating action. If GDP growth is higher than expected the challenge of emissions reduction becomes greater and additional Government action may be needed to influence consumer and car manufacturer behaviour.

Charge Point Manufacturers and Operators

PHEV/REEVs dominate PiV sales under all scenarios considered. The willingness to pay for public recharging of PHEV/REEV drivers is likely to be limited to the cost of running the vehicle in non-electric mode. The demand for public recharging is also likely to be reduced as consumers will be less concerned about running out of charge, so are less likely to top-up away from their regular charging location.

The business case for charging infrastructure is subject to a great deal of uncertainty around factors such as consumer recharge behaviour, likely utilisation of charge points and the value of any benefits to businesses of providing charge points over and above the price of charging. Installing infrastructure will remain high risk until there is greater clarity on these issues and PiV deployment is widespread.

Vehicle Manufacturers

Sales of both PHEVs and REEVs rise steadily. Their combined annual sales in 2050 vary considerably, ranging from 45k when external factors are unfavourable, 800k in the baseline, to 3,100k when all factors are favourable.

BEV sales are more susceptible to external factors, due to their high purchase price and perceived reduced utility. High volume sales are dependent on further battery development, on changes in consumer attitudes , or on Government emissions targets almost unreachable by other technologies. Their annual sales in 2050 range from 0.4k when conditions are unfavourable, and 30k in the baseline, to 1750k when factors are all favourable.

In all scenarios PHEV/REEVs outsell BEVs considerably. PHEVs/REEVs look like they will dominate for the medium term, and BEVs remain a niche market. If the EU emissions targets continue to fall BEVs are likely to become more widespread in the longer term.

It therefore appears that the majority of investment by vehicle manufacturers will be in PHEV/REEVs rather than BEVs.

Electricity Utilities

Due to their smaller battery size, on average a PHEV and to a lesser extent a REEV uses less electricity than a BEV. Therefore the domination of PiV sales by PHEV/REEVs means overall electricity demand will be lower than would be the case if BEV take-up was more significant. Demand for rapid charging is likely to be very low due to the capability of PHEV/REEVs to revert to non-electric mode when low on charge, unless there is a financial benefit in doing so.

The increase in peak grid demand due to PiVs is small (in the order 5%) even in the most optimistic scenario for PiV take-up. Whilst this reduces the need for additional generation capacity, it also reduces the potential to smooth the demand load by encouraging PiVs to charge overnight.

Where there are concentrations of PiVs on a local domestic network or contention with other electricity demand such as heat pumps, there are likely to be requirements for network reinforcement unless smart grids can stagger charging.

Oil Companies

The UK vehicle parc is likely to remain dominated by vehicles with an internal combustion engine (either conventional vehicles or PHEV/REEVs), so petrol and diesel will continue to have an important role to play in UK car transport. However, demand for fuel will drop dramatically by 2050, by at least 65% on 2010 levels, due to the increase in fuel efficiency of internal combustion engines and due to take-up of PHEV/REEVs.

It is likely that vehicle manufacturers will reduce fuel tank sizes rather than increase vehicle range for conventional vehicles. Hence the number of re-fuelling visits and the number of fuel stations is likely to stay similar to the number today.

Further Research

This project was instigated to provide guidance on a number of questions that are dependent upon the speed and level of deployment and usage of PiVs. Vehicle manufacturers want to know where and when to invest in development programmes and manufacturing facilities for PiVs. Charging behaviour affects the business case for investment in charging infrastructure and back office services, and in additional generation capacity, smart grids and network reinforcement. In addition, a reliable prediction of the future number of PiVs allows Government to plan its incentives, taxes and regulatory strategy to meet its commitments to future CO_2 reductions.

Although the project has provided insight into the effect of the major levers that will affect the deployment of PiVs, there are still areas of uncertainty that prevent a confident forecast. Some of these are unpredictable external factors, e.g. oil price and battery prices, but, for others, future data collection and correlation of the assumptions in the Consumer Response Model (CRM) will reduce the current wide range of predicted results.

Further research into consumer attitudes will contribute substantially to reducing uncertainty in the model output. Research should focus on: acceptance of the idea of PiVs and how that might change with time including the effect of product diffusion; and the importance attached to domestic and non-domestic charging infrastructure and how that might change over time.

The deployment and potential profitability of non-domestic charging infrastructure is highly dependent on consumer recharge behaviour and achievable utilisation, which are currently poorly understood, due to a lack of large scale trial data. Research in this area will significantly reduce uncertainty related to charging infrastructure.

Maintenance and updating of the databases and algorithms that underpin this work would be worthwhile, and allow the Consumer Response Model (CRM) to be updated and validated to produce improved forecasts in the future.

Recommendations

The Government should plan for the vast majority of PiVs to be PHEVs and REEVs when they become available. A large swing from these to BEVs will require a combination of a significant change in consumer attitudes, a breakthrough in battery technology, strict EU emission limits and penalties, and larger financial incentives than considered in this project.

Government should work with the EU to assess the costs and benefits in changing the EU fleet average emissions target to be based on WTW rather than TTW emissions.

With a VKT value of 453 billion km in 2050, the target for EU maximum fleet average emissions should be around 18g CO_2/km by 2050 if a 90% reduction in 1990 car emissions to 8.1MtCO_2 is to be achieved. Our results suggest that the current EU penalty on manufacturers of €95 per g CO_2/km above target will be insufficient to achieve compliance by 2050. Further work is required to derive a suitable penalty which might increase with time.

Government, in conjunction with EU, should set a standard methodology to measure production and scrappage emissions and consider the introduction of a regulation or taxation for reducing these.

Government should consider how it will replace lost fuel duty revenue due to improved vehicle efficiency and increased sales of PiVs. A structure directly relating tax to emissions is recommended. E.g. increased fuel duty or road user charging.

Strict emission limits for beneficial rates of VED, employee company car tax, write-down rates for corporation tax will all assist the move towards PiVs. The emissions bands should be revised in line with the expected future reduction in all vehicles' emissions.

Government should seek to remove the plug-in car grant subsidy as soon as a self-sustaining market for PiVs is achieved, since it will quickly become an expensive subsidy. It should therefore revisit the value of the plug-in car grant annually to achieve PiV sales growth, with a view to its eventual removal.

Government should continue to subsidise the installation of charging infrastructure, in a similar manner to the Plugged-in Places schemes, but at a national level. Subsidies should include domestic and workplace charge points.

Network reinforcement costs and charge point intelligence costs (CIC) should be added to the regulated asset base to minimise the cost of electricity at public charging points, and to improve the business case for charge point operators. It is anyhow difficult to isolate the costs of network reinforcement associated with PiV charging. It is recommended that one central back office for billing at charging points is established to minimise CIC, negate the need for roaming charges between regions, and assure interoperability.

Government should initiate a study to investigate the potential effectiveness of campaigns to change consumer attitudes towards PiVs, as the attitudes were shown to be a critical factor in the successful uptake of the vehicles.

Further research should be commissioned on recharge behaviour as soon as sufficient vehicles are sold and data becomes available. This should ideally be based on mass market consumers, and should cover both time and location of recharging to predict effects on the Grid and required numbers of public charge points. Analysis of charging rate and electricity price elasticity at the various locations will underpin the business case for both standard and rapid public charge points.

Consideration should be given to future maintenance and updating of the databases and behavioural algorithms that underpin this work. In particular this should concentrate on consumer attitudes, recharge behaviour, charge point deployment algorithm, vehicle technology and costs.

This would then allow the CRM to be updated and validated to produce improved forecasts in the future.

Research should be performed to understand the shift in the time of vehicle charging that can be achieved by the use of variable tariffs. This will have benefits in minimising electricity CO_2 emissions, generating capacity requirements, and network reinforcement costs.

Abbreviations

BEV	Battery Electric Vehicle (a fully electric vehicle)
CCC	Committee on Climate Change
CIC	Charge point intelligence costs (also described as NIC or network intelligence costs in previous project reports and the attached peer review)
CO_2e	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	Charge Point Cost
CRM	Consumer Response Model
ETI	Energy Technologies Institute
ETI ESME	ETI Energy System Modelling Environment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IA&S	International Aviation & Shipping
ICEV	Internal Combustion Engine Vehicle
LEV	Low Emission Vehicle
M1	Vehicle category as defined in 2007/46/EC:- Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.
NEDC	New European Drive Cycle
NR	Network Reinforcement
NRC	Network Reinforcement Cost
OEM	Original Equipment Manufacturer (a car manufacturer)
P&S	Production and scrappage
PHEV	Plug-in hybrid electric vehicle, i.e. a parallel hybrid electric vehicle
PiV	Plug-in vehicle, includes battery electric vehicles, plug-in hybrid electric vehicles and range-extended electric vehicles
PiVEIP	Plug-in Vehicle Economics & Infrastructure Project
REEV	Range-extended electric vehicle, i.e. a series hybrid electric vehicle
SP1	Sub-Project 1 – Consumers & Vehicles Sub-project

SP2	Sub-Project 2 – Electricity Distribution & Intelligent Infrastructure Sub-project
SP3	Sub-Project 3 – Economic & Carbon Benefits Sub-project
TTW	Tank-To-Wheel
UK	United Kingdom (although the term UK is widely used within this report, the project was limited to GB, i.e. UK excluding Northern Ireland)
UKERC	United Kingdom Energy Research Centre
WTT	Well-To-Tank
WTW	Well-To-Wheel

1 Introduction

1.1 Background

The Energy Technologies Institute's (ETI) Plug-in Vehicle (PiV) Economics and Infrastructure Programme (PiVEIP) 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 has seen significant new research being performed in various sectors important to the deployment of PiVs. The research has yielded comprehensive datasets for use as input data to a consumer purchase model for UK passenger vehicle purchases between 2010 and 2050. The research and the resulting datasets are described more fully in Section 2.2.

Stage 1 has covered technical, behavioural and economic aspects and has enabled the potential role and economics of PiVs to be extensively evaluated.

Proposed further stages of the project will conduct more extensive real-world trials to deliver the necessary commercial confidence for mass-scale investment.

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

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

This final project report documents the conclusions of the economics and carbon benefits analysis (Project 3, led by Arup) presenting:

- An outline of the new research undertaken within the first two projects
- An overview of the modelling and analysis methodology
- The key results from the modelling and analysis work.
- Key observations and insights emerging from the modelling and analysis together with top-down confirmation using key supporting data; and
- The overall conclusions and recommendations, with reference to implications for particular stakeholders.

For further detail on the analysis completed within the economics and carbon benefits project please see key deliverables:

- WS3/ARUP/06 - Generic Business Models
- WS3/ARUP/10 – Scenarios Development Final Report
- WS3/ARUP/13 – New Revenue Streams
- WS3/ITS/02 – Detailed report on Computer Modelling
- WS3/EON/03 – Energy Scenarios Comparison Report

1.2 Carbon Reduction Targets

The Climate Change Act was introduced in the UK in 2008 and set up a legal framework to tackle the issues of climate change. The Act requires that emissions are reduced by at least 80% by 2050, compared to 1990 levels.

This report assumes that the UK will remain committed to meeting the legally binding GHG emission targets by 2050.

Appendix E describes the economy wide and surface transport carbon reduction targets. A discussion on Tank-To-Wheel (TTW) and WTW targets for the passenger car sector based on analysis by the Committee on Climate Change (CCC), and by the ETI using the Energy System Modelling Environment (ESME), is also provided.

This project reports WTW emissions in order to provide a true comparison between Internal Combustion Engine Vehicles (ICEVs) and PiVs. No recommendation is made on the WTW emissions reduction target for 2050, but for the purposes of discussion, we have assumed a reference level of 90% (see Appendix E) reduction from 1990 levels by 2050. This equates to 8.1 $MtCO_2$ down from 80.6 $MtCO_2$ in 1990 (DECC).

1.3 Project Objectives

The two primary objectives of the PiVEIP (as outlined in Section 1.1) are:

Evaluate the potential role and economics of plug-in vehicles in the low carbon transport system: generate a quantified understanding of the market potential, cost models and carbon benefits case under defined scenarios of infrastructure investments, government intervention packages and finance model options across a number of key plug-in vehicle type/size/capability points; and

Develop the technology tool-kit for delivering an intelligent infrastructure: create a verified open interoperability architecture and generate information to aid infrastructure planning (e.g. to indicate how many recharging points are needed and where they should be located, what mix of power levels are required, how the impact of plug-in vehicle recharging on the electricity distribution network should be managed, how the overall system can be simplified for consumers, etc).

The Project is limited to vehicles of the M1[2] category within the UK, excluding Northern Ireland, between 2010 and 2050.

Analysis of hydrogen vehicles was initially included at a superficial level. They were removed mid-way through the Project as it was considered that a much more detailed study (requiring significant new research to achieve a comparable level of robustness) was required to understand their impact. The results presented in this report assume that no hydrogen vehicles are sold.

2 Vehicle category as defined in 2007/46/EC:- Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.

2 Modelling and Scenarios

2.1 Methodology

In the creation of a computer representation of the PiV market, it has been necessary to perform new research, described in outline in Section 2.2, to allow the project to determine the influence of the following factors.

- Vehicle specification and performance
- Vehicle technology development
- Vehicle costs
- Fuel costs including electricity as well as liquid and gaseous fuels
- Taxes and incentives
- Consumer views and expectations
- Grid generation future strategy
- Charging infrastructure business case
- Regulatory environment
- Macroeconomic environment

Various variables have been defined which characterise these factors, e.g. vehicle range, cost, GDP growth, oil price. Each has been assigned a 'base case' (most likely) and bounding (low and high) values. 29 of the variables are policy levers available to the Government. The variables and policies are listed in Appendix D.[3]

These variables, policies and their associated base, low and high values were agreed through a stakeholder engagement process with Government, ETI members and external stakeholders. The policy values were agreed with consideration of what was 'likely' and would be 'politically acceptable'.

In order to investigate fully the space of possible futures, it would be necessary to consider all the combinations of settings of all the factors. This is infeasible as the number of analyses required would be many billions. Instead the approach has been to explore the space for specific scenarios where a scenario is defined by a set of values for all of the input variables.

Two approaches have been utilised to explore the space adjacent to the base case (most likely) scenario which is defined by setting all the variables to their base case values.

- Sensitivity analyses have been performed by changing each variable to "high" or "low" in turn, keeping the remaining variables at their baseline value. This provides information on the sensitivity of the key outputs to the variable being changed. Note that care should be taken in using these sensitivities away from their datum of the base case scenario.
- Optimisation to identify the "best package" of the 29 Government's policies has been performed, maximising their effect for the case where other

[3] WS3/ARUP/10 – Scenarios Development Final Report – v2 Final Issue – The report describes in detail the variables and each of the scenario tests.

"external" factors are set to their base case values. "Best package" was defined as the set of values for the 29 available policy levers which, while meeting a target reduction in CO_2 by 2050, did so at minimum cost to the Exchequer. The levers are listed in Appendix D. The policy optimisation work has been performed by Leeds ITS.

In addition, a small set of consistent "Themed Scenarios" has been analysed, and reviewed in more detail. These consider specific possible futures, both in terms of Government policy and external factors. The "Themed Scenarios" are described in Section 2.3.2, and are 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 computer models (described in Section 2.2) predict the yearly figures for a variety of outputs associated with PiV deployment between 2010 and 2050. These include the sales of different M1 vehicle types, the deployment of charge points, the carbon emissions from the vehicles, and the net cost to the Exchequer of taxes and incentives. In particular the following four key indicators have been used to classify the scenario results:

- PiV % of GB car parc in 2050 split by BEV and PiV
- Total number of non-domestic charge points installed in 2050
- Whole life WTW emissions in 2050[4]
- Exchequer spend between 2010 and 2050.

2.2 Derivation of the Constituent Datasets

The **Consumer Response Model (CRM)** is the product that accesses the datasets created by the project. At its heart is a rational consumer 'choice' model whose overall focus is on determining consumers' car purchase decisions. This leads to a prediction of the number of each type of vehicle sold each year, and allows calculation of vehicle parc characteristics, CO_2 emissions, and economic measures. The CRM has been developed by Element Energy.

The eight attributes that influence consumer purchase behaviour have been determined by a qualitative consumer survey as follows: -

- Capital cost of vehicles
- Annual running costs including fossil fuel and electricity costs
- Vehicle performance (0-60mph relative to a typical vehicle)

[4] Electricity emissions have been calculated using the average Grid carbon intensity factor at the time of vehicle charging - calculated by E.ON and EDF.

- Vehicle emissions
- All-electric range
- Recharging time
- Availability of home or work charging infrastructure
- Availability of public recharging infrastructure

The consumer choice model itself is based on a quantitative Discrete Choice survey of 2,700 buyers of new or nearly new cars, performed in November 2010 by TRL. The survey is the most detailed research ever conducted into consumer attitudes to PiVs, and was designed to gain insight into the relative importance of the eight attributes. Private consumers were segmented into seven groups (from pioneers to rejecters). In addition, an eighth segment was created to represent company car buyers. Having segmented the survey returns, the data was analysed to produce coefficients for use in the utility equations of a Logit model within the CRM. For each consumer segment, the model predicts the share of market purchases of different types of vehicle based on their attributes.

The consumers chose their vehicles from a virtual vehicle showroom based on the first six attributes, with their choice being influenced by the level of available charging infrastructure – attributes 7 and 8. Installation of charging infrastructure in each year is dependent upon the usage of the infrastructure in the previous year. The project has conducted research into each of the attributes to provide forecast values for each year through to 2050.

- **Vehicle technology –** A database has been created using a vehicle technology roadmap to 2050, for 16 powertrain types and 10 vehicle segments (sub-mini, mini, supermini, lower medium, upper medium, executive, luxury saloon, special sports, dual purpose and MPV). It predicts the development of vehicle performance over this timeframe measured as attributes 3, 4 and 5. The dataset has been developed by Ricardo.
- **Vehicle costs –** The vehicle cost dataset has also been developed by Ricardo with the creation of a bottom-up database of vehicle cost predictions to 2050 for the vehicles covered in the vehicle technology database. The database includes purchase costs, maintenance and insurance costs for attributes 1 and 2.

In addition, research has been undertaken to allow analysis of the implications of large numbers of PiVs on the Grid and the wider economy. This allowed prediction of the cost of electricity from both private and public charging points, and the CO_2 emissions that are associated with electricity generation and distribution. Areas of research are summarised below.

- **Grid generation analysis -** The modelling has investigated the way in which future electricity demand could be met for a set of different capacity mix and commodity price scenarios. The capacity mix scenarios are based on UKERC's Energy 2050 study. The utilisation of the mix to meet demand is based on an economic and operational assessment using the prevailing fuel prices. The modelling provides consumer electricity prices and emission factors through to 2050. The grid generation modelling has been developed by EON and EDF[5].

- **Network reinforcement requirements –** The likely incremental impact of PiVs on the GB distribution networks was assessed. Costs were quantified through evaluating likely network reinforcements needed to support the increase in electricity demand at the DNO level. The network reinforcement modelling has been developed by Imperial College Consultants.

- **Charge point costs –** The supply chain and component costs within the PiV recharging infrastructure have been assessed. These were developed into system costs (components and installation) for each type of recharging infrastructure for each year out to 2050. The charge point cost modelling has been developed by EON.

- **Charge point intelligence modelling –** This work predicted the future costs associated with operating and maintaining a network of charging points including the back office costs required to bill for the electricity and manage the interactions of PiVs with public infrastructure. The charge point intelligence modelling has been developed by IBM. The costs exclude those associated with smart grid and smart meters which are assumed to be necessary with or without electrification of transport.

2.3 Analysis

2.3.1 Sensitivity Tests

Sensitivity tests are performed to determine single variable sensitivity about the Base Case for all variables in the overall system model. In some cases variables are changed together where this is considered to be necessary for the sensitivity test to make sense.

The 103 tests are split into the following categories depending on the type of variable being tested:

- Vehicle technology tests
- Electricity generation and grid impact tests
- Electricity price tests
- Charging infrastructure and deployment tests
- Consumer behaviour tests
- Government policy tests

2.3.2 Themed Scenarios

Twelve Themed Scenarios explore PiV take-up and carbon emissions under a range of different potential future states.

[5] WS3/EON/03 – Energy Scenarios Comparison Report

- The Base Case (T0) scenario has all variables set to their most likely values or to a business-as-usual value.
- Five scenarios explore the upper and lower bounds of PiV take-up and emissions:
  a) all variables are set to be maximally favourable to PiV take-up (T1) or minimally favourable to PiV take-up (T2); and
  b) Government incentives are as announced, but all other factors are maximally favourable to PiV take-up (T3) or minimally favourable to PiV take-up (T4).
  c) Minimum Carbon Emissions (T12) considers the effects of all variables being set to minimise CO_2 emissions in 2050: high commodity prices, low UK GDP growth, high vehicle development, a supportive environment for charge point deployment, consumer attitudes positive for PiV take-up, and supportive Government policies.
- High rate of UK GDP growth (T5) and low rate of UK GDP growth (T6), which affects the size of the parc, total vehicle kilometres travelled, electricity base load (all positively correlated with GDP) and consumer sensitivity to prices (negatively correlated with GDP).
- Five scenarios explore the effects of the global economic environment:
  a) High (T7) and low (T11) rates of growth in the global economy are assumed to be positively correlated with commodity prices, UK GDP growth, and vehicle development.
  b) Medium global growth with a green emphasis (T8) is associated with high commodity prices, low UK GDP growth, high vehicle prices with advanced vehicle attributes, a supportive environment for charge point deployment, consumer attitudes positive for PiV take-up, and supportive Government policies.
  c) High oil price (T9) and Oil Price Spike (T10) take base values for all variables except the price of oil, which is either high or follows the base price curve with a temporary spike in price between 2020 and 2030.

2.3.3 Optimisation of Policy

The purpose of the optimisation test is to identify the policy package that meets a CO_2 emissions target in 2050 at minimum cost to the Exchequer with all non-policy variables set to their base values. The policy package is defined by the policy levers in the overall system model.

The CO_2 target is set to be 5% higher than the lowest emissions found from a systematic search of the policy space around the Base Case scenario, in order to give the optimisation room for manoeuvre.

The minimum cost to the Exchequer is defined as the present value of the excess of expenditure over revenue summed over the years 2010 to 2050 including the value of CO_2 emissions during that period valued at the mid-range values quoted by DECC[6].

The optimisation work also included a further investigation of the trade-off between CO_2 emissions and net expenditure by the Exchequer.

[6] DECC (2010) Carbon Valuation in UK Policy Appraisal – Updated short term traded carbon values for UK public policy appraisal – June 2010

3 Results

3.1 Base Case Results

The base case represents the most likely scenario and is defined by all variables taking most likely or median values. The key outcomes in the base case are:

- In-use CO_2 emissions from passenger cars reduce to 25Mt in 2050 (69% reduction on 1990 levels), driven largely by improvements in the fuel efficiency of non-PiVs
- Exchequer spend related to PiVs from 2010 to 2050 is £5billion
- PHEV/REEVs make up 19% of the UK vehicle parc in 2050 with BEVs making up 0.6%
- PiVs have only a localised effect on grid demand

Between 2010 and 2050 the UK vehicle parc grows from 29million to 45million. The share of PHEV/REEVs and diesel non-PiVs grow at the expense of gasoline non-PiVs, reaching 19% and 46% respectively by 2050 (Figure 1). Sales of BEVs remain low and in 2050 they only make up 0.6% of the UK parc (Figure 1).

- In 2020, basic petrol and diesel vehicles are discontinued with stop-start vehicles becoming the least hybridised vehicle architecture and OEMs begin to adjust vehicle prices to influence sales to achieve fleet average emissions targets.
- Vehicle emissions reduce more slowly than the assumed emissions target, so by 2035, in segments C and D, the emissions of all non-PiVs apart from diesel full hybrids exceed 90% of the target[7].
- By 2035 non-PiV emissions near or exceed the fleet average emissions target, so increasing price adjustments are applied. However, these are insufficient to encourage consumers to buy PiVs, so by 2046 the target is exceeded and remains so through to 2050.

[7] Vehicle attributes for 2010 to 2050, Ricardo, 16 November 2010.

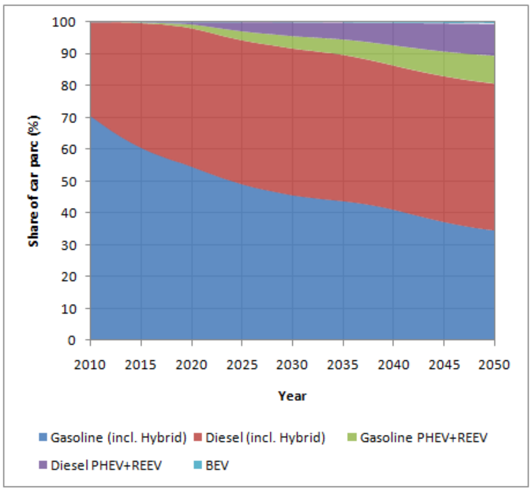

Figure 1 Share of cars in the parc

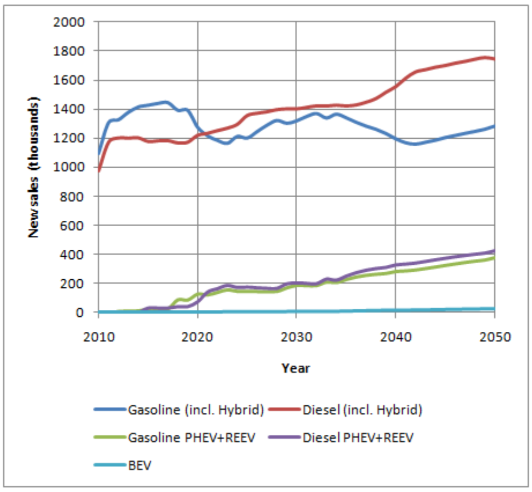

Figure 2 New car sales by type

CO_2 emissions from car use reduce from 78Mt/year in 2010 to 25Mt/year in 2050 (Figure 3), a 69% reduction on 1990 levels, which is far less than the 90% reduction estimated to be required by CCC[8].

- Most of the in-use emissions reduction comes from the improvement in fuel efficiency of non-PiVs (Figure 4) – an entirely non-PiV parc would emit around 28Mt/year in 2050, a 65% reduction on 1990 levels.
- The CO_2 emissions of PHEV/REEVs are on average 46% of those of non-PiVs. Replacing 19% of the parc with PiVs contributes a further 4% reduction in 1990 levels.
- The contribution of PHEV/REEVs is limited somewhat by their smaller battery size meaning only shorter journeys are powered by grid electricity. Longer journeys, which have the greatest contribution to CO_2 emissions, are liquid fuel powered. To further decrease CO_2 emissions battery size would need to be optimised for emissions.
- The CO_2 emissions of BEVs in 2050 are very low, as the grid is assumed to be largely decarbonised by then. However, the low take-up of BEVs means only 0.6% of the parc is fully electric and their effect on overall emissions is correspondingly small.

Emissions from production and scrappage increase by 53% from 15Mt in 2011 to 22Mt in 2050 (Figure 3).

- The vehicle parc increases by 55%, from 29million to 45million, over this period, indicating that average production and scrappage emissions per vehicle only decrease by a small amount.
- In 2050 generally all vehicle types are forecast to have lower production and scrappage emissions than a 2010 petrol or diesel, except BEVs, which

[8] CCC – The Fourth Carbon Budget – Reducing Emissions through the 2020s (December 2010).

have significantly higher emissions than other vehicle types due to their large battery[9].

- Production and scrappage emissions are treated differently from in-use emissions in terms of the UK's carbon obligations – they are attributed to the country of manufacture not the country of purchase.

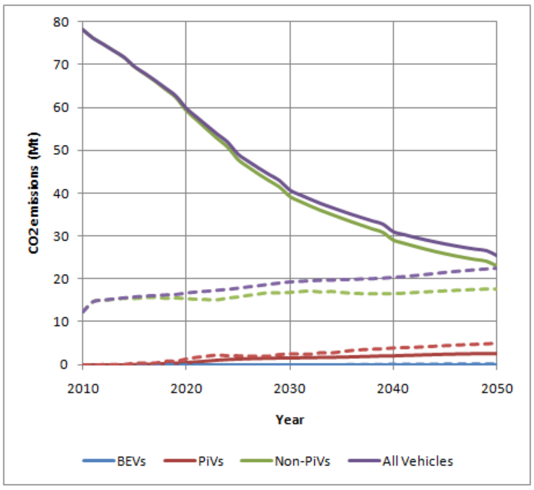

Figure 3 In-use[10] (solid lines) and production and scrappage[11] (dashed lines) CO_2 emissions

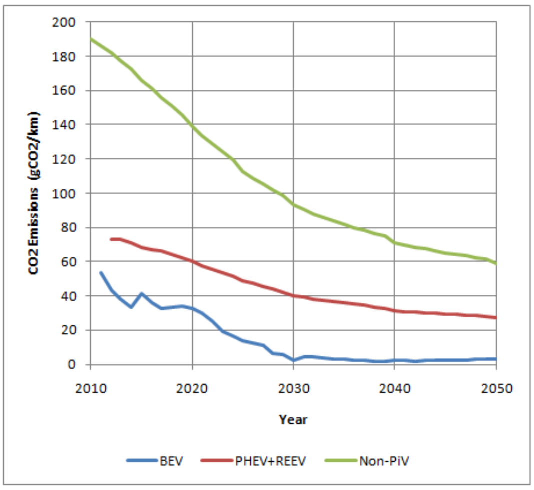

Figure 4 Emissions per kilometre of cars in the parc by type

Exchequer spend includes subsidies to PiVs and charging infrastructure and corporation tax lost to incentives for LEVs, which dominates the overall spend (Figure 5).

Lost corporation tax is really delayed receipt of corporation tax, due to faster allowable write-off of LEVs, which shows as a loss in an expanding LEV market. For example, the sharp increase in LEV sales in 2020, due to withdrawal from sale of base gasoline and diesel cars in 2019, causes a spike in corporation tax between 2020 and 2025, which returns to a much lower level when LEV sales become steadier (Figure 5).

Exchequer revenues are dominated by fuel duty and VAT. Fuel duty reduces substantially over the forty year period largely due to improved fuel efficiency of non-PiVs, but also due to the introduction of PiVs (Figure 6). In the base case a "revenue preserving" tax compensates for any reduction in fuel duty revenue below 2010 levels and is triggered in 2017. VAT and company car tax increase over the 40 year period reflecting increasing vehicle sales, but this effect is largely counteracted in VED by discounts for low emission vehicles reducing the average tax per car.

---

[9] Vehicle attributes for 2010 to 2050, Ricardo, 16 November 2010.
[10] In-use emissions have been calculated using the average CO_2 emissions of generation. Analysis has shown that the difference in in-use emissions between average, marginal and tapered methods of calculation is negligible in comparison with the overall CO_2 emissions from passenger cars.
[11] Production and scrappage emissions are important, but are treated differently from in-use emissions in terms of the UK's carbon obligations – they are attributed to the country of manufacture, not the company of purchase.

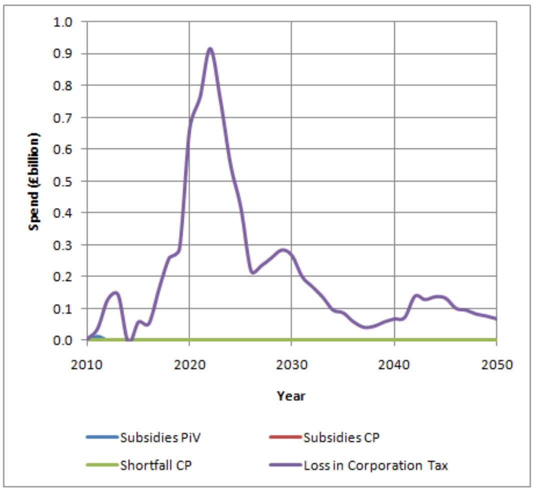

Figure 5 Exchequer spend including 'lost' tax

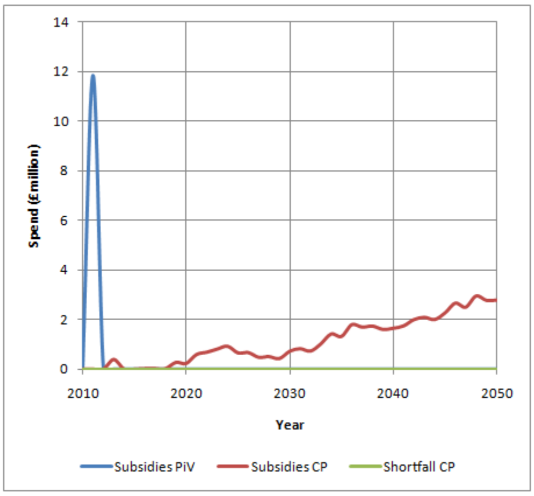

Figure 6 Exchequer spend on PiV related subsidies

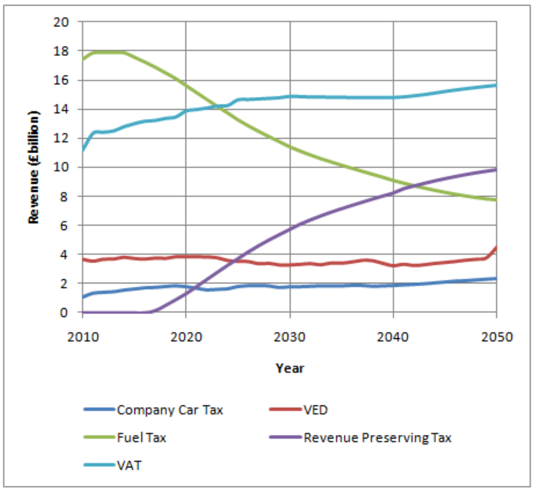

Figure 7 Exchequer revenue

The demand for electricity due to PiV recharging follows the take-up of vehicles, increasing steadily up to 2050 (Figure 8). Vehicles annual mileage is assumed to not vary with vehicle type, so BEVs draw more than twice as much electricity from the grid as PHEV/REEVs, which use liquid fuels to power some of their annual mileage. However, the low take-up of BEVs means electricity demand from PHEV/REEVs dominates.

The effect of PiVs on overall electricity demand is small (Figure 9). Most recharging is assumed to take place overnight, when the base load on the grid is low. However, if the price of liquid fuel increases relative to the price of electricity from non-domestic charge points, PHEV/REEV drivers may seek to recharge away from home instead of using liquid fuel to extend their range. This would put more pressure on public and workplace charge points and increase the amount of recharging carried out during the day.

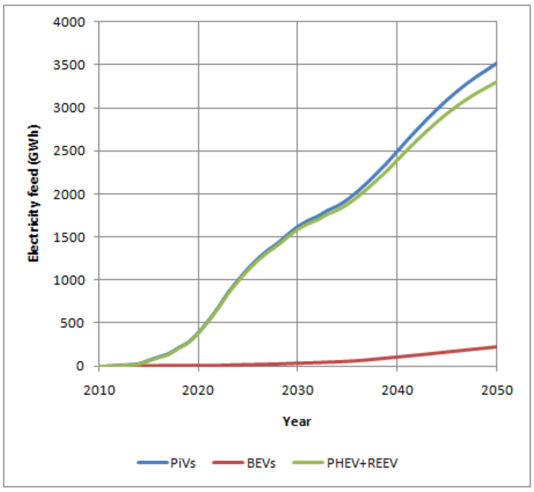

Figure 8 PiV electricity demand

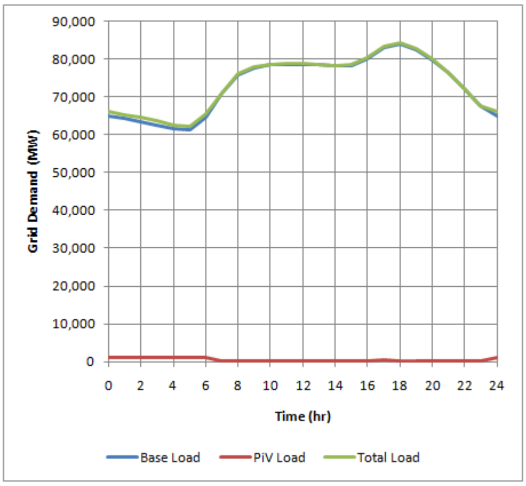

Figure 9 Effect of PiV electricity demand on the grid for winter weekday in 2050

The base case assumes consumers recharge primarily at home, if they have charging available there. The remainder of their charging is split between non-domestic charge point locations in fixed ratios, depending on availability (Figure 11).

Non-domestic charge points are installed if commercially justified based on revenue predictions, costs and other commercial considerations, e.g. the value derived from additional footfall at retail outlets and the value of employee goodwill for workplaces. Consequently the growth in charge point numbers reflects assumptions made about where consumers will recharge (Figure 10) and, as the number of charge points deployed rises, access to charge points improves so the proportion of recharging carried out at non-domestic charge points increases (Figure 11).

Providing charge points will be a source of differentiation for retailers and employers as long as their competitors do not provide a similar facility. Once most retailers and employers provide CPs their value in terms of attracting consumers or employees who would otherwise have gone elsewhere is diminished (although not providing CPs could then result in a negative effect).

In the base case the value of CPs to retailers is taken to be £3 for a 2hr visit and for £2.50 per day for employers. Although they are estimates these figures are reasonable compared to other ‘free’ benefits offered by retailers and employers, for example free parking and free buses.

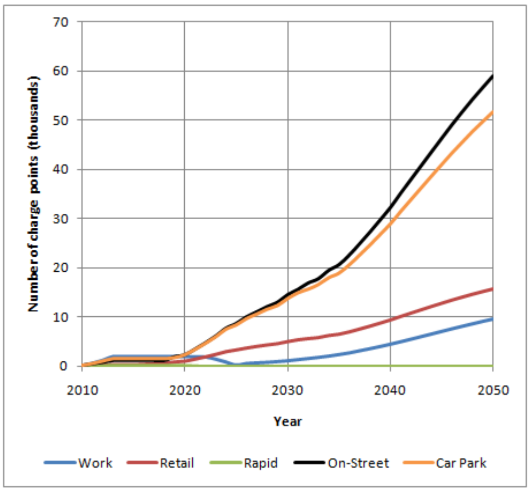

Figure 10 Charge points installed

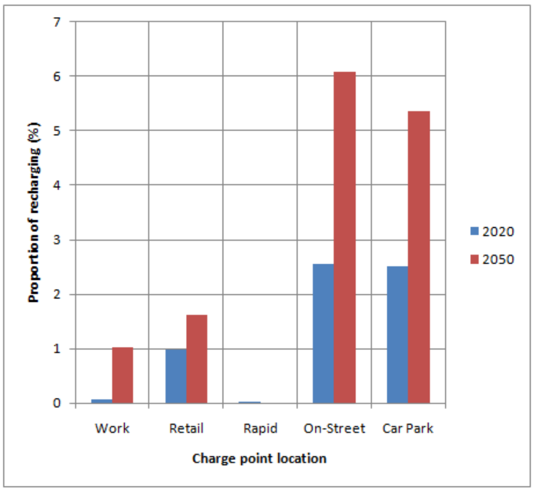

Figure 11 Share of recharging in different non-domestic locations

3.2 Sensitivity Test Results

The results of the sensitivity tests are summarised in this section. For each of the variable categories described in Section 2.3.1 the most important observations and corresponding insights are highlighted. Note that these sensitivity results are strictly only applicable in the vicinity of the base case scenario.

3.2.1 Vehicle Technology

Technology improvements across a range of vehicle attributes drive increases in PiV take-up.

- PHEV/REEV share of the parc in 2050 increases from 18.8% to 23.1% if upfront vehicle prices, excluding the battery, reduce by 20%, but only increases to 18.9% if battery prices are 40% lower. This is because PHEV/REEV batteries are relatively small and make up a small proportion of the overall cost of the vehicle.
- PHEV/REEV share of the parc in 2050 increases from 18.8% to 20.9% for 10% faster acceleration, which is a proxy for overall vehicle performance. Other technology improvements result in smaller increases in parc share.
- PHEV/REEV share of the parc in 2050 only increases to 19.2% if electric-only range increases by 30%, because consumers place a relatively low value on electric range in PHEV/REEVs, recognising that the range can be extended using liquid fuel[12].
- BEV share of the parc in 2050 increases from 0.6% to 0.7% when battery prices are 40% lower, reflecting the large proportion of overall cost that the battery represents in a BEV, and to 0.8% if range increases by 30%, reflecting the high value attributed to BEV range by most of the consumer segments[12]. Nevertheless, BEVs remain a small niche of the market.

[12] Quantifying Consumer Behaviour, WP1.4.8, Element Energy, 12 June 2011.

If all aspects of vehicle technology considered in the model are favourable, PiV share of the parc in 2050 increases from 19.3% to 30.3%. This increase is lower than that resulting from more positive consumer attitudes to PiVs (31.8% of parc in 2050) or high levels of charge point deployment (21.2% up to 49.1% of parc in 2050).

The development of vehicle technology is largely outside the direct influence of the UK Government (although within the influence of the European Union, for example through Fleet Average Emissions legislation), as it depends on the actions of global OEMs responding to the global environment. However, take-up can be affected more significantly by charge point deployment, over which the Government has more control, and consumer attitudes.

3.2.2 Electricity Generation and Grid Impacts

UKERC electricity generation scenarios have little effect on the overall PiV system apart from small impacts on emissions in some cases. Although the full benefits of PiVs depend on decarbonising electricity generation, some emission benefits can be realised across the full range of UKERC scenarios.

3.2.3 Electricity Price

The price premium of electricity from non-domestic CPs is calculated within the CRM to ensure that the required rate of return for CP owners is realised, using an algorithm[13] that takes into account:

- The average utilisation achievable at a CP.
- The notional value of CP use (increased footfall for retailers, goodwill for employers).
- That an electricity price above the cost of running a PHEV/REEV on liquid fuel instead is untenable (this would not necessarily hold if BEVs made up a much more significant proportion of PiVs).
- The cost of installing a CP.

The number of charge points that need to be installed to satisfy a level of demand will depend on the achievable utilisation of CPs. If higher than expected utilisations are achieved in operation, then fewer CPs need to be installed, which will reduce the perceived value of availability of infrastructure for consumers, resulting in lower PiV sales. If utilisation is 2.5 times higher, CPs deployed in 2050 will fall from 136k to 22k and PiV share of the parc in 2050 will fall from 19.3% to 16.2%.

Notional value is not required to make workplace and retail CPs commercially viable – when it is ignored CP deployment is unchanged – but it does affect the price that employers and retailers might be willing to offer for recharging, which would have an effect on demand, although in the model this effect is generally not captured. In the extreme if retailers and employers offer free electricity the anticipated increase in recharging at these locations would lead to an increase in

[13] WS3/ARUP/10 – Scenarios Development Final Report – v2 Final Issue – The report describes in detail the variables and each of the scenario tests.

non-domestic CP deployment in 2050 from 136k to 1,360k and due to the value consumers place on infrastructure availability an increase in PiV share of the parc in 2050 from 19.3% to 44.5%. Offering free electricity results in losses for workplace charge points, even when the value of goodwill is taken into account, suggesting that this is unlikely to be a viable approach for employers. However, it is expected that the value of additional footfall would be higher for retailers, so it may be financially justified to offer free electricity.

Low prices at CPs where the owner gains notional value might limit the potential for profitable operation of nearby CPs that do not offer notional value to their owners.

The capital and operational costs of a workplace, retail and public CP depends greatly on whether the CIC and NRC are regulated. Because CIC+NRC are not a fixed cost per charge point, these costs vary depending on the number of charge points installed between 5 and 30 times the CPC[14]. If CIC+NRC are not regulated, the cost of recharging to achieve profitable operation exceeds the assumed maximum reasonable price that CP operators could charge, making profitable CP operation highly unlikely. To achieve a sustainable charging infrastructure market CIC+NRC should be regulated.

3.2.4 Charging Infrastructure & Deployment

Consumers place a significant value on the availability of charging infrastructure (Figure 12). For PHEV/REEVs this can be sufficient to make consumers willing to pay more for a PHEV/REEV than for a non-PiV. However, for BEVs even with full availability of all types of charging infrastructure consumers would still require the vehicles to be cheaper than a non-PiV before purchasing one.

Increasing the availability of home charging from 80% to 100% of those with off-street parking increases the share of the parc in 2050 of PHEV/REEVs from 18.8% to 20.8% and BEVs from 0.59% to 0.65%. To maximise the potential take-up of PiVs CPs could be provided on-street or in communal car-parks for PiV owners without off-street parking.

PiV take-up can also be increased by subsidising non-domestic CP deployment, which is discussed in Section 3.2.6 on Government Policy.

[14] In the base case (CIC + NRC) = (30.1 x CPC) in 2025 and (5.6 x CPC) in 2050.

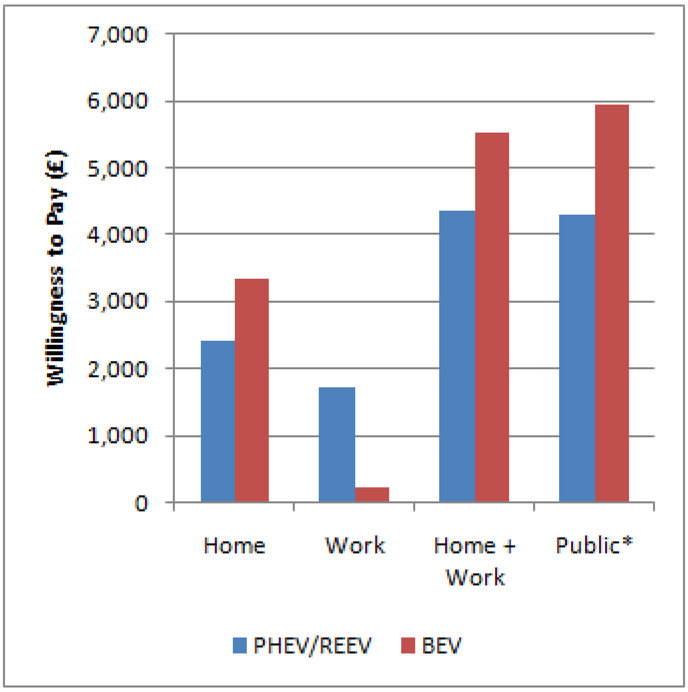

Figure 12 Unsegmented consumer willingness to pay for charging infrastructure in different locations[15] (*willingness to pay for public infrastructure varies linearly with availability, value shown for 100% availability)

3.2.5 Consumer Behaviour

Consumer attitudes to PHEV/REEVs and BEVs have been studied using consumer surveys[16], and the financial penalty consumers apply to the vehicles has been calculated from the collected data. Different biases have been derived for a range of consumer segments, but on average these are -£7960 for PHEV/REEVs and -£24,440 for BEVs[16]. These constants are partially offset by the positive value of available recharging infrastructure, vehicle range and other factors such as performance.

Halving the constant representing consumer attitudes results in an increase in the share of the parc in 2050 of PHEV/REEVs from 18.8% to 31.8% and of BEVs from 0.6% to 3.3%. Nevertheless, PiVs still form a minority of the UK parc with only a 35% share. The extent to which consumer attitudes can be influenced by Government campaigns is subject to debate[17], but studies have shown that familiarity with PiVs can improve stated opinion[18]. If attitudes can be changed, or change over time naturally, the effect on PiV take-up will be significant (although not necessarily positive).

Where consumers choose to recharge determines the demand for non-domestic CPs. If consumers increase the amount of recharging they do at non-domestic CPs, then more CPs will be deployed to meet this additional demand. The increased level of infrastructure has value to consumers (Figure 12), which increases PiV sales, further increasing CP demand.

---

[15] Quantifying Consumer Behaviour, WP1.4.8, Element Energy, 12 June 2011.
[16] Quantifying Consumer Behaviour, WP1.4.8, Element Energy, 12 June 2011.
[17] Individual behaviour change: evidence from transport and health, Centre for Transport and Society, November 2009.
[18] The UC Davis MINI E Consumer Study, May 2011..

It is expected that consumers will choose to delay recharging of many of their outbound journeys until the end of the day and then recharge at home resulting in only 14% of recharging taking place at non-domestic CPs in 2050. However, if half of the outbound journeys that are expected to be delayed are instead recharged at the destination this increases non-domestic CP use to 51% of all recharging in 2050. To meet this additional demand the number of deployed CPs increases from 136k to 841k in 2050 and the higher availability of charging infrastructure increases the value of PiVs to consumers with PHEV/REEV share of the parc increasing from 18.7% to 33.5% in 2050.

3.2.6 Government Policy

The policy space explored by this work was defined through a stakeholder engagement process with Government, ETI members and external stakeholders. The policy values were agreed with consideration of what was ‘likely’ and would be ‘politically acceptable’. Most policy choices within this space have little effect on PiV take-up, but three policy levers are effective – EU Emissions Legislation, CP subsidies, and congestion charging exemption (which is not sustainable if combating congestion is the true purpose of the charge).

EU Emissions Legislation is effective in driving down overall emissions. If a manufacturer’s fleet average exceeds the specified limit, the manufacturer is currently fined €95 per new car sale per g CO_2/km that the fleet is over the limit.[19] The model assumes that this penalty is passed on directly to purchasers of higher emitting vehicles (and an equivalent discount is given to purchasers of lower emitting vehicles). However, between 2040 and 2050, the penalty becomes too small to change consumer preferences sufficiently to return the fleet average below the limit.

Consumers place a significant value on the availability of non-domestic charging infrastructure (Figure 12). For PHEV/REEVs this can be sufficient to make consumers willing to pay more for a PHEV/REEV than for a non- PiV. However, for BEVs even with full availability of all types of charging infrastructure, consumers would still require the vehicles to be cheaper than a non-PiV before purchasing one.

In the base case, low levels of demand result in low levels of charging infrastructure deployment. Workplace and public CPs can be encouraged by Government through subsidy. For example, if the Government spends £7.7billion in subsidies of CPC and covering shortfalls in CP profits, CP deployment can be increased to 241k CPs in 2050 (compared to 136k CPs in the base case). This results in PiV share of the parc in 2050 increasing from 19.3% to 21.2%. This can be compared to an unlimited PiV purchase subsidy package to 2022, which costs £9.9billion and only increases PiV share of the parc in 2050 to 19.9%. The level of CP deployment does not become self-sustaining by 2050, so continued Government support would be required. Nevertheless subsidy of charging infrastructure offers a better return in terms of emissions reduction per pound spent than vehicle subsidy.

Increasing fuel duty and CO_2-based taxes such as VED, have the effect of increasing Exchequer revenues, and also reducing CO_2 emissions.

---

[19] Regulation (EC) No 443/2009 of the European Parliament and of the Council

3.2.7 Sensitivity Results Summary

The critical market enablers are consumer attitudes and charging infrastructure availability. Vehicle price is also important.

Consumer attitudes can increase the share of the parc of PHEV/REEVs from 18.7% to 31.8% and BEVs from 0.6% to 3.3%. The effect of charging infrastructure varies depending on whether it is domestic, workplace or public, and on the level of deployment. For very high levels of non-domestic CP deployment PHEV/REEV share can reach 48.3% and BEV share 0.8%. Low vehicle prices are expected to increase PHEV/REEV share to 23.2% but BEV share remains at 0.6%.

PHEV/REEVs will dominate the PiV market as no variables are sufficient to overcome the large consumer bias against BEVs. This conclusion is strongly supported by extensive consumer survey data[20].

Non-domestic CPs can be operated profitably with the size of the market limited by consumer demand to around 136,00 charge points. Extensive infrastructure deployment at a level that will stimulate large increases in PHEV/REEV take-up is likely to require strong and sustained Government support in the order of at least £10billion over the period to 2050.

Conclusions relating to charging infrastructure depend greatly on the recharging behaviour of consumers, about which there is currently very limited data. For example, CP deployment in 2050 could vary between 136k and 841k depending on where consumers choose to recharge.

[20] Quantifying Consumer Behaviour, WP1.4.8, Element Energy, 12 June 2011.

3.3 Themed Test Results

The results of the 12 themed scenarios are summarised in Table 1. All financial figures are net present values of spend/revenues between 2010 and 2050. The scenarios can be categorised as: the base case; bounding scenarios; scenarios related to the UK economic environment; and scenarios relating to the global economic environment. An overview of the scenarios is given in Section 2.3.2; details of the variable settings are given in Appendix D.

Table 1 Summary of themed test results

Theme	PiV as % of 2050 Car Parc	BEV as % of 2050 Car Parc	Parc 2050 (million)	VKT 2050 (km billion)	Charge points deployed 2010 to 2050 (thousands)	Production and scrappage emissions in 2050 (Mt)	WTW emissions in 2050 (Mt)	Total subsidy to all PiV purchases (£million)	Net cost to Treasury of CP Installation (£million)	Total Exchequer Spend (£billion)	Total Exchequer Revenue (£billion)	Total Exchequer Net Spend (£billion)
Base case (T0)	19.4	0.6	45	453	228	22.4	25.4	11.4	17	5.0	817	-812
Maximally favourable to PiV take-up (T1)	90.2	28.8	61	484	10900	23.9	12.6	69200	1183	75.4	836	-761
Minimally favourable to PiV take-up (T2)	1.2	0.0	34	405	1	19.7	24.1	0.0	0	3.8	735	-731
Maximally favourable to PiV take-up with base case policy(T3)	88.6	27.8	61	484	8610	23.9	13.1	302	278	6.1	802	-796
Minimally favourable to PiV take-up with base case policy (T4)	1.7	0.0	34	405	8	19.7	23.8	0.9	1	3.8	757	-753
Minimise emissions (T12)	93.0	24.4	34	405	9840	12.3	10.9	59400	0	62.4	817	-754
High UK GDP (T5)	18.7	0.7	61	484	228	31.3	26.8	12.5	18	6.5	877	-870
Low UK GDP (T6)	19.9	0.5	34	405	218	15.9	23.2	10.4	16	3.9	766	-762
High global growth (T7)	26.1	1.3	61	484	411	25.0	25.4	13.4	32	6.3	883	-877
Medium global growth with a green emphasis (T8)	80.2	17.5	34	405	6230	12.0	12.2	47200	0	50.4	848	-797
Medium global growth with high oil price (T9)	19.7	0.6	45	453	232	22.4	24.6	11.7	17	5.0	836	-831
Medium global growth with oil price spike (T10)	19.4	0.6	45	453	233	22.4	25.3	11.4	17	5.0	820	-814
Low global growth (T11)	6.8	0.1	34	405	55	19.4	25.1	9.8	5	3.9	766	-762

3.3.1 Bounding Themed Scenarios

The bounding scenarios represent extremes (of favourability to PiV take-up and of emissions reduction) and indicate the boundaries of the space of exploration (and uncertainty) within which conclusions can be drawn. They are not necessarily achievable as not all the factors are within the control of Government, and not all factors are otherwise desirable, for example low UK growth leads to low emissions.

The bounding scenarios give a range in 2050 of PHEV/REEV take-up between 1% and 69% and a range of BEV take-up between 0% and 29%. The ranges of charge points deployed and exchequer spend are also correspondingly large.

Government policy has little effect on PiV take-up, CP deployment and emissions, when scenario variables are either maximally or minimally favourable to PiVs. However, the cost of vehicle subsidies can be large when take-up is high.

Minimum emissions are achieved with low cost, advanced vehicles, green consumer attitudes, supportive government policies and low UK growth to reduce the parc and reduce total vehicle kilometres travelled. In-use emissions can then be reduced to 10.9Mt/year or 13% of 1990 levels. Even with favourable conditions, there may not be any set of policy options considered in this model that can deliver the 90% level of car transport in-use emissions reduction thought to be necessary to meet the UK’s overall 80% target in 2050[21].

3.3.2 UK Economic Growth Themed Scenarios

An increase in GDP growth from 2% to 3% results in in-use emissions increasing from 25.4Mt to 26.8Mt in 2050 compared to the base case, because total vehicle-kilometres-travelled increases without a shift in the composition of the parc to lower emission vehicles. This effect is one of the strongest drivers of in-use emissions, so plans for achieving target reduction in transport emissions by 2050 must provide for higher than expected GDP growth.

GDP growth is particularly significant for production and scrappage emissions (Figure 13). However, it should be noted that these are dealt with differently to in-use emissions in terms of the UK’s carbon obligations, as they are currently attributed to the country of production.

[21] CCC – The Fourth Carbon Budget – Reducing Emissions through the 2020s (December 2010)

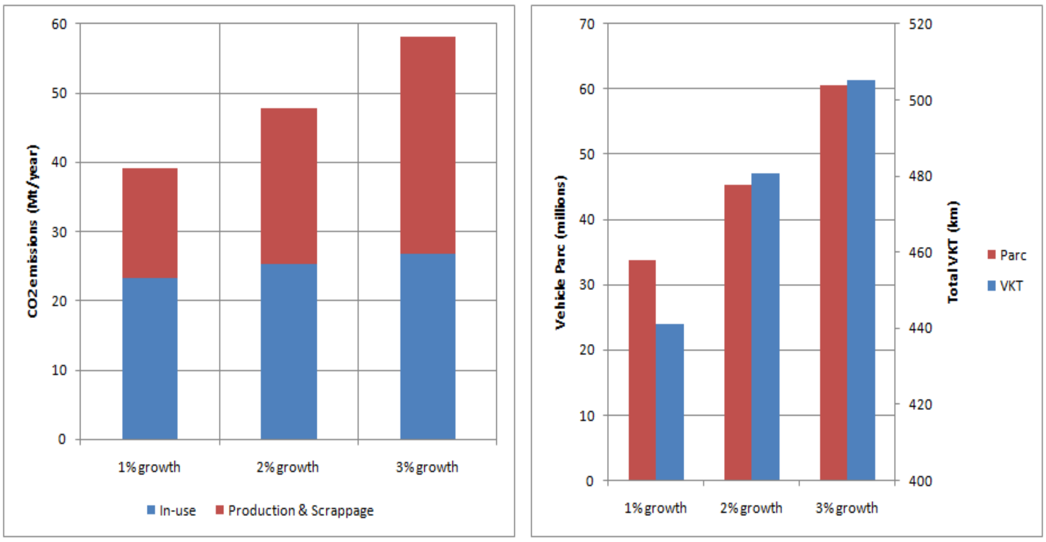

Figure 13 Effect of UK GDP growth on CO2 emissions from cars in 2050 (left) and corresponding vehicle parc size and VKT in 2050 (right)

3.3.3 Global Economic Environment Themed Scenarios

Global economic environment scenarios consider the likely effects of different global growth assumptions and different oil price trends on the UK PiV system.

Variations in oil prices have little effect on the PiV system, reflecting that vehicle fuel costs are not the main driver of consumers' purchase decisions.

Rapid development of PiVs is expected to occur under conditions of high global growth, as these will enable OEMs to invest in R&D. However, the availability of low cost and high performing PiVs is not sufficient on its own to drive high levels of take-up – in the high global growth scenario PiVs form 26% of the parc in 2050.

However, if low cost and high performing PiVs are available, consumers have positive attitudes towards them, and Government policy is supportive, as in the green global growth scenario, PHEV/REEV take-up can reach 63% by 2050 and BEV take-up 18% of the parc with a correspondingly high reduction in emissions. The success of the PiV system is reliant on favourable vehicles, consumer attitudes and CP deployment (supported by favourable Government policies).

A favourable vehicle showroom depends on a supportive global economic situation enabling OEMs to invest in vehicle development, or EU emissions regulations that encourage them to do so, so lies outside UK Government's direct control. However, Government policies towards charge point deployment and vehicle subsidy can be chosen and consumers' attitudes can be changed through exposure to PiVs[22], although this change will not necessarily be positive.

[22] The smart move trial, Cenex, 2010.

3.3.4 Themed Scenario Summary

The themed scenarios show the critical drivers of the PiV market are consumer attitudes, Government policies towards charge point deployment and, to a lesser extent, vehicle development. For high levels of PiV take-up these drivers must be favourable and act in combination, in which case PiV take-up over 80% of the parc can be reached by 2050.

Like the sensitivity analyses, the themed scenarios show that the PiV market will be dominated by PHEV/REEVs, which will limit the maximum reduction of in-use car transport emissions to a level that may not be sufficient to achieve the reduction required to contribute fully to meeting UK's 80% target for overall emissions.

An extensive and sustainable charging infrastructure market can develop without ongoing Government subsidies given otherwise maximally favourable conditions (faster than expected vehicle development, positive consumer attitudes, etc).

3.4 Optimisation Results

The optimisation analysis aims to find policy solutions that reduce whole life car CO_2 emissions (i.e. including production and scrappage emissions) to 46Mt/year by 2050 while minimising exchequer net spend including carbon costs. The CO_2 target is higher than 20% of 1990 levels (19.1Mt/year), as this was not found to be achievable, given the agreed constraints on policy levers. The chosen target is around 5% higher than the lowest emissions found from a systematic search of the policy space and gives scope for the optimisation process to adjust the policy package.

The search for the optimal policy package required the consumer response model to be run several hundred times and found the policies below to be optimal. Although these are optimum policies, the analysis is specific to conditions adjacent to the baseline scenario and excludes effects such as the effects that government policy has on OEM behaviour.

These policies, in combination, have a very significant impact on PiV take-up, Exchequer spend or revenue:

- Abandon PiV purchase subsidies in 2011, as soon as permitted, and limit subsidies before then to the minimum level, because the cost of subsidies outweighs the value of the carbon saved;
- Apply a more stringent tailpipe based criterion to the company car tax incentive;
- Raise VED to the highest permitted level (double current levels) and base it on well-to-wheel emissions, which increases exchequer revenues and encourages the purchase of low emitting vehicles;
- Raise fuel duty to the highest permitted level (double current levels), which generates significant revenue and penalises the purchase and use of higher emitting vehicles;

These policies have some impact on PiV take-up, Exchequer spend or revenue:

- Treat network reinforcement and charge point intelligence as regulated assets, to enable charge points to be more profitable;
- Set the maximum price of electricity at public CPs to its highest level, to maximise charge point profitability and maximise deployment; (this conclusion may be a consequence of the fact that the analysis has no elasticity of recharging behaviour on electricity price at CPs. In reality it would be expected that consumers would recharge less at non-domestic charge points if they were more expensive and the price for maximum profitability may be lower than the maximum level).
- Install 30% more non-domestic charge points than necessary to meet the expected level of demand in the following year and meet any shortfall in their revenues, to take advantage of the high value consumers place on charging infrastructure;

These policies are complimentary but do not have a significant impact in themselves on PiV take-up, Exchequer spend or revenue:

- Raise the rate of VAT on domestic electricity to 20%, as this increases exchequer revenues from PiV recharging;
- Charge revenue preserving tax on a per-km basis, rather than a per-vehicle basis (revenue preserving tax has a significant impact on Exchequer revenue, but whether it is charged per km or per vehicle has only a small effect on the factors considered);
- Double the initial deployment of charge points, to take advantage of the high value consumers place on charging infrastructure;
- Set 2050 fleet average emissions target to 30g CO_2/km well-to-wheel, the lowest value allowed within the policy space considered

Table 2 Summary indicators for the optimal policy package

Theme	2050 values						Values for 2210-2050 discounted at 3.5% p.a.				
	PiV as % of Car Parc	BEV as % of Car Parc	Charge Points Deployed (thousands)	WTW emissions (Mt)	Production and scrappage emissions (Mt)	Total whole life emissions (Mt)	Total subsidy to all PiV purchases (£m)	Total subsidy for CP deployment (excl. NRC & NIC (£m)	Total Exchequer Spend[23] (£bn)	Total Exchequer Revenue (£bi)	Total Exchequer Net Spend (£bn)
Base Case (T0) Policy package	19.4	0.6	136	25.4	22.4	47.8	11.4	17.2	5.0	817	-812
Optimal Policy Package	25.6	0.7	350	23.5	22.4	45.9	0.0	323.7	1.8	962	-961

[23] Exchequer spend includes subsidies of PiVs, charging infrastructure and loss in corporation tax due to treatment of PiVs for corporation tax purposes.

The pattern of sales and share is similar to the base case, but PiV take up is higher due to the beneficial effect of high charge point deployment and largely at the expense of gasoline non-PiVs, which are penalised relative to the more efficient diesel non-PiVs by the tight fleet average emissions target.

A key feature of the optimal policy run is the high number of charge points deployed due to: the high initial deployment; the greater demand resulting from the higher take up of PiVs; and the policy of deploying 30% more charge points than would strictly be required to meet the expected level of demand in the following year. A consequence of the high charge point deployment is that workplace, car park and on-street charge points are loss-making and deployment is only supported because government meets this shortfall (see Figure 14).

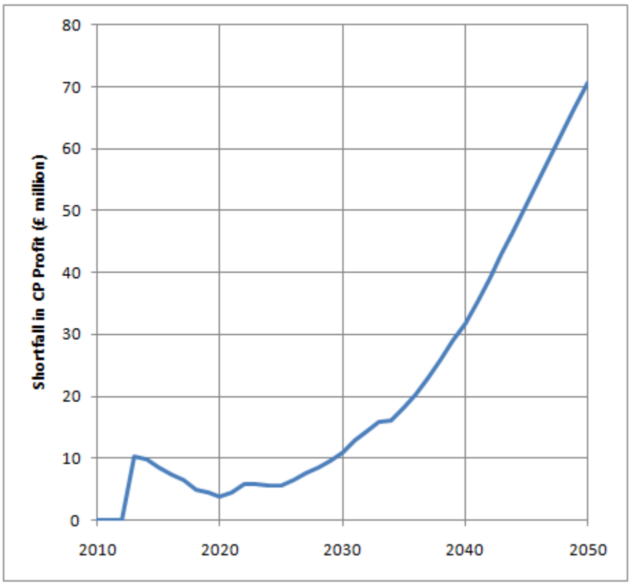

Figure 14 Shortfall in CP profits for optimal policy run

The three most important effects on exchequer spend are very small expenditure on vehicle subsidies, much smaller loss of corporation tax due to the tighter criterion, and higher spend on charge point subsidies due to meeting the shortfall. Overall the savings outweigh the increases and spend is much lower than in the base case. Exchequer revenues are increased primarily by: higher fuel duty receipts in the early years (in later years the revenue preserving tax prevents revenues falling below 2010 level, so higher fuel duty merely reduces the required level of this tax); and higher VED receipts due to increased rates and changing the basis from tank-to-wheel to well-to-wheel.

The optimal policy package achieves the target of reducing whole life emissions to below 46Mt/year through encouraging a more fuel efficient parc (average emissions of new cars in the optimum case are 47g CO_2/km compared to 50g CO_2/km in the base case). Production and scrappage emissions remain constant.

Further investigation of the trade-off between CO_2 emissions and net expenditure by the Exchequer was conducted via the graph shown as Figure 15 Trade off between emissions and expenditure (in base scenario)

. The graph shows that a number of policy packages (which are identified and described in the modelling report[24]) are on a “frontier” of minimum emissions and/or minimum net expenditure. A number of conclusions can be drawn from this graph. Firstly; the shape of the frontier indicates that, for 2050 whole life emissions above 42 Mt, the marginal cost to the Exchequer (total cost between 2010 and 2050) per unit reduction in annual emissions is fairly stable at about £4bn of Exchequer expenditure per annual Mt reduction in emissions in 2050[25]. Below 42Mt, the cost accelerates markedly – appearing to reach £200bn of Exchequer expenditure per Mt reduction in 2050 emissions for reductions below 41.5 Mt. Secondly; it is clear that the base policy is not on the “frontier” – indicating that it offers neither the cheapest way of achieving a given level of emissions nor the lowest emissions for a given level of net expenditure by the Exchequer.

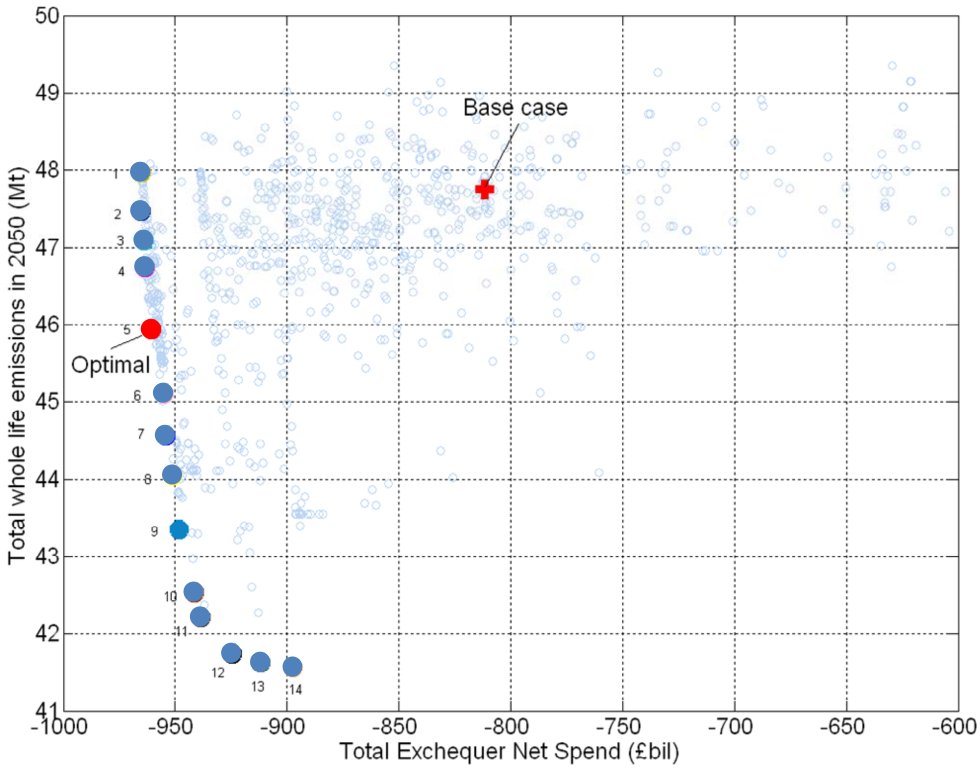

Figure 15 Trade off between emissions and expenditure (in base scenario)

3.5 Carbon Abatement Costs

PiVs are widely viewed as an efficient means of reducing transport CO_2 emissions. This section quantifies the efficiency through calculation of the abatement cost for the deployment of PiVs. The abatement cost is a measure of

[24] WS3/ITS/02 – Detailed report on Computer Modelling
[25] Note that, although the graph shows only the emissions in 2050, any reduction in 2050 emissions is likely to have been preceded by 40 years of reduced emissions ; the benefit gained by the Exchequer expenditure is not simply the reduction in 2050 emissions. Thus the measure cannot be directly compared to standard carbon abatement costs (Annual cost / Annual CO_2 saving).

the cost effectiveness of a carbon saving action and is defined as the net present value of the social cost of saving 1 tonne of CO_2 (e.g. if an action has an NPV cost to society of £230 and saves 2t of CO_2, the abatement cost for that action is £115/t CO_2).

A number of assumptions have been made, as follows:

- The cost analyses are based on vehicles in the medium-sized C-segment as described by SMMT.
- The analyses are undertaken at 2010, 2020, 2030, 2040 and 2050.
- The costs are the costs to society, and therefore exclude all taxes and duties.
- The carbon savings and costs are relative to the performance of a reference vehicle, which is taken as a 2010 model year conventional gasoline vehicle. The use of a current conventional vehicle as the reference is in line with Committee on Climate Change analysis, which is based on the premise that, without carbon penalties, vehicle manufacturers have little incentive to improve vehicle efficiency. The graphs below therefore show values for the reference vehicle and the various plug-in vehicle types.
- Production and scrappage emissions have been excluded from the carbon abatement costs in line with analyses in other publications. The production and scrappage emissions are shown in Figure 16. The effect of their inclusion would be to increase carbon abatement costs in 2010 and 2020 when it is assumed that the PiVs have a shorter life than the reference vehicle. After 2030 the effect is small.
- Purchase price, running costs, and CO_2 emissions are based on values used in the project's baseline scenario with an annual mileage of 13000km per vehicle.
- Allowance has been taken for the cost of charge point installation at home, work and in public locations. Costs per vehicle for these have been taken from the baseline scenario results, with the assumption that all users install domestic charging units.
- A social discount rate of 3.5% has been used throughout.

Figure 16 and Figure 17 show how the production and scrappage and the in-use emissions vary with time. It can be seen that by 2050, the production and scrappage emissions dominate the whole life emissions for all PiVs.

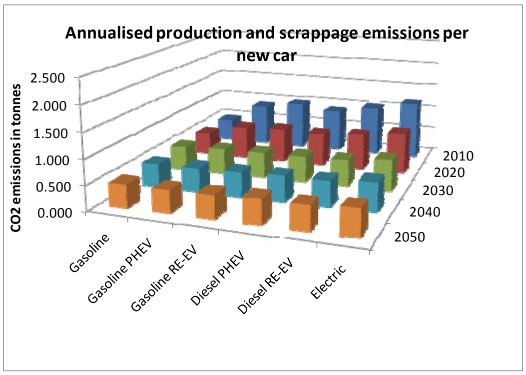

Figure 16 Annual production & scrappage emissions

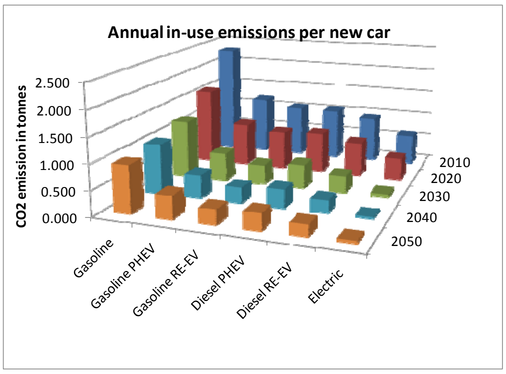

Figure 17 Annual in-use emissions

A comparison of the annualised emissions of the different vehicles is shown in the figures below, for 2010, 2030 and 2050.

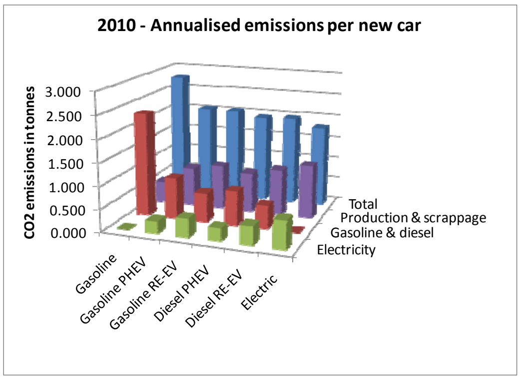

Figure 18 Annualised emissions breakdown in 2010

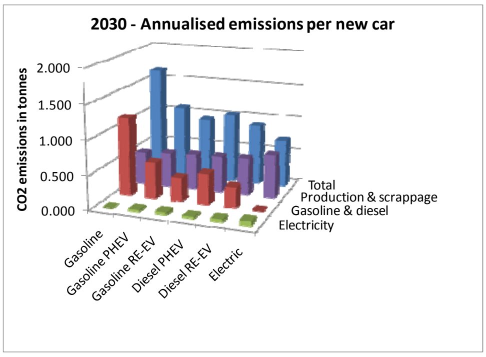

Figure 19 Annualised emissions breakdown in 2030

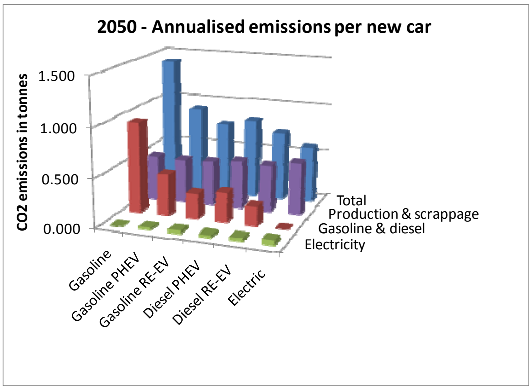

Figure 20 Annualised emissions breakdown in 2050

A breakdown of the annual costs excluding taxes and duty is given in the figures below, again for 2010, 2030 and 2050, and for a conventional gasoline vehicle, plus the different PiV types.

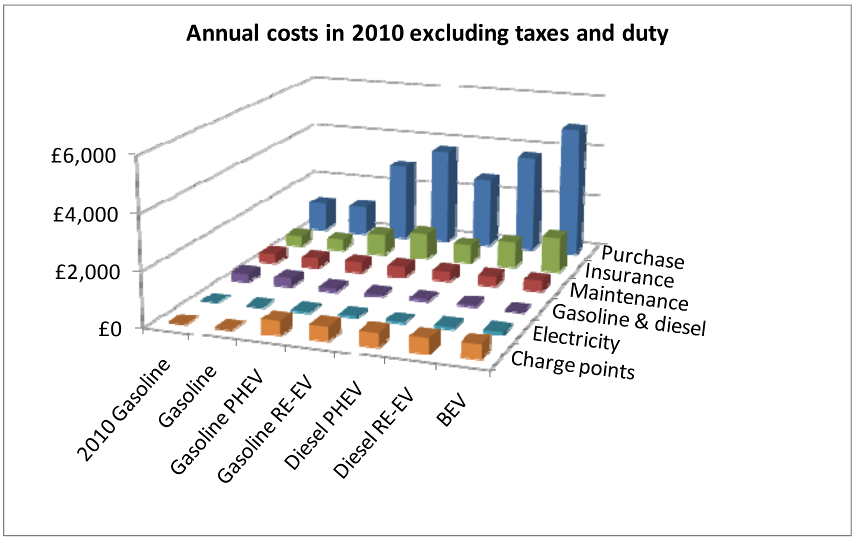

Figure 21 Annual costs in 2010

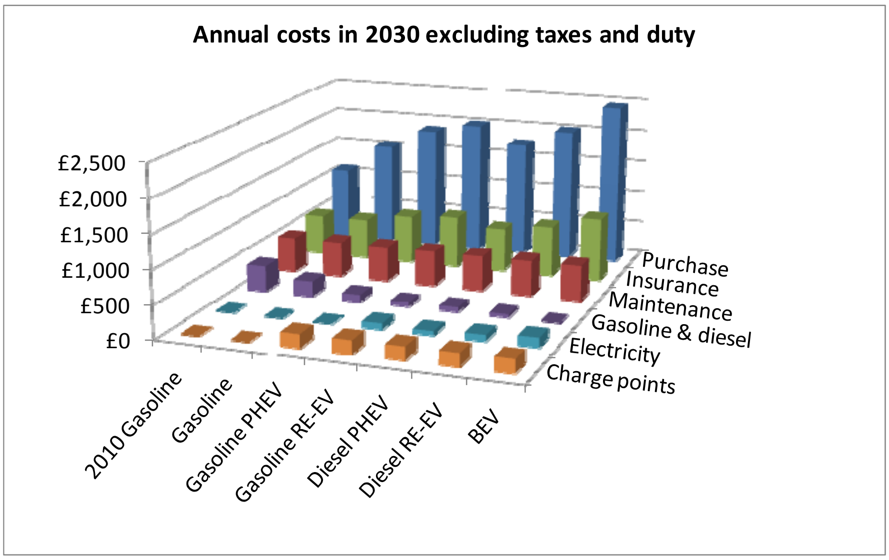

Figure 22 Annual costs in 2030

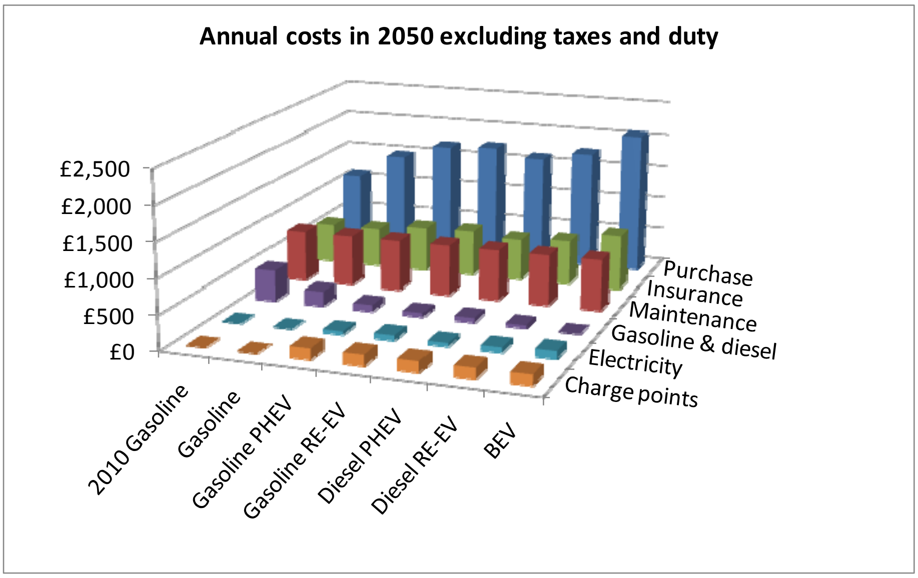

Figure 23 Annual costs in 2050

The calculated carbon abatement costs are summarised for the baseline results in Table 3 with the data used to calculate them shown in the table in Appendix C. For example, in 2050, the additional annual cost to society of a BEV compared to a 2010 gasoline vehicle (including purchase, maintenance, insurance, fuel and electricity costs, but excluding taxes and duties) is £1,014 (£3,913 - £2,899 from Appendix C), and the annual CO_2 saving is 1.912t (1.963t – 0.051t from Appendix C). Hence the abatement cost is £1,014/1.912t = £531 per tonne.

Table 3 Carbon abatement costs using baseline data (£/t CO_2)

	Using 2010 conventional gasoline vehicle as reference				
Vehicle type	**2010**	**2020**	**2030**	**2040**	**2050**
Gasoline	-	£240	£364	£215	£131
Gasoline PHEV	£2,304	£1,026	£575	£440	£341
Gasoline RE-EV	£2,801	£1,230	£676	£463	£339
Diesel PHEV	£1,756	£875	£449	£303	£229
Diesel RE-EV	£2,558	£1,145	£638	£430	£318
BEV	£2,990	£1,594	£872	£671	£531

The calculated abatement costs are significantly higher than those reported in Chapter 4 of The CCC's Fourth Carbon Budget report (in 2030, BEV cars - £26, PHEV cars - £80). The differences in the calculated costs can be attributed to the following factors in our analysis in order of significance for BEVs:

- Shorter PiV life in 2010 and 2020
- Higher purchase price differential between PiVs and conventional cars, mainly associated with assumed cost of batteries (we assume around £215 per kWh in 2030 and £150 per kWh in 2050)Higher insurance costs for PiVs (assumed proportional to purchase costs)

- Inclusion of costs for the installation of charging infrastructure in home, workplace and public locations

It can be seen that the abatement costs are very high for PiVs in 2010 and 2020. This is due to the high purchase price and shorter assumed life of the PiVs for these dates, plus the additional cost of the charge points which must be covered. There is also a lower CO_2 abatement due to the emissions from electricity generation.

Diesel plug-in hybrids, in general, have lower abatement costs than gasoline equivalents because of their lower emissions. PHEVs perform better than REEVs due to their lower purchase price.

The purchase price of BEVs keeps their abatement costs higher than the plug-in hybrids.

The above values are based on an annual mileage of 13,000km. If a higher annual mileage is assumed, e.g. 25,000km for company cars, the abatement costs in 2050 for PHEVS and REEVs range between £22/t and £85/t, with £191/t for BEVs.

The analysis was also repeated using the optimistic forecast for vehicle technology development (battery cost of £90 per kWh in 2050[26]) and gave the values in Table 4. As expected, the values are considerably reduced, but remain in general above CCC predictions. Note that the 2050 PHEV values are negative, indicating that CO2 is not only saved, but also that the cost to society is less for a PHEV than the 2010 reference vehicle.

Table 4 Carbon abatement costs using optimistic vehicle technology data

	Using 2010 conventional gasoline vehicle as reference				
Vehicle	**2010**	**2020**	**2030**	**2040**	**2050**
Gasoline	-	£269	£407	£251	£168
Gasoline PHEV	£2,304	£980	£485	£230	-£80
Gasoline REEV	£2,801	£1,184	£587	£292	£16
Diesel PHEV	£1,756	£855	£382	£167	-£30
Diesel REEV	£2,558	£1,102	£541	£260	£24
BEV	£2,990	£1,518	£755	£480	£227

[26] As defined in the Ricardo cost model

4 Discussion

The UK Government has committed to reduce carbon emissions by 80% of 1990 levels by 2050. This overall emissions reduction target is disaggregated into targets for individual sectors of the UK economy taking into account the technical feasibility and cost of carbon abatement in those sectors.

The CCC state that, given their assessment of what is possible in other sectors, it is likely that emissions reductions of 90% or more will be required from surface transport to meet the economy-wide 80% target. PiVs offer the potential to deliver this level of emissions reduction, if combined with decarbonised electricity generation, but this would require a high proportion of BEVs emitting close to zero carbon to compensate for the use of higher emitting vehicles by those for whom a BEV is unsuitable.

How much are emissions likely to reduce by?

Our analysis of the PiV system shows that in the base case, which represents the most likely scenario, in-use passenger car emissions reduce by 69% on 1990 levels by 2050.

65% reduction is attributed to OEMs improving the fuel efficiency of conventional vehicles to avoid fines under the EU Fleet Average Emissions regulations, which are clearly expected to be effective. Because PiV take-up is only 19% and BEV take-up is less than 1%, only 4% reduction is attributed to PiVs.

Despite the substantial emissions reduction the CCC target is not met by a significant margin, raising the question of what can be done to further reduce emissions.

Production and scrappage (P&S) emissions increase significantly with time as the parc size increases. Their proportion of total emissions increases even more as in-use emissions decrease, and represent 47% of the parc's emissions in 2050 compared to 14% in 2010 in the base case. P&S emissions are currently accounted in the industrial sector emissions of the country of production, and our work, other than the optimisation analysis, excludes P&S emissions for this reason. However, it is possible that this approach will be revisited by 2050 to count emissions in the country of end use. In this case, any tendency for PiVs to be bought as additional cars in multi-car families would be detrimental.

How can greater carbon reduction be encouraged?

The three categories of factors that have been found to have a particularly significant impact on PiV take-up in order of significance were: -

- Charge point deployment
- Consumer attitudes and recharge behaviour
- Vehicle development, in particular those developments that reduce price

These factors interact as shown in Figure 24.

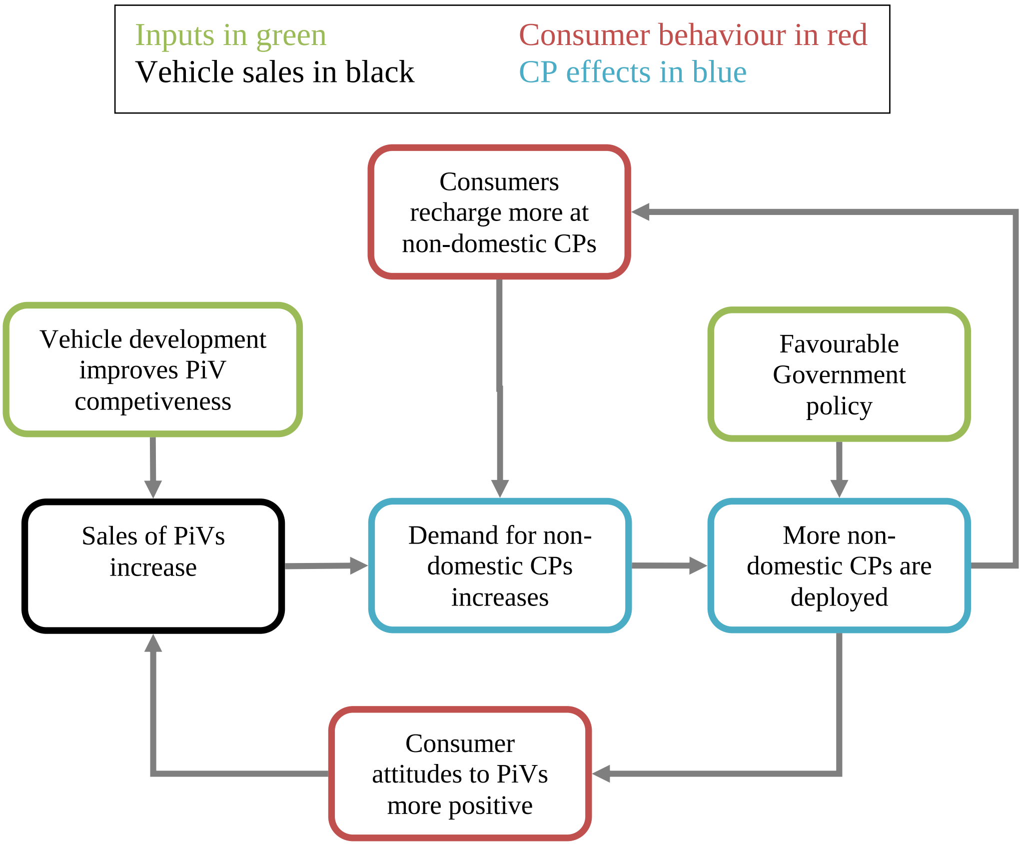

Figure 24 Interaction of consumer attitudes and recharge behaviour, vehicle development and charge point deployment

How consumers recharge their PiVs is very important to the development of the PiV system. The greater the proportion of recharging that takes place away from home, the higher the deployment of non-domestic charge points to meet that demand will be. This has two effects that are beneficial to the PiV system as can be seen in the two feedback loops in Figure 24. Firstly, the lower loop, consumers value widespread and available charging infrastructure highly at the purchase decision stage, so a higher deployment of charge points leads to increased PiV sales. Secondly, the upper loop, larger number of charge points means more PiV drivers have access to non-domestic charge points, so more of overall recharging takes place at non-domestic charge points. Both these effects increase the demand for non-domestic charging and further increase deployment, resulting in virtuous circles.

Consumer recharge behaviour is currently not well understood, due to the lack of large scale trials. It may prove to be more sensitive to fiscal incentives than the consumer purchase decision. It has not been possible to collect consumer data relating to PiV usage in this project due to the current small number of informed consumers experienced in using PiVs, and we have therefore covered this uncertainty with a range of recharge behavioural scenarios.

Consumer surveys performed within this project have found that consumers perceive a large disbenefit of PiVs, and particularly BEVs, compared to conventional vehicles, which significantly affects the purchase decision. In the base case, in 2050, the OEMs provide cross-subsidies between cars to encourage purchase of low emission cars to avoid exceeding the EU fleet emissions limit. Penalties of the order of £10,000 are given to gasoline stop-start cars (which emit the most CO_2 of vehicles available in 2050) compared to BEVs, but still the conventional vehicles outsell the BEVs many times over.

Consumers' negative perception of PiVs is difficult to overcome with the fiscal policies investigated in this study, because they do not result in a large enough financial incentive. (The range of analysed incentives was agreed with stakeholders as being at the limit of political acceptability. Section 2.1.) It may be more cost effective to reduce negative perceptions through campaigns to educate and inform consumers about the reality and potential benefits of owning and using a PiV, but further work is required to ascertain both whether perceptions will become more positive, and whether the anticipated level of change will be worthwhile.

Consumers' perception will be affected by those of their peers. It is therefore extremely important to ensure that early adopters gain a good ownership experience.

Vehicle development is important to take-up, with improvements in battery technology to reduce price and increase range being the highest priority. Vehicle development can be considered part of the UK's external environment as it depends on the actions of global OEMs responding to transnational drivers, for example global economic growth and regional emissions legislation.

As mentioned above, the availability of widespread charging infrastructure is valued highly by consumers considering purchasing a PiV. For charging infrastructure to be commercially viable, the costs of associated network reinforcement and the charge point intelligence required to bill consumers for use and enable demand management must be included in the regulated asset base. However, this may be politically sensitive as it could lead to claims that the costs of PiV use are being subsidised by all electricity users, even those who do not own a car. The maximum annual cost per household between 2010 and 2050 is estimated at £15-£35 per annum depending upon the themed scenario. However, the parallel widescale deployment of heat pumps in this period will also require network reinforcement, and the incremental cost of catering for PiV load will be significantly less than that of reinforcing for PiVs alone.

Charge point deployment may be controlled much more directly by UK Government (e.g. through passing responsibility to local authorities, through direct subsidy or through planning legislation) leading to higher levels of charge point deployment than would result from allowing the charging infrastructure market to decide. However, this is likely to require Government to meet the shortfalls in charge point profits that result. The required level of subsidy will be dependent upon the willingness of the commercial market to risk investment in an uncertain future for PiVs. Please refer to Table 1 for levels of subsidy,

And how low could that bring emissions?

If the factors above are all as favourable for PiV take-up as it is expected they could be, Government policy continues as present, and UK GDP growth is low (resulting in lower total vehicle kilometres travelled), emissions in 2050 reduce by 84% of 1990 levels. This is much closer to but still slightly short of the 90% reduction in surface transport emissions sought by the CCC.

The likelihood of all the factors above aligning is very low, as many of the factors are outside the control of Government, and also not necessarily desirable. For example, low UK GDP growth would have other undesirable consequences. For the approach to passenger car emissions reduction to be robust, the target must be achievable when external variables are at likely levels as represented by the base case scenario, in which only a 69% reduction was achieved.

As stated in Section 3.5, by 2050, the emissions due to production and scrappage are comparable to those during the useful life of vehicles. Revision to the current regulations will be required to ensure that whole life emissions are minimised.

So what more can be done?

To achieve the level of emissions reduction given by CCC for the passenger car sector, a large proportion of the UK parc needs to be close to zero emissions on a WTW basis.

Hydrogen and 100% biofuel vehicles may offer part of the solution. They have been omitted from this study, because insufficient data was available to model their impact accurately. If the vehicles and the fuels are made available at a price competitive with conventionally fuelled vehicles, and the necessary infrastructure is deployed, they could displace some conventional vehicles (and some PiVs) in the UK parc and help to reduce emissions further than predicted in our scenarios.

BEVs may also be part of the solution, but some way must be found to overcome the preference that consumers have for conventional vehicles and/or PHEV/REEVs in all scenarios. The Government incentives considered in this project were discussed and agreed in a process that included Government, ETI members, and external stakeholders. However, it appears that more extreme policies that support ultra-low WTW emission vehicles, may be required (i.e. lower emissions than PHEV and REEV capabilities).

For example potential government policies could include:

- Only allowing ultra-low WTW emission vehicles in major cities around the UK
- Raising taxes even more significantly for all vehicles other than ultra-low WTW emission vehicles to overcome the preference consumers have for the former.

What will it cost?

In 2050, the additional social cost of a BEV over a 2010 gasoline vehicle is predicted to be approximately £1000 per vehicle per annum and for a PHEV/REEV between £370 and £570 per vehicle per annum, in the baseline case.

Compared to a 2050 stop-start vehicle, the equivalent per annum figures are £880 per annum for a BEV and between £240 and £430 for a PHEV/REEV.

The additional cost is reducing in line with battery prices and highlights how important battery prices are to the success of PiVs.

In summary, the larger the battery from conventional to PHEV to REEV to BEV, the higher the social cost and the higher abatement cost per tonne of CO_2 saved, but also the higher the CO_2 saving per vehicle and potential CO_2 saving in transport emissions. The optimum route will therefore depend on how far the car sector needs to decarbonise, which in turn is dependent upon the carbon abatement costs in other sectors.

How accurate are these results?

The PiV 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.

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.

Listed below are the most important qualifications associated with the modelling presented in this report.

- The Project is limited to vehicles of the M1 category within the UK, excluding Northern Ireland, between 2010 and 2050.
- 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 H_2 vehicles from the analysis will affect the prediction of CO2 emissions, and make it difficult to compare to any target reduction in CO2 by 2050.
- 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[27]. There is little real world data on recharging patterns, which requires trials with many consumers and a comprehensive charging infrastructure. We therefore developed a representation of PiV usage and recharge behaviour which reflects a series of reasonable assumptions rather than being based on real evidence or a 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 made significant assumptions in this respect which will require calibration when data is available.
- The consumer purchase model is calibrated on survey work conducted in 2010. It assumes that behavioural preferences will remain unchanged until 2050.
- The proportion of consumers purchasing from each vehicle segment remains constant, so the effects of, for example, a tendency to downsize cannot be explored.
- The evolution of the showroom offer (specification, price and availability of individual vehicle models) is not affected by sales in previous years.

[27] 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.

- The evolution of the showroom offer is not affected by changes in emissions regulations, although the baseline assumptions assume a reducing emissions target.
- The purchase of vehicles is not constrained by any shortage of supply of individual models, batteries or other component parts.
- 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).

A number of these simplifying assumptions are inevitable at this early stage in the overall project. Evidence-based models should be used in later stages.

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

In summary

- the conclusion that PHEVs / REEVs will significantly outsell BEVs is considered to be robust.
- the absolute vehicle uptake predictions are however sensitive to changing consumer attitudes, vehicle prices and CP availability.
- the CP deployment predictions are not only dependent upon vehicle uptake, but also recharge behaviour and are thus more uncertain.
- It is due to the uncertainties associated with some of the input data that a wide range of scenarios has been explored.
- The sensitivity analyses provide an insight into the importance of the input variables to the predicted outcomes.

5 Conclusions & Recommendations

This project has used an overall model of the PiV system to evaluate the potential role and economics of PiVs in the low carbon transport system.

PiVs and in particular BEVs offer the potential to decarbonise significantly a large proportion of passenger car transport, allowing the 2050 emissions target to be met without significant behavioural change.

5.1 Government

PHEV/REEVs dominate PiV sales under all scenarios considered, are more efficient than conventional vehicles and enable 80% reduction in in-use emissions by 2050.

BEVs offer the potential, when combined with very low carbon electricity generation, to eliminate carbon emissions almost completely.

With all factors in favour of PiV sales, a parc dominated by PHEV/REEVs could achieve an 85% emissions reduction.

When the size of the vehicle parc is at the low end of future predictions, the maximum reduction of in-use emissions predicted in 2050 is 87% of 1990 levels. CCC analysis suggests that this may not be sufficiently low to meet the in-use emissions reduction of passenger car transport required to meet UK's overall 80% target reduction in 2050.

Given that PiVs are likely to make up around 20% of the vehicle parc in 2050, the vast majority of emissions reduction is likely to come from improvements in the fuel efficiency of conventional vehicles. This improvement is primarily driven by fleet average emissions legislation. Setting an appropriate 2050 target to achieve required emissions reduction and a penalty to incentivise OEMs adequately to develop their showroom offer within that target will form an important part of emissions reduction strategy.

In-use emissions will be greatly reduced by 2050, so production and scrappage emissions will become a significant proportion of whole life emissions. To reduce this contribution, increasing the life of vehicles will be important and, in the case of PiVs, the hurdles to battery replacement may need to be addressed, so vehicle life is not limited to battery life. This could lead to a market for vehicle reconditioning – upgrading dated powertrain components, including batteries, and potentially reskinning chasses to meet changing fashions. A high carbon tax would encourage the retention of vehicle systems with high-embodied carbon.

Within the agreed range of policy options that were explored, the net cost to the Exchequer of achieving reductions in whole-life 2050 emissions accelerates sharply if reductions to below 42 Mt are sought.

Exchequer revenues from fuel duty will fall as fuel efficiency improves, regardless of the composition of the vehicle parc.

The success of the PiV market depends critically on the purchase cost of PiVs, which depends on the actions of OEMs responding to global drivers and is therefore outside the direct control of the UK government. Fleet average emissions legislation may encourage cross-subsidy of PiVs, if they offer OEMs a cost effective way to meet emissions targets.

The success of the PiV market also depends critically on consumer behaviour and attitudes. The (primarily financial) incentives resulting from most of the policies modelled have little effect on consumers' purchase decision. Other types of Government action targeting attitude change may be more cost effective.

The UK Government can control its financial support of PiV sales and charging infrastructure deployment. Of these two options, charging infrastructure offers a more cost effective means to stimulate PiV sales and subsequent emissions reduction. However, in a market where PiVs do not sell in large numbers, short term PiV subsidies can be sufficient to allow the market to become self-sustaining without further subsidy. Levels of subsidy vary widely between the themed scenarios (See Table 1).

A particularly cost effective policy might be to subsidise domestic and workplace charging infrastructure.

The plug-in car grant achieves little long term benefit in the base case, as can be seen from the optimisation results. It can however assist in creating a self-sustaining market when external factors are unfavourable for PiVs. Its removal would also send a negative message to vehicle manufacturers, who currently see the UK as a prime market for early sales of PiVs.

Increases in fuel duty and CO_2-based VED or the introduction of road user charging could help finance Government support. These measures would also assist in reducing transport emissions, by increasing PiV uptake and reducing VKT.

Growth in the vehicle parc and increase in vehicle usage are linked to GDP growth, which consequently has a significant effect on emissions in the absence of mitigating action. If GDP growth is higher than expected the challenge of emissions reduction becomes greater and additional Government action may be needed to influence consumer and OEM behaviour.

5.2 Charge Point Manufacturers and Operators

PHEV/REEVs dominate PiV sales under all scenarios considered. The willingness to pay for non-domestic recharging of PHEV/REEV drivers is likely to be limited to the cost of running the vehicle in non-electric mode. The demand for non-domestic recharging is also likely to be reduced as consumers will be less concerned about running out of charge, so are less likely to top-up away from home.

Analysis of the survey results concludes that consumers place a high value on widespread and available non-domestic charging infrastructure (even consumers considering purchasing a PHEV/REEV). Subsidising charging infrastructure is a more cost effective way for government to encourage PiV sales than vehicle subsidies. Therefore infrastructure deployment may receive substantial government support, in particular, the regulation of the network reinforcement and intelligence costs associated with charge point deployment.

The availability of a domestic charge point carries a high value to consumers; the value of a workplace charge point is much greater when combined with a domestic charge point; the value of public infrastructure depends on availability.

The business case for charging infrastructure is subject to a great deal of uncertainty around factors such as consumer recharge behaviour, likely utilisation of charge points and the value of any benefits to businesses of providing charge points over and above the price of charging. Installing infrastructure will remain high risk until there is greater clarity on these issues.

Demand for recharging in non-domestic locations will depend on price. In the extreme, if charging is offered free to the consumer, demand might be expected to be substantially increased, providing opportunities for businesses or employers that derive additional benefits from consumers using their charge points, but potentially restricting the profitability of operators who do not offer free electricity.

5.3 Vehicle Manufacturers

Sales of both PHEVs and REEVs rise steadily. Their combined annual sales in 2050 vary considerably, ranging from 45k when external factors are unfavourable, 800k in the baseline, to 3,100k when all factors are favourable.

BEV sales are more susceptible to external factors, due to their high purchase price and perceived reduced utility. High volume sales are dependent on further battery development, on changes in consumer attitudes, or on Government emissions targets almost unreachable by other technologies. Their annual sales in 2050 range from 0.4k when conditions are unfavourable, 30k in the baseline, to 1750k when factors are all favourable.

In scenarios that are unfavourable to PiVs the plug-in car grant can be effective in initialising a self-sustaining market, but the benefits do not last beyond the end of the grant. Once the market has been established, the grant quickly becomes a poor value incentive, and is likely to be withdrawn within a short period.

5.4 Electricity Utilities

Due to their smaller battery size, on average a PHEV and to a lesser extent a REEV uses less electricity than a BEV. Therefore, the domination of PiV sales by PHEV/REEVs means overall electricity demand will be lower than would be the case if BEV take-up was more significant. Demand for rapid charging is likely to be very low due to the capability of PHEV/REEVs to revert to non-electric mode when low on charge, unless there is a financial benefit in doing so.

The increase in peak grid demand due to PiVs is small (in the order 5%) even in the most optimistic scenario for PiV take-up. Whilst this reduces the need for additional generation capacity, it also reduces the potential to smooth the demand load by encouraging PiVs to charge overnight. Nevertheless, there is the potential to use incentives to encourage consumers to recharge during troughs in the base load.

Where there are concentrations of PiVs on a local domestic network or contention with other electricity demand such as heat pumps, there are likely to be requirements for network reinforcement unless smart grids can stagger charging.

There is a strong case for adding these costs and the costs of charge point intelligence to the regulated asset base in order to facilitate a sustainable charging infrastructure market.

5.5 Oil Companies

The UK vehicle parc is likely to remain dominated by vehicles with an internal combustion engine (either conventional vehicles or PHEV/REEVs), so petrol and diesel will continue to have an important role to play in UK car transport. However, demand for fuel will drop dramatically by 2050, by at least 65% on 2010 levels, due to the increase in fuel efficiency of internal combustion engines and, in small part, due to take-up of PHEV/REEVs.

5.6 Further Research

This project was instigated to provide guidance on a number of questions that are dependent upon the speed and level of deployment and usage of PiVs. Vehicle manufacturers want to know where and when to invest in development programmes and manufacturing facilities for PiVs. Charging behaviour affects the business case for investment in charging infrastructure and back office services, and in additional generation capacity, smart grids and network reinforcement. In addition, a reliable prediction of the future number of PiVs allows Government to plan its incentives, taxes and regulatory strategy to meet its commitments to future CO_2 reductions.

Although the project has provided insight into the effect of the major levers that will affect the deployment of PiVs, there are still areas of uncertainty that prevent a confident forecast. Some of these are unpredictable external factors, e.g. oil price and battery prices, but, for others, future data collection and correlation of the assumptions in the Consumer Response Model (CRM) will reduce the current wide range of predicted results.

The development of the PiV system is critically dependent on consumer attitudes to vehicles and infrastructure. Research in these areas will contribute substantially to reducing uncertainty in the model output. Research should focus on: acceptance of the idea of PiVs and how that might change with time including the effect of product diffusion; the importance attached to domestic and non-domestic charging infrastructure and how that might change over time.

The deployment and potential profitability of non-domestic charging infrastructure is highly dependent on consumer recharge behaviour, which is currently poorly understood, due to a lack of large scale trial data. Research in this area will significantly reduce uncertainty related to charging infrastructure.

The price and potential profitability of non-domestic charging infrastructure depends on feasible utilisation, which is uncertain due to a lack of trial data. Establishing a robust figure for the utilisation of a non-domestic charge point will benefit future assessments of charge point profitability.

The models are underpinned by a large body of research into future vehicle technology and costs, future electricity infrastructure, and consumer behaviour. In addition, algorithms have been derived to represent the behaviour of consumers, vehicle manufacturers, generating companies and private and public charge point operators. Maintenance and updating of the resulting databases and algorithms would be worthwhile, and allow the CRM to be updated and validated to produce improved forecasts in the future.

5.7 Recommendations

Government should work with the EU to assess the costs and benefits in changing the EU fleet average emissions target to be based on WTW rather than TTW emissions.

Government should work with the EU to set a sufficiently strict target for WTW car emissions to achieve necessary emissions reduction, and set a high enough penalty to incentivise OEMs adequately, in order to minimise the requirement for subsidies to vehicles and charging infrastructure. With a VKT value of 453 billion km in 2050, the target for maximum fleet average emissions should be around 18g CO_2/km by 2050 if the reference emissions of 8.1MtCO_2 are to be achieved. Our results suggest that the current €95 per g CO2/km above target is an insufficient penalty to achieve compliance. Further work is required to derive a suitable penalty.

The Government should plan for the vast majority of PiVs to be PHEVs and REEVs when they become available. A wide scale swing from these to BEVs will require a combination of a significant change in consumer attitudes, a breakthrough in battery technology, strict EU emission limits and penalties, and larger financial incentives than considered in this project.

Government, in conjunction with EU, should set a standard methodology to measure production and scrappage emissions and consider the introduction of a regulation or taxation for reducing these.

Government should consider how it will replace lost fuel tax revenue due to improved vehicle efficiency and increased sales of PiVs. A structure directly relating tax to emissions is recommended. E.g. increased fuel duty or road user charging.

Strict emission limits for beneficial rates of VED, employee company car tax, write-down rates for corporation tax will all assist the move towards PiVs. The emissions bands should be revised in line with the expected future reduction in all vehicles' emissions.

Government should seek to remove the plug-in car grant subsidy as soon as a self-sustaining market for PiVs is achieved, since it will quickly become an expensive subsidy. It should therefore revisit the value of the plug-in car grant annually to achieve PiV sales growth, with a view to its eventual removal.

Government should continue to subsidise the installation of charging infrastructure, in a similar manner to the Plugged-in Places schemes, but at a national level. Subsidies should include domestic and workplace charge points.

Network reinforcement costs and charge point intelligence costs (CIC) should be added to the regulated asset base to minimise the cost of electricity at public charging points, and to improve the business case for charge point operators. It is anyhow difficult to isolate the costs of network reinforcement associated with PiV charging. It is recommended that one central back office for billing at charge posts is established to minimise CIC, negate the need for roaming charges between regions, and assure interoperability.

Government should initiate a study to investigate the potential effectiveness of campaigns to change consumer attitudes towards PiVs, as the attitudes were shown to be a critical factor in the successful uptake of the vehicles.

Further research should be commissioned on recharge behaviour as soon as sufficient vehicles are sold and data becomes available. This should ideally be based on mass market consumers, and should cover both time and location of recharging to predict effects on the Grid and required numbers of public charge points. Analysis of charging rate and electricity price elasticity at the various locations will underpin the business case for both standard and rapid public charge points.

Consideration should be given to future maintenance and updating of the databases and behavioural algorithms that underpin this work. In particular this should concentrate on consumer attitudes, recharge behaviour, charge point deployment algorithm, vehicle technology and costs.

This would then allow the CRM to be updated and validated to produce improved forecasts in the future.

Research should be performed to understand the shift in the time of vehicle charging that can be achieved by the use of variable tariffs. This will have benefits in minimising electricity CO_2 emissions, generating capacity requirements, and network reinforcement costs.

Appendix A

Dieter Helm Peer Review

Introduction

A final draft version of this report was submitted to Professor Dieter Helm for Peer Review in July 2011, and his comments are presented in full below. This version of the report has been variously modified and clarified in light of these comments. Additionally, responses to some comments are included in italics below.

Peer review
E&CB Analysis Final Report

Professor Dieter Helm
University of Oxford
27th July 2011

1. PiVs have the potential to play a central role in the decarbonisation of the economy. The design of policy instruments to facilitate their takeup is likely to involve a carbon price and specific measures in respect of the supporting infrastructure. Given the uncertainties, it is an open question as to whether this design depends upon the detailed empirical modelling and "themed" scenarios.

2. This peer review focuses on the role of modelling in the report, the importance of technical change, the 3 key findings and the 6 recommendations.

3. The final report reviewed here is one part of a wider study. The consultant has "undertaken analysis and modelling to determine the potential role, economics and carbon benefits of PiVs in the UK's future low carbon transport system". The first point to make in this peer review is that this is a very general question. Without being clear about the precise question or questions, it is not easy to work out whether the report provides good answers. What is a "potential role"? Is a full cost benefit study required? Which aspects of the "economics" should be considered? The consultant has therefore had the difficult task of first trying to make the project coherent.

The role of modelling in the report

4. The final report is based upon a very complex set of models and modelling runs. Key issues are the relation of this modelling to the conclusions, and the justification for the recommendations.

5. I found this model driven approach extremely hard to penetrate. There are many variables involved and many model runs, so that I found it practically impossible to work out how the conclusions are derived – and indeed whether the recommendations actually depend upon the modelling. For example, in section 2.1, optimisation of the "best package" involves 29 policies. These are

presumed to minimise the Exchequer costs – not to maximise producer and consumer surplus. Thus they are not economic welfare optimising.

The central role of technical change and uncertainty

6. This is not simply a question about the coherence of the report – it is about the overall methodology. The time period is 4 decades. Over this period a whole host of things could happen. In particular, there is enormous scope for technical change – both in cars, and in electricity generation, storage and transmission. Indeed, there are reasons to believe that the technical changes could be as profound as those witnessed in the communications industry in the last two decades. It is therefore important to consider whether the right methodology is to try to model as many scenarios and options as possible or to use a more parsimonious approach.

Agreed. The themed scenarios provide a selection of futures to explore the possible space. The sensitivity analyses provide some insight into the size and direction of change of outputs due to variations in individual factors.

7. The report in large measure takes the electricity system as given – and here as with PiVs there can be expected to be profound technical change over the period.

The electricity system is modelled 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. These scenarios look at a range between 60-90% CO_2 reductions by 2050.

The modelling also considered the network reinforcement, network intelligence and charging point costs associated with Plug-in vehicles as regulated and un-regulated assets.

8. The report – and the modelling – could easily lead the reader to a set of conclusions which are not warranted. Indeed, so open is the period that the report provides a list of 44 caveats in an annex. The consultant therefore recognises this, but the relation of the caveats to the conclusions is not spelt out. As the degree of uncertainty increases, the consultant faced the choice between increasing the complexity of the modelling to try to capture this uncertainty, or alternatively to use a simplified framework.

It is acknowledged that the period is open. The caveats are necessary to ensure that an already very complex project (with a large number of unknowns) is not made unduly more complicated. They also add context and validity to the results.

9. An alternative way of looking at this problem is to consider the constraint implied by the 2050 targets, and work through the framework within which this electrification might be achieved. A good example of this sort of approach is to consider an EPS which mapped the trajectory required by the target. This does not necessarily require complex modelling – indeed the modelling would not necessarily add very much at all.

This is a valid alternative approach to looking at the problem. However, it was decided by the stakeholders that the methodology used was an appropriate way to complete this project.

10. Complex modelling can encourage unwarranted precision. This is well represented by predicting that the social cost of a BEV over a 2010 gasoline vehicle by 2050 would be £1031. How could we possibly know this? What value could we possibly place upon this? What is the number most sensitive to? How could this be useful in designing policy now – 40 years earlier?

There are a range of scenarios (generally high / medium / low) for each variable to ensure there is a range of output values. The scenario input values have been agreed through a stakeholder engagement process with Government, ETI members and external stakeholders.

The £1031 was for the baseline only. There are a range of other values (for the social cost of a BEV over a 2010 gasoline vehicle by 2050) for the different scenarios. However, the report wording has been modified to reflect the level of uncertainty.

The key findings

11. The report gives 3 "key findings". The first is that "a 69% reduction on 1990 in-use CO_2 emissions from passenger car transport is likely in 2050". This is derived in part from the precise cost estimate. Note: not "possible" but "likely"; not a range, but "69%". Whatever the actual number, it is extremely unlikely that the answer will turn out to be "69%"! This is followed by an obvious – and vacuous – statement: "There is potential for greater savings if external factors are favourable to PiV take-up". How could it possibly be otherwise?

The executive summary has been considerably re-worked post the peer review. The key findings have been expanded and re-worded, and an implications section added prior to the recommendations.

As stated previously, there are a range of scenarios (generally high / medium / low) for each variable to ensure there is a range of output values. The scenario input values have been agreed through a stakeholder engagement process with Government, ETI members and external stakeholders.

The finding has been modified to show a range of values. Values are now provided under the "most likely" assumptions and for "very high levels" of PiV take-up.

12. The second "key finding" is that "Most government incentives, including vehicle subsidies, have little lasting effect on PiV take-up and CO_2 emissions". The report does not establish this key finding in a generalised sense for a rather obvious reason: as long as the incentives are big enough (even, in extreme, "free"), then there is likely to be a response. If the authors mean "most *existing* incentives" then again it is not obvious that much modelling is needed to establish this conclusion – and not much is learned as a result.

This "key finding" has been reworded to "Government incentives considered in this study, including vehicle subsidies, have little lasting effect on PiV take-up and CO_2 *emissions."*

The list of policy levers (including incentives and subsidies) tested was listed in Appendix D.

The values of incentives and subsidies that have been used in each scenario test (as stated previously) have been agreed through a stakeholder engagement process with Government, ETI members and external stakeholders. The policy values were agreed with consideration of what was 'likely' and would be 'politically acceptable'.

13. It is not clear that the full set of alternative policies have been explored to substantiate the further key finding that emissions regulations at the EU level or subsidising the deployment would be desirable – and much more important, it is hard to work out whether there has been a full cost benefit analysis of the alternatives to establish this conclusion. The fact that it is intuitively plausible is irrelevant: the claim here appears to be that the modelling establishes this result. I am sceptical about this.

The list of policy levers (including incentives and subsidies) tested was listed in Appendix D.

The Government incentives and policies considered in this project have been agreed through a stakeholder engagement process with Government, ETI members, and external stakeholders. The policy values were agreed with consideration of what was 'likely' and would be 'politically acceptable'.

The fleet average emissions regulations and subsidising the deployment of charge points were the most effective policies of those tested within the modelling.

14. The third "key finding" is badly stated and very unclear. It is stated that: "The DECC pricing issued in 2010 for carbon is not high enough to give the Exchequer a financial incentive to encourage a switch from conventionally fuelled vehicles to PiVs". I am completely puzzled by the "financial incentives of the Exchequer". What are the financial incentives of the Exchequer? Is this subsidy minimisation? Minimum social costs? Maximisation of economic welfare – producer plus consumer surplus? Or have the authors been studying the behaviour of Treasury civil servants and Ministers? It is a very ambiguous statement. This point relates back to the economic framework of the report, and whether it is cost-benefit based.

This statement has been removed. The carbon abatement costs in 2050 are now compared to the forecasted DECC 2050 carbon prices.

The recommendations

15. Turning to the "recommendations", 6 are presented. The first is that government should "lobby for a European passenger car emissions target". This seems to me to be way beyond the scope of the project, and there is no analysis of the economic impacts of "lobbying" in the report. It reflects too the absence of analysis of government failure and its implications for the choice of instruments. The latter point is a major flaw: market failure is necessary but not sufficient to justify policy recommendations.

The executive summary has been considerably re-worked post the peer review. The recommendations have been expanded and re-worded.

The recommendation has been reworded as follows, "Government should work with the EU to assess the costs and benefits in changing the EU fleet average emissions target to be based on WTW rather than TTW emissions."

16. The second recommendation is that "manufacturers of plug-in hybrids may need to be incentivised to install batteries that allow a high percentage of electric driving real world usage to minimise emissions". This sentence is either obvious or incoherent. What does "high percentage" and "driving" and "real world usage" mean? Is minimum emissions zero or the cost-benefit optimal level of pollution?

This recommendation has been removed.

17. The third is that the government "should encourage rapid deployment of charging infrastructure through subsidies on their installation and operation". It is a very general statement. It may well be the optimal policy, but the report provides little way of evaluating against the alternatives, and the social net present value is not reported in the conclusions. Do the authors have in mind a marginal incentive – or a large scale subsidy? What sort of subsidy? How would this relate to the rest of the electricity infrastructure? What about the alternative of customers incorporating the costs in the electricity use of system charge?

The finding now states "Government should continue to subsidise the installation of charging infrastructure, in a similar manner to the Plugged-in Places schemes, but at a national level. Subsidies should include domestic and workplace charge points."

18. Fourth, it is recommended that "network reinforcement costs and network intelligence costs should, if possible, be added to the regulated asset base". This may be a good idea. The recommendation however has no obvious connection to the modelling. Also what does "if possible" mean? How could it not be "possible"? The cost of capital implications are not clear.

Scenario tests were completed that tested NRC and NIC as regulated and unregulated assets.

Scenario tests were also completed for the rate of return of capital (4%, 6.5% & 9%).

The recommendation now states "Network reinforcement costs and charge point intelligence costs (CIC) should be added to the regulated asset base to minimise the cost of electricity at public charging points, and to improve the business case for charge point operators."

19. The fifth recommendation is an alternative to the fourth – presumably only for the network intelligence cost? It is not at all clear what this alternative is, but presumably it is related to the smart metering proposals – which are not well developed in these recommendations.

This recommendation has been merged into the recommendation described under point 18. It is not an 'alternative'.

"It is recommended that one central back office for billing at charging points is established to minimise CIC, negate the need for roaming charges between regions, and assure interoperability"

It is not related to smart metering proposals. It is recommended to minimise the regulated NIC/CIC cost.

20. Finally, it is recommended that "Government should initiate a study to investigate the potential cost effectiveness of campaigns to change consumer attitudes towards PiVs". This again may be a good idea – and indeed it might be thought that the consumer research in the wider study might have addressed this. But again, it is far from obvious what this has to do with the modelling.

The consumer research completed within the wider study enabled the definition of the coefficients (based upon a 3000 person consumer survey) used to measure the perceived disutility of plug-in vehicles.

These coefficients for measures such as 'range' and 'charging time' imposed significant financial penalty on plug-in vehicles.

The education of consumers could change this perceived disutility and improve the uptake of plug-in vehicles.

21. Whatever the merits of each of the recommendations, the report does not obviously lead to the conclusion that these are the 6 key things government should do.

The executive summary has been considerably re-worked post the peer review. The recommendations have been expanded and re-worded.

Conclusions

22. The report contains much useful information. My own view is that this approach to policy formation over very long time periods is of limited value. An alternative approach is to set a general framework and "learn-by-policy". The case for market based policies precisely rests on ignorance of both the demand and the supply sides. For example, a useful starting point is to set a carbon price, and then see what happens. In the face of major technical change over 4 decades, the framework approach with *ex post* flexibility is more likely to yield the highest welfare outcomes (once proper attention has been paid to government failure). This report very well illustrates the difficulties of taking the model-led approach to policy selection, and it is recommended that, notwithstanding the detailed empirical analysis, its conclusions are treated with considerable scepticism.

Appendix B

Modelling Caveats

B1 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 proposed further stages of the project 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.

B1.1 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 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.

B1.2 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 CIC 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 has been necessary to scale the model to avoid gross under/over prediction. During the stage 1 work, the scaling has 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 segments (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 segment 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 segment/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, PHEVs and ICEs – or of the effect of ownership of one on the use of another e.g. in multi-car families.

35. There is 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 C

Carbon Abatement Costs

	Vehicle type	Purchase cost	Life in years	Annual equivalent purchase costs	Annual maintenance cost	Annual insurance cost	Annual liquid fuel cost	Annual electricity cost	Annual charge point cost	Total Annual Costs	Annual liquid fuel emissions	Annual electricity emissions tCO_{2e}	Carbon Abatement Costs £ per tCO_{2e}
2010	2010 Gasoline	£10,796	12	£1,117	£388	£427	£329	£0	£0	£2,262	2.293	0.000	-
	Gasoline	£10,796	12	£1,117	£388	£427	£329	£0	£0	£2,262	2.293	0.000	£0
	Gasoline PHEV	£20,169	8	£2,934	£388	£797	£132	£48	£514	£4,814	0.918	0.268	£2,304
	Gasoline RE-EV	£25,179	8	£3,663	£388	£995	£93	£74	£514	£5,728	0.645	0.411	£2,801
	Diesel PHEV	£18,438	8	£2,682	£388	£710	£97	£51	£514	£4,443	0.767	0.284	£1,756
	Diesel RE-EV	£25,387	8	£3,693	£388	£978	£67	£75	£514	£5,715	0.525	0.419	£2,558
	BEV	£33,819	8	£4,920	£388	£1,337	£0	£111	£514	£7,270	0.000	0.618	£2,990
2020	2010 Gasoline	£10,796	12	£1,117	£456	£529	£360	£0	£0	£2,463	2.150	0.000	-
	Gasoline	£13,114	12	£1,357	£456	£529	£262	£0	£0	£2,604	1.561	0.000	£240
	Gasoline PHEV	£17,806	10	£2,141	£456	£719	£115	£53	£287	£3,770	0.684	0.191	£1,026
	Gasoline RE-EV	£20,170	10	£2,425	£456	£814	£82	£81	£287	£4,145	0.490	0.292	£1,230
	Diesel PHEV	£17,139	10	£2,061	£456	£674	£89	£55	£287	£3,623	0.623	0.201	£875
	Diesel RE-EV	£20,309	10	£2,442	£456	£799	£57	£82	£287	£4,124	0.401	0.298	£1,145
	BEV	£26,950	10	£3,240	£456	£1,088	£0	£121	£287	£5,192	0.000	0.437	£1,594
2030	2010 Gasoline	£10,796	12	£1,117	£536	£612	£391	£0	£0	£2,657	1.963	0.000	-
	Gasoline	£15,172	12	£1,570	£536	£612	£231	£0	£0	£2,950	1.159	0.000	£364
	Gasoline PHEV	£18,171	12	£1,880	£536	£734	£107	£0	£204	£3,461	0.536	0.029	£575
	Gasoline RE-EV	£19,539	12	£2,022	£536	£789	£70	£96	£204	£3,717	0.351	0.044	£676
	Diesel PHEV	£17,070	12	£1,766	£536	£671	£76	£67	£204	£3,320	0.455	0.031	£449
	Diesel RE-EV	£19,598	12	£2,028	£536	£771	£51	£98	£204	£3,687	0.304	0.045	£638
	BEV	£23,836	12	£2,467	£536	£962	£0	£143	£204	£4,312	0.000	0.066	£872
2040	2010 Gasoline	£10,796	12	£1,117	£633	£597	£422	£0	£0	£2,769	1.963	0.000	-
	Gasoline	£14,788	12	£1,530	£633	£597	£215	£0	£0	£2,975	1.002	0.000	£215
	Gasoline PHEV	£17,218	12	£1,782	£633	£695	£97	£53	£168	£3,427	0.450	0.017	£440
	Gasoline RE-EV	£18,015	12	£1,864	£633	£727	£61	£80	£168	£3,534	0.285	0.026	£463
	Diesel PHEV	£16,299	12	£1,687	£633	£641	£69	£56	£168	£3,253	0.350	0.018	£303
	Diesel RE-EV	£18,039	12	£1,867	£633	£710	£45	£82	£168	£3,503	0.228	0.026	£430
	BEV	£21,837	12	£2,260	£633	£882	£0	£119	£168	£4,061	0.000	0.038	£671
2050	2010 Gasoline	£10,796	12	£1,117	£748	£580	£453	£0	£0	£2,899	1.963	0.000	-
	Gasoline	£14,376	12	£1,488	£748	£580	£217	£0	£0	£3,033	0.939	0.000	£131
	Gasoline PHEV	£16,394	12	£1,697	£748	£662	£99	£50	£160	£3,415	0.428	0.023	£341
	Gasoline RE-EV	£16,814	12	£1,740	£748	£679	£60	£77	£160	£3,464	0.262	0.035	£339
	Diesel PHEV	£15,694	12	£1,624	£748	£617	£70	£54	£160	£3,273	0.305	0.024	£229
	Diesel RE-EV	£16,937	12	£1,753	£748	£666	£45	£78	£160	£3,449	0.194	0.035	£318
	BEV	£20,104	12	£2,080	£748	£812	£0	£113	£160	£3,913	0.000	0.051	£531

Appendix D

Theme Descriptions

	Commodity Prices			UK GDP			Vehicle Showroom									Electricity Generation	
	Oil	Gas & Coal	Carbon Credit	UK vehicle parc	Annual VKT	Reduced sensitivity to prices	Up front price (exc. Battery)	Battery Price	Other costs of owner	Fossil fuel cons per 100 km	Elec cons per 100 km	Max fully electric range	Perf (acc)	Ave. life exp	Prod & Scrap Emm	UKERC Base Load	UKERC associated theme
Base Case (T0)	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	CAM
Maximally favourable to PiV take-up (T1)	H	L	L	H	H	H	L	L	L	H	H	H	H	H	L	H	CLC
Minimally favourable to PiV take-up (T2)	L	H	H	L	L	N	H	H	H	L	L	L	L	L	H	L	CCSP
Maximally favourable to PiV take-up with base case policy(T3)	H	L	L	H	H	H	L	L	L	H	H	H	H	H	L	H	CLC
Minimally favourable to PiV take-up with base case policy (T4)	L	H	H	L	L	N[2]	H	H	H	L	L	L	L	L	H	L	CCSP
High UK GDP (T5)	M	M	M	H	H	H	M	M	M	M	M	M	M	M	M	H	CAM
Low UK GDP (T6)	M	M	M	L	L	L	M	M	M	M	M	M	M	M	M	L	CAM
High global growth (T7)	H	H	H	H	H	H	L	L	L	L	L	H	H	H	L	H	CAM
Medium global growth with a green emphasis (T8)	H	H	H	L	L	L	H	H	L	L	L	H	H	H	L	L	CSAM
Medium global growth with high oil price (T9)	H	M	M	H	H	H	M	M	M	M	M	M	M	M	M	M	CAM
Medium global growth with oil price spike (T10)	S[1]	M	M	L	L	L	M	M	M	M	M	M	M	M	M	M	CAM
Low global growth (T11)	L	L	L	L	L	L								L	H	L	CAM
Minimise emissions (T12)	H	H	H	L	L	L								H	L	L	CSAM

[1] "S" indicates a spiked oil price

[2] "N" indicates link between sensitivity to prices and GDP ignored

	Electricity Price						Supply and Price of CPs		Consumer Behaviour									
	Costs for NR, NI & CP	Required rate of return on capital	Employers and Retailers charge for Elec?[1]	Notional Value	Likely utilisation	Peak/Off Peak Elec Price Ratio	Domestic Avail	Non-domestic max utilisation	Segment Preference[2]	% private buyers[3]	Attitude to PiV idea	Sensitivity to range	Sensitivity to price	Sensitivity to CP availability	Sensitivity of car use to running costs[4]	Private owner recharge pattern[5]	Company driver Patterns[5]	Response to off-peak pricing[6]
T0	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T1	L	L	F	M.	M	H	H	H	SM	HP	L	L	L	L	E	FWR	B	Y
T2	H	H	FP	L	H	L	L	L	L	C	H	H	H	H	I	PR	PR	ND
T3	L	L	F	M.	M	H	H	H	SM	HP	L	L	L	L	E	FWR	B	Y
T4	H	H	FP	L	H	L	L	L	L	C	H	H	H	H	I	PR	PR	ND
T5	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T6	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T7	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T8	L	L	F	M.		H	H	H	SM	HP	L	L	L	L	E	FWR	B	Y
T9	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T10	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T11	M	M	FP	M	M	M	M	M	B	C	B	B	B	B	E	B	B	Y
T12	L	L	F	M.		H	H	H	L	HP	L	L	L	L	E	FWR	B	Y

[1] FP means employers and retailers charge full price for electricity, F means employers and retailers provide free electricity

[2] B means base preference, SM means small car preference, L means large car preference

[3] C means current share (42%), HP means share increases to 52% by 2020 and continues at 52% until 2050

[4] E means apply an elasticity of 0.26 to the VKT of all vehicles, I means ignore the elasticity effect for all vehicles

[5] FWR means pattern reflects free electricity at workplaces and retail locations, PR means pattern reflects non-availability of normal speed charge points

[6] B means end-of-day charging is delayed until off-peak, ND means end-of-day recharging is not delayed

Policy levers	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
A. Subsidy on purchase of PiVs													
A1. Max budget for subsidy (£bn)	43	na	0	43	43	43	43	43	na	43	43	43	na
A2. End yr for PiV subsidy	11	22	11	11	11	11	11	11	22	11	11	11	22
A3. Max subsidy per PiV %	25	25	0	25	25	25	25	25	25	25	25	25	25
A4. Max subsidy per PiV (£k)	5	5	0	5	5	5	5	5	5	5	5	5	5
A5. End yr for BEVs–only subsidy	0	0	0	0	0	0	0	0	0	0	0	0	0
A6. Max subsidy per BEV (%)	0	0	0	0	0	0	0	0	0	0	0	0	0
A7. Max subsidy per BEV (£k)	0	0	0	0	0	0	0	0	0	0	0	0	0
B. Company car tax treatment													
B1. Tighter limit on tax benefit for LEV purchases by companies?		Y							Y				Y
B2. Tax treatment of PiVs as company cars based on WTW (rather than tailpipe) emissions?			Y										
C. VAT													
C1. Raise domestic electricity rate to 20%?			Y										
D. VED													
D1. Multiplier relative to base VED rates	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	2.0
D2. VED based on WTW (rather than tailpipe) emissions?		Y							Y				Y
E. Fuel tax													
E1. Multiplier on current rates	1.0	2.0	0.5	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	2.0
E2. Relating all fuel taxes to their emissions relative to petrol?													
E3. Recovering any reductions in fuel tax by a fee per vehicle?	Y			Y	Y	Y	Y	Y		Y	Y	Y	
E4. Recovering any reduction from fuel tax by a usage charge?			Y						Y				Y
F. Congestion charges													
F1. Extend charging to all major cities?		Y							Y				Y
F2. Exemptions apply only to PiVs?		Y							Y				Y
G. Regulated assets													
G1. Network reinforcement is an R.A.?	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
G2. Charge points are R.As ?									Y				Y
G3. Charge point intelligence is an R.A.?	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
H. Charge point incentives													
H1. Initial deployment multiplier	1.0	2.0	0.25	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	2.0
H2. Level of capital grants 2013-2015	0	50	0	0	0	0	0	0	50	0	0	0	50
H3. Is tax write-off available?	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
H4. Maximum electricity price premium factor	1	1	0.5	1	0.5	1	1	1	1	1	1	1	1
H5. Excess provision coefficient	1	1.1	1	1	1	1	1	1	1.1	1	1	1	1.1
H6. Does government cover shortfall beyond 2013?		Y							Y				Y
J. Average fleet emissions regulations													
J1. Emission level limit in 2050	42	25	50	42	42	42	42	42	25	42	42	42	25
J2. Measurement ton WTW (rather than tailpipe) emissions?			Y										

Appendix E

Carbon Reduction Targets

E1 Carbon Reduction Targets

E1.1 Economy Wide Targets

In 2007 the European Commission proposed "20-20-20" targets. These are a series of climate and energy targets to be met by 2020 as follows:

- A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
- 20% of EU energy consumption to come from renewable resources
- A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency

In January 2008 the European Commission proposed binding legislation to implement the 20-20-20 targets, and this 'climate and energy package' was agreed by the European Parliament and became law in 2009. The UK committed to binding national targets of 15% renewable energy sources in the final energy demand by 2020.

Following analysis of a range of scenarios, the European Commission reported a plan to meet the long term target of reducing domestic emissions by 80 to 95% by 2050. So far, over the past two decades, EU emissions have gone down by 16%, whereas the economy has grown by 40% over the same period.[28]

The Climate Change Act was introduced in the UK in 2008 and set up a legal framework to tackle the issues of climate change. The Act requires that emissions are reduced by at least 80% by 2050, compared to 1990 levels. The UK emissions from greenhouse gases (GHG) in 1990 were 780 $MtCO_2e$.[29] The Act introduces legally binding interim carbon budgets which set a cap on the levels of greenhouse gases that can be emitted. As part of the Climate Change Act an independent body called the Committee on Climate Change (CCC) was established. The CCC monitors and reports back to Parliament on an annual basis on the progress made in meeting carbon budgets.

Following the first report from the CCC[30], the UK Government passed into legislation (May 2009) carbon budgets for the period 2008-2022 (see Table 1).

Table 5 UK Legislated carbon budgets[31]

	Budget 1	Budget 2	Budget 3
	2008-2012	**2013-2017**	**2018-2022**
Carbon budgets (MTCO2e)	3018	2782	2544
Percentage reduction below 1990 levels	22%	28%	34%

[28] European Commission - 'A Roadmap for moving to a competitive low carbon economy in 2050' (March 2011)
[29] DECC 'UK Greenhouse Gas Emissions 1990-2009, progress towards the Kyoto Protocol and Carbon Budgets Targets'
[30] CCC 'Building a low-carbon economy' (December 2008)
[31] CCC 'Meeting Carbon Budgets – the need for a step change' (October 2009)
Table 1.1 Legislated carbon budgets and split between traded and non-traded sectors

On the 17th May 2011 the UK Secretary of State announced that the Government would accept the CCC's recommendations on the 4th Carbon Budget (2023-2027) in full. It will limit emissions over the budget period to 1950 $MtCO_2e$.

E1.2 Implications for Surface Transport

So what are the implications of the reduction targets for surface transport?

The following figure shows the sectoral GHG emissions from 1990-2009 by 'end-user'. The term 'end user' is used to signify that the emissions from the energy sector (e.g. due to electricity generation and oil refinement) have been transferred to the end user. This is equivalent to the term well-to-wheel (WTW) emissions.

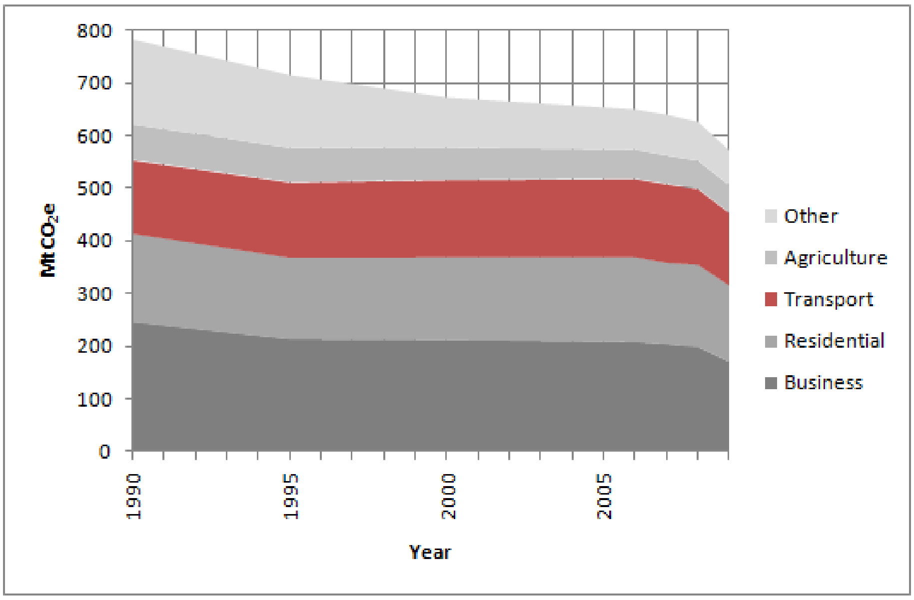

Figure 25 Greenhouse gas emissions by end-user, 1990-2009 ($MtCO_2e$)[32] Note: Transport does not include International Aviation & Shipping (IA&S)

In 2009, the transport sector (excluding IA&S) contributed 24% of end-user (WTW) GHG emissions in the UK. Since 1990 end-user GHG emissions from the transport sector have decreased very slightly by just 1%, whereas substantial savings have been seen in other sectors during the period.

Of the 2009 GHG emissions 474 Mt were CO_2 emissions (excluding IA&S) and 129 Mt of these were from 'end-user' surface transport. Within the transport sector, passenger cars contributed the following 'end-user' emissions:

[32] DECC - UK Climate Change Emission Statistics – 2009 Final UK Figures (31st March 2011) http://www.decc.gov.uk/assets/decc/Statistics/climate_change/1215-2009-final-uk-ghg-emissions-data-tables.xls

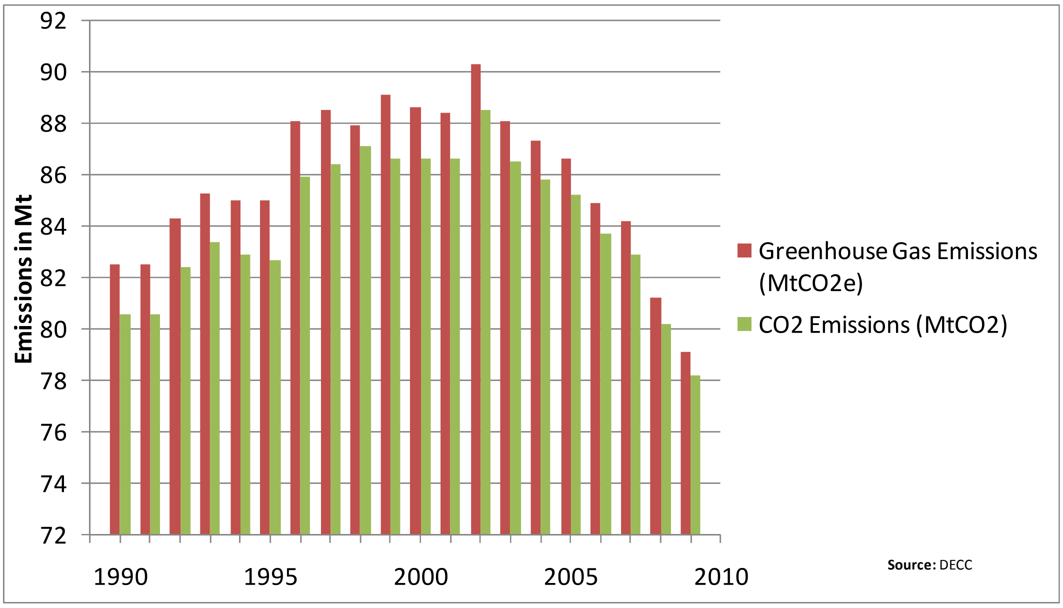

Figure 26 Passenger Car emissions by end-user, 1990-2009[33]

E1.2.1 Tank-To-Wheel Emissions

The European Commission report 'A Roadmap for moving to a competitive low carbon economy in 2050' (March 2011) proposed the following range of sectoral emission reductions to meet the 2050 target:

Table 6 EU Sectoral Reductions[33]

GHG reductions compared to 1990 (TTW)	2005	2030	2050
Total	-7%	-40 to -44%	-79 to -82%
Sectors			
Power (CO_2)	-7%	-54 to -68%	-93 to -99%
Industry (CO_2)	-20%	-34 to -40%	-83 to -87%
Transport (incl. CO_2 aviation, excl. maritime)	+30%	+20 to -9%	-54 to -67%
Residential and services (CO_2)	-12%	-37 to -53%	-88 to -91%
Agriculture (non-CO_2)	-20%	-36 to -37%	-42 to -49%
Other non-CO_2 emissions	-30%	-72 to -73%	-70 to -78%

The CCC suggests that to be on target for 80% GHG emission reductions across the economy by 2050 (under their medium abatement scenario)[34], surface transport TTW CO_2 emissions will need to decrease by 44% in 2030 compared to 2008 levels. This sector will still be a large contributor to overall emissions at 22%. CCC believes this proportion of overall emissions will reduce through the 2030s and 2040s with increasing penetration of electric cars and vans. They suggest that with 100% penetration of BEVs in new vehicle sales in 2035, there

[33] European Commission – 'COM(2011) 112 final' (March 2011)
Table 1 Sectoral reductions
[34] CCC – The Fourth Carbon Budget – Reducing Emissions through the 2020s (December 2010)

would be no emissions from these vehicles in 2050. (It is implicit that power generation will be decarbonised to meet the 2050 targets).

Both the European Commission and the CCC state that the following changes will be required in surface transport in order to meet the 2050 targets:

- Consumer behaviour change (public transport, car pooling, working from home, road pricing, eco-driving techniques)
- Conventional vehicle efficiency improvements
- Introduction of battery electric and plug-in hybrid electric cars and vans
- Increased penetration of biofuels
- The possibility of hydrogen vehicles
- Speed limit enforcement
- Electrification of rail

The CCC state that the UK needs to reduce total greenhouse gas emissions to 80% below 1990 levels, non-IA&S emissions by 85%, and non-IA&S CO_2 emissions by around 90%, and that these emissions reductions will need to be achieved entirely domestically. Given their "assessment of what is possible in other sectors, it is likely that TTW CO_2 emissions reductions of 90% or more will be required from surface transport to meet the economy-wide 80% target. The implication of this is that conventional cars and vans should be fully phased out by the mid-2030s, in order that the car and van fleet is zero- or low-carbon by 2050. In 2009 passenger cars contributed 61% of the CO_2 emissions from surface transport.

Based on an 85% reduction of CO_2 emissions below 1990 levels, the ETI Energy System Modelling Environment (ESME) states that emissions should be 91.9 $MtCO_2$ (including IA&S) across the economy by 2050. Passenger cars contribute 17.7 $MtCO_2$ TTW to this total, providing a 75% reduction compared to 1990 passenger car CO_2 emissions.

It is clear from the above that there are a range of views on the TTW CO_2 reductions required in the UK passenger car sector, with CCC proposing greater than 90% and ESME proposing 75%.

E1.2.2 Well-To-Wheel Emissions

This project reports WTW emissions in order to provide a true comparison between ICEVs and EVs.

The ratio of WTW to TTW emissions in 2050 is predicted, by Ricardo, to be 1.07 for gasoline, and 0.93 for diesel (less than 1.0 due to the biodiesel content). This compares to ratios of 1.16 and 1.17 respectively in 2010.

Similarly ESME includes negative WTT emissions for the production of biofuels in its 2050 forecast which would reduce the WTW value from the 17.7 $MTCO_2$ TTW passenger car emissions.

WTW emissions for electricity are small in 2050 due to the largely decarbonised grid. ESME actually assumes negative WTW emissions, although the EON and EDF predictions in this project are for small positive WTW emissions.

It is thus reasonable to expect that the WTW emissions in 2050 will be less than the TTW emissions in absolute terms, and also that the percentage reduction achievable will be higher for WTW than TTW.

This project makes no recommendation on the WTW emissions reduction target for 2050, but for the purposes of discussion, we have assumed a reference level of 90% reduction from 1990 levels by 2050. This equates to 8.1 $MtCO_2$ down from 80.6 $MtCO_2$ in 1990 (DECC).